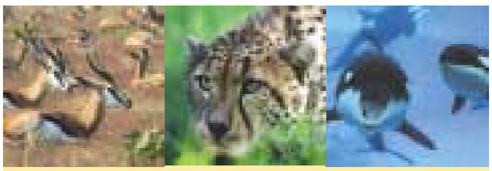
Unit 3 What Is the Evidence for Evolution?

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

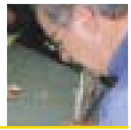
Access the Web resources referenced in this guide—from handouts to video segments to Web features—by going to **pbs.org/evolution** and clicking on Teachers and Students, and then going to the *Evolution Teacher's Guide,* where the material is presented by unit.

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?

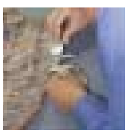
Gingerich wanted to return to Pakistan to find the animal's legs. War nearby kept him from returning. Instead, he went to a place called Zeuglodon Valley, Valley of the Whales, in Egypt. Here in the middle of the Sahara Desert hundreds of whale skeletons lie buried in sandstone. Gingerich's excitement 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.

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 **anthro.palomar.edu/time/default.htm** (tutorial on fossil formation and dating techniques from Palomar College).

Know More

Web Sites

http://www.indiana.edu/~ensi web/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

www.scilinks.org

Topic	Keyword
fossils	EG15A
radiometric dating	EG15B

Activities

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**

In-depth Investigation

The Molecular Connection to

(adapted with permission from a Beth Kramer ENSI lesson)

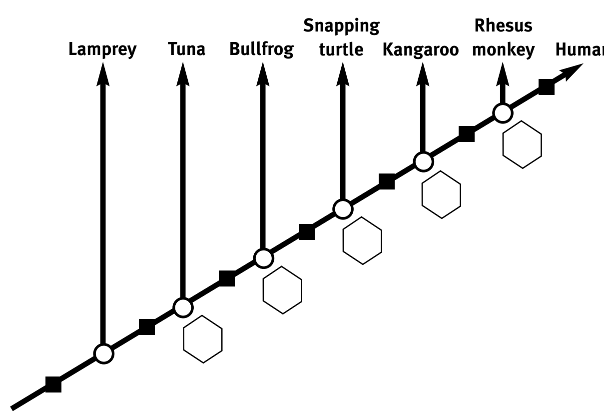
Cytochrome c, an **enzyme** found in virtually all organisms, is needed for the release of energy from food. The amino acid sequences in this protein are compared for several different animals, and the number of differences found are used to infer degrees of relationship. These data are also compared 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.