CHAPTER

24 Animal Evolution, Diversity, and Behavior

24.1 Introduction to Animals

24.2 Animal Evolution and Diversity

24.3 Primate Evolution

24.4 Social Interactions and Group Behavior

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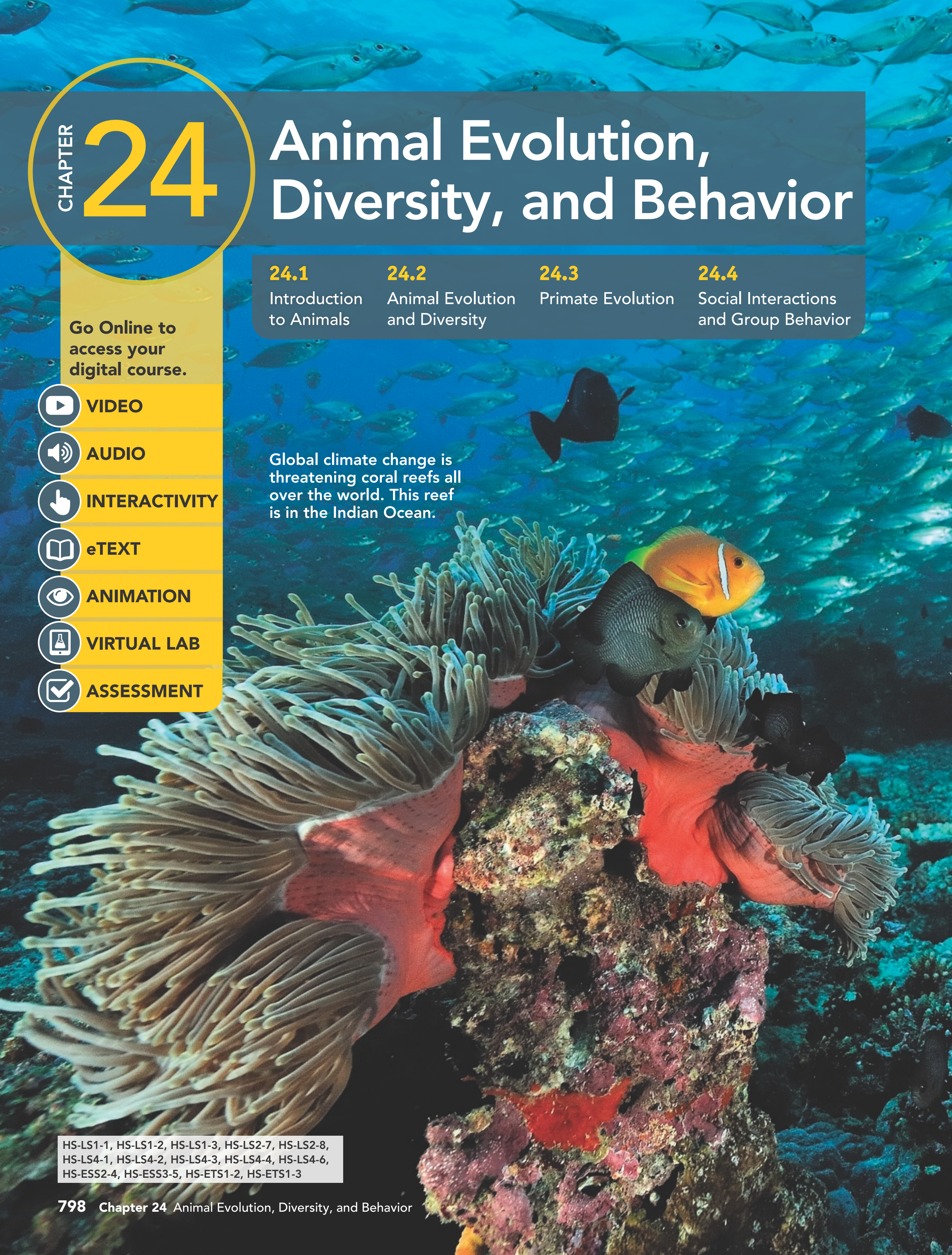


Global climate change is threatening coral reefs all over the world. This reef is in the Indian Ocean.

HS-LS1-1, HS-LS1-2, HS-LS1-3, HS-LS2-7, HS-LS2-8, HS-LS4-1, HS-LS4-2, HS-LS4-3, HS-LS4-4, HS-LS4-6, HS-ESS2-4, HS-ESS3-5, HS-ETS1-2, HS-ETS1-3

CASE STUDY

How are reefs affected by global change?

Articles about Australia's Great Barrier Reef have always described this diverse community as "magnificent," "enormous," or "spectacular." Like other modern reefs, Australia's is built by remarkable organisms called corals. Over the long history of life, different kinds of reef ecosystems, not based on corals, have evolved, thrived, and disappeared. The history of those ancient reef ecosystems can offer important insights into the state of modern coral reefs. Why? Because these days, journalists describe the Great Barrier Reef in ways that bring tears to biologists' eyes: "Dead." "Dying." "Bleached." What might we learn about the future of reefs today by studying ancient reefs and their inhabitants?

Modern coral reefs are diverse and productive ecosystems. They inhabit less than 2 percent of the ocean, yet they provide food or shelter for 25 percent of marine species. In fact, a list of all species that live on reefs would include at least one member of nearly every animal group you'll learn about in this chapter! Reefs also provide ecosystem services, such as food and jobs based on tourism, for millions of people.

Where does reef productivity come from? Corals are a group of "hybrid" organisms that are a partnership between animals and single-celled algae. Together, the organisms extract limiting nutrients from seawater and build solid skeletons of calcium carbonate from carbonate ions. Those skeletons form the structure of the reef, which provides shelter for scores of animals and algae. The coral partnership also provides food for other reef organisms. So, the reef consists of partnerships, built by partnerships, built on partnerships!

But reefs everywhere are in trouble. In 2017, *The New York Times* ran an "ecosystem obituary" in the form of an article entitled "Large Sections of Australia's Great Reef Are Now Dead."

Back in the days of the dinosaurs, a completely different reef community thrived in shallow seas. Those reefs were based not on corals, but on peculiar sorts of clamlike animals called rudists. Although they thrived for millions of years worldwide, they disappeared—both before and during the mass extinction that also wiped out the dinosaurs.

To understand what happened to rudists, and what is happening to corals, you need to understand animal body plans, their evolutionary adaptations, and their relationships to the environments.

Why should we care about what is happening to coral reefs today? And what might we learn about the state of our planet today by studying ancient communities that thrived in similar shallow-water marine ecosystems?

Throughout this chapter, look for connections to the CASE STUDY to help you answer these questions.

LESSON 24.1

Introduction to Animals

Is that a white flower? No, it is an insect called the orchid mantis.

KEY QUESTIONS

- *What characteristics do all animals share?*
- *What essential functions must animals perform to survive?*
- *What are some features of animal body plans?*

HS-LS1-1: Construct an explanation based on evidence for how the structure of DNA determines the structure of proteins which carry out the essential functions of life through systems of specialized cells.
HS-LS1-2: Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms.
HS-LS1-3: Plan and conduct an investigation to provide evidence that feedback mechanisms maintain homeostasis.
HS-LS4-1: Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence.

VOCABULARY
invertebrate
chordate
vertebrate
feedback inhibition
radial symmetry
bilateral symmetry
zygote
coelom
cephalization

READING TOOL

As you read, keep track of the five things that animals do to survive. Describe each process in the graphic organizer in your **Biology Foundations Workbook.**

We all know an animal when we see one—or do we? Four legs and fur may be what first comes to mind. However, other animals have scales and fins or feathers and talons. A few animals are easily mistaken for plants. Still other animals are too small to be seen with the unaided eye. It's a whole different world under the microscope!

What Is an Animal?

Although animals may look very different from one another, they all share certain characteristics. ***Animals are multicellular, heterotrophic, eukaryotic organisms with cells that lack cell walls.*** Animals are often classified into two broad categories: invertebrates and chordates.

Invertebrates More than 95 percent of animal species are informally called invertebrates. **Invertebrates** include all animals that lack a vertebral column, such as worms, jellyfishes, and spiders. Because this category lumps organisms that lack a characteristic, rather than those that share a characteristic, "invertebrates" are not a clade.

Chordates Fewer than 5 percent of animal species are **chordates**, members of the clade known as phylum Chordata. All members of the phylum Chordata exhibit certain characteristics during at least one stage of life: a dorsal, hollow nerve cord; a tail that extends beyond the anus; and pharyngeal pouches. Most chordates—including fishes, amphibians, reptiles, birds, and mammals—are **vertebrates** that develop a backbone, or vertebral column, made of bones called vertebrae (singular: vertebra). Nonvertebrate chordates do not have backbones. As you see in **Figure 24-1**, the hollow nerve cord runs along the dorsal (back) part of the body. Nerves branch from this cord at intervals. At some point in their lives, all chordates have a tail that extends beyond the anus. Pharyngeal pouches are paired structures in the throat region or pharynx that may develop into gills.

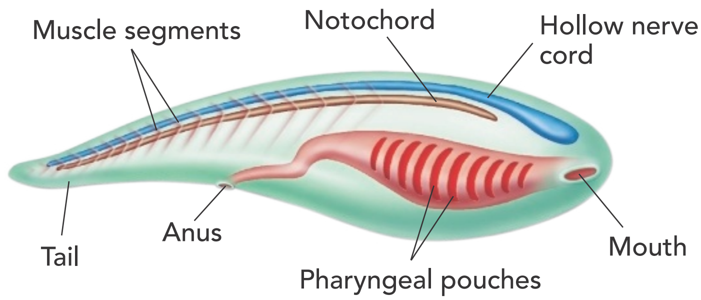


Figure 24-1

Characteristics of Chordates

All chordates have a dorsal, hollow nerve cord; a notochord; pharyngeal pouches; and a tail that extends beyond the anus. Some chordates possess all these traits as adults; others possess them only as embryos.

What Animals Do to Survive

All organisms keep their internal environment stable, a process known as maintaining homeostasis. ***Animals maintain homeostasis by gathering and responding to information, obtaining and distributing oxygen and nutrients, and collecting and eliminating carbon dioxide and other wastes. They must also reproduce.***

INTERACTIVITY

Investigate what it means to be an animal.

Maintaining Homeostasis

If your house gets too cold, the thermostat turns the heat on. As heat warms the house, the thermostat turns the heater off. This is an example of **feedback inhibition**, or negative feedback, which occurs when the product or result of a process limits the process. Homeostasis in your body often works the same way. If you get cold, your body's thermostat makes you shiver, which uses muscle activity to generate heat. When you are no longer cold, the shivering stops. If you get too hot, you sweat, which helps you lose heat.

Gathering and Responding to Information

The nervous system gathers information using cells called receptors that respond to sound, light, chemicals, and other stimuli. Other nerve cells collect and process that information and determine how to respond. Responding quickly and appropriately to the environment can be a matter of life—or death. Thanks to its nervous system, the pheasant in **Figure 24-2** has narrowly escaped becoming lunch for a hungry hawk. In some invertebrates, such as sponges, individual cells sense and respond to the environment. Some invertebrates have only a loose network of nerve cells. Other invertebrates and most chordates have large numbers of nerve cells concentrated into a brain.

The nervous system interacts with other systems to help animals respond to their environment. Muscle tissue generates force by becoming shorter when stimulated by the nervous system. Muscles work together with a supporting skeleton to make up the musculoskeletal system. Some invertebrates, such as earthworms, have flexible skeletons that function through the use of fluid pressure. Insects and some other invertebrates have external skeletons. The bones of vertebrates form an internal skeleton.

Figure 24-2

Responding to the Environment

The hawk's nervous system helps it to spot prey and swoop down to capture it. The pheasant's nervous system helps it to elude the hawk's strike and to flee. **Infer** In what other ways do animals respond to their environment?

Figure 24-3

Gas Exchange

All animals must take in oxygen and eliminate carbon dioxide. Fishes exchange gases directly with water across their gills.

Obtaining and Distributing Oxygen and Nutrients

All animals must obtain oxygen to perform cellular respiration, including the fish shown in **Figure 24-3**. Oxygen can diffuse across the skin of small animals in water or wet places. Larger animals use a respiratory system based on gills, lungs, or air passages. In addition, almost all animals eat to obtain nutrients, and they have a digestive system that breaks down food into usable forms. After acquiring oxygen and nutrients, animals must transport them throughout their bodies. This task often requires interactions between some kind of circulatory system and a respiratory system or digestive system. Several internal feedback mechanisms control these interactions to maintain homeostasis.

Collecting and Eliminating Carbon Dioxide and Other Wastes Animals' metabolic processes generate carbon dioxide and other wastes that must be eliminated. Many animals get rid of carbon dioxide through respiratory systems. Most complex animals have a specialized excretory system that concentrates or processes other wastes and expels them or stores them before eliminating them.

Reproducing Most animals reproduce sexually, a process that helps create and maintain genetic diversity. Many invertebrates and a few vertebrates can also reproduce asexually, usually producing offspring genetically identical to the parent.

READING CHECK **Identify** How do the various body systems work together to maintain homeostasis?

READING TOOL

Use the key idea and the headings to help you organize the features of animal body plans.

Animal Body Plans

Each animal clade has a unique organization of particular body structures, often called a body plan. Body plans are an important part of biological classification. Follow the cladogram in **Figure 24-4** as you read through the different types of body plans. ***Features of animal body plans include levels of organization, body symmetry, formation of body cavities, patterns of embryological development, segmentation, cephalization, and limb formation.***

INTERACTIVITY

Practice your classification skills as you identify an unknown animal.

Levels of Organization As the cells of most animals develop, they differentiate into specialized cells organized into tissues. Animals typically have several types of tissues. Epithelial tissues cover both the inside and outside of body surfaces. Muscle tissue is organized to move the body. Nervous tissue sends messages. Connective tissue, which includes bone and cartilage, has a variety of functions.

During growth and development, tissues combine to form organs. Organs together make up organ systems that carry out complex functions. Organ systems work together to maintain homeostasis in the organism.

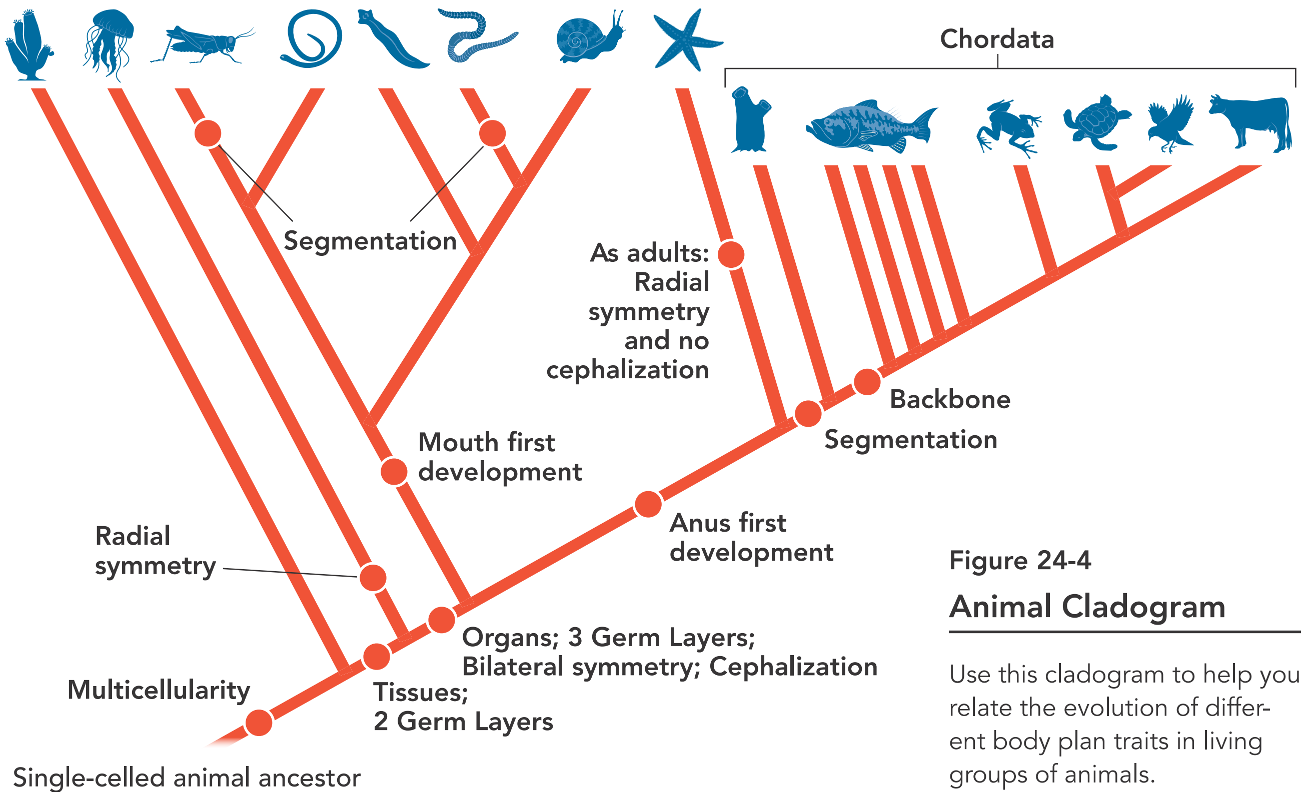


Figure 24-4

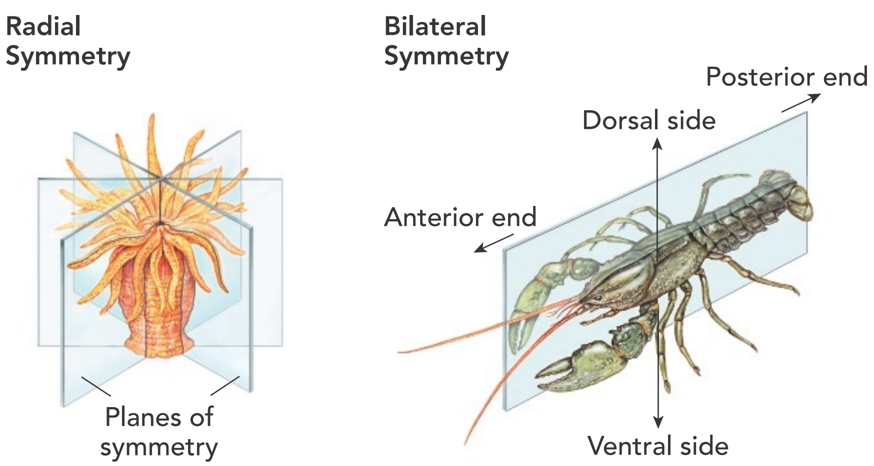
Animal Cladogram

Use this cladogram to help you relate the evolution of different body plan traits in living groups of animals.

Body Symmetry Most animals exhibit some type of symmetry. The sea anemone in **Figure 24-5** has **radial symmetry**, with body parts that extend outward from the center like spokes of a bicycle wheel. Any number of imaginary planes drawn through the center of the body could divide it into equal halves. Many animal groups exhibit **bilateral symmetry**, in which a single imaginary plane divides the body into left and right sides that are mirror images of each other. Animals with bilateral symmetry have a front, or anterior, end and a back, or posterior, end. Bilaterally symmetrical animals also have an upper, or dorsal, side and a lower, or ventral, side. When you ride a horse, you are riding on its dorsal side.

BUILD VOCABULARY

Use Prior Knowledge A radius is a line from the center of a circle to its edge. In radial symmetry, body parts follow lines that extend from a center.



INTERACTIVITY

Figure 24-5

Body Symmetry

Animals with radial symmetry have body parts that extend from a central point. Animals with bilateral symmetry have distinct anterior and posterior ends and right and left sides.

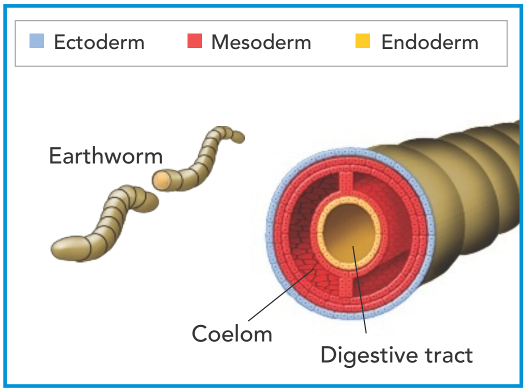


Figure 24-6

Body Cavity

Earthworms are some of the simplest animals with a coelom.

Patterns of Embryological Development

Every animal that reproduces sexually begins life as a **zygote**, or fertilized egg. As the zygote develops, it forms a hollow ball of cells like an inflated balloon. As that ball develops, it folds in on itself, as if you were holding the balloon and pushing your thumbs toward the center. This folding changes a ball of cells into an elongated structure with a tube that runs from one end to the other. This tube becomes the digestive tract. At first, this digestive tract has only a single opening to the outside. An efficient digestive tract, however, needs two openings: a mouth through which food enters and an anus through which wastes leave. In some animal clades the mouth develops first. In other animal clades, the anus develops first.

During embryological development, the cells of most animal embryos differentiate into three layers, called germ layers: the endoderm, mesoderm, and ectoderm. The endoderm develops into the lining of the digestive tract and most of the respiratory system. The mesoderm develops into the muscles and much of the circulatory, reproductive, and excretory systems. The ectoderm develops into the nervous system and the outer layer of the skin. Animals with radial symmetry have two germ layers—the endoderm and the ectoderm.

Most animals have some kind of body cavity—a fluid-filled space between the digestive tract and body wall, which contains internal organs. Your stomach and other digestive organs are suspended in your body cavity. Most complex animals have a type of body cavity called a **coelom** (see lum) as shown in **Figure 24-6**. Some invertebrates lack a body cavity, while others have only a primitive jellylike layer.

Figure 24-7

Segmentation

In this colorful millipede, most of the segments are functionally alike. In other animals, the segments are more specialized.

Segmentation

As many bilaterally symmetrical animals develop, their bodies divide into repeated parts, or segments. Segmented animals typically have at least some internal and external body parts that repeat on each side of the body. Bilateral symmetry and segmentation are found together in many animal groups. The millipede in **Figure 24-7** provides one example.

Segmentation has been important in animal evolution because of the way genes control the production and growth of body segments. In segmented animals, simple mutations can cause changes in the number and form of body segments. Different segments can specialize in performing functions such as information gathering, feeding, or movement.

Quick Lab — Guided Inquiry

How Can Body Symmetry Affect Movement?

1. Use modeling clay to make models of two animals. Make one model radially symmetrical and the other long, narrow, and bilaterally symmetrical.
2. Make grooves to divide each model into similar segments.
3. Add legs to some segments of your models.

ANALYZE AND CONCLUDE

1. **Infer** Which type of body symmetry is more suited to walking forward?
2. **Use Models** How is bilateral symmetry an advantage to animals that walk or run?

Cephalization Animals with bilateral symmetry typically exhibit **cephalization**, the concentration of sense organs and nerve cells at their anterior end. This anterior end is often different enough from the rest of the body that it is called a head. You could say that arthropods and vertebrates have gotten ahead by "getting a head"! Both insect and vertebrate heads are formed by fusion and specialization of body segments during development.

As segments fuse, internal and external parts combine in ways that concentrate sense organs, such as eyes, in the head. Nerve cells that process information and "decide" what the animal should do also become concentrated in the head. Animals with heads usually move in a "head-first" direction, which allows for sense organs and nerve cells to come in contact with new parts of the environment first.

Limb Formation Segmented, bilaterally symmetrical animals typically have external appendages on both sides of the body. These appendages vary from simple bristles in some worms to spiders' jointed legs, dragonfly wings, bird wings, dolphin flippers, and monkey arms. These very different appendages have evolved several times, and have been lost several times, in various animal groups.

HS-LS1-1, HS-LS1-2, HS-LS1-3, HS-LS4-1

LESSON 24.1 Review

KEY QUESTIONS

1. A classmate is looking at a unicellular organism under a microscope. She asks you if it is an animal. What would you say, and why?
2. Why must waste products produced by metabolic processes be eliminated from an animal's body?
3. List five features of animal body plans.

CRITICAL THINKING

4. **Compare and Contrast** How do vertebrates differ from other chordates?
5. **Synthesize Information** What happens to a clade over time if its body plan doesn't enable its members to survive and reproduce?
6. **CASE STUDY** Adult corals do not travel from place to place. How can this impact their ability to maintain homeostasis in changing environmental conditions?

LESSON 24.2

Animal Evolution and Diversity

KEY QUESTIONS

- *How are animal clades defined?*
- *What does the cladogram of invertebrates illustrate?*
- *What can we learn by studying the chordate cladogram?*

HS-LS4-1: Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence.

VOCABULARY

cartilage
tetrapod

READING TOOL

Identify the major events in animal evolution. As you read, take notes in the chart in your **Biology Foundations Workbook.**

New genetics data suggests that "giraffes" are actually four separate species, roughly as genetically different from one another as polar bears are from brown bears. That's interesting, but is this information useful? Yes! Two of those giraffe species have very small populations, so they are at high risk for extinction and require extra effort at conservation. These kind of genetic studies also help us understand evolutionary relationships among larger clades.

The Cladogram of Animals

The features of animal body plans provide information for building the cladogram shown in **Figure 24-8**, showing current hypotheses of relationships among animal clades. ***Animal clades are typically defined according to adult body plans and patterns of embryological development.***

Differences Between Clades Every clade has a unique combination of ancient traits inherited from its ancestors and new traits found only in that clade. It is tempting to think of this cladogram as a story about "improvements" over time. But complex body systems of vertebrates aren't necessarily better than "simpler" invertebrate systems. Any body system in living animals functions well enough to enable those animals to survive and reproduce.

Evolutionary Experiments You can think of each clade's body plan as an evolutionary "experiment," in which a set of body structures perform essential functions. The first appearance of a clade represents the beginning of this "experiment." The original versions of most major animal body plans were established hundreds of millions of years ago. They have been modified over time as species have adapted to changing conditions.

Land vertebrates, for example, typically have four limbs. Many, such as frogs, walk (or hop) on four limbs we call "legs." Among birds, front limbs have evolved into wings. In many primates, front limbs have evolved into "arms." Both wings and arms evolved through changes in the standard vertebrate forelimb.

Origins of the Invertebrates

In Darwin's time, paleontologists defined the Cambrian Explosion, which started about 542 million years ago, as a time when many modern phyla seemed to appear suddenly in the fossil record. We use the word "suddenly" in the geological sense, because the Cambrian Explosion lasted over 15 million years! It looked like an "explosion" to early paleontologists because few older fossils had then been found. Why? Earlier animals were tiny, and were composed of soft tissues rarely preserved as fossils.

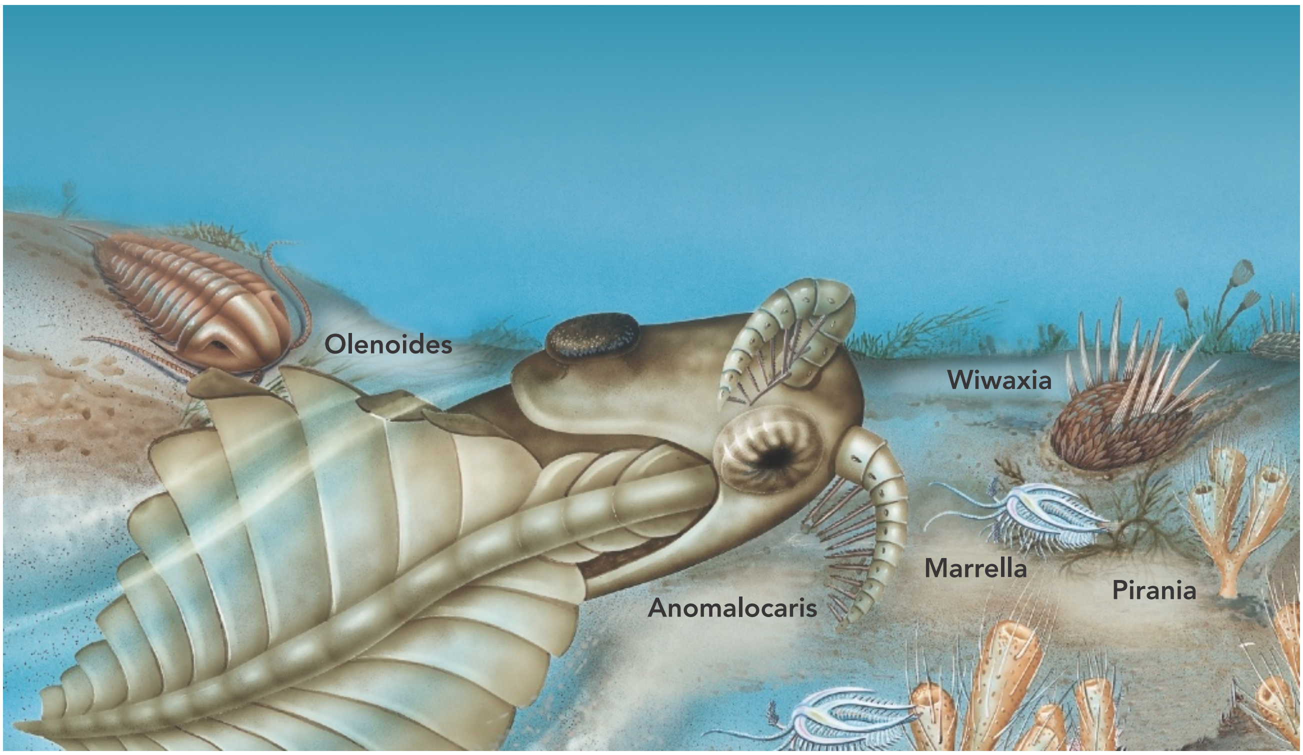
The Earliest Animals For roughly 3 billion years after the first prokaryotic cells evolved, all life remained single-celled. Current data support the hypothesis that the first animals evolved from ancestors they shared with living choanoflagellates, which share several characteristics with sponges, the simplest animals.

Our oldest evidence of multicellular life comes from recently discovered microscopic fossils roughly 600 million years old. The fossil record indicates that the first animals began evolving long before the Cambrian Explosion. These fossils include eggs, embryos, and small body parts, as well as "trace fossils" such as tracks and burrows.

Figure 24-8

Cambrian Animals

This illustration shows what some of the Cambrian animals may have looked like.



INTERACTIVITY

Explore the diversity of invertebrates.

The Ediacaran Fauna Exciting and important fossil evidence of animal life before the Cambrian comes from Australia's Ediacara Hills. These fossils date from roughly 565 to about 544 million years ago, and formed during the Ediacaran Period at the end of the Proterozoic Eon. Most Ediacaran animals had body plans different from anything alive today, although some seem to be related to jellyfishes and worms.

The Cambrian Explosion Some of the best fossils from the Cambrian Period, which began about 542 million years ago, are found in Chengjiang, China, and in the Burgess Shale of Canada. These animals evolved complex body plans, including specialized cells, tissues, and organs. Many had body symmetry, segmentation, a front and back end, and appendages such as legs or antennae. Some Cambrian animals also evolved shells, skeletons, and other hard body parts that fossilize well. That's one reason Cambrian fossils are more numerous than, and were discovered before, Ediacaran fossils.

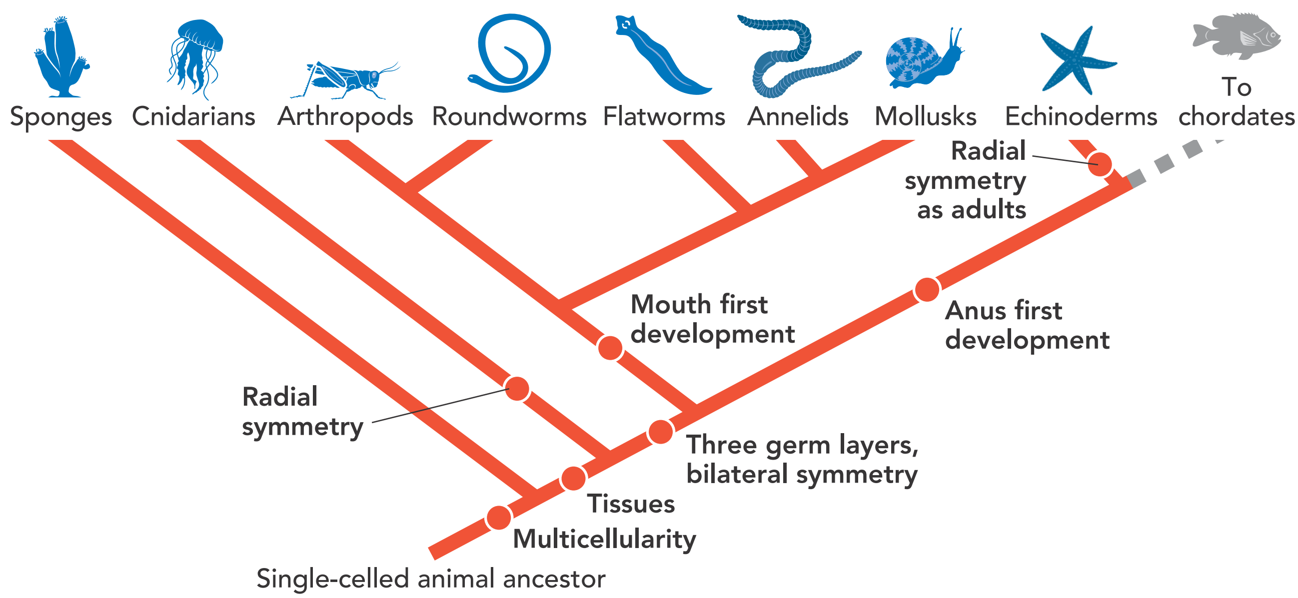
Some early Cambrian fossils are so peculiar that no one knows what to make of them! Others are classified as ancient members of modern invertebrate clades such as arthropods. Others appear to be early chordates. By the end of the Cambrian, the basic body plans of many modern clades had been established. But this does not mean that we would recognize Cambrian organisms as modern members of these phyla. Many millions of years passed before evolutionary change produced the familiar body structures of modern animals.

Cladogram of Invertebrates The major clades of living invertebrates are shown in **Figure 24-9**. ***This cladogram shows current hypotheses about evolutionary relationships among major living invertebrate groups, and indicates the order in which important features evolved.*** The invertebrates alive today are summarized in **Figure 24-10.**

Figure 24-9

Cladogram of Invertebrates

This diagram shows current hypotheses of evolutionary relationships among major groups of animals. During the course of evolution that produced these different groups, important traits evolved. These are shown by the red circle (nodes). Note that invertebrates do not form a clade.



Visual Summary

CASE STUDY

Figure 24-10 Modern Invertebrate Diversity

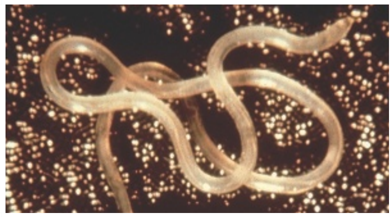
Invertebrates live nearly everywhere, participate in nearly every food web, and vastly outnumber vertebrates.

Sponges Sponges are members of the clade Porifera, Latin for "pore bearers," named for the tiny openings, or pores, they have all over their bodies. Sponges are among the simplest organisms in the clade Metazoa, with all other multicellular animals.

Cnidarians Jellyfishes, sea fans, sea anemones, hydras, and corals are members of the clade Cnidaria. Cnidarians are aquatic, mostly soft-bodied, carnivorous, radially symmetrical animals with stinging tentacles arranged in circles around their mouths. Some, such as corals, have skeletons. Some live as independent individuals, while others live in colonies.

Arthropods Members of the clade Arthropoda include spiders, centipedes, insects, and crustaceans. Arthropods have segmented bodies, a tough external skeleton, cephalization, and jointed appendages. At least a million species have been identified—more than three times the number of all other animal species combined!

Roundworms The roundworms, or nematodes, are unsegmented worms with specialized tissues and organ systems, and digestive tracts with two openings—a mouth and an anus. Some are free-living and live in soil or water. Others are parasites that infect plants and animals.

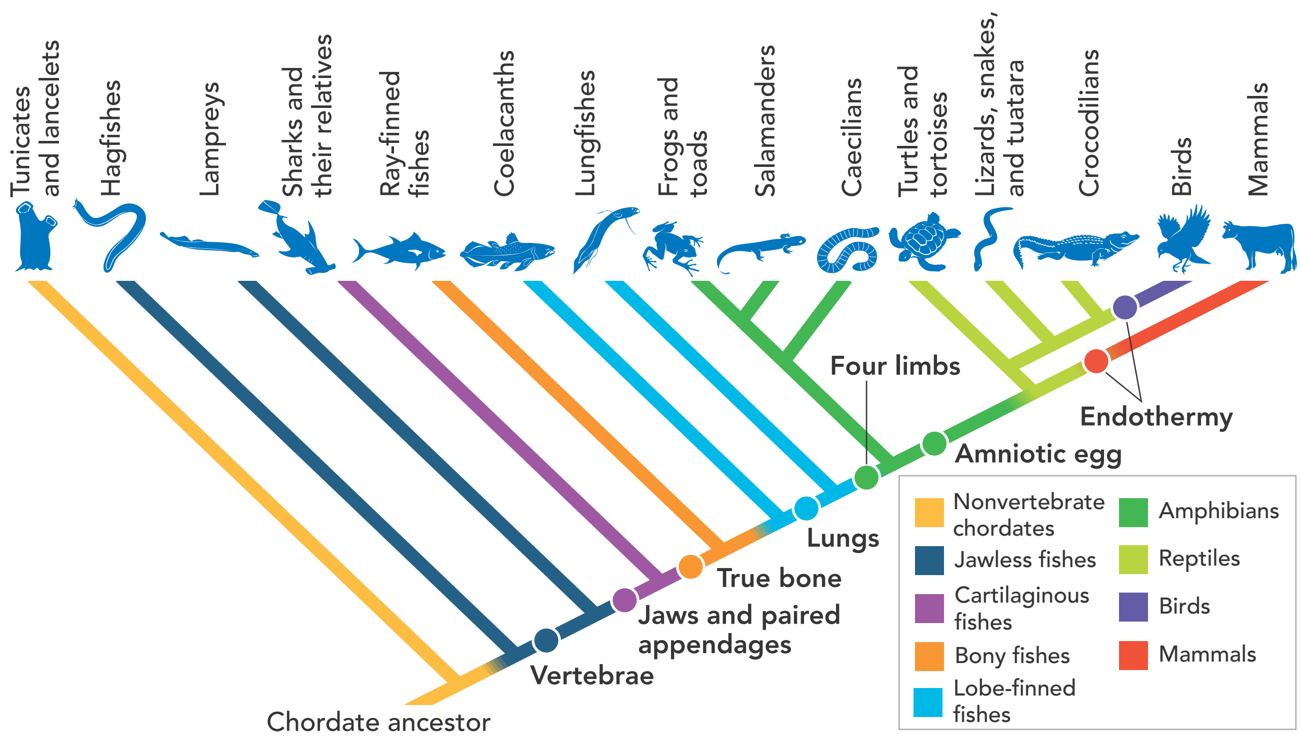


Flatworms Members of clade Platyhelminthes, or flatworms, include planarians, tapeworms, and flukes. Flatworms are soft, flattened, unsegmented worms that lack a coelom and an anus.

Annelids The clade Annelida contains segmented worms such as earthworms and bloodsucking leeches. The name Annelida is derived from the Latin *annellus*, which means "little ring," referring to the ringlike appearance of their body segments.

Mollusks Members of clade Mollusca, or mollusks, include snails, slugs, clams, squids, and octopi. Mollusks are soft-bodied animals that typically have an internal or external shell and complex organ systems.

Echinoderms The marine clade Echinodermata includes sea stars, sea urchins, and sand dollars. Adult echinoderms have spiny skin, five-part radial symmetry, an internal skeleton of calcium carbonate plates, and a network of water-filled tubes called a water vascular system. This water vascular system is used for walking and for gripping prey.



INTERACTIVITY

Figure 24-11

Cladogram of Chordates

The different-colored lines represent the traditional groupings of these animals, as listed in the key. The circles (nodes) indicate the evolution of some important chordate adaptations.

Origins of the Chordates

The most ancient chordates were related to the ancestors of echinoderms. The rich Cambrian fossil record includes some early chordate fossils, such as *Pikaia* (pih KAY uh). When *Pikaia* was first discovered, it was thought to be a worm. Then scientists determined that it had paired muscles arranged in a series, similar to those of simple modern chordates. In 1999, fossil beds from later in the Cambrian yielded fossils of the earliest known vertebrate. These fossils show muscles arranged in a series, traces of fins, sets of feathery gills, a head with paired sense organs, and a skull and skeletal structures likely made of cartilage. **Cartilage**, a strong connective tissue, is softer and more flexible than bone. These characteristics are shared—during some part of the life cycle—by all chordates.

READING TOOL

As you read about the chordates, find them on the cladogram and identify their derived characters.

Cladogram of Chordates Modern chordates consist of six groups: nonvertebrate chordates and five groups of vertebrates—fishes, amphibians, reptiles, birds, and mammals. Almost all living chordates are vertebrates, and most of those are fishes. Because hard body structures fossilize well, this clade has an excellent fossil record. ***The chordate cladogram in Figure 24-11 presents current hypotheses about evolutionary relationships among chordate groups.*** The circles (nodes) in the cladogram represent the appearance of important characteristics during evolution. Each new adaptation—jaws, true bone, and paired appendages—jump-started a major adaptive radiation.

Nonvertebrate Chordates Tunicates and lancelets are chordates that lack backbones. Cambrian fossil evidence suggests that their ancestors diverged from vertebrate ancestors more than 550 million years ago. Adult tunicates, such as the salps shown in **Figure 24-12**, look like sponges, but their larvae all have key chordate characteristics. The small, fishlike lancelets live on the sandy ocean bottom.

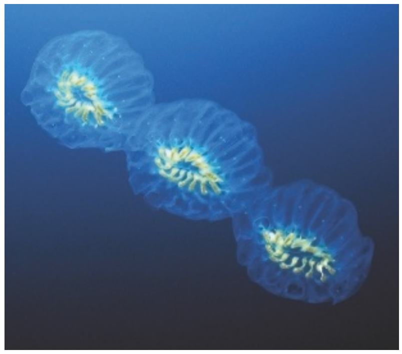


Figure 24-12
Nonvertebrate Chordates

Salps are colonial nonvertebrate chordates.

Jawless Fishes The earliest fishes appeared about 510 million years ago. They had no true jaws or teeth, and their skeletons were made of cartilage. However, fossils reveal that many had bony shields on their heads and other armor. Two other clades gave rise to modern lampreys and hagfishes. Lampreys, shown in **Figure 24-13**, are filter feeders as larvae and parasites as adults. Hagfishes have pinkish-grey, wormlike bodies, secrete lots of slime, and tie themselves into knots!

Figure 24-13
Jawless Fishes

An adult lamprey uses its teeth-filled mouth to attach to a host.

Sharks and Their Relatives Other ancient fishes evolved jaws, which make it possible to bite and chew. Early fishes also evolved paired pectoral (anterior) and pelvic (posterior) fins attached to supporting structures called limb girdles. Paired fins offer more control of body movement, while tail fins and muscles gave greater thrust. These adaptations launched the adaptive radiation of the Chondrichthyes (kahn DRIK theez): sharks, rays, and skates. The hundreds of cartilaginous fishes include the shark shown in **Figure 24-14**.

Figure 24-14
Sharks

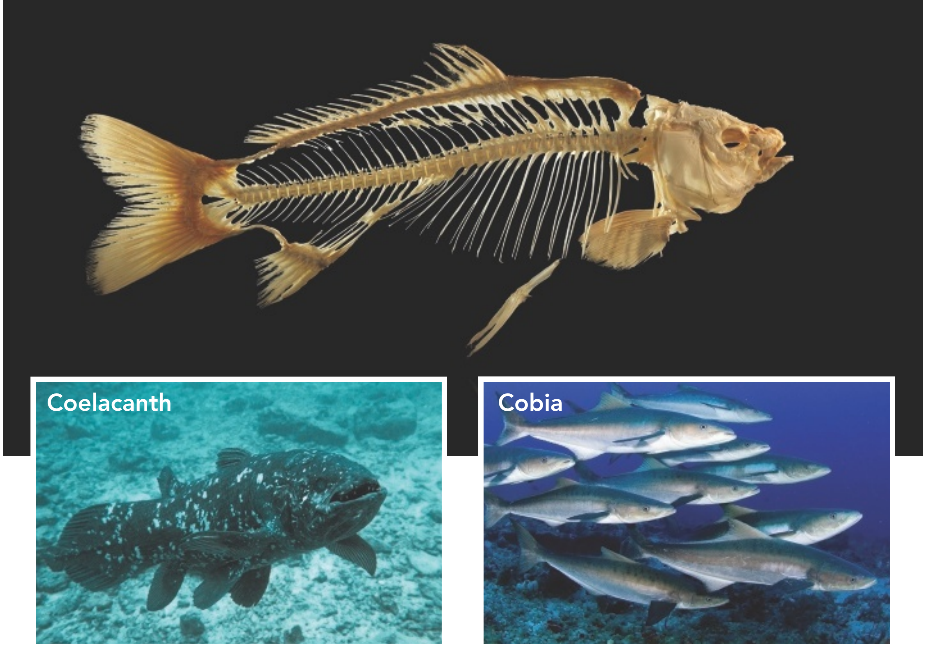
The great white shark is one of the fiercest predators of the ocean.

READING CHECK Review Why were jaws a significant evolutionary development?

Figure 24-15

Bony Fishes

Bony fishes, such as these examples, have skeletons made of true bone. Most fishes alive today are bony fishes.



INTERACTIVITY

Investigate biodiversity on a coral reef.

Bony Fishes Another group of ancient fishes evolved skeletons of true bone, launching the radiation of bony fishes, the Osteichthyes (ahs tee IK theez), as shown in **Figure 24-15**.

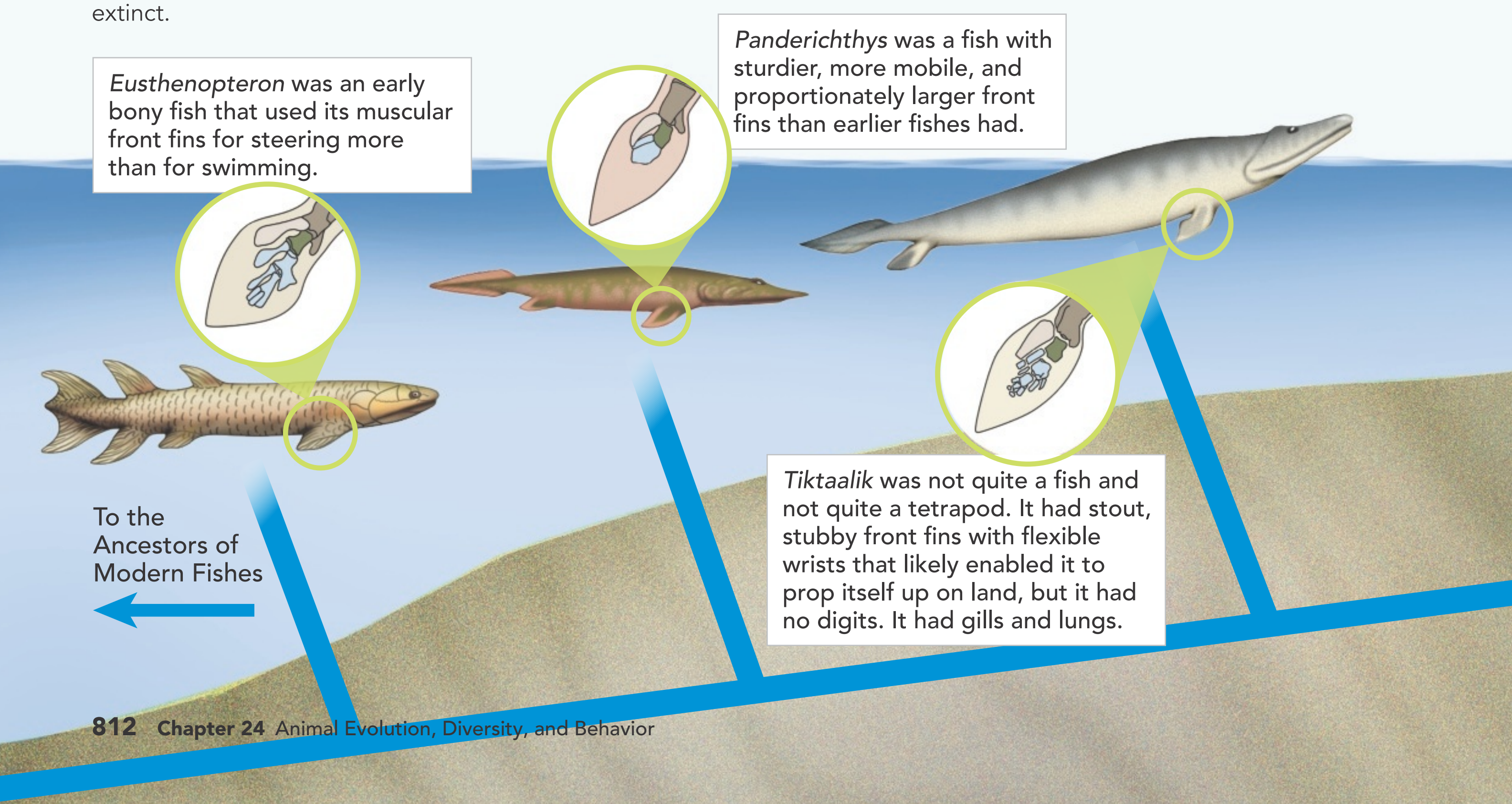
Ray-finned Fishes Most modern bony fishes belong to a huge group called ray-finned fishes, referring to fins formed from bony rays connected by a layer of skin.

Lobe-finned Fishes Lobe-finned fishes evolved fleshy fins supported by larger bones. Modern lobe-finned fishes include lungfishes and coelacanths (SEE luh kanths). One group of ancient lobe-finned fishes evolved into the ancestors of four-limbed vertebrates, or **tetrapods**.

Figure 24-16

From Fins to Feet

The cladogram shows a few of the animal groups in the evolution of the feet of tetrapods from the fins of ancient bony fishes. All of the illustrated animal groups are extinct.



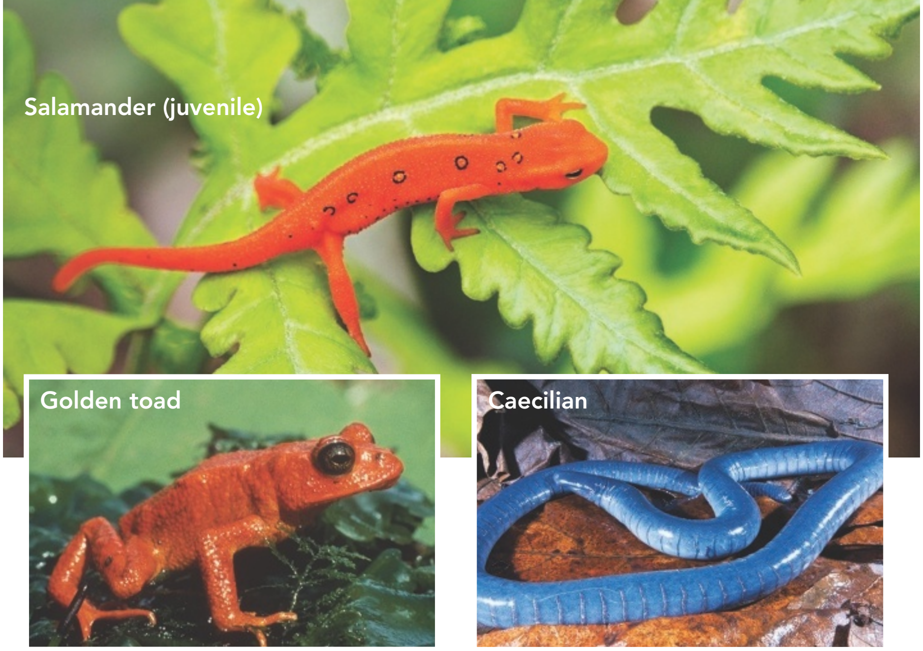


Figure 24-17
Amphibians

The three living orders of amphibians are salamanders, frogs and toads, and caecilians (see SIL ee uhnz). Because amphibians are particularly sensitive to changes in their environment, species have been disappearing at an alarming rate. The Costa Rican golden toad is one of the earliest well-known amphibian species to become extinct due global change.

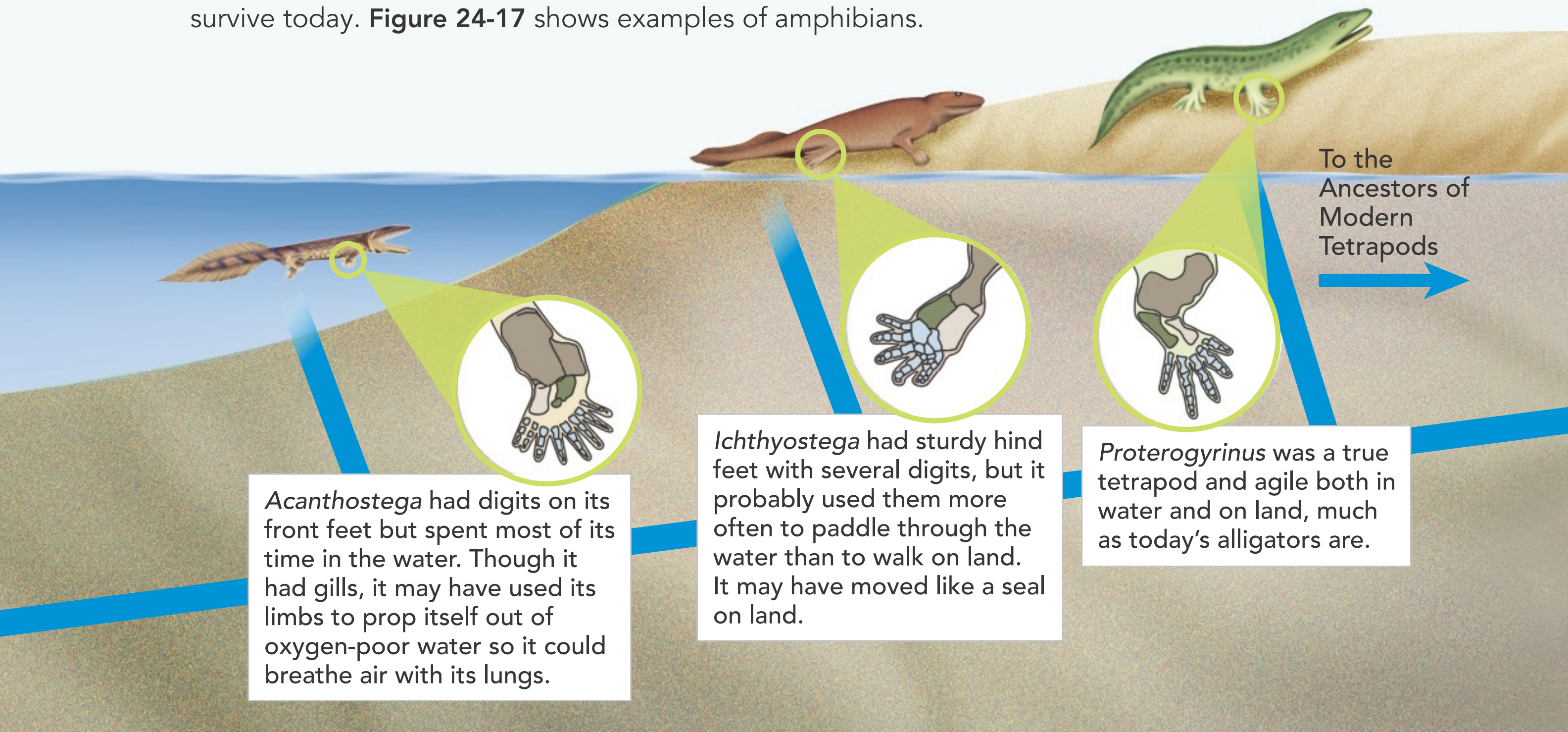
The "Fishapod" A series of spectacular transitional fossils shows how lines of lobe-finned fishes evolved sturdier appendages, as shown in **Figure 24-16**. One of these, *Tiktaalik*, has such a mix of fish and tetrapod features that it could be called a "fishapod"—part fish, part tetrapod.

Amphibians The word *amphibian* means "double life," because most amphibians live in water as larvae but on land as adults. Most require water for reproduction, breathe with lungs as adults, have moist skin with mucous glands, and lack scales and claws.

Early amphibians were the ancestors of reptiles, birds, and mammals. Their adaptations to breathe air and protect themselves from drying out fueled another adaptive radiation. Although they were once the dominant land vertebrates, only three orders of amphibians survive today. **Figure 24-17** shows examples of amphibians.

BUILD VOCABULARY

Root Words The prefix *tetra-* means "four," and the suffix *-pod* means "foot." Tetrapods have four feet or other types of limbs.



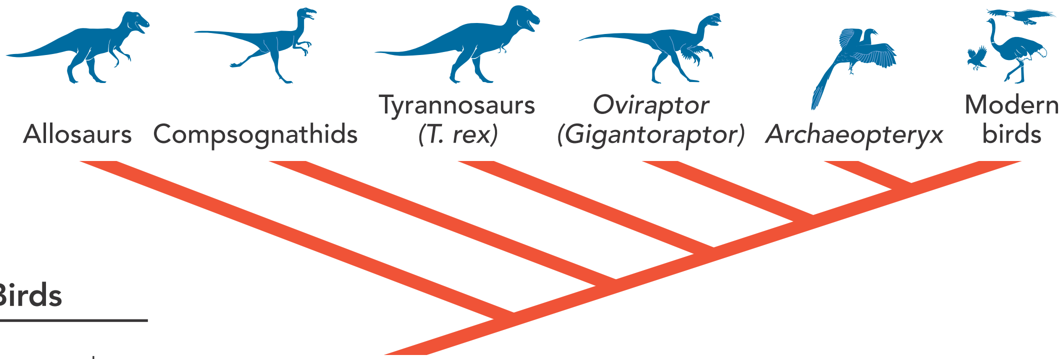


Figure 24-18

Dinosaurs and Birds

The cladogram shows current hypotheses about the relationship between dinosaurs and modern birds.

Reptiles Reptiles evolved from ancient amphibians with dry scaly skin, well-developed lungs, strong limbs, and shelled eggs that do not develop in water. There are five groups of living reptiles: lizards and snakes, crocodilians, turtles and tortoises, the tuatara, and birds.

Enter the Dinosaurs A great adaptive radiation of reptiles continued through the Triassic and Jurassic Periods. Some ate plants; others were carnivorous. Fossils show that some lived in family groups and cared for eggs and young. Some dinosaurs even had feathers, which may have first served as a means of regulating body temperature. The evolutionary lineage that led to modern birds came from one group of feathered dinosaurs.

Exit the Dinosaurs The Cretaceous Period ended with a mass extinction during which most dinosaurs disappeared, along with many other animal and plant groups. This extinction was probably caused by a combination of natural disasters, including massive and widespread volcanic eruptions, a fall in sea level, and a huge asteroid smashing into what is now the Yucatán Peninsula in Mexico.

Birds A series of well-preserved ancient birds and feathered dinosaurs has "connected the dots" between modern birds and their dinosaur ancestors. Look at **Figure 24-18**, and you will see that modern birds form a clade within the clade containing dinosaurs. Because dinosaurs are part of a larger clade of reptiles, modern birds are also reptiles. The first birdlike fossil discovered was *Archaeopteryx* (ahr kee AHP tur iks), from about 150 million years ago during the late Jurassic. *Archaeopteryx* looked so much like a small, running dinosaur that it would be classified as a dinosaur except for its highly evolved feathers. Characteristics of birds include feathers; strong, lightweight bones; two scale-covered legs used for walking or perching; and front limbs modified into wings. Birds also are endotherms. Other living reptiles are almost all ectotherms.

Analyzing Data

Feather Evolution

The information in the table shows the evolution of feathers in some groups of dinosaurs that preceded modern birds.

Group (listed alphabetically)	Feather Status
Allosaurs	None
Archaeopteryx	Flight feathers
Compsognathids	Hairlike feathers
Oviraptors	True feathers
Tyrannosaurs	Branched feathers

1. **Develop Models** Use the information in the table to place these traits correctly on a cladogram. (**Hint:** Use Figure 24-18 as a guide.)
2. **Draw Conclusions** Which type of feathers would you expect modern birds to possess?

Figure 24-19

Mammals

Modern mammals include monotremes, such as echidnas; marsupials, such as opossums; and placentals, such as deer.

Mammals

Members of the clade Mammalia include about 5000 species that range in size from mice to whales and that share characteristics, including mammary glands, which produce milk to nourish young, and hair. Mammals breathe air, have four-chambered hearts, and are endotherms.

The First Mammals True mammals first appeared during the late Triassic, about 220 million years ago. They were very small and resembled modern tree shrews. While dinosaurs ruled, mammals remained small and were probably active mostly at night. New fossils and DNA analyses suggest, however, that the first members of modern mammalian groups, including primates, rodents, and hoofed mammals, evolved during this period. After the great dinosaur extinction at the end of the Cretaceous, mammals underwent a long adaptive radiation. The Cenozoic Era, which began at the end of the Cretaceous, is often called the Age of Mammals.

Modern Mammals By the beginning of the Cenozoic, three major mammal groups had evolved—monotremes, marsupials, and placentals. These three groups differ in their means of reproduction and development.

The egg-laying monotremes, which exist today only in Australia and New Guinea, include the duckbill platypus and four species of echidnas. A short-beaked echidna is shown in **Figure 24-19**. Marsupials, which include kangaroos and koalas, bear live young that usually complete their development in an external pouch. Most familiar mammals are placental mammals, which have embryos that develop completely inside the mother.

HS-LS4-1

LESSON 24.2 Review

KEY QUESTIONS

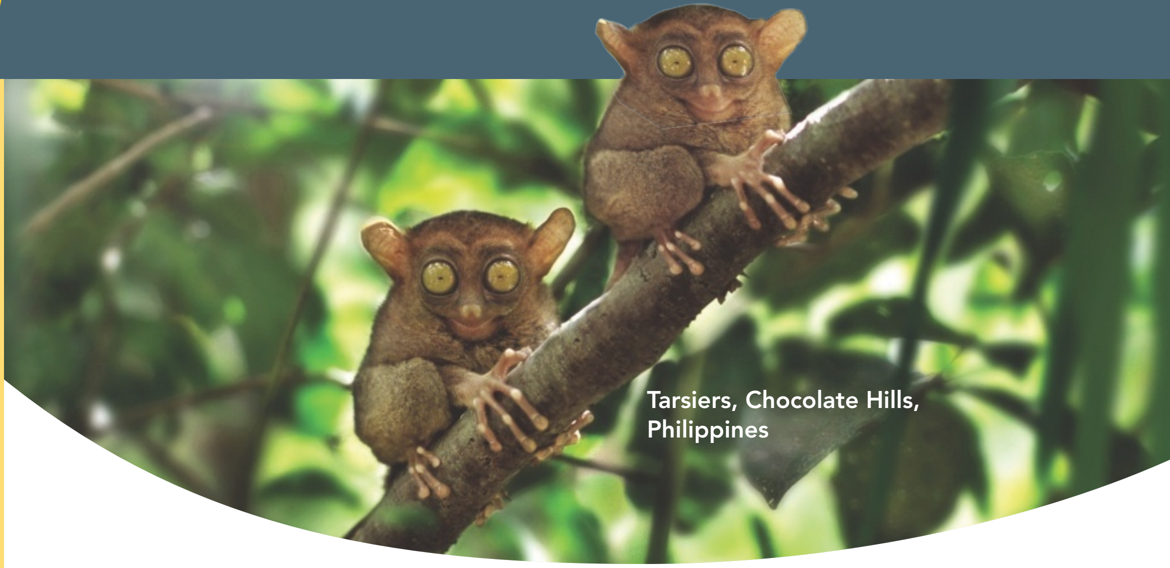
1. What two features define animal phyla?
2. According to fossil evidence, when did the first animals evolve?
3. Did true bones or lungs evolve first? Explain how Figure 24-11 shows the answer.

CRITICAL THINKING

4. **Develop Models** Design a "new" invertebrate. Create an illustration on which you point out its body plan features. Then show its place on the cladogram of invertebrates, and write a caption explaining how its features helped you decide where it belongs.
5. **CASE STUDY** Corals live in a symbiotic relationship with photosynthetic algae. Based on what you know about photosynthesis and the needs of animals, how do you think this relationship benefits these cnidarians?

LESSON 24.3

Primate Evolution



Tarsiers, Chocolate Hills, Philippines

KEY QUESTIONS

- *What characteristics do all primates share?*
- *What are the major groups of primates?*
- *What adaptations enable later hominin species to walk upright?*
- *What is the current scientific thinking about the genus Homo?*

HS-LS4-1: Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence.

VOCABULARY
hominoid
opposable thumb
bipedal

READING TOOL

Use the timeline in your **Biology Foundations Workbook** to identify in which order each species of primate developed.

VIDEO

Travel to Kenya to learn about baboons.

Human beings are part of the family of primates. Primates are intelligent and social creatures who exhibit complex behaviors. Many primates live in tropical and subtropical regions and are well adapted to living in trees, but humans are an exception to this.

What Is a Primate?

Primates, including lemurs, monkeys, and apes, share several adaptations for a life spent in trees. ***In general, a primate is a mammal with relatively long fingers, toes with nails instead of claws, arms that can rotate around shoulder joints, a strong clavicle, binocular vision, and a well-developed cerebrum.***

Fingers, Toes, and Shoulders Primates typically have five flexible fingers and toes on each hand or foot that can curl to grip objects firmly and precisely. Most primates also have thumbs and big toes that can move against the other digits. Primates' arms are well suited for climbing because they can rotate in broad circles around a strong shoulder joint attached to a strong collarbone, or clavicle.

Binocular Vision Both eyes of many primates face forward, with overlapping fields of view that provide excellent binocular vision. This offers depth perception and a three-dimensional view of the world—a handy thing to have for judging the locations of tree branches, from which many primates swing.

Well-Developed Cerebrum In primates, the "thinking" part of the brain—the cerebrum—is large and intricate, enabling complex behaviors. Many primate species create elaborate social systems that include extended families, adoption of orphans, and even warfare between rival troops.

Evolution of Primates

Humans and other primates evolved from a common ancestor that lived more than 65 million years ago. Early on, primates split into two groups, as shown in **Figure 24-20**. ***Primates in one group, which contains the lemurs and lorises, don't look much like typical monkeys. The other group includes tarsiers and the anthropoids, or humanlike primates.***

READING TOOL

As you read about primate evolution, use the cladogram in Figure 24-20 to identify and compare the groups.

Lemurs and Lorises

With few exceptions, lemurs and lorises are small and nocturnal. They have large eyes adapted to seeing in the dark and long snouts. Living members include the bush babies of Africa, the lemurs of Madagascar, and the lorises of Asia.

Tarsiers and Anthropoids

Primates more closely related to humans than to lemurs belong to a different group, members of which have broader faces and widely separated nostrils. This group includes the tarsiers of Asia and the anthropoids. Anthropoids split into two groups around 45 million years ago, as the continents on which they lived moved apart.

INTERACTIVITY

Investigate the evolution of primates.

New World Monkeys Members of one anthropoid branch, the New World monkeys, are found in Central and South America. (Europeans called the Americas the "New World.") Members of this group, which include spider monkeys and squirrel monkeys, live mainly in trees. They have long flexible arms that help them swing from branch to branch. They also have a long prehensile tail that can coil tightly around a branch to serve as a "fifth hand."

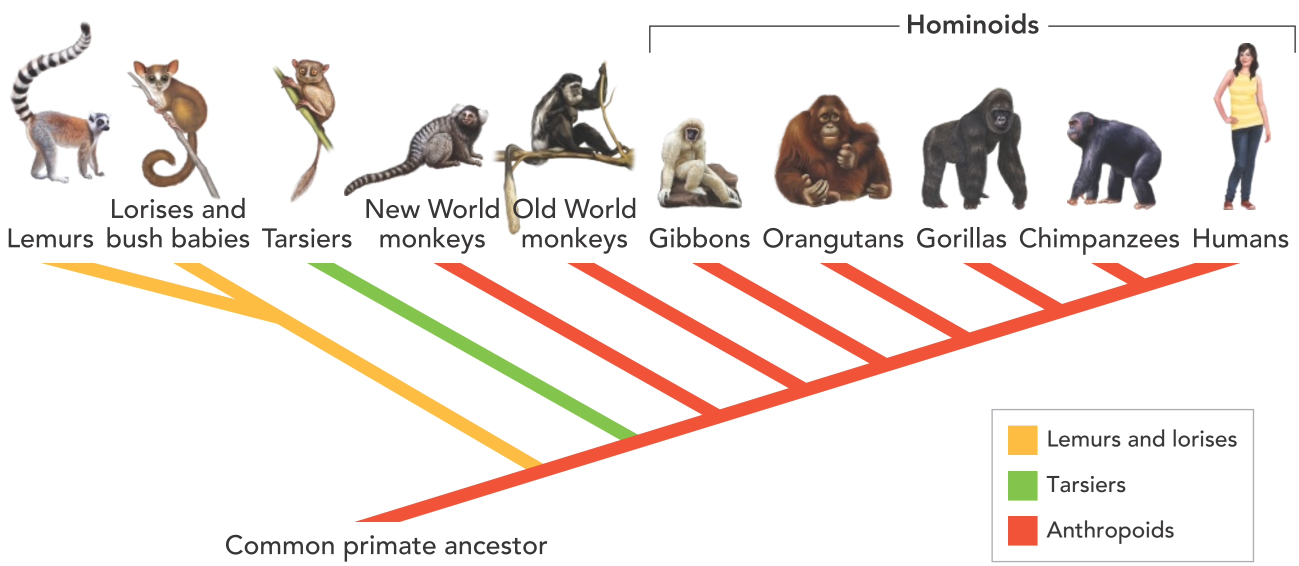
Old World Monkeys and Great Apes The other anthropoid branch, which evolved in Africa and Asia, includes Old World monkeys and great apes. Old World monkeys, such as langurs and macaques, spend time in trees but lack prehensile tails. Great apes, also called **hominoids**, include gibbons, orangutans, gorillas, chimpanzees, and humans. Recent DNA analyses confirm that among the great apes, chimpanzees are humans' closest living relatives.

INTERACTIVITY

Figure 24-20

Cladogram of Primates

The diagram illustrates current hypotheses about evolutionary relationships among modern primates.



Hominin Evolution

Between 6 and 7 million years ago, hominins, the lineage that includes modern humans and closely related species, split from the lineage that led to chimpanzees. Hominins evolved grasping thumbs and large brains. ***The skull, neck, spinal column, hip bones, and leg bones of early hominin species changed shape in ways that enabled later species to walk upright.*** Hominins also evolved an **opposable thumb** that could touch other fingertips, enabling them to grasp objects and use tools.

In addition, hominins evolved much larger brains. The brains of chimpanzees range in volume from 280 to 450 cubic centimeters. Our brains, on the other hand, range from 1200 to 1600 cubic centimeters! Most differences in brain size between species result from a greatly expanded cerebrum.

Hominin Relationships Most paleontologists agree that the hominin fossil record includes seven genera—*Sahelanthropus, Orrorin, Ardipithecus, Australopithecus, Paranthropus, Kenyanthropus*, and *Homo*—at least 20 species, and a few subspecies. All these hominin species are *relatives* of modern humans, but not all are human *ancestors*. To understand that distinction, think of your family. Your aunts, uncles, cousins, parents, grandparents, and great-grandparents are all your relatives. But only parents, grandparents, and great-grandparents are your ancestors.

Distinguishing hominin relatives from ancestors is an ongoing challenge. Researchers once thought that human evolution took place in simple steps in which hominin species evolved more human-like traits over time. But it is now clear that hominin adaptive radiations produced a number of species whose relationships are not at all clear. At present, there is no single, universally accepted hypothesis about the hominin family tree, so **Figure 24-21** presents current data in the form of a timeline, rather than as a cladogram.

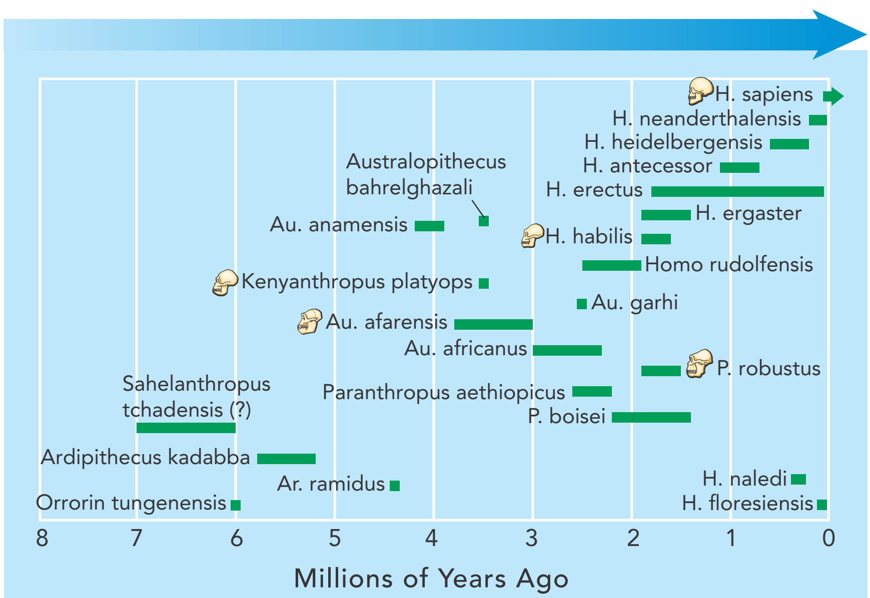
INTERACTIVITY

Explore the traits that distinguish primates from one another.

Figure 24-21

Hominin Time Line

The diagram shows hominin species known from fossils and the time ranges during which each species probably existed. These time ranges may change as paleontologists gather new data.



New Findings and New Questions The study of human ancestors, which now includes both traditional studies of fossils and DNA analysis, is constantly changing. Since the 1990s, fossil discoveries more than doubled the number of known hominin species. The oldest hominin may be *Sahelanthropus*, known from a skull roughly 7 million years old that was discovered in 2002. Scientists still debate whether *Sahelanthropus* was a hominin, and how it and other fossil hominins are related to one another, and to humans. Exciting breakthroughs in recovery and analysis of ancient DNA have recently made it possible to piece together significant amounts of genetic material from some hominin fossils. Researchers are now comparing those partial genomes with each other, and with modern human DNA. Early results suggest strongly that at least one, and possibly three other species in the genus *Homo* interbred with each other and with the ancestors of modern humans! Stay tuned for further developments!

Australopithecus The genus *Australopithecus* lived from about 4 million to about 1.5 million years ago. They were **bipedal** apes, which means they walked on two feet. Their skeletons suggest that they probably spent time in trees. Their tooth structure suggests a diet rich in fruit. The best-known species is *Australopithecus afarensis*, which lived from roughly 4 million to 2.5 million years ago. Other fossils of this genus indicate that males were much larger than females. The best-known *A. afarensis* specimen is a female nicknamed "Lucy," discovered in 1974, and shown in **Figure 24-22**. Lucy stood about 1 meter tall and lived about 3.2 million years ago.

In 2006, an Ethiopian researcher announced the discovery of well-preserved 3.3-million-year-old fossils of a young female hominin. This fossil was assigned to *A. afarensis*, the same species as Lucy, and nicknamed "the Dikika Baby," after the region in Africa where it was discovered. Leg bones confirmed that the Dikika Baby walked bipedally, while her arm and shoulder bones suggest that she would have been a better climber than modern humans.

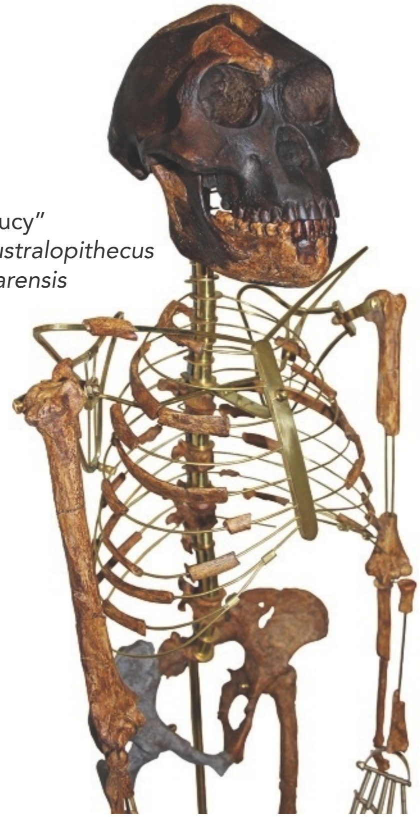
The Road to Modern Humans

Hominins that we have discussed so far lived millions of years before modern humans. ***Many species in our genus existed before Homo sapiens, and at least three other Homo species existed alongside early humans at the same time.*** Paleontologists still don't fully understand the evolutionary and genetic relationships among species in our genus.

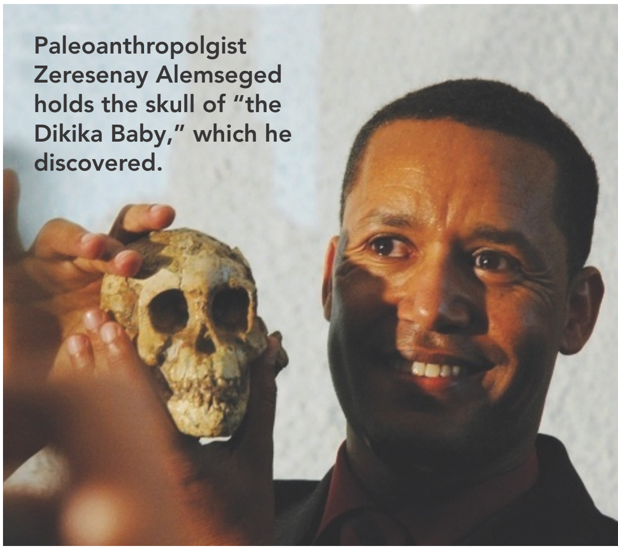
Figure 24-22

Lucy and the Dikika Baby

"Lucy" and "the Dikika Baby" are nicknames of two very important fossils of the hominin *A. afarensis*. These two fossils were discovered just 6 miles apart in Ethiopia.



"Lucy" *Australopithecus afarensis*



Paleoanthropolgist Zeresenay Alemseged holds the skull of "the Dikika Baby," which he discovered.

BUILD VOCABULARY

Multiple Meanings The prefix *homo*- can mean "alike," as in *homologous* or *homogenous*. This prefix has Greek origins. In this lesson, *Homo*, which has a Latin origin, refers to the genus for humans.

The Genus *Homo* About 2 million years ago, a new group of hominin species appeared in the fossil record. Several resemble modern humans closely enough to be classified in the genus *Homo*. One set of fossils was found with tools made of stone and bone, so it was named *Homo habilis*, which means "handy man" in Latin. The earliest fossils most researchers definitely assign to the genus *Homo* have been called *Homo ergaster*. *H. ergaster* was larger than *H. habilis* and had a bigger brain and downward-facing nostrils that resemble those of modern humans. *Homo rudolfensis* appeared before *H. ergaster*, but some researchers choose to classify it in the genus *Australopithecus* instead of *Homo*.

Homo naledi In 2015, researchers announced the discovery of an astonishing collection of hominin remains in a cave near Johannesburg, South Africa. This fossil treasure-trove included several remarkably complete skeletons from several small-brained hominins with a confusing mix of ape-like and human-like characteristics. These specimens have been named *Homo naledi*.

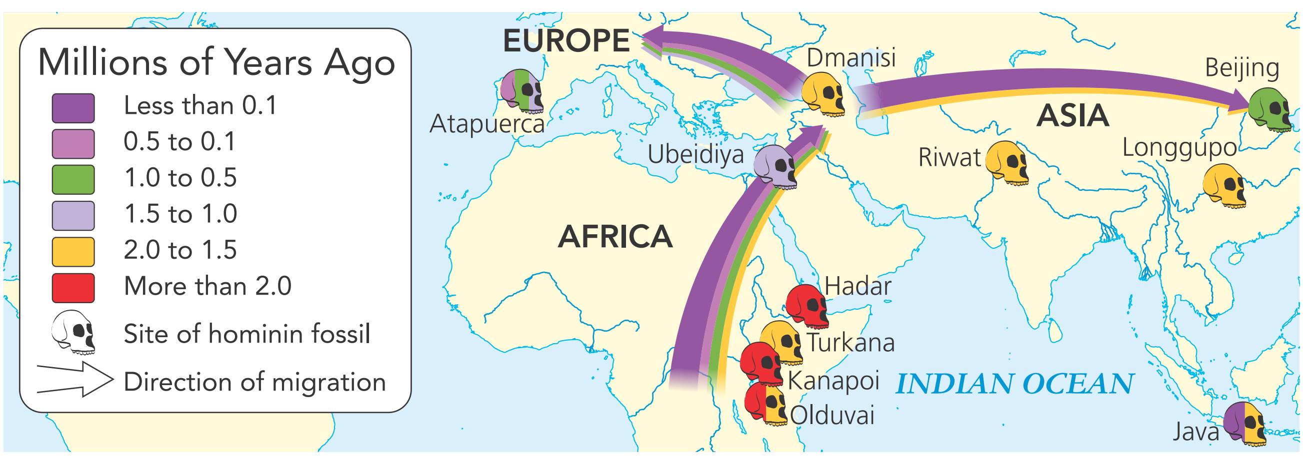
Homo neanderthalensis (or H. sapiens neanderthalensis)
Neanderthals—which some scientists consider a separate species, and others consider a sub-species of *H. sapiens*—flourished in Europe and western Asia beginning about 200,000 years ago. Evidence suggests that they made stone tools, lived in complex social groups, had controlled use of fire, and were excellent hunters. They buried their dead with simple rituals. Individuals whose fossils have been identified as Neanderthals survived in parts of Europe until about 28,000 to 24,000 years ago.

Out of Africa—But When and Who? Researchers agree that our genus originated in Africa and migrated from there to populate the world. But several questions remain about the evolution and migrations of species within our genus. Some of those questions have been complicated by recent genetic evidence for interbreeding among early humans and their relatives. You can explore some current hypotheses with **Figure 24-23**.

Figure 24-23

Out of Africa

Data show that relatives and ancestors of modern humans left Africa in waves. But when—and how far did they travel? By comparing the mitochondrial DNA of living humans and continuing to study the fossil record, scientists hope to improve our understanding of the complex history of *Homo sapiens*. (Note: The skull symbol represents any hominin fossils found—they might not have included skulls.)



Fossil and molecular evidence both suggest that some hominins left Africa long before *Homo sapiens* evolved. It also appears that several *Homo species* made the trip later, in waves. Experts differ about the identity of some fossils, but agree that hominins began leaving Africa at least 1.8 million years ago.

Homo erectus in Asia According to some researchers, groups of *Homo erectus* left Africa and traveled across India and China to Southeast Asia. In fact, some of the oldest specimens of *H. erectus* were uncovered on the Indonesian island of Java. This suggests that these ancient wanderers spread rapidly once they left Africa.

The First _Homo sapiens_ Paleontologists debate where and when *Homo sapiens* arose. The multiregional hypothesis suggests that modern humans evolved independently, in several places, from separated *H. erectus* populations. Still-emerging genetic evidence suggests that some differences among populations of modern humans can be traced back to interbreeding among hominin species and different groups of ancient humans. The "out-of-Africa" hypothesis proposes that modern humans evolved in Africa about 200,000 years ago, migrated through the Middle East, and replaced descendants of earlier hominin species.

Molecular biologists have analyzed mitochondrial DNA from living humans around the world to determine when we last shared a common ancestor. The estimated date for that African common ancestor is between 200,000 and 150,000 years ago. More recent DNA data suggest that a subset of those African ancestors left northeastern Africa between 65,000 and 50,000 years ago.

Modern Humans

Homo sapiens with modern skeletons arrived in the Middle East about 100,000 years ago. By about 50,000 years ago, they were using sophisticated tools of stone, bones, and antlers. They produced cave paintings, and buried their dead with rituals. In other words, these people, began to behave like modern humans. Neanderthals and *H. sapiens* lived side by side for thousands of years. Researchers once thought that Neanderthals disappeared. More recent genetic evidence suggests Neanderthals interbred with *H. sapiens* ... and survive today as parts of our modern human genomes! For whatever reason, our species, *Homo sapiens*, is the only surviving member of the once large and diverse hominin clade.

HS-LS4-1

LESSON 24.3 Review

KEY QUESTIONS

1. How do the characteristics of primates help them to survive in their environment?
2. At what point did the two groups of anthropoids split, and why?
3. How was bipedal locomotion important to hominin evolution?
4. List other *Homo* species that existed at the same time as *Homo sapiens*.

CRITICAL THINKING

5. **Compare and Contrast** How are modern humans similar to other primates? What traits set humans apart?

LESSON 24.4

Social Interactions and Group Behavior

KEY QUESTIONS

- *How can behavior serve as an adaptation that affects reproductive success?*
- *What are the major types of learning?*
- *How do periodic environmental changes affect behavior?*
- *How can social behaviors increase evolutionary fitness?*
- *How do animals communicate?*

HS-LS2-8: Evaluate the evidence for the role of group behavior on individual and species' chances to survive and reproduce.

HS-LS4-4: Construct an explanation based on evidence for how natural selection leads to adaptation of populations.

VOCABULARY

behavior
society
kin selection
communication
language

READING TOOL

Compare and contrast the similarities and differences among each type of social interaction. List them in your **Biology Foundations Workbook.**

Outside a seaside restaurant, a young tourist eats a hamburger, unaware that he's being watched—by an iguana. When the boy spots the iguana, he jumps up onto his chair with a shriek. But the iguana, a shy, tree-dwelling vegetarian, ignores the boy. She rushes for some French fries that were knocked to the ground. Iguanas don't normally approach humans. But this one has learned that getting close to humans can provide access to food.

Behavior and Evolution

The hungry iguana is demonstrating **behavior**, a response to stimuli in the environment. Although many behaviors are triggered by an external stimulus, an individual's response to that stimulus often depends on its internal condition. If the iguana hadn't been hungry, for example, it would probably have kept its distance from the boy and his French fries!

You've learned how physical characteristics, including the nervous system, are shaped by genetic instructions. So, it shouldn't surprise you to learn that some behaviors are also influenced by genes, can be inherited, and can therefore evolve in response to natural selection. For example, genes that code for the behavior of the moth in **Figure 24-24** help the moth escape predators. ***If a behavior influenced by genes serves as an adaptation that increases an individual's fitness, that behavior will tend to spread through a population.***

How do newly hatched birds know to beg for food moments after hatching? How does a spider know how to spin its web? These innate behaviors, also called instincts, appear in fully functional form the first time they are performed, without any previous experience.

Figure 24-24

Anti-Predatory Display

Moths of the genus *Automeris* normally rest with the front wings over their hind wings. If disturbed, however, the moth will move its front wings to expose a striking circular pattern on its hind wings. This behavior may scare off predators that mistake the moth's hind-wing pattern for the eyes of a predatory owl, such as the great horned owl.

Learned Behavior

Many complex animals live in unpredictable environments where fitness can depend on behaviors that can be changed as a result of experience, or what we call learning. ***Four major types of learning that scientists have identified are habituation, insight learning, classical conditioning, and operant conditioning.***

READING TOOL

As you read about the types of learned behaviors, make a list of examples of your own experiences of learning or of your observations of young children or pets.

Habituation The simplest type of learning is habituation, a process by which an animal decreases or stops responding to stimuli that neither rewards nor harms it. Consider the common shore ragworm, which lives in a sandy tube that it leaves to feed. If a shadow passes overhead, the worm will instantly retreat to the safety of its burrow. Yet if repeated shadows pass, the worm will learn that the shadow is neither food nor threat and stop responding. The worm will have become habituated to the stimulus.

Insight Learning The most complicated form of learning is insight learning, or reasoning, which occurs when an animal applies something it has already learned to a new situation. For instance, if you are given a new math problem on an exam, you may apply principles you have already learned to solve it. Insight learning is common among humans and some other primates. It may occur in birds and might possibly occur in some octopuses.

VIDEO

Learn how turkeys became domesticated.

Figure 24-25

Operant Conditioning

After this dog randomly picked up its leash, its owner took it for a walk. This reinforced the behavior. The dog now picks up its leash when it wants to go for a walk—and its owner is similarly trained to attach the leash and take the dog out, lest the dog resort to less positive means of communicating.

Classical Conditioning One evening, you eat a kind of food you've never tried before. Shortly after eating it, you get sick from a stomach virus. You feel better the next day, but when your parents present you with leftovers of the same food, you feel sick again. From that time on, whenever you smell that particular food, you become nauseated. This is an example of classical conditioning, a form of learning in which a certain stimulus comes to produce a particular response, usually through association with a positive or negative experience. In this case, the stimulus is the smell of that particular food, and the response is nausea. The food didn't make you sick, but you've been conditioned to associate the smell of that food with feeling sick.

Operant Conditioning Operant conditioning occurs when an animal learns to behave in a certain way to receive a reward or to avoid punishment. Operant conditioning was first described by the American psychologist B. F. Skinner. Skinner invented a procedure using what is called a "Skinner box," which contains a button or lever that delivers a food reward when pressed. After an animal is rewarded several times, it learns that it gets food whenever it presses the button or lever. At this point, the animal has learned by operant conditioning how to obtain food. In **Figure 24-25**, you can see how a dog can be trained to constructively communicate its desire to go for a walk.

Behavioral Cycles

Animals, including humans, do not behave in the same way at all times or in all places. We are affected by our environment, which is often changing. ***Many animals respond to periodic environmental changes with daily or seasonal behavioral cycles.*** Behavioral cycles that occur daily are called circadian rhythms. Other cycles are seasonal. In temperate and polar ecosystems, many species enter a sleeplike state, or hibernation, during winter. This behavioral and physiological adaptation allows organisms to survive periods when food and other resources may not be available.

Another seasonal behavior is migration, the seasonal movement from one environment to another. For example, many songbirds travel to warm tropical regions where food remains available during northern winters. When these birds fly north in the spring, they take advantage of seasonally abundant food and find space to nest and raise their young.

INTERACTIVITY

Explore the migration patterns of bats.

READING CHECK Compare How do hibernation and migration differ from circadian rhythms?

HS-LS2-8

Modeling Lab

Open Ended Inquiry

The Role of Group Behavior

Problem How can group behaviors help animals survive?

In this lab, you will develop and use a model to demonstrate how group behavior can help prey avoid attacks from predators. Then you will use the model to present an explanation for how group behaviors affect an animal's chances to survive and reproduce, and how these behaviors became common in animal populations.

You can find this lab in your digital course.

Social Behavior

Whenever birds sing, bighorn sheep butt heads, or chimpanzees groom each other, they are engaging in social behavior. Social behaviors include courtship, territoriality, aggression, and the formation of societies. ***Social behaviors, such as choosing mates, defending territories or resources, and forming social groups, can increase evolutionary fitness.***

INTERACTIVITY

Investigate the social behavior of various animals.

Courtship Members of sexually reproducing animal species must locate and mate with other members of their species to reproduce. Courtship is behavior during which members of one sex (usually males) advertise their willingness to mate, and members of the opposite sex (usually females) choose which mate they will accept. Typically, males send out signals that include sounds, visual displays, or chemicals, which attract females. The musical trill of a tree frog, for example, is a breeding call. In some species, courtship involves an elaborate series of behaviors, called rituals, that consist of specific signals and responses that continue until mating occurs. For example, gannets bond by engaging in "beak pointing," or intertwining their necks while pointing their beaks to the sky. Other birds dance for each other, as shown in **Figure 24-26**.

Figure 24-26

Courtship

Male and female cranes perform a dance for each other as a form of courtship.

Territoriality and Aggression Many animals occupy and defend a specific area, or territory, that contains resources, such as food, water, nesting sites, shelter, and potential mates. If a rival enters a territory, the "owner" attacks in an effort to drive the rival away. While competing for resources, animals often show aggressive, threatening behaviors used to exert dominance. Fights between male sea lions over territory and "harems" of females often leave both rivals bloodied.

INTERACTIVITY

Figure 24-27
Animal Societies

As these African wild dog pups play, they reinforce social bonds that grow into mature social behaviors. Honeybees have extremely complex societies, in which worker bees cooperate to perform complex tasks ranging from finding food to building honeycombs.

Animal Societies A **society** is a group of animals of the same species that interact closely and often cooperate. Societies can offer a range of advantages that can produce differential reproductive success between group members and individuals. Zebras, for example, are safer from predators when they are part of a group than when they are alone. Societies can also improve animals' ability to hunt, to protect their territory, to guard their young, or to fight with rivals. In wild African dog packs, for instance, adult females take turns guarding all the pups in the pack, while the other adults hunt for prey. Macaque, baboon, and other primate societies hunt together, travel in search of new territory, and interact with neighboring societies.

Members of a society are often related to one another. Elephant herds, for example, consist of mothers, aunts, and their offspring. (Males are kicked out when they reach puberty.) The theory of **kin selection** holds that helping relatives can improve an individual's evolutionary fitness because related individuals share a large proportion of their genes. Helping a relative survive, therefore, increases the chance that the genes an individual shares with that relative will be passed along to offspring.

The most extreme examples of relatedness, and the most complex animal societies (other than human societies), are found among social insects such as ants, bees, and wasps. In social insect colonies, all individuals cooperate to perform extraordinary feats, such as building complex nests. In a bee colony, such as the one in **Figure 24-27**, all workers in the colony are females who are very closely related—which means that they share a large proportion of each others' genes. Worker bees are also sterile. For this reason, it is advantageous for them to cooperate to help their "mother" (the queen) reproduce and raise their "sisters" (other workers). Male bees function only to fertilize the queen.

BUILD VOCABULARY

Use Prior Knowledge The word *society* is used to describe interactions within human communities. Many animal societies involve close interactions and cooperation.

Communication

Because social behavior involves more than one individual, it requires **communication**—the passing of information from one individual to another. Communication is an important adaptation among many species. ***Animals may use a variety of signals to communicate, including visual signals, chemical signals, sound, and language.*** See the examples shown in **Figure 24-28**.

Visual Signals Many animals use visual signals, and they have eyes that sense shapes and colors. In many species, males and females have different color patterns, and males use color displays to advertise their readiness to mate.

Chemical Signals Many animals have well-developed senses of smell, and they communicate with chemical signals. Some animals, including lampreys, bees, and ants, release chemical messengers called pheromones that affect the behavior of other individuals of the same species. Pheromones could be used to mark a territory or signal a readiness to mate.

Sound Signals Many species make and detect sounds, and some have evolved elaborate systems of communication. Dolphins communicate using sound signals that travel long distances. Elephants, and some other animals, can send messages through the ground, or through water, that recipients feel rather than hear.

Language The most complicated form of communication is **language**—a system that combines sounds, symbols, and gestures according to rules about sequence and meaning, such as grammar and syntax. Many animals, including elephants, primates, and dolphins, have complex communication systems. Some seem to have "words"—calls with specific meanings, such as "lions on the prowl." Many species, including honeybees, convey complex information using various kinds of signals. However, untrained animals don't seem to use the rules of grammar and syntax that we use to define human language.

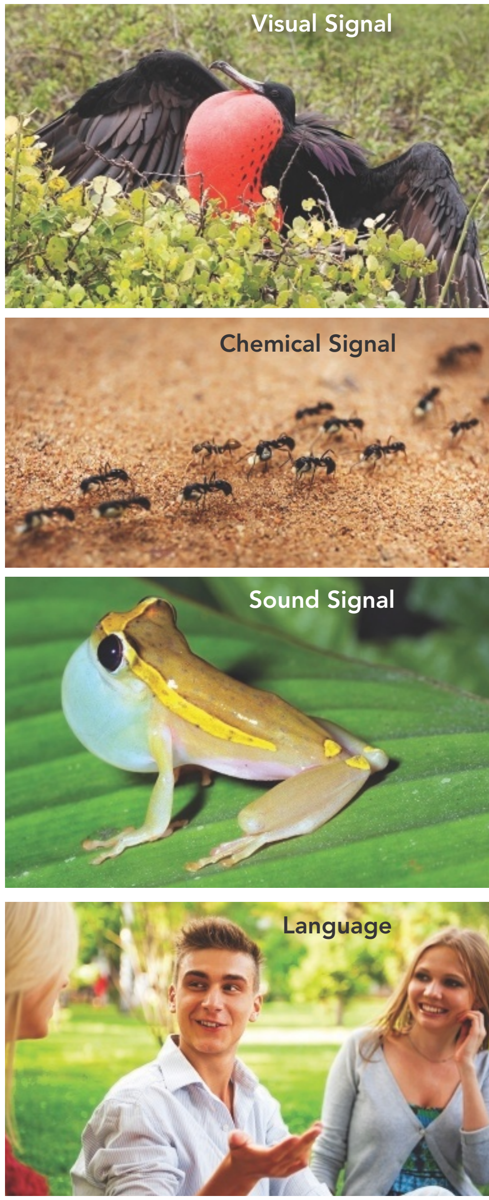


Figure 24-28

Communication Signals

Animals use many strategies to send and receive messages.

HS-LS2-8, HS-LS4-4

LESSON 24.4 Review

KEY QUESTIONS

1. How does natural selection affect behavior?
2. Give one example of how humans might learn through classical conditioning.
3. Name two ways in which animal behavior is related to environmental cycles.
4. How does membership in a society increase the evolutionary fitness of individuals in the society?
5. What are the main ways in which animals communicate with one another?

CRITICAL THINKING

6. **Apply Scientific Reasoning** Explain two ways that an animal's social behavior can influence its evolutionary fitness.

CASE STUDY WRAP-UP

How are reefs affected by global change?

As atmospheric carbon dioxide concentrations increase, both air and water temperatures also increase, and the ocean becomes more acidic. What other aspects of global change affect reefs?

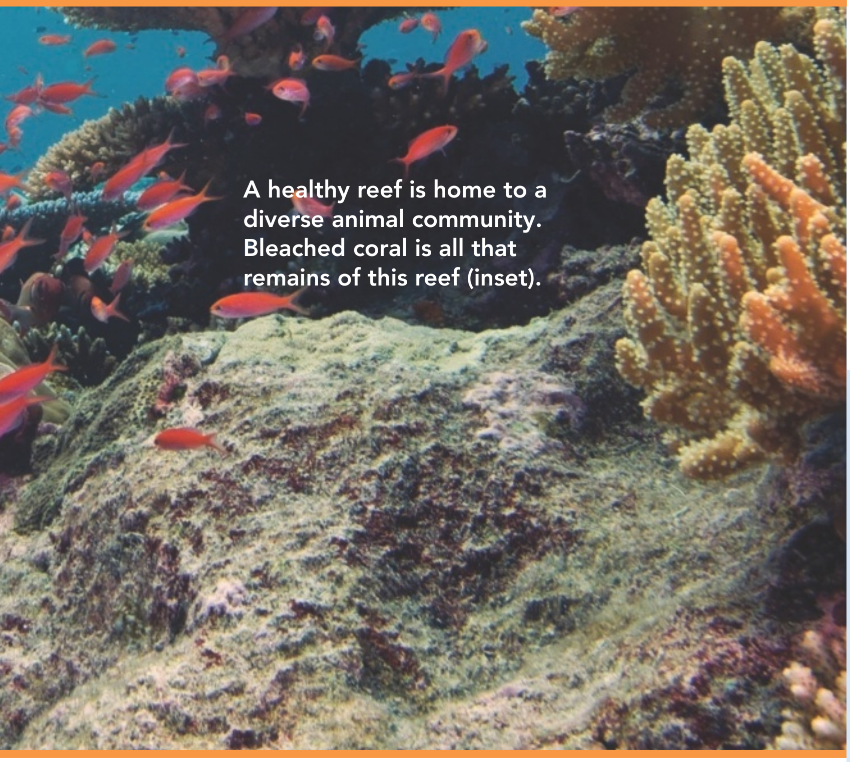
HS-LS2-7, HS-LS4-3, HS-LS4-6, HS-ESS2-4, HS-ESS3-5, CCSS.ELA-LITERACY.RST.9-10.1, CCSS.ELA-LITERACY.RST.9-10.2, CCSS.ELA-LITERACY.WHST.9-10.2, CCSS.ELA-LITERACY.WHST.9-10.7, CCSS.ELA-LITERACY.WHST.9-10.8, CCSS.ELA-LITERACY.WHST.9-10.9

Make Your Case

Each clade of animals has evolved a range of physical, physiological, and behavioral adaptations that allow them to “make a living” and maintain homeostasis in the environments they inhabit. When environmental conditions change slowly, some populations can adapt. If conditions change too rapidly, species are stressed and can go extinct. And, if a keystone species or group of species such as corals goes extinct, entire ecosystems can collapse.

Construct an Explanation

1. **Conduct Research** Find out what is happening to coral reefs around the world as oceans warm and become more acidic. Then search for various ways that other forms of human-caused global change are affecting reef ecosystems. Include at least three additional factors.
2. **Defend Your Claim** Compare what we know about the ways corals and coral reefs respond to these changes with what scientists think happened to rudists and their ancient reefs. What other clades of organisms are involved? Propose a hypothesis about the future of coral reefs. Gather further information about global change and its effects to defend your explanation.


A healthy reef is home to a diverse animal community. Bleached coral is all that remains of this reef (inset).

Society on the Case

A Helping Hand to Wildlife

Climate change is arguably the most serious long-term threat to wildlife. It certainly is not the only threat. Human activities that threaten wild animals include cutting down forests, draining wetlands, and letting cities and suburbs expand into wilderness regions. Pollution also takes its toll on wildlife, as does overhunting and overfishing.

The good news is that everyone can take actions to help wildlife. Here are a few simple things you can do that can make a difference.

Conserve Energy, Fresh Water, and Other Resources Conserving all resources helps wildlife and people worldwide. The use of fossil fuels contributes to climate change, so reducing their use is a small step in the right direction.

Eat Sustainable Food A sustainable practice is able to last for many years. Some animal foods, especially many seafoods, might not be available in the future if their current rates of harvest continue. Begin by learning more about the foods you eat. Try to eat foods raised locally on small farms.

Visit a Zoo or an Aquarium Part of your admission fee to these places is used to support wildlife conservation around the world. You also will learn more about wildlife and how you can help wildlife in your community.

Care for the Animals Near You Look for easy ways to protect wildlife in your neighborhood. A statue of an eagle or owl can keep birds from crashing into windows. Keeping your cat indoors can protect young birds, snakes, and other prey.

Careers on the Case

Work Toward a Solution

People in all sorts of careers are studying climate change and its wide-ranging effects. Some scientists are investigating ways to slow or stop climate change, or even reverse it. Others are working to manage its effects, including those on wildlife.


Jane Goodall

Ethologist

Ethology is the study of animal behavior. Experts in ethology work at zoos and wildlife sanctuaries, as well as at universities and government institutions. They often are asked to predict how animals will respond to changes in their environment—and how harmful responses can be altered.

VIDEO

Watch this video to learn about other careers in biology.

hhmi | BioInteractive

CHAPTER 24

STUDY GUIDE

Lesson Review

Go to your Biology Foundations Workbook for longer versions of these lesson summaries.

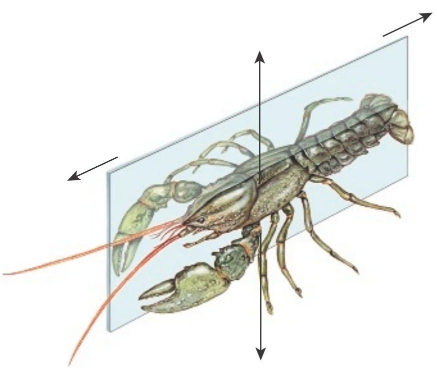
24.1 Introduction to Animals

Animals are multicellular, heterotrophic, eukaryotic organisms, with cells that lack cell walls. Animals can be grouped into two large groups: invertebrates and chordates. Invertebrates include all animals that lack a backbone, or vertebral column. All chordates exhibit four characteristics during at least one stage of life: a dorsal, hollow nerve cord; a notochord; a tail that extends beyond the anus; and pharyngeal pouches.

Like all organisms, animals must keep their internal environment relatively stable, in a process known as homeostasis. Animals maintain homeostasis by gathering and responding to information, obtaining and distributing oxygen and nutrients, and collecting and eliminating carbon dioxide and other wastes. They must also reproduce.

Each animal phylum has a unique organization of particular body structures that is often referred to as its body plan. Features of animal body plans include levels of organization, body symmetry, formation of body cavities, patterns of embryological development, segmentation, cephalization, and limb formation.

- invertebrate
- chordate
- vertebrate
- feedback inhibition
- radial symmetry
- bilateral symmetry
- zygote
- coelom
- cephalization



Use Visuals Discuss how the features of animal body plans relate to this visual.

24.2 Animal Evolution and Diversity

Animal clades are typically defined according to adult body plans and patterns of embryological development.

The fossil record indicates that the first animals began evolving long before the Cambrian Explosion. The cladogram of invertebrates presents current hypotheses about evolutionary relationships among major groups of modern invertebrates. It also indicates the sequence in which some important features evolved.

The chordate cladogram presents current hypotheses about evolutionary relationships among chordate groups. It also shows at which points important vertebrate features, such as jaws and limbs, evolved.

- cartilage
- tetrapod

Interpret Photos What new adaptation led to the success of the bony fishes?

24.3 Primate Evolution

In general, a primate is a mammal with relatively long fingers, toes with nails instead of claws, arms that can rotate around shoulder joints, a strong clavicle, binocular vision, and a well-developed cerebrum.

Primates are often divided into two groups. Primates in one group look very little like typical monkeys and include lemurs and lorises. The other group includes tarsiers and the anthropoids. The anthropoids is the group that includes monkeys and apes, including humans.

The skull, neck, spinal column, hip bones, and leg bones of early hominin species changed shape in ways that enabled later species to walk upright.

Many species in our genus existed before our species, *Homo sapiens*, appeared in the fossil record. Furthermore, at least three other *Homo* species existed at the same time as early humans.

- hominoid
- opposable thumb
- bipedal

24.4 Social Interactions and Group Behavior

If a behavior influenced by genes serves as an adaptation that increases an individual's fitness, that behavior will tend to spread through a population.

Four types of learning that scientists have identified are habituation, insight learning, classical conditioning, and operant conditioning.

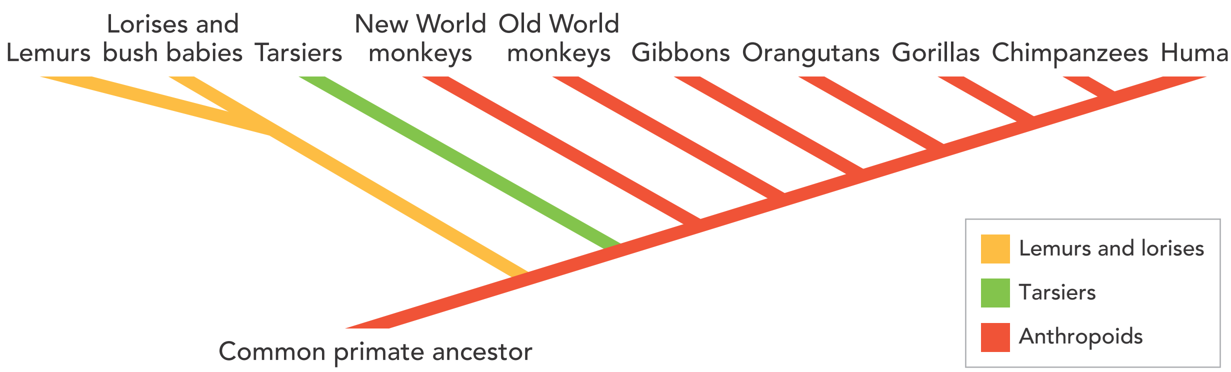
Many animals respond to periodic environmental changes with daily or seasonal behavior cycles.

Social behaviors, such as choosing mates, defending territories or resources, and forming social groups, can increase evolutionary fitness.

Animals may use a variety of signals to communicate.

- behavior
- society
- kin selection
- communication
- language

Construct an Explanation How do bee colonies increase the chance of survival for the bees that are part of the colony?

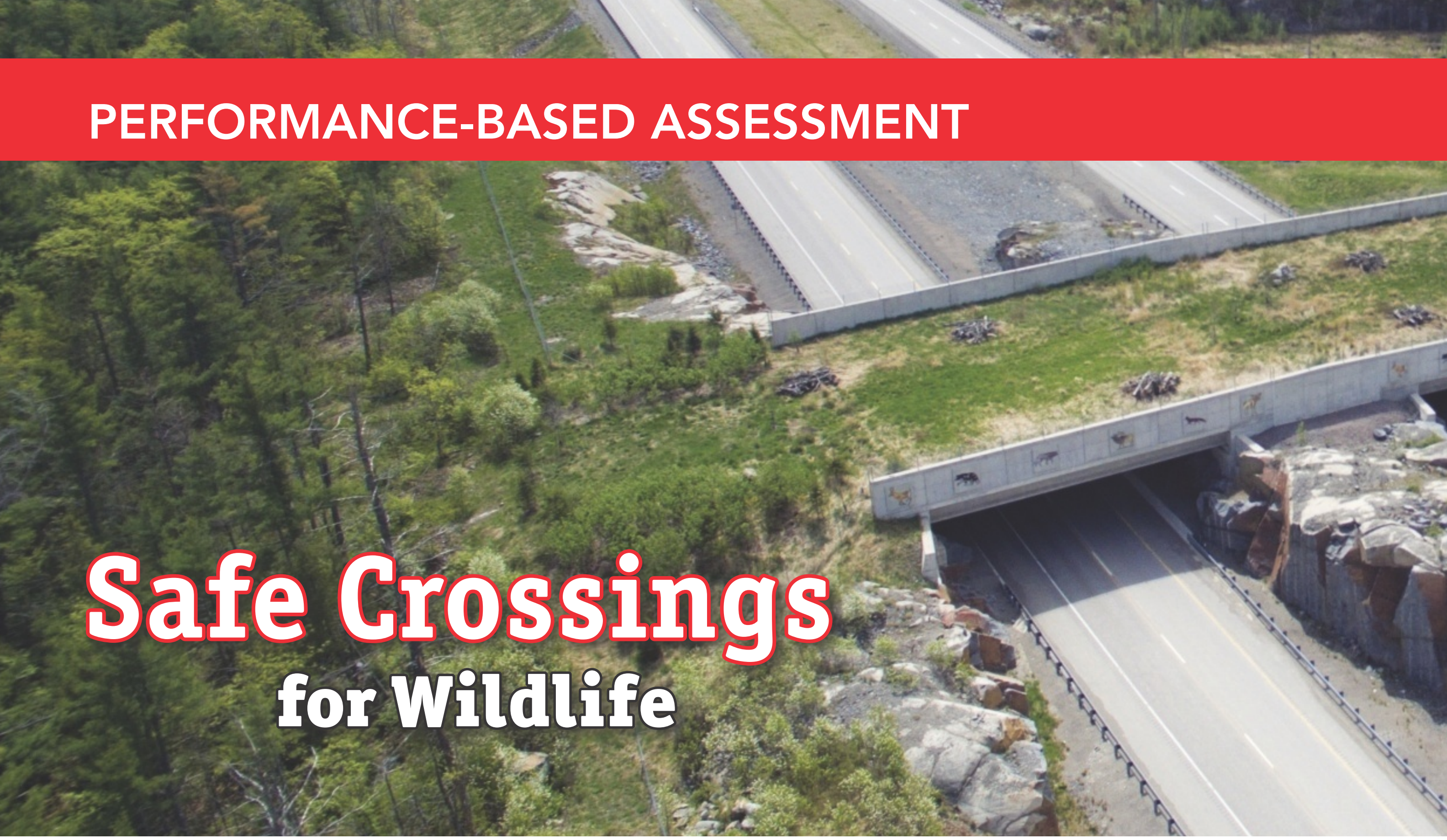


Develop Models Add nodes to this primate cladogram to represent prehensile tail and bipedal locomotion.

Organize Information

Complete the table to describe the evolution of these vertebrate groups.

Group	Sharks and Rays	Bony Fishes	Amphibians	Reptiles	Birds	Mammals
Defining Character	Jaws	1.	2.	3.	4.	5.



Safe Crossings for Wildlife

Construct a Solution

HS-LS2-7, HS-LS4-6, HS-ETS1-2, HS-ETS1-3, CCSS.ELA-LITERACY.RST.9-10.3, CCSS.ELA-LITERACY.WHST.9-10.2, CCSS.ELA-LITERACY.WHST.9-10.7

STEM Roads and highways pose many threats to wild animals. Roadways cause habitat loss and habitat fragmentation. When wild animals follow or cross the roads to obtain necessary resources in other areas, they put their lives and the lives of motorists at risk. Fatal collisions are not uncommon. All of these factors can lead to a decrease in animal populations and the loss of biological diversity in an area.

In this activity, you will identify the criteria for and constraints on an animal crossing to be built on a new highway planned through your community. The highway will pass through a forest ecosystem, effectively dividing the forest into two parts. You will consider and evaluate competing design solutions that meet the criteria and account for the constraints, and then construct a model to show the design solution that you think is optimal.

1. **Specify Design Criteria** With other members of your group, agree on a list of criteria for and constraints on the animal crossing. Consider each of these properties:
   - The length of the crossing, which corresponds to the total width of the highway at the site of the crossing
   - The size of the forest ecosystem through which the highway passes
   - The types of animals that are predicted to use the crossing
   - The budget for constructing the animal crossing
   - The opinions and concerns of community members
2. **Design a Solution** With members of your group, discuss at least three different design solutions for the animal crossing. Draw simple sketches to illustrate each solution.

ENGINEERING PROJECT

3. **Research a Problem** With members of your group, discuss the answers to the questions below. These questions will help you build a model that meets the criteria for and constraints on the animal crossing. Conduct research, if necessary, to help you develop or support your answers.
    - What types of animal populations are found in your area?
    - What behaviors or activity patterns do these animals have? Evaluate how to best accommodate their need to travel.
    - Which design solution will be most likely to keep animals off the highway?
    - For which solutions are the construction costs within the budget?
    - Do any of the design solutions pose safety hazards, such as insufficient fencing, to animals or motorists? If so, how could the hazards be eliminated?
4. **Develop Models** With member of your group, decide which design is best. Work with group members to sketch your model for the animal crossing.
5. **Refine Your Plan** Revise the sketch of your animal crossing to include important details, such as its length and width; its height above the highway or distance below it; and components such as plantings, fences, and gates.
6. **Construct a Solution** Agree on roles for constructing the model. Different group members can construct each feature of the model, such as the framework for the crossing, the plants covering the crossing, and fences or other details. Or you may choose to work together on the entire model.
7. **Refine Your Plan** As you construct the model, refer to the detailed sketch as necessary. You may need to revise your sketch or your ideas. Or you may need to revise the list of materials you are using to build the model.
8. **Evaluate Your Plan** Evaluate the finished model against the list of criteria and constraints you had identified. If it fails to meet one of the criteria or to consider the constraints, revise your plans or the model.

CHAPTER 24

ASSESSMENT

KEY IDEAS AND TERMS

24.1 Introduction to Animals

HS-LS1-1, HS-LS1-2, HS-LS1-3, HS-LS4-1

1. Which of the following is characteristic of all chordates but not found in invertebrates?
   a. a notochord
   b. four legs
   c. a circulatory system
   d. an exoskeleton
2. Animals that have a backbone, also called a vertebral column, are known as
   a. invertebrates.
   b. prokaryotes.
   c. homeostasis.
   d. vertebrates.
3. A concentration of sense organs and nerve cells in the anterior end of the body is known as
   a. fertilization.
   b. cephalization.
   c. symmetry.
   d. multicellularity.
4. List the characteristics shared by all members of the animal kingdom.
5. Describe how feedback inhibition works.
6. Explain why the term *invertebrate* may be a useful term but is not a true category in the system of classification.
7. The sea star below shows what kind of symmetry?

24.2 Animal Evolution and Diversity

HS-LS4-1

8. The ancestors of many modern animal phyla first appeared during the
   a. Burgess Period.
   b. Precambrian Era.
   c. Cambrian Period.
   d. Ediacaran Period.
9. Most chordates that live on land have
   a. two limbs.
   b. four limbs.
   c. six limbs.
   d. eight limbs.
10. The evolution of jaws and paired fins was an important development during the rise of
    a. tunicates.
    b. lancelets.
    c. fishes.
    d. amphibians.
11. Name two body plan characteristics shared by arthropods and vertebrates.
12. What body plan features did Cambrian animals evolve that made them more likely to become fossils?
13. What is the single most important characteristic that separates birds from other living animals?
14. Which two major groups of fishes evolved from the early jawed fishes and still survive today?
15. Describe how the young of monotremes, marsupials, and placental mammals obtain nourishment.

24.3 Primate Evolution

HS-LS4-1

16. Anthropoids include monkeys and
    a. lemurs.
    b. lorises.
    c. tarsiers.
    d. humans.
17. Which of the following is a characteristic specific to primates?
    a. body hair
    b. rotation at the shoulder joint
    c. notochord
    d. ability to control body temperature
18. How many hominin species exist today?
    a. one
    b. two
    c. nine
    d. twelve
19. What anatomical characteristic allows for the binocular vision that occurs in primates?
20. Describe the adaptations that make some primates successful tree dwellers.
21. List the unique characteristics of hominins. Give an example of a hominin.

24.4 Social Interactions and Group Behavior

HS-LS2-8, HS-LS4-4

22. The way an organism reacts to stimuli in its environment is called
    a. behavior.
    b. learning.
    c. conditioning.
    d. imprinting.

23. Animal behaviors can evolve through natural selection because
    a. what an animal learns is incorporated into its genes.
    b. all behavior is completely the result of genes.
    c. all behavior is completely the result of environmental influences.
    d. genes that influence behavior that increases an individual's fitness can be passed on to the next generation.
24. Which of the following is NOT a type of social behavior?
    a. operant conditioning
    b. territoriality
    c. hunting in a pack
    d. courtship
25. Describe an example of a stimulus and a corresponding response in animal behavior.
26. What is operant conditioning?
27. What is kin selection?

CRITICAL THINKING

HS-LS1-2, HS-LS2-8, HS-LS4-1, HS-LS4-2

28. **Classify** What characteristics distinguish vertebrates from nonvertebrate chordates?
29. **Cite Evidence** Why is bilateral symmetry an important development in the evolution of animals? Cite evidence from the chapter to support your analysis.
30. **Interpret Visuals** List three primate characteristics shown by the monkey in the photo.

31. **Design a Solution** Describe how you could use operant conditioning to train a pet dog to complete a useful task.
32. **Organize Data** Rank the following developments in the order of their appearance during evolution: tissues, anus-first development, multicellularity, mouth-first development.
33. **Form a Hypothesis** Animals with radial symmetry, such as sea anemones, lack cephalization, while animals with bilateral symmetry have it. State a hypothesis that would explain this observation.
34. **Construct an Explanation** Which anatomical characteristics of nonvertebrate chordates suggest that, in terms of evolutionary relationships, these animals are more closely related to vertebrates than to other groups of animals? Draw evidence from the text to support your answer.
35. **Synthesize Information** Life on Earth began in water. What were some of the major adaptations that animals evolved that allowed them to survive out of water?
36. **Infer** A baby smiles when her mother comes near. Often, the baby is picked up and cuddled as a result of smiling. Explain what type of learning the baby is showing.
37. **Form a Hypothesis** Although the members of many animal species derive benefits from living in social groups, members of other species live alone. What might be some of the advantages of solitary living?
38. **Construct an Explanation** Because a highway has been constructed through a forest, many of the animals that once lived there have had to move to a different wooded area. Is their move an example of migration? Explain your answer.
39. **Construct an Explanation** Analyze and explain how aggression and territorial behavior are related.

ASSESSMENT

CROSSCUTTING CONCEPTS

40. **Structure and Function** In what ways do the digestive and respiratory systems depend on the circulatory system to carry out the functions of obtaining nutrients and eliminating wastes?

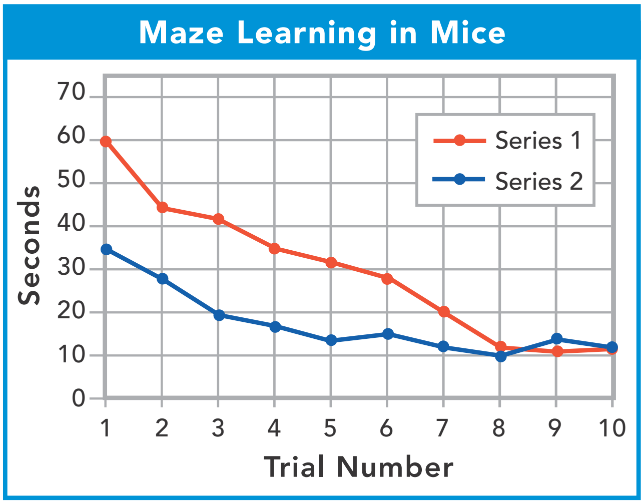
41. **Cause and Effect** Describe generally how the nervous and musculoskeletal systems of a rabbit react when it sees a predator such as a coyote.

MATH CONNECTIONS

Analyze and Interpret Data

CCSS.MATH.CONTENT.MP2

Mice can learn to run through a maze to find a food reward. As they have more practice runs in the maze, they take fewer wrong turns and reach the food more quickly. Twelve mice are put in a maze once a day for 10 days. The mean of their times to reach the food is calculated and plotted as the red line below. The mice are then kept out of the maze for a month. The blue line shows the results of those later trials. Use the graph to answer questions 42–44.



42. **Analyze Graphs** Explain what is happening after trial 8 on both sets of trials.

43. **Ask Questions** After the first set of trials, what kinds of questions might the experimenters have asked that resulted in their performing the second set of trials?

44. **Interpret Data** Explain the difference in the shapes of the graphs of the two trials.

The table shows the estimated numbers of living members of the reptile clade. Use the table to answer questions 45 to 48.

Reptile Clade Diversity

Group	Estimated Number of Species
Lizards and snakes	8400
Turtles and tortoises	310
Crocodilians	23
Tuataras	2
Birds	10,000

45. **Graph** Construct a circle graph that presents the data in the table.

46. **Evaluate Information** What was your biggest challenge in representing these data in a circle graph?

47. **Analyze Data** Consider other methods of graphing data. Which type of graph might represent these data in a more helpful way?

48. **Graph** Graph these data using a method you would consider more helpful to a reader, or explain why none would be more helpful.

LANGUAGE ARTS CONNECTION

Write About Science

CCSS.ELA-LITERACY.WHST.9-10.2, CCSS.ELA-LITERACY.RST.9-10.7

49. **Write Procedures** Outline the steps of a procedure for classifying a vertebrate as a fish, an amphibian, a reptile, a bird, or a mammal.

50. **Write Technical Processes** Choose one of the cladograms presented in the chapter. Write a paragraph that describes the evolutionary relationships that the cladogram defines.

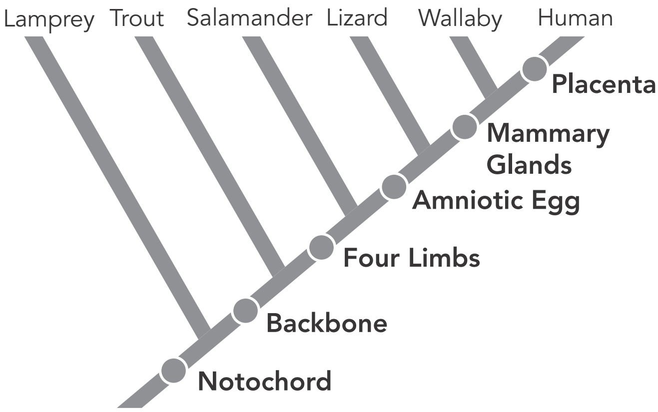
Read About Science

CCSS.ELA-LITERACY.RST.9-10.2, CCSS.ELA-LITERACY.RST.9-10.7

51. **Determine Central Ideas** Describe how animals have achieved diversity through segmentation and cephalization.

END-OF-COURSE TEST PRACTICE

1. Scientists use cladograms like this one to illustrate evolutionary relationships.



Based on the cladogram, which anatomical feature do modern humans and trout share with a common ancestor?
A. Notochord
B. Placenta
C. Four limbs
D. Amniotic egg
E. Mammary glands

2. Fossil records provide evidence for the scientific theory of evolution. Based on the fossil record, which is the correct order for the appearance of bone, jaws, notochords, and vertebrae in chordate evolution?
A. bone, notochord, jaws, vertebrae
B. bone, notochord, vertebrae, jaws
C. notochord, bone, vertebrae, jaws
D. notochord, vertebrae, jaws, bones
E. vertebrae, notochord, bones, jaws

3. Between 6 and 7 million years ago, the lineage that led to hominins split from the lineage that led to chimpanzees. Which of the following best describes one of the ways hominins evolved?
A. Hominins evolved a smaller skull and smaller brain capable of designing tools.
B. Hominins evolved an opposable thumb that enabled hands to grasp objects.
C. Hominins evolved shoulder bones that enabled them to walk faster on all four limbs.
D. Hominins evolved more chromosomes that enabled them to reason and solve problems.
E. Hominins evolved forward-facing eyes that enabled them to have binocular vision.

4. In a bee colony, all the worker bees are closely related females. They work together to complete complicated tasks such as building nests. What is the evolutionary benefit of this type of behavior?
A. This behavior allows related individuals to compete for resources.
B. This behavior increases the chances that diseases will spread to related individuals.
C. This behavior makes them more attractive to mates and increases genetic diversity.
D. This behavior increases the chances that genes shared by relatives will be passed to offspring.
E. This behavior increases the chances that syntax rules will be communicated to related individuals.

ASSESSMENT

For additional assessment practice, go online to access your digital course.

If You Have Trouble With...				
Question	1	2	3	4
See Lesson	24.2	24.2	24.3	24.4
Performance Expectation	HS-LS4-1	HS-LS4-1	HS-LS4-1	HS-LS2-8