Whale Adaptations

Overview

Before Your Visit: Students will read and discuss an informational text on whale evolution.

During Your Visit: Students will observe the materials in the *Whales: Giants of the Deep* exhibition and take notes on how whales have evolved over time.

After Your Visit: Students will use what they learned from the Museum visit and reading to produce an illustrated text that describes how have whales evolved over time.

Next Gen Science Standards
MS-LS4-2: Apply scientific ideas to construct an explanation for the anatomical similarities and differences among modern organisms and between modern and fossil organisms to infer evolutionary relationships.

Background for Educators

Adaptations are behavioral or physical characteristics that help an animal survive in its environment: find food, stay cool or warm, move, and defend itself. Many adaptations are visible. They can consist of body parts, coverings, or behaviors. Adaptation is a result of natural selection. Typical adaptations of mammals to life in water include a streamlined shape, and layer of blubber that insulates against the cold.

Before Your Visit

Plan how your students will explore the *Whales* exhibition using the worksheets.

Distribute the worksheets to the students beforehand. You may want to review the worksheets and the map of the exhibition with them to make sure they understand what they are to do.

Activity 1: How Have Whales Evolved?

Have students read "How Have Whales Evolved?" Ask:

- **What are all these scientists trying to figure out?**
  (The scientists in the article are trying to identify the closest living relative to whales, and determine how Cetaceans should be placed relative to other groups on the Tree of Life.)
- **Scientists are using two different approaches to studying whale evolution. What kind of evidence does each group investigate? Why?**
  (Morphologists study whale fossils and the physical features of living whales and compare them to the features of other animals, living and extinct. Molecular biologists look at DNA sequences to see how much the genomes of different living species overlap. The more they overlap the more closely related the species are.)
- **What are some limitations of each kind of evidence?**
  (We don't have fossils for every animal that ever lived, so fossil evidence is limited. Also, features change and sometimes disappear as organisms evolve, which makes it hard to tell if they descended from an ancestor with those features. Fossils don't contain DNA, so molecular biologists can only study living species; this can leave questions about extinct ancestors and where they fit in the Tree of Life.)

Activity 2: Where Do Whales Belong on the Tree of Life?

Have students read “Understanding Cladograms.” Ask:

- **What information about groups of living things is represented in a cladogram?**
  (Answer: The cladogram shows how closely groups of living things are related to one another by comparing advanced features and making inferences about the features of shared common ancestors.)
- **How can you determine how closely animals on the cladogram are related?**
  (Answer: The more recently an organism has a shared common ancestor with another organism, the more closely related they are.)

Have students write a short text explaining how scientist’s view about whales’ relationship to the rest of the Artiodactyl group has changed using the information on the two cladograms from “How Have Whales Evolved?” as evidence.

During Your Visit

Whales: Giants of the Deep

Using their worksheets, students will:

- Make observations about whale ancestors
- Compare extinct animals to living species
- Find structural evidence for evolution and adaptation in modern whales

Students should focus on the Whale Lab portion of the exhibit that deals with whale evolution, behavior, and anatomy. Encourage them to also investigate the sections on whaling and whale artifacts, although they’re not relevant to this activity

Back in the Classroom

Activity 1: Sharing Observations

Have student groups present what they learned in *Whales: Giants of the Deep* to the rest of the class. On the board, or on chart paper, have students list the animals they took notes on to compile a class list of all the organisms that were studied, and the features that they labeled in their sketches. Discuss as a group what students learned about whale evolution overall, taking care to elicit the descriptions that students wrote on their notes sheets.

Activity 2: Writing Informational Texts About Whale Evolution

Drawing on their reading, their museum visit, and their notes, have each student create a 1-2 page text that describes how whales have evolved over time, supported by at least one example each of:

- Fossil evidence
- Molecular evidence
- Structural evidence (evidence from modern whale's bodies)

The text should include sketches of the fossil and structural evidence.

Student Reading: How Have Whales Evolved?

Consider these enormous, intelligent animals. They're mammals, but they abandoned dry land over 50 million years ago to recolonize the sea. And they look nothing like the land ancestors they left behind. They no longer have hair, they've lost their back legs completely, and their front legs have been transformed into flippers that look from the outside more like a fish's fin than a forelimb.

How did this extraordinary transition occur? By studying living animals and fossils of extinct ones, scientists can investigate the process step-by-step over time. They've discovered that whales started out as dog- or pig-like animals.

Fossils and DNA: Two Different Kinds of Evidence

Before the discovery of DNA and the genomic revolution, scientists relied entirely on morphology — physical features like the shapes of bones or muscles, or the presence of fins or fur — to figure out how organisms are related to one another. They compare similarities and differences among both living animals and the fossils of extinct organisms in order to classify them into species. Then they construct evolutionary trees. Scientists who deal mostly with this kind of evidence are called morphologists.

Studying ancient extinct animals means dealing primarily with skeletons and the shapes of bones, since these are the parts of animals that most commonly fossilize. Morphologists often focus on a particular bone that has a unique shape or structure, and use the presence or absence of that type of bone to determine whether or not a newly discovered species belongs in that group. A famous example is the hip-bone of dinosaurs, which has a distinctive hole. Morphologists make a strong argument that birds are part of the dinosaur group by pointing out that they have the same shaped hip-bone as dinosaurs like T. rex, down to the hole in the hip.

In the 1980s, new tools made it possible to use DNA and other molecules to compare the genomes, or complete sets of genes, of different organisms. The more similar their genomes, the more closely related the organisms are. DNA can be used to study living organisms or recently preserved specimens, but not fossils. Scientists who work primarily with DNA evidence to determine organisms' evolutionary relationships are called molecular biologists.

The methods are different but the goal is the same: to figure out how closely living and extinct organisms are related to each other. This kind of research involves choosing at least three species and identifying features to compare across them. For morphologists, these features consist of specific physical characteristics; for molecular biologists, they consist of nucleotide sequences in DNA.

Student Reading Continued

A Mystery in the Whale Tree of Life

Whales, dolphins, and porpoises have long been recognized as being more closely related to each other than to other mammals. So they are united in a group called Cetaceans (say it: "si-TEY-shuns").

Cetaceans are related to Artiodactyls (say it: "ar-tee-oh-DAK-tils"), a group of mammals that consists of camels, deer, pigs, hippopotamuses, and their living and extinct relatives. These animals have an even number of digits on their hands and feet: two or four, unlike our five fingers and toes. Early fossil whales also had even-numbered digits on their feet, which is one of many features that suggest a relationship to Artiodactyls on the Tree of Life.

The bone that morphologists look at to determine membership in the Artiodactyl group is the ankle-bone. In animals like hippos, deer, and pigs, it has a distinctive "double pulley" structure that gives it additional flexibility.

Artiodactyl ankle-bone

The Artiodactyl ankle has a joint on both the top and bottom of the ankle-bone, allowing it more flexibility than the ankles of non-Artiodactyls.

As molecular biologists started investigating whale ancestry, they began to find DNA evidence that cetaceans were more closely related to hippos than any other Artiodactyl. In fact, hippos seemed to be closer relatives to whales than to other Artiodactyls, such as pigs and deer! This was evidence that whales should be considered members of the Artiodactyl group.

Molecular biologists continued to find more evidence of this relationship, but morphologists did not. No fossil Cetaceans had the definitive Artiodactyl anklebone, and living whales have no ankles at all! So morphologists were reluctant to believe the molecular evidence.

Molecular biologists argued that it was wrong for morphologists to assume that the shape of the anklebone couldn't evolve and change, or even disappear, within a group. They insisted that morphologists not disregard the new molecular evidence.

Only new fossil evidence could end the stalemate.

Look at the diagrams at the end of the reading to see the two theories of where whales belong on the Artiodactyl family tree.

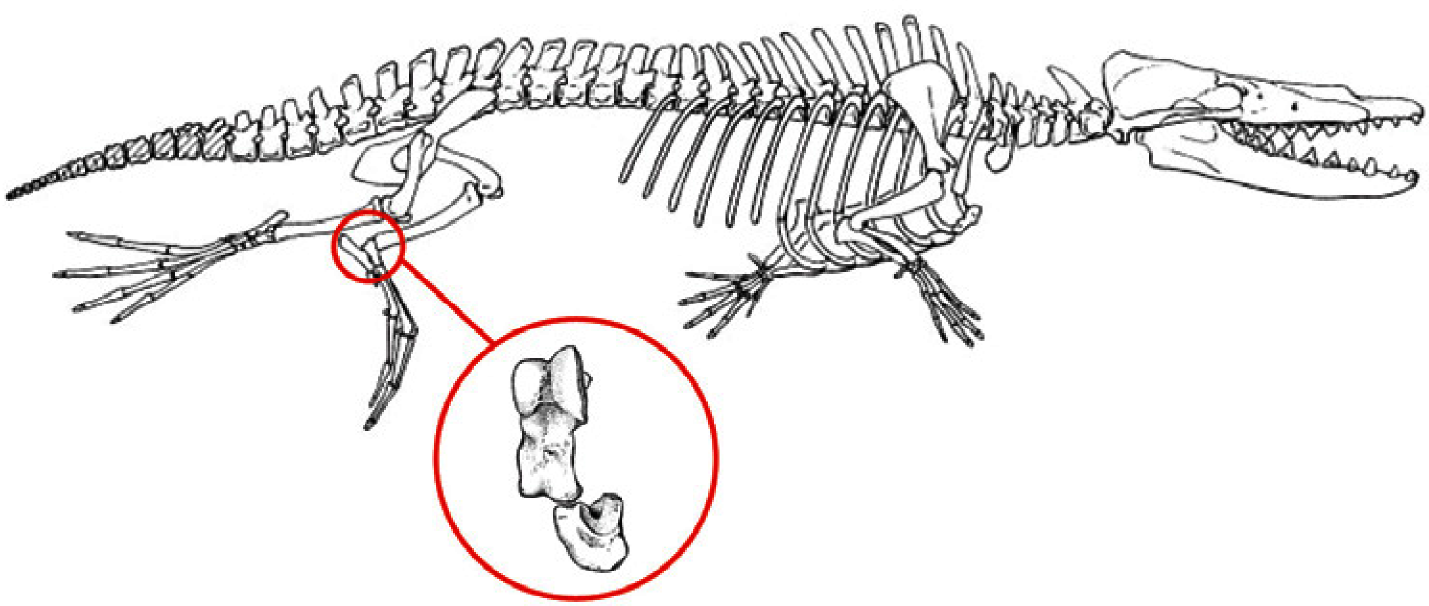
Student Reading Continued

New Fossil Evidence

In Pakistan in 2000, University of Michigan professor Philip D. Gingerich discovered the 47-million-year-old Rodhocetus. This fossil whale had fully developed hind limbs and ankles very much like the Artiodactyls', down to the pulley at both ends. Other Rodhocetus features, such as the shape of its skull and ear bones, were also unmistakably whale-like. This helped convince many morphologists that whales really do belong in the Artiodactyl group.

Further morphological evidence has been uncovered by studying skulls. In hippos, there is a large gap between the incisors (front teeth). This gap also appears in the teeth of whales' fossil ancestors, but not in the skulls of others in the artiodactyl group, such as pigs and deer. This supports the molecular evidence showing that whales and hippos are closely related.

Intermediate fossils — of animals that reflect the transition between life on land to life in water — are especially interesting to whale paleontologists. Recent excavations in India, Pakistan, and Egypt have sparked increasing interest. Recently, paleontologists discovered a fossil of an animal not much bigger than a large dog, called Ambulocetus (Latin for 'walking' plus 'whale'). Ambulocetus had large legs that look like they could support its weight on land. More fossils finds will help us fill in the story of how these fascinating animals came to inhabit our planet's oceans.

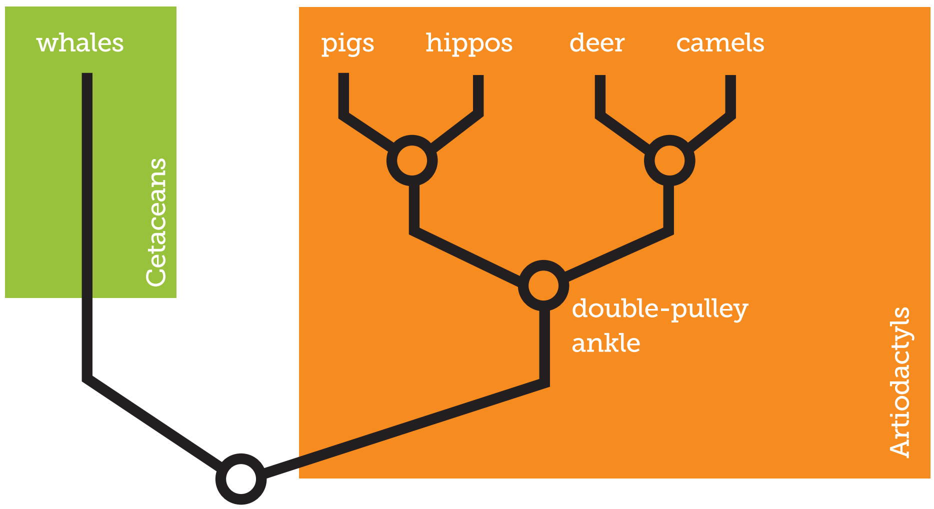


An illustration of an articulated skeleton of Rodhocetus.

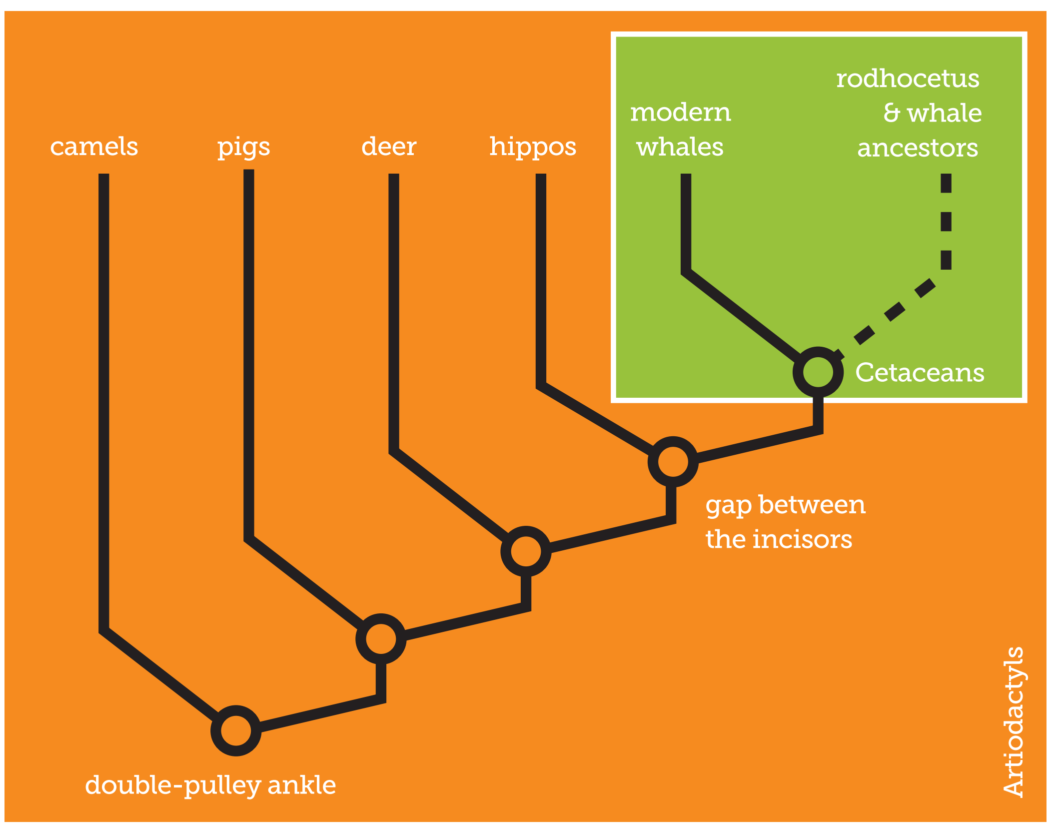
Student Reading Continued

Two Theories of the Artiodactyl Family Tree

Old Artiodactyl family tree based on morphological evidence



New Artiodactyl family tree based on DNA and morphological evidence



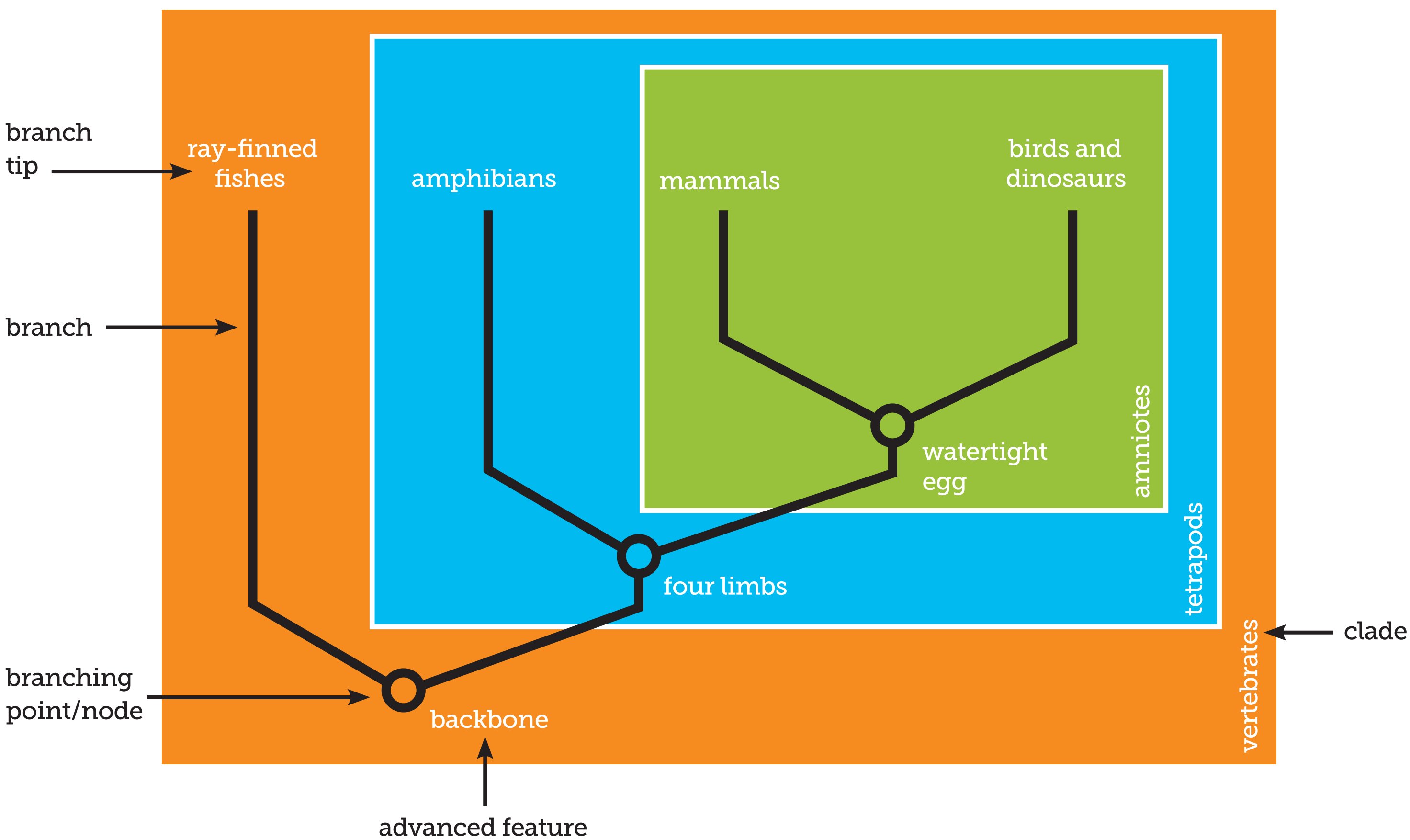
Student Reading: Understanding Cladograms

What is the best way to reconstruct evolutionary history?

Scientists build evolutionary trees using a method called cladistics, in which organisms are grouped according to shared features. The distribution of features forms a set of nested groups, in which smaller groups are contained within larger ones. For example, the group "tetrapods" (animals with four limbs) is contained within the larger group "vertebrates" because tetrapods, like other vertebrates, have a backbone and a braincase, which are the defining features of the group called vertebrates. Each group, or clade, is recognized by a set of such advanced features inherited from a common ancestor. A clade contains all descendants of the common ancestor.

What is a cladogram?

A cladogram is a visual reconstruction of the evolutionary history of a group of animals, based on the distribution of newly evolved ("advanced") features. Cladograms are drawn as branching diagrams, with the advanced features noted at the appropriate branching points, or "nodes." Look at the cladogram below, which shows the evolution of vertebrates.



Student Reading Continued

What is an advanced feature?

As species evolve, they develop new features, or characteristics. An advanced feature can be any attribute of an animal, from the shape of its bones and muscles to its genetic chemistry and DNA. The descendants often diversify and form other groups, and sometimes even lose the advanced feature, but they all share an ancestor that did possess that feature. For example, in this cladogram, reptiles are shown in a clade that shares the advanced feature "four limbs;" but we know that snakes are reptiles without any limbs at all! What this cladogram shows us is that all reptiles (like mammals and amphibians, but unlike fishes) share an ancestor that did possess four limbs. The term "advanced" is relative — it does not necessarily mean that the feature is better than the primitive feature that it evolved from, it merely appeared later.

What does the cladogram show?

Cladograms show the relatedness of living things. The branches represent the evolutionary relationship among the organisms shown at the branch tips. The more recently an organism has a shared common ancestor with another organism, the more closely related they are. For example, this cladogram shows that mammals and reptiles are more closely related than mammals and amphibians, because their shared ancestor that had a watertight egg was more recent than the most recent ancestor of mammals and amphibians that had four limbs.

Student Worksheet

Name: ______________________________

1. **Choose** two fossil whale ancestors. **Sketch** a skeletal feature that changes from the earlier whale to the later one.

Earlier animal name: Age of fossil:	Later animal name: Age of fossil:

Describe the feature in each animal and how it changed:

2. **Compare** the later species above to one of the living whales for which a skeleton is shown (pygmy right whale, sperm whale, hector's dolphin, or gray beaked whale). **Sketch** the same skeletal feature in this animal in the box to the right. **Describe** how this feature appears now:

Living whale name:

3. **Sketch** what the whale you chose looks like when alive. (You can refer to a model or a picture from the whale family tree or the scale model case.) **Label** all the animal's adaptations for living in the water. Add more as you move through the exhibition.