Chapter 15
Animals

Have you ever seen a living sea star (shown right)? Sea stars (group name Stelleroidea) are sometimes called starfish, though they are not real fish. But like fish, sea stars are animals. So is a tree frog, a dog, a luna moth, and a great blue heron (all shown right). You can probably name many other types of animals. What characteristics do all animals share? What characteristics do scientists use to place animals into different categories? Read this chapter to learn more about different groups of animals.

Key Questions

1. ***What do you have in common with a worm, sea star, frog, fish, and a bird?***
2. ***Why is a sponge an animal?***
3. ***Why is the sea squirt one of your distant cousins?***

15.1 What Is an Animal?

What do you have in common with a frog, a sponge, and a planarian (Figure 15.1)? If you guessed that you're all animals, you are right! Animals come in many shapes, forms, and sizes. Scientists estimate that there are between 1 and 2 million species of animals! Some, like whales and elephants, are bigger than a truck. Others, like dust mites, are microscopic. What are animals?

Figure 15.1: *What do these organisms have in common?*

The Kingdom Animalia

Invertebrates and vertebrates

Scientists divide the Kingdom Animalia into two major groups: invertebrates and vertebrates. In Chapter 11 you learned that a *vertebrate* is an animal with a backbone. An **invertebrate** is an animal without a backbone. About 98 percent of all animals are invertebrates. This diverse group includes sponges, jellyfish, worms, insects, and mollusks. Only about two percent of all animals are vertebrates which belong to the *Phylum Chordata*. Vertebrates include fish, amphibians, reptiles, birds, and mammals. The table below shows the major animal phyla and their estimated number of living species.

VOCABULARY

invertebrate - an animal without a backbone.

Phylum	Estimated number of species	Phylum	Estimated number of species	Phylum	Estimated number of species	Phylum	Estimated number of species	Phylum	Estimated number of species
Sponges	10,000	Flatworms	25,000	Mollusks	110,000	Arthropods	1,000,000	Vertebrates (Phylum chordata)	50,000
Cnidarians	9,500	Roundworms	80,000	Annelids	9,000	Echinoderms	6,000		

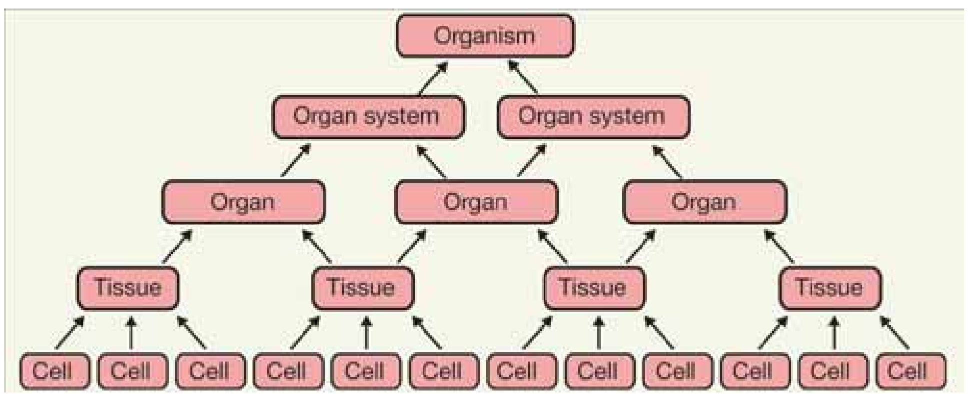
Characteristics of animals

What makes an animal?

Have you ever seen a hydra? If so, you probably used a microscope (Figure 15.2). Like you, a hydra is an animal. **All animals must perform certain functions to stay alive. These include response to the environment, feeding, digestion, respiration, transport of materials, and reproduction.** The process of evolution has produced great diversity in adaptations to these functions. Despite this diversity, most animals share all of the following characteristics.

Figure 15.2: *What do you have in common with a hydra?*

1. **Animals are multicellular and have eukaryotic cells.** Except for sponges, animal cells are arranged into tissues. Tissues are necessary to produce organs and organ systems. Tissues, organs, and organ systems are what enabled the evolution of organisms with large, multicellular bodies.



2. **Animal cells lack cell walls.** A *skeleton* supports the tissues of some animals. The skeleton may be internal or external (Figure 15.3). In some tissues, protein molecules found outside the cell membrane hold the cells together and provide support.

Figure 15.3: *Many animals have a skeleton. This lobster has an external skeleton.*

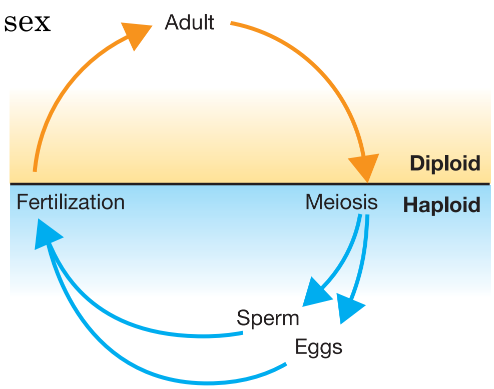
3. **Animals have a period of embryonic development.** Each animal starts out as a one-celled *zygote* (a fertilized egg) that divides into a multicellular *embryo*. Recall that an embryo is an organism in its earliest stage of development. During embryonic development, cells become specialized and tissues form. The growth of tissues, organs, and organ systems requires a period of embryonic development.

4. **Animals are consumers.** A consumer is an organism that eats other organisms. Animals cannot make their own food. To get energy and nutrients, they must eat other organisms or organic substances. This is a major characteristic that sets animals apart from plants.

5. **Animals can move.** Being a consumer often requires movement in order to capture prey. Most animals can move during at least some part of their life cycle.

6. **Most animals have muscle and nervous tissue. Muscle tissue** is made of muscle cells (Figure 15.4) and allows animals to move. **Nervous tissue** is made of nerve cells and enables coordinated movement and response to stimuli.

7. **Animals are diploid.** Their sex cells are haploid and are produced by meiosis. A basic animal life cycle is shown to the right.



VOCABULARY

muscle tissue - tissue made of muscle cells that allows animals to move.

nervous tissue - tissue made of nerve cells that enables coordinated movement and response to stimuli.

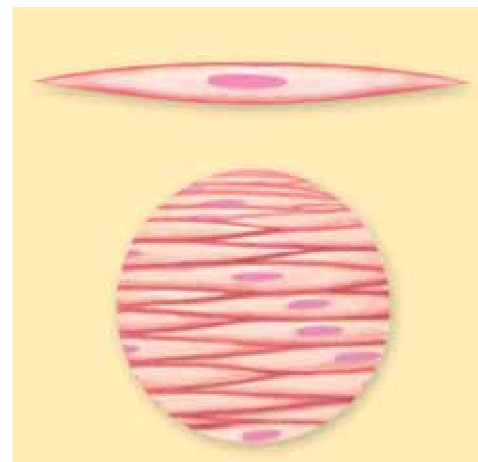
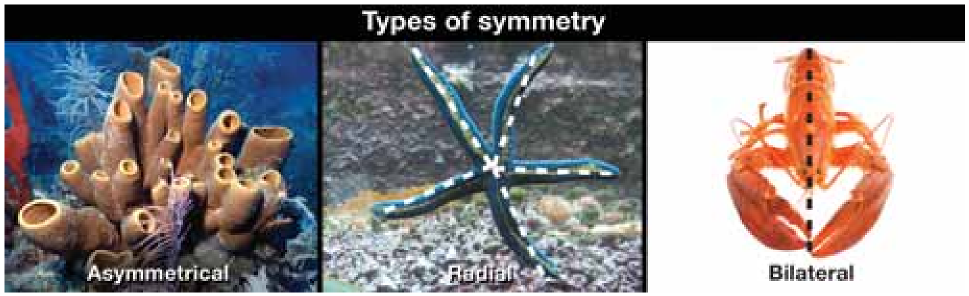


Figure 15.4: *Muscle tissue is made of muscle cells.*

Animal body plan and cavity

Symmetry

The body plan of an animal is called its *symmetry*. Animals that do not have symmetry, like sponges, are called **asymmetrical**. Some animals, like sea urchins, have radial symmetry. **Radial symmetry** means that the body parts are arranged in a circle around a central point. Other animals, like insects and all vertebrates, have bilateral symmetry. In **bilateral symmetry**, the body consists of two similar halves.



VOCABULARY

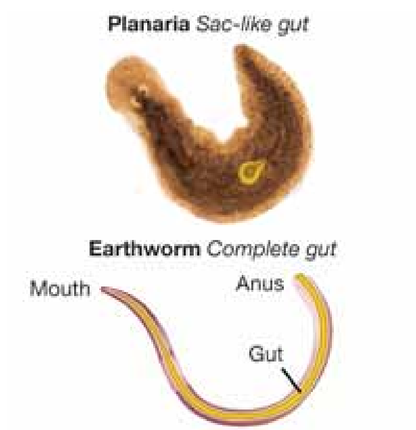
asymmetrical - organisms that do not have symmetry.

radial symmetry - a body plan in which the body parts are arranged in a circle around a central point.

bilateral symmetry - a body plan that consists of two similar halves.

The gut and body cavity

The *gut* is the digestive tract. It enables an animal to digest food outside of its cells. In animals without a gut (like sponges), food is digested inside of their cells. Simple animals have a *sac-like gut* with only one opening. More complex animals have a *complete gut* that runs from a mouth to an anus (shown right). Complex animals also have a *body cavity* that holds the gut and other organs. The body cavity provides an open space for organs to grow and function. The cross-section of an earthworm (Figure 15.5) reveals its body cavity.



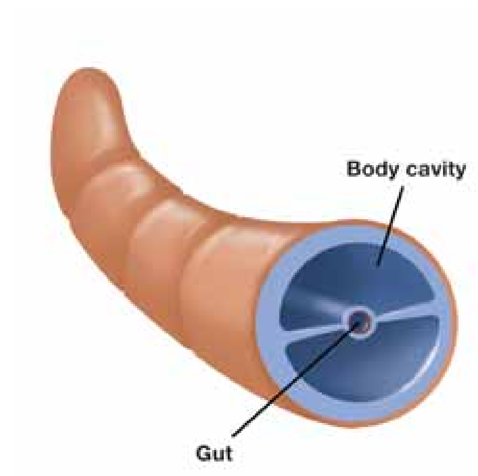


Figure 15.5: *A cross section of an earthworm reveals its body cavity.*

Organ systems

What is an organ system? Recall that an organ system is a group of organs that work together to perform a function. The simplest animals do not have organ systems. **As animals evolved and became more complex, they developed organ systems to perform basic functions.** Some important organ systems are described below.

Support and movement The **skeletal system** is a group of organs whose primary function is support. Some animals, like jellyfish and worms, do not have a skeletal system. Others, like lobsters, have *external skeletons* (Figure 15.6). All vertebrates have an *internal skeleton* that is made of organs called *bones*. The **muscular system** is a group of organs whose primary function is movement. In vertebrates, the skeletal and muscular systems work together to provide movement and support.

Circulation Since animals are multicellular, they need to transport water and other materials to and from all of their cells. In simple animals, substances diffuse into cells from surrounding fluids and tissues. The *circulatory system* is a group of organs whose primary function is to transport materials to and from cells. Since all animals use cellular respiration, their cells need oxygen. Complex animals have a *respiratory system* that allows them to take in oxygen and release *carbon dioxide,* a waste product of cellular respiration.

Digestion The **digestive system** is a group of organs whose primary function is to take in and digest food, and eliminate wastes. Simple animals do not have digestive systems. Others have simple cavities where food is digested by enzymes. Complex animals have complete digestive systems that run from mouth to anus.

VOCABULARY

skeletal system - a group of organs that provide support.

muscular system - a group of organs whose primary function is movement.

digestive system - a group of organs that take in and digest food, and eliminate wastes.

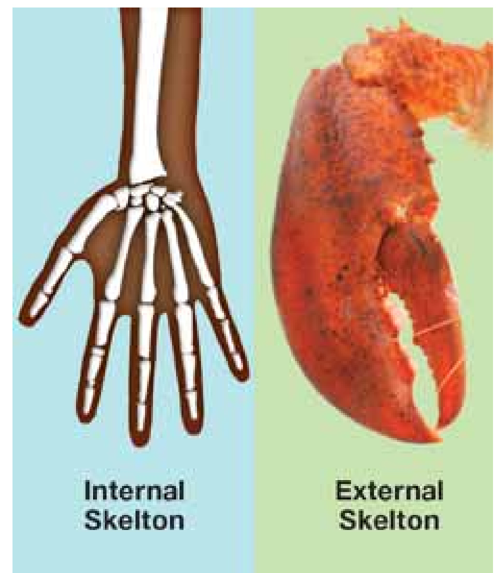
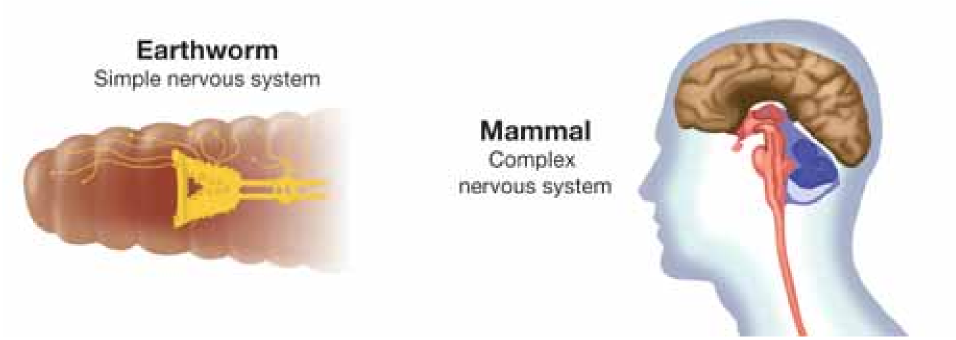


Figure 15.6: *You have an internal skeleton. A lobster has an external skeleton.*

Response To provide quick responses to stimuli, all animals except sponges have fibers called nerves. A **nerve** is a group of nerve cells whose function is to carry signals to control movements. Simple invertebrates have nerves arranged in fibers called *nerve cords* which run through their bodies. The **nervous system** is a group of organs and nerves that gather, interpret, and respond to information. The nervous system of an earthworm consists of a primitive *brain* and ganglia. *Ganglia* are bundles of nerves that control a body part. More complex animals have a nervous system with a brain stored in a well-formed *head*.



Reproduction All animals are capable of sexual reproduction. Some invertebrates are also capable of asexual reproduction. A planarian, for example, can be cut into several pieces, each of which grows into a complete worm (Figure 15.7). The new worms are genetically identical to the parent worm. Sexual reproduction involves exchange of genetic material which creates genetic variation. More complex animals have a **reproductive system** that functions in all reproductive processes. **Reproductive processes include production of sex cells and fertilization.** Some organisms, like earthworms, have both male and female reproductive systems on the same organism. Such an animal is called a **hermaphrodite**. More complex animals like vertebrates have separate male and female individuals.

VOCABULARY

nerve - a group of nerve cells whose function is to carry signals to control movements.

nervous system - a group of organs and nerves that gather, interpret, and respond to information.

reproductive system - a group of organs that function in all reproductive processes.

hermaphrodite - an individual organism that has both male and female reproductive parts.

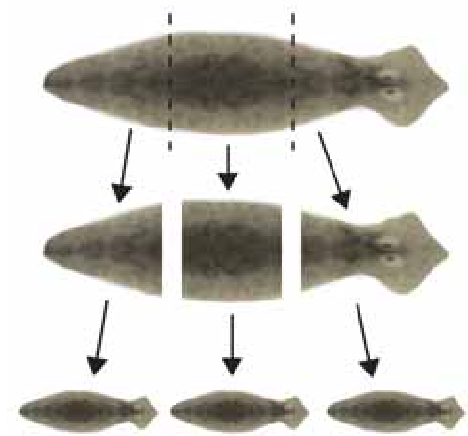


Figure 15.7: *A planarian can be cut into smaller pieces. Each piece develops into a new worm.*

15.1 Section Review

1. Classify each organism as either an invertebrate or a vertebrate:
   a. sponge
   b. turtle
   c. earthworm
   d. planarian
   e. human
2. All of the following are characteristics of animals except:
   a. are multicellular eukaryotes
   b. produce their own food
   c. are consumers
   d. have specialized tissues
3. How are cells, tissues, and organs related?
4. Name a characteristic that animals and plants share. Name a characteristic that distinguishes animals from plants.
5. Which type of symmetry does each object in Figure 15.8 have?
6. Match each organ system to its function.

Organ system	Function
1. circulatory system	a. response and control
2. reproductive system	b. take in and digest food
3. nervous system	c. movement
4. skeletal system	d. support
5. digestive system	e. transport materials
6. muscular system	f. production of sex cells and fertilization

SOLVE IT!

Make an Animal Kingdom pie chart. Use the information in the table on page 308. Convert the estimated number of species into percentages by dividing the number by the total number of animal species. Review pie charts on page 17.

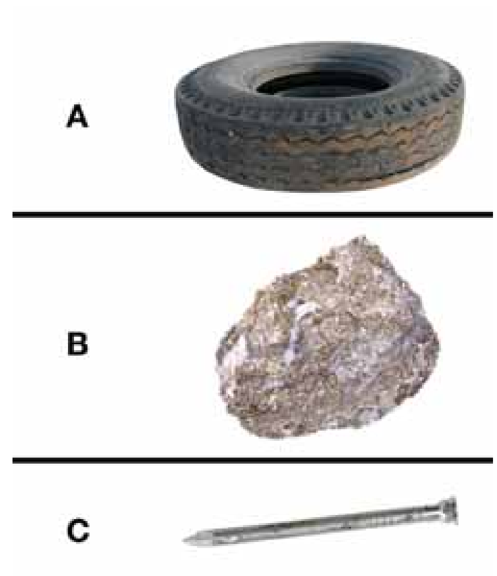


Figure 15.8: *Use this picture to answer question 5.*

15.2 Invertebrate Structure and Function

For centuries, sailors have written about giant, menacing sea monsters with long tentacles. These stories may have originated from sightings of the largest invertebrate—the giant squid. Giant squids can reach lengths of 15 meters and can swim at speeds of up to 30 km/hr! They have long, powerful tentacles that they use to grab their prey. They tear their prey apart with an enormous beak. Because they live in the deep ocean and are rarely seen, giant squids are still a mystery to scientists. Squids (Figure 15.9) are just one of a diverse group of organisms called invertebrates. In this section, you will learn about the structure and function of invertebrates.

Figure 15.9: *A squid.*

Sponges

Phylum Porifera

Sponges belong to the *Phylum Porifera* ("pore bearing.") They are asymmetrical and do not have a body cavity. **Sponges are different than other animals because they do not have organs or tissues.** Different sponges form different shapes, including tubes, fans, blobs, and barrels. Sponges range in size from only a few millimeters to 2 meters tall.

Feeding, reproduction, and habitat

Sponges do not move around. They feed by pulling water into the pores of their bodies and filtering out food particles. They have specialized cells that move water and collect and digest food. They reproduce asexually by a process called *budding*. In budding, a piece of a sponge breaks off and forms a new sponge. They also produce egg and sperm cells for sexual reproduction. Most sponges live in the ocean but there are a few freshwater species. Figure 15.10 shows a cross section of a sponge.

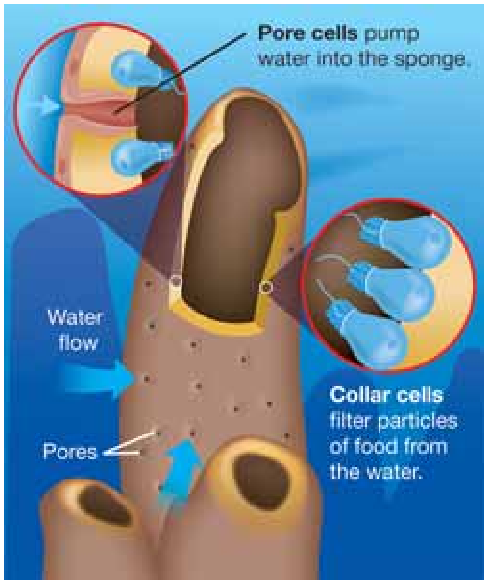


Figure 15.10: *A cross section of a simple sponge.*

Cnidarians and flatworms

Jellyfish are Cnidarians

The *Phylum Cnidaria* includes jellyfish, coral, sea anemones, and hydra. They have radial symmetry and do not have a body cavity. **Cnidarians have differentiated cells that are organized into two layers of tissues and nerves that form a network.** Cnidarians have a free-swimming form (called a *medusa*) and a stationary form (called a *polyp*). The jellyfish (shown right) is an example of the free-swimming form. Figure 15.11 shows a sea anemone, an example of the stationary form. The life cycle of most cnidarians includes both forms. All cnidarians live in water. They reproduce sexually and asexually.

Figure 15.11: *A sea anemone is an example of a cnidarian in the polyp form.*

Planarians are flatworms

Planarians belong to the *Phylum Platyhelminthes*—the flatworms. **Flatworms are the simplest animals having bilateral symmetry.** They have a sac-like gut but no body cavity. Figure 15.12 shows the anatomy of a planarian. Planarians secrete digestive enzymes onto their food and suck the food particles through an organ called a *pharynx*. They digest food in a *gastrovascular cavity*. Planarians have a primitive nervous system that consists of two *eyespots* connected to ganglia. Both are centralized in a head-like region. The ganglia act as a control center for sensory functions and movement. Planarians also have nerve cords that run down each side of their body, connected by other nerves. Planarians are hermaphrodites and reproduce both sexually and asexually.

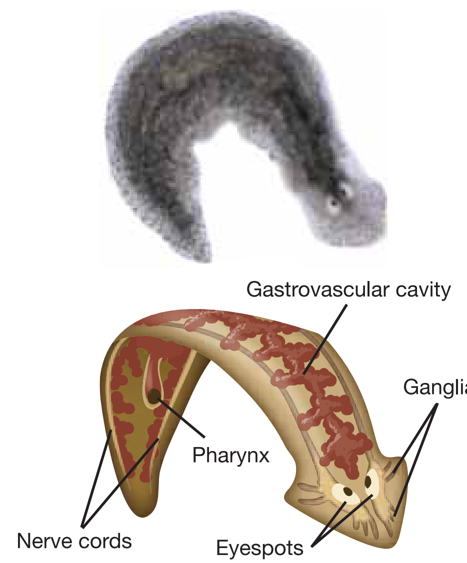
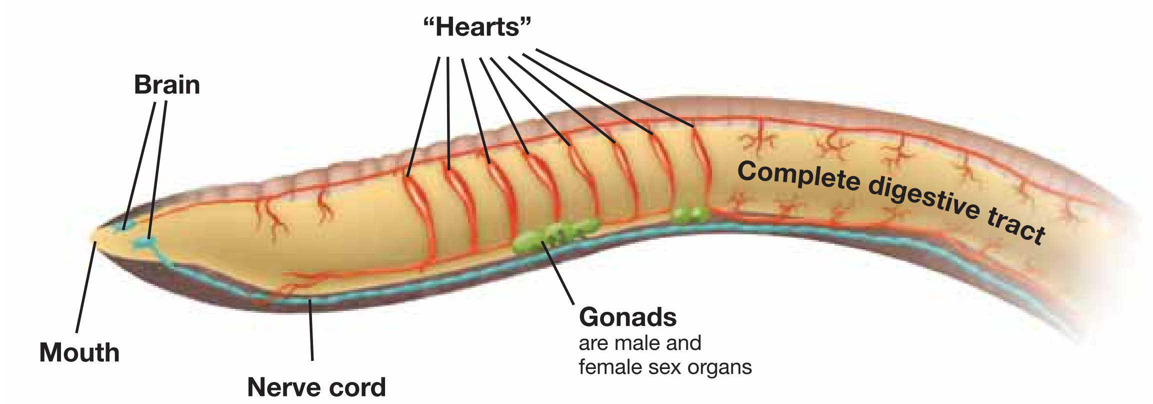


Figure 15.12: *The anatomy of a planarian.*

Roundworms and annelids

Roundworms Members of the *Phylum Nematoda* are called roundworms. Figure 15.13 shows a marine roundworm. **Roundworms are the simplest animals with a complete gut that runs from mouth to anus**. They have bilateral symmetry and a primitive body cavity. You may have never heard of roundworms but they play an important role in Earth's ecology. Billions of microscopic roundworms live in the soil. They eat bacteria and fungi and release compounds that help plants grow. Some scientists think that roundworms may be the most numerous animals on Earth! Roundworms reproduce asexually and sexually.

Annelids Earthworms belong to the *Phylum Annelida*—the annelids. **All annelids have bodies that are divided into individual segments.** Annelids have bilateral symmetry and a true body cavity. Earthworms are very important because they enrich the soil. They have a closed circulatory system with several heart-like structures that pump blood. Earthworms must mate to reproduce even though they are hermaphrodites. The anatomy of an earthworm is shown below.



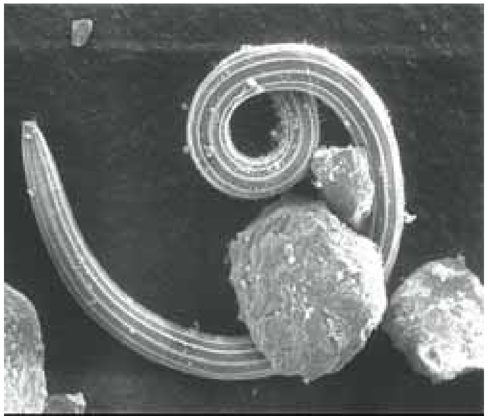


Photo - courtesy of William Fowle, Electron Microscopy Center, Northeastern University

Figure 15.13: *A marine roundworm next to grains of sand. As you can tell, many roundworms are very small.*

STUDY SKILLS

Make phylum flashcards

Write the phylum name on one side of a 3 x 5 card. Write the major characteristics and examples on the other side of the card. You may also find pictures in magazines or the Internet and paste them onto the card. Do this for each animal phylum.

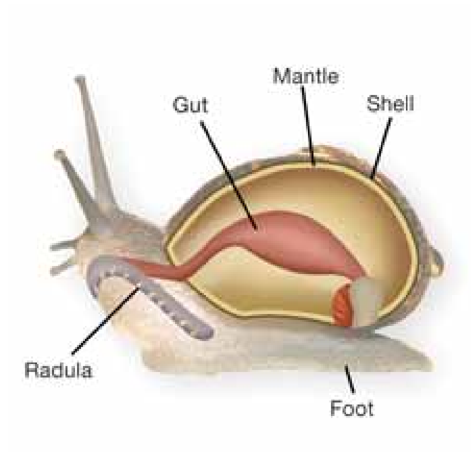
Mollusks

The Phylum Mollusca

Snails, clams, and squids are all members of the *Phylum Mollusca*—the mollusks (Figure 15.14). Mollusks are more advanced than roundworms but not as advanced as annelids. There is great diversity among mollusks, but each type of mollusk has a similar body plan. **Mollusks have bilateral symmetry and a true body cavity. The body of a mollusk typically has a *foot*, *gut*, *mantle*, and *shell*.**

The mollusk body

The *foot* is a soft, muscular structure that usually contains the *mouth*. The mouth may have a feeding structure called a *radula*. The *gut* is the mollusk's digestive tract. The *mantle* is a thin layer of tissue that surrounds part of the mollusk's body. Glands in the mantle secrete calcium carbonate, a compound that makes up the *shell*. Some mollusks do not have a shell but may have evolved from ancestors that had a shell.



Other organ systems and reproduction

Mollusks have a circulatory system with a simple heart. They also have a nervous system. Clams and their relatives have a simple nervous system with nerve cords and a few ganglia. Octopi and their relatives have a more advanced nervous system. They have a well-developed brain and eyes. They even have a sense of touch and taste. All mollusks reproduce sexually and have a life cycle that includes a stage called a larva. Some mollusks are hermaphrodites.

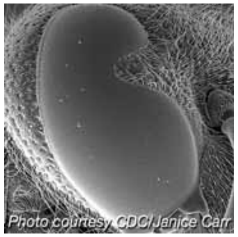
Figure 15.14: *Representative mollusks.*

Arthropods

What are arthropods? The *Phylum Arthropoda* includes insects, spiders, and crustaceans (lobsters and crabs). **Arthropods have segmented bodies, jointed limbs, an exoskeleton, and well-developed organ systems.** They have bilateral symmetry and a true body cavity. Arthropods are the most successful animals on Earth. For each human, scientists estimate that there are over 200 million insects alone! Scientists believe that annelids and arthropods evolved from a common ancestor. The first arthropod was the *trilobite* (Figure 15.15). Trilobite fossils have been dated at about 400 million years old!

Figure 15.15: *A trilobite fossil.*

The insect body Like annelids, insect bodies are segmented. In insects, some segments grow together to form three distinct regions: a *head*, a *thorax*, and an *abdomen*. Many segments contain specialized parts like wings, antennae, pinchers, and claws. Insects have a head with a well-developed brain. Most insects have *compound eyes* that are made of many identical light-sensing cells (right). They can see images, but not as well as you. Have you ever tried to sneak up on an insect? Even from behind, an insect can sense you are there, in part because they have antennae. *Antennae* are organs that respond to smell, touch, and taste. Figure 15.16 shows the external features of one insect, a cricket.



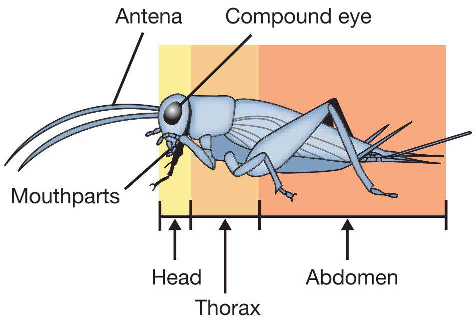


Figure 15.16: *The external features of a cricket.*

Life cycles All arthropods reproduce sexually and most have separate male and female individuals. Many have a life cycle that involves a change in form called *metamorphosis*. For example, a moth starts off as a fertilized egg that hatches into a *larva* (the caterpillar). The larva transforms into a *pupa* (the cocoon). The adult moth eventually emerges from the pupa.

Echinoderms and a summary of the invertebrate phyla

What are echinoderms?

The *Phylum Echinodermata* (meaning “spiny skin”) includes starfish, sea urchins, and sea cucumbers (Figure 15.17). **Echinoderms have radial symmetry, a body cavity, an internal skeleton, and spiny skin.** They also have an unusual feature called a water vascular system. The *water vascular system* is a network of fluid-filled canals connected to hundreds of tiny, tube-like feet. The water vascular system helps them move and capture food. Echinoderms do not have a head or a brain but they do have specialized nerve cells that provide senses of touch, taste, and smell. Some species have eyespots that can only detect light and dark. All echinoderms live in marine environments. They reproduce sexually and most have separate male and female individuals.

Summary: the evolution of animal phyla

The diagram below shows evolutionary relationships among the invertebrate phyla and vertebrates.

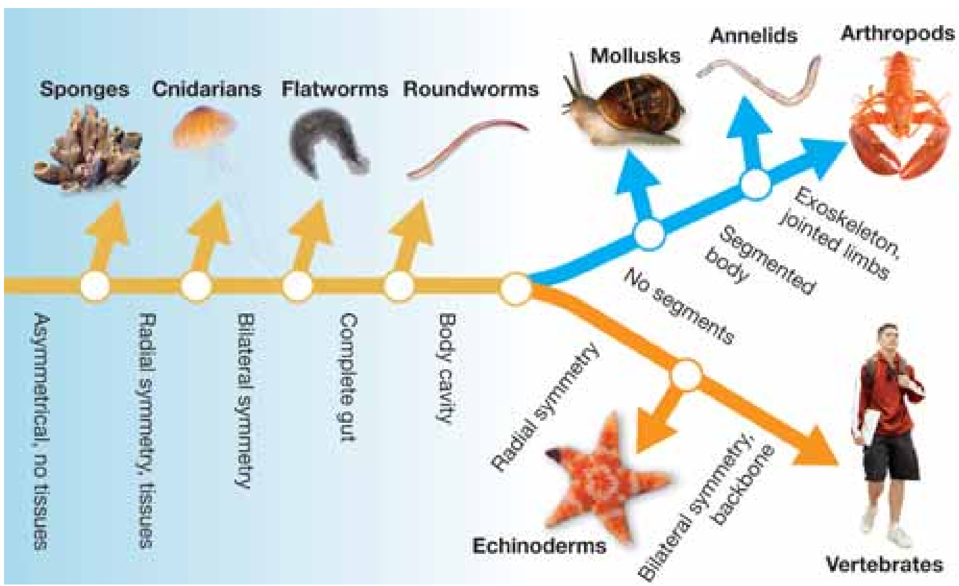


Figure 15.17: *Echinoderms include starfish (top), sea urchins (middle), and sea cucumbers (bottom).*

15.2 Section Review

1. Why do scientists classify sponges as animals?
2. Complete the table below. The first row is done for you.

Phylum	Symmetry	Body cavity	Example
Porifera	asymmetrical	none	sponges
Cnidaria			
Flatworm			
Roundworm			
Annelid			
Mollusk			
Arthropod			
Echinoderm			

3. Use the list of phyla in the table above to answer the following questions:
   a. Which phylum does not have tissues, organs, or nerves?
   b. Which phyla have a well-developed nervous system?
   c. Which phyla do not have a brain or head?
   d. Which phyla do not have an internal or external skeleton or shell?
   e. Which phylum has an exoskeleton?
   f. Which phyla have segmented bodies?
   g. Which phyla have a complete gut?
   h. Which phylum has a foot, mantle, and shell?
   i. Which phyla live only in water?

CHALLENGE

The diagram on the previous page shows evolutionary relationships among invertebrates and vertebrates. The trilobite shown below is a fossil organism. Propose where to place the trilobite on the diagram.

15.3 Vertebrate Structure and Function

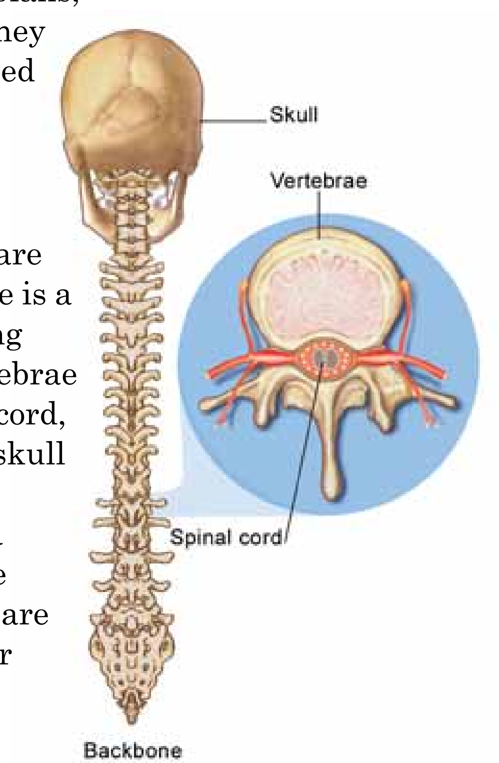
Have you ever seen a sea squirt (Figure 15.18)? At first glance, they look similar to a sponge. Did you know that you are more closely related to a sea squirt than a squid? Humans and sea squirts are members of the *Phylum Chordata* (called *chordates*). All chordates have a structure called a notochord. A **notochord** is a flexible, rod-shaped structure found in the embryos of all chordates. Chordates also have a *hollow nerve cord*. The hollow nerve chord is fluid-filled and runs along the back of the organism. Sea squirt larvae have both of these characteristics. In this section, you will learn about *vertebrates*—the largest group of chordates.

Figure 15.18: *A sea squirt adult.*

Characteristics of vertebrates

Vertebrates Vertebrates include fish, amphibians, reptiles, birds, and mammals. They share the characteristics discussed below.

Vertebrates have a backbone and skull **All vertebrates have a *backbone* and a *skull*.** The backbone and skull of a human are shown at the right. The backbone is a segmented column of interlocking bones called **vertebrae**. The vertebrae surround and protect the nerve cord, also called the *spinal cord*. The skull is made of cartilage or bone and protects the brain. *Cartilage* is a tough, elastic tissue found in the bodies of vertebrates. Your ears are made of cartilage. *Bone* is harder and denser than cartilage.



VOCABULARY

notochord - a flexible, rod-shaped structure found in the embryos of all chordates.

vertebrae - a set of interlocking bones that form the backbone of a vertebrate.

Internal skeleton All vertebrates have an internal skeleton. **The skeleton provides support, protection, and a place for muscles to be attached.** The skeleton of all vertebrate embryos is made of cartilage. In most vertebrates, cartilage is replaced by bone as the organism grows and develops.

Bones and muscles work together **The bones and muscles of vertebrates work together to provide a structural framework for movement.** Muscles are attached to bones by tendons. A *tendon* is band of tough, fibrous tissue that connects a muscle to part of a bone. Nerve signals cause muscle groups to contract (shorten) and relax which, in turn, causes bones to move.

Body cavity **All vertebrates have a body cavity that holds the organ systems.** The body cavity of vertebrates has two regions (Figure 15.19). The *thoracic cavity* holds the heart and the lungs of air-breathing vertebrates. The *abdominal cavity* holds the digestive organs including the stomach, intestines, and liver.

Organ systems **Vertebrates have well-developed organ systems.** The major organ systems are summarized in Table 15.1.

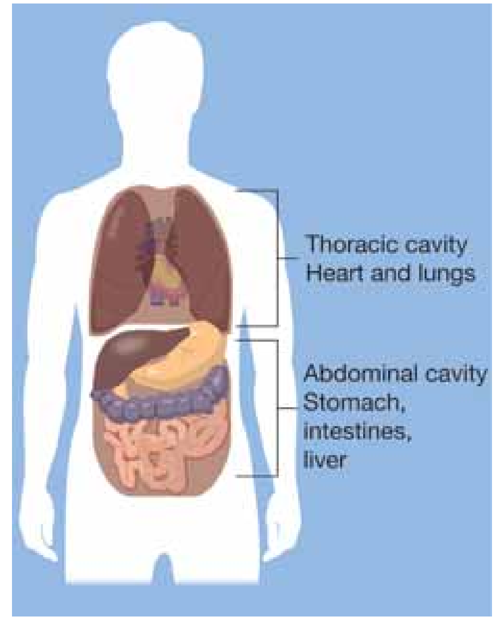


Figure 15.19: *The body cavity of a vertebrate.*

Table 15.1: Vertebrate organ systems, their functions, and major organs.

Organ system	Main function	Major organs
Integumentary	Barrier to external environment	Skin, scales, feathers, fur
Skeletal	Support and movement	Bones, cartilage
Muscular	Movement	Muscles, tendons
Digestive	Take in and digest food	Stomach, intestines, liver, pancreas
Respiratory	Exchange of oxygen and carbon dioxide	Lungs or gills
Circulatory	Transport materials to cells	Heart, blood vessels
Reproductive	Produce offspring	Testes, ovaries
Nervous	Response and movement	Brain, nerves
Urinary	Clean wastes from the blood	Kidneys
Endocrine	Regulate body functions	Glands that produce hormones

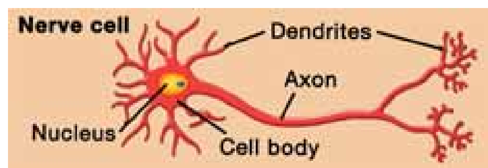
Vertebrate organs are made of four types of tissues

Four types of tissues An *organ* is a group of tissues that function together. Vertebrate organs are made of four types of tissues: epithelial, connective, muscle, and nerve. Figure 15.20 shows some organs where each tissue is found.

Epithelial tissue **Epithelial tissue** is made up of closely-packed cells in one or more layers. It forms the covering or lining of all internal and external body surfaces. Epithelial tissue protects the body and organs from dehydration, damage, and invasion by bacteria.

Connective tissue **Connective tissue** provides strength, support, and protection to the soft parts of the body. The cells of connective tissue are embedded in a large amount of extracellular material. This material, secreted by the cells, is made up of protein fibers. Cartilage and bone are both made of connective tissue. Another type of connective tissue is the binding material for organs. Muscles are surrounded by a layer of connective tissue.

Nerve tissue *Nerve tissue* transmits signals throughout the body. It is made of specialized cells called *neurons*. Each neuron (shown right) consists of a cell body which contains the nucleus, *dendrites*, and a single long fiber called the *axon*. The nerve signal, called an *impulse,* is conducted along the axon.



Muscle tissue Three kinds of *muscle tissue* are found in vertebrates. *Skeletal muscle* is made of long fibers in bundles and causes bones to move. *Smooth muscle* lines the walls of organs and blood vessels. Contractions of smooth muscle help organs like the stomach and intestines to function. The heart is made of *cardiac muscle*.

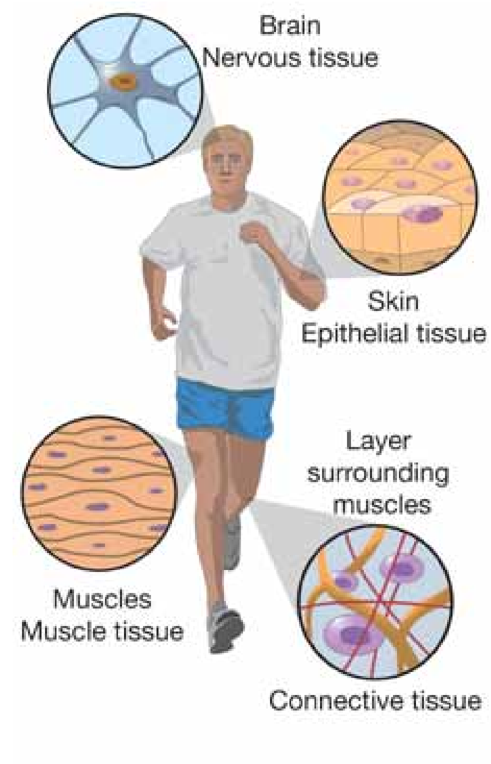


Figure 15.20: *The four types of tissues work together in the stomach.*

VOCABULARY

epithelial tissue - made up of closely packed cells in one or more layers. Lines the internal and external body surfaces.

connective tissue - provides strength, support, and protection to soft body parts.

Other characteristics of vertebrates

Temperature and chemical reactions Most animals need to keep their bodies at a certain temperature. This is because the chemical reactions inside of their cells can operate only at temperatures that are neither too hot nor too cold.

Ectotherms Animals that are not able to control their body temperature are called **ectotherms**. They are sometimes called *cold-blooded*. The body temperature of an ectotherm changes with the temperature of its environment. When it is cool, some ectotherms warm their bodies by basking in the sun (Figure 15.21). Nearly all fish, amphibians, and reptiles are ectotherms.

Endotherms Birds and mammals are endotherms. **Endotherms** use the heat produced by the chemical reactions in their cells to maintain a constant body temperature. Endotherms are sometimes called *warm-blooded*. Because they are able to keep their body temperature warm, many endotherms are adapted to survive in cold climates.

Fertilization and development Vertebrates reproduce sexually and have separate male and female individuals. Fertilization in vertebrates may occur externally or internally. In **external fertilization**, the female lays eggs and the male drops sperm onto them. Most fish and amphibians use external fertilization. In **internal fertilization**, the male deposits sperm inside of the female. In most reptiles and birds, the female lays eggs that contain the developing embryo. The eggs hatch and the young offspring emerge. In some cases, the eggs develop and hatch inside of the mother. In most mammals, the fertilized egg becomes an embryo that develops inside of the mother. Then, the mother gives birth to fully-developed offspring.

Figure 15.21: *A lizard basks in the sun to warm its body temperature.*

VOCABULARY

ectotherms - animals that are not able to control their body temperature.

endotherms - animals that use the heat produced by chemical reactions in their cells to maintain a constant body temperature.

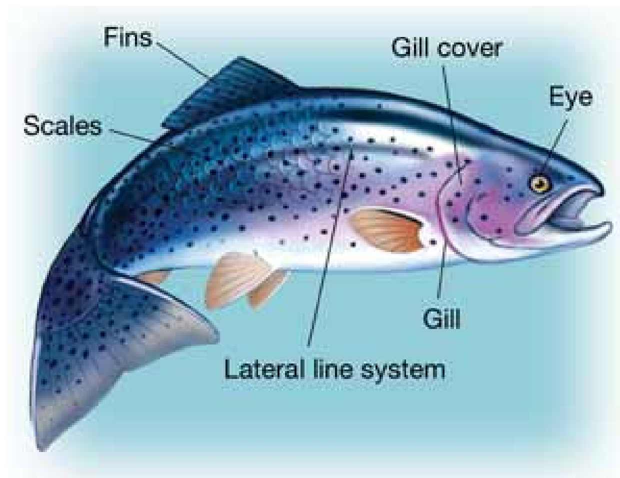
external fertilization - the female lays eggs and the male deposits sperm on the eggs.

internal fertilization - the male deposits sperm inside of the female.

Fish

What are fish? **Fish are ectothermic, aquatic vertebrates with fins, gills, and a streamlined body**. They were the first vertebrates, and evolved about 500 million years ago. There are three classes of fish living today (Figure 15.22). *Jawless fish*, as the name suggests, do not have jaws. The lamprey is an example. *Cartilaginous fish*—the sharks and rays—have skeletons made of cartilage. They have fully-functional jaws and a backbone. *Bony fish* include all other living fish species. They have a bony skeleton.

Adaptations Fish have many adaptations for life in water. *Fins* are fanlike structures that help fish move, balance, steer, and stop. Fish have strong muscles attached to their backbones allowing them to move their bodies and increase their speed through the water. The bodies of many fish are covered with *scales* for protection. Most fish have a **lateral line system** that consists of rows of sense organs along each side. This system detects vibrations. To breathe, fish have **gills** that extract oxygen from the water and remove carbon dioxide from the blood.



Reproduction External fertilization is more common in fish species than internal fertilization. Usually, the eggs hatch outside of the mother's body but in some species, the eggs develop and hatch inside of the mother, who gives birth to live offspring.

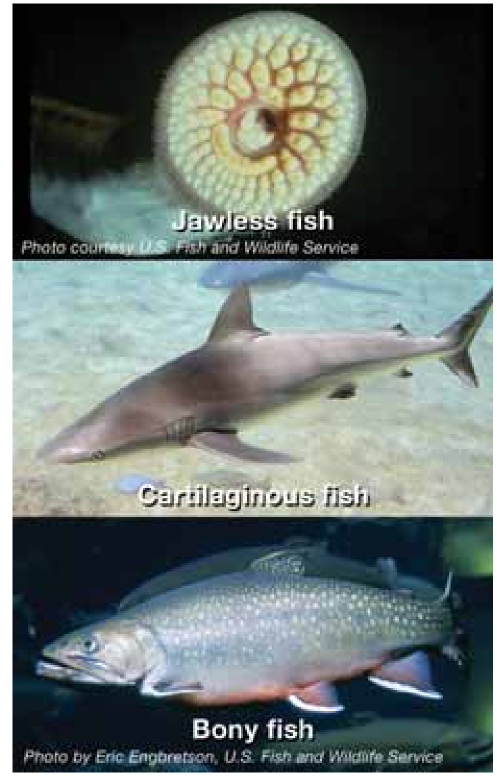


Figure 15.22: *The three classes of fish.*

VOCABULARY

lateral line system - rows of sense organs along each side of a fish that detect vibrations.

gills - organs that extract oxygen from water and remove carbon dioxide from the blood.

Amphibians

What are amphibians? **Amphibians are ectothermic, smooth-skinned vertebrates, such as frogs and salamanders, that usually hatch as an aquatic larva with gills.** Scientists think the first amphibians evolved from an ancestor of the lungfish (Figure 15.23). Lungfish have lungs like most amphibians. A **lung** is a sac-like organ that takes oxygen from the air and transfers it to the blood. Lungfish have limb-like fins that help them to scuttle across mud on the shore. The fins of the ancient lungfish evolved to become strong enough to support their body weight on land. Eventually, amphibians that could live on land most of the time evolved.

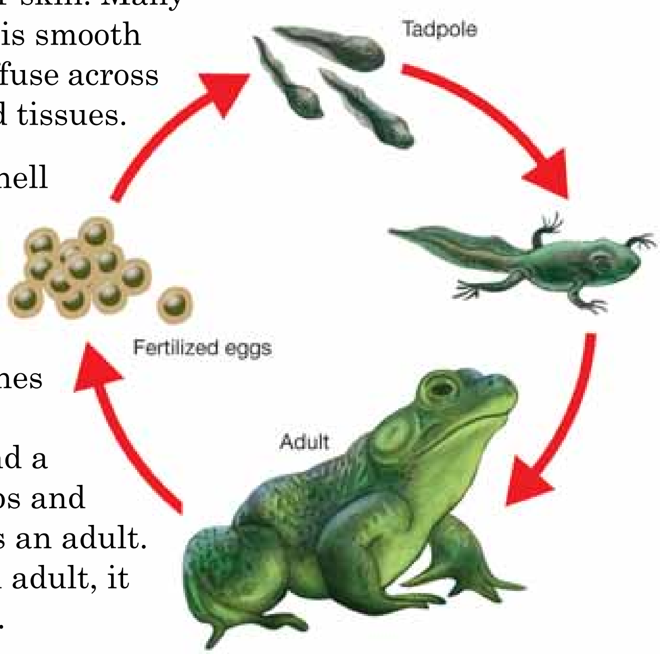
VOCABULARY

lung - a sac-like organ that takes oxygen from the air and transfers it to the blood.

Figure 15.23: *A lungfish.*

Adaptations Many amphibians are adapted to live part of their lives on land. Many live in damp habitats and some live in the water. Amphibians breathe by taking oxygen into their lungs. But many also absorb oxygen through their skin. Many amphibians have thin skin that is smooth and moist. Oxygen can easily diffuse across the skin and into their blood and tissues.

Reproduction and life cycle Amphibian eggs do not have a shell and are usually laid in the water. In frogs, fertilization is external while salamanders have internal fertilization. The amphibian embryo usually hatches in the water as a larva called a *tadpole*. The tadpole has gills and a tail. Eventually, it develops limbs and lungs, loses its tail, and becomes an adult. Once the amphibian becomes an adult, it can live part of the time on land.



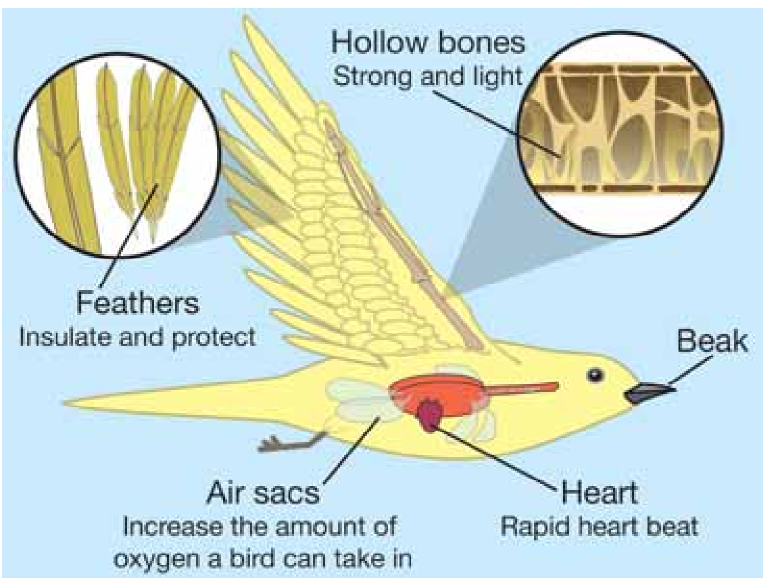
Reptiles and birds

Reptile characteristics

Reptiles are ectothermic, egg-laying vertebrates, that have an external covering of scales and breathe with lungs. Examples of reptiles are lizards, snakes, turtles, crocodiles, and dinosaurs (now extinct). Reptiles are adapted for life on land, although some, like crocodiles, live in water. The most important adaptation for life on land was the amniotic egg. An **amniotic egg** is surrounded by a shell that protects it from drying out. The parts of an amniotic egg are shown in Figure 15.24. Amniotic eggs are fertilized inside of the female. A shell then forms around the egg and it is laid on land. The embryo develops into a tiny reptile. Unlike amphibians, reptiles do not have a larval stage.

Bird characteristics

Birds are endothermic, egg-laying vertebrates with forelimbs modified to form wings. Like reptiles, birds have amniotic eggs. However, bird eggs have a harder shell than the leathery shells of reptile eggs. Also, birds use their body heat to keep their eggs warm until they hatch. This process is called *brooding*. Unlike reptiles, birds are endothermic and some species can tolerate the cold polar regions. Birds have beaks instead of jaws. They also have many adaptations for flight such as feathers, wings, hollow bones, and air sacs. The structures of a bird and their functions are shown to the left.



VOCABULARY

amniotic egg - an egg that is surrounded by a shell to prevent it from drying out.

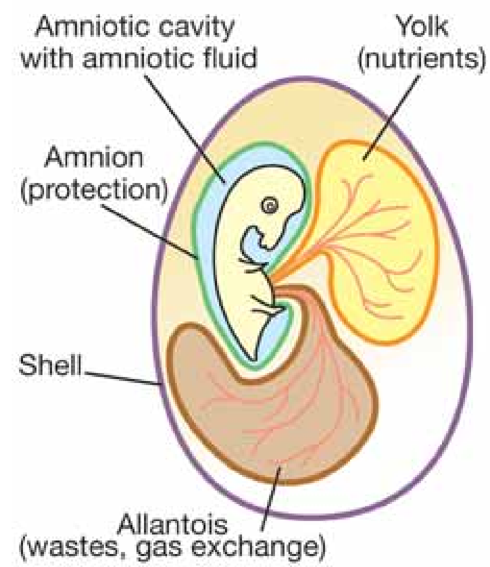


Figure 15.24: *The structure of the amniotic egg.*

Mammals

What is a mammal?

Mammals are endothermic vertebrates that have mammary glands. **Mammary glands** are organs that produce a nutritious fluid called milk. Most mammals are covered with hair or fur and have specialized teeth that help them to cut or chew their food. Mammals have highly-developed nervous systems and large brains. As a result, many mammal species have evolved intelligence and resourcefulness. Figure 15.25 show some examples of mammals.

Reproduction

Mammals have internal fertilization and most give birth to developed young. An exception is the duck-billed platypus which lays eggs! Most mammals are *placental mammals*. In placental mammals, embryos develop inside the mother in an organ called a *uterus*. An attachment to the uterus called a **placenta** supplies food and oxygen from the mother's blood to the developing embryo. The *gestation period* is the time it takes for an embryo to develop and varies among mammals. In humans, the gestation period is around nine months. Despite differences in development, all young mammals are fed milk from their mother's mammary glands.

Evolution of mammals

Mammals evolved from a now-extinct group of reptiles called **therapsids** (shown to the right). The earliest true mammals appeared over 200 million years ago. Since that time, mammals have evolved to live in different habitats. Modern mammals include animals that live on land and in water. The largest mammal—the blue whale—can grow to be over 30 meters long! The smallest mammal—the bumblebee bat—is only about 3 centimeters long and weighs about 2 grams!

VOCABULARY

mammary glands - organs that produce a nutritious fluid called milk.

placenta - an attachment to the uterus that supplies food and oxygen from the mother's blood to the embryo.

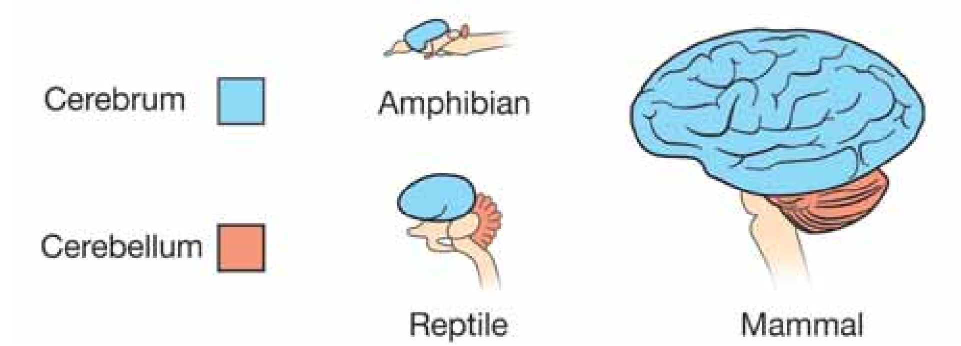
therapsids - an extinct group of reptiles from which mammals evolved.

Figure 15.25: *Some mammals.*

The mammalian brain and eye

The central nervous system

The brain of a mammal is more developed than that of other vertebrates. One difference is that mammals have a larger cerebrum and cerebellum, as shown below. The *cerebrum* is the part of the brain where most thinking takes place. The *cerebellum* coordinates movement and balance. Their well-developed brains allow mammals to think, learn, and quickly respond to changes in their environment.



The mammalian eye

Vision is an important way mammals perceive their environment. Figure 15.26 shows the structures of the mammalian eye. The *lens* is a transparent structure that, along with the **cornea**, refracts and focuses light. The *pupil* is a hole in the iris that controls the amount of light entering the eye. The *iris* is the pigmented part of the eye. A ring of tiny *ciliary muscles* connects the lens to the inner surface of the iris. Ciliary muscles contract to change the shape of the lens. The **retina** is a thin layer of cells in the back of the eye that converts light into nerve signals. Those signals are transmitted to the brain by the **optic nerve**. The *sclera* is the protective outer layer that gives the eye its shape. The *chroroid* provides oxygen and nutrients to the retina. The eye is filled with a jelly-like substance called *vitreous* and *aqueous humor*. *External muscles* control eye movement and help focus images.

VOCABULARY

cornea - part of the eye that, along with the lens, refracts and focuses light.

retina - a thin layer of cells in the back of the eye that converts light into nerve signals.

optic nerve - a nerve that transmits signals from the eye to the brain.

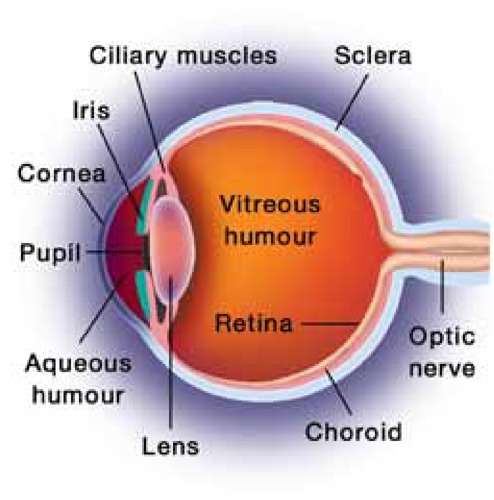


Figure 15.26: *The mammalian eye.*

15.3 Section Review

1. What are the similarities between a sea squirt and a fish? What are the differences?
2. Name the main function of each organ system.
   a. respiratory
   b. excretory
   c. integumentary
   d. circulatory
3. Name one organ from each system in question 2.
4. List the four types of tissues that make up vertebrate organs and explain their functions.
5. Name the three types of muscle tissue and where each is found in the body.
6. Tell whether each organism is an ectotherm or an endotherm.
   a. cat
   b. frog
   c. turtle
   d. swan
7. Match the organisms to their place on the cladogram in Figure 15.27. Explain your reasoning for each.
8. Name the function of each structure of the mammalian eye.
   a. lens
   b. cornea
   c. sclera
   d. pupil
   e. retina

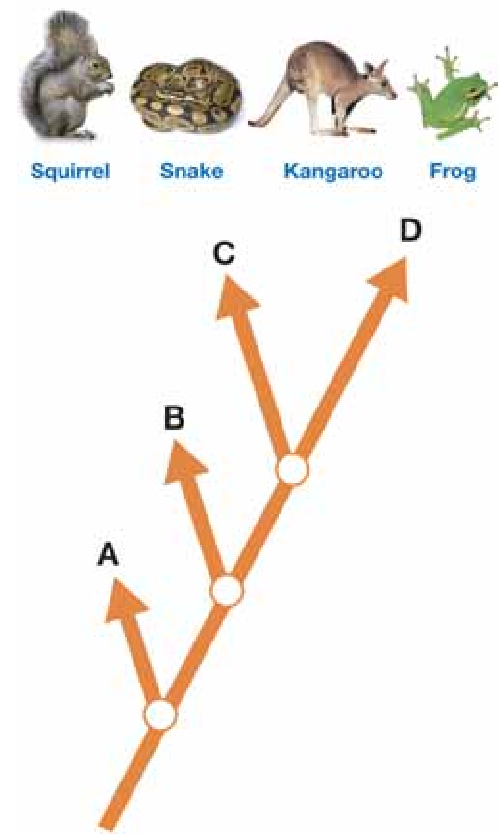
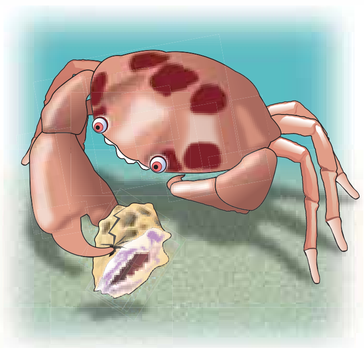


Figure 15.27: *Use the diagram above to answer question 7.*

RESEARCH CONNECTION

Snails vs. Crabs: An Undersea Arms Race

Wedged in the rocky hollow of a coral reef, a red-spotted crab, *Carpilius maculatus,* reaches out with its hefty right claw and grabs an unsuspecting snail from the ocean floor. Snip! The crab's claw clamps down on the shell's thick lip, producing a hairline crack.



The snail withdraws deep into its knobby shell, safely out of the crab's reach. Unable to cut the shell open, the hungry crab tries another tactic: squeezing the shell with crushing force until at last it gives way with a loud pop. The snail's armor shatters into tiny pieces. The crab, having won this round of battle, enjoys her feast.

An embedded observer

Witnessing this struggle off the coast of Guam is Dr. Geerat (Gary) Vermeij, a marine biologist. Earlier, Dr. Vermeij studied how snail shells differ around the world. He noted that some differences in shells can't be explained simply by environmental conditions. Tropical shells from Guam and Jamaica, for example, have evolved differently despite their similar climates. Now he is ready to test a new hypothesis. He thinks that some variations in shells may be linked to the different types of predators faced by snails in different areas.

Testing the hypothesis

Dr. Vermeij, who has been blind since age three, holds lightly to an assistant's elbow. Together they wade in the shallow water along Guam's seashore until they reach a coral reef. Then Dr. Vermeij uses his hands to explore the habitat, gathering live snails, empty shells, and several species of crabs including *Carpilius maculatus*. These are carried back to salt water aquariums in a marine lab.

The snails are measured, numbered, and placed in a tank. Each crab gets its own aquarium with rocks for shelter. The crabs are given snails of various sizes and shapes for prey.

Throughout the summer, Dr. Vermeij and his assistants kept careful records of the outcome of each crab and snail encounter. They learned which features help the snails withstand attacks and which features make them likely to become crab lunch.

Although his observations showed that crabs crush snails, this didn't yet prove that predators influence the size and shapes of shells in the wild. Dr. Vermeij still needed to know if shell breakage is a frequent cause of death for snails in Guam and other tropical environments.

Attitude adjustment

Dr. Vermeij went back to the reef, this time collecting hundreds of empty shells. Back in the lab, he turned each one over in his hands. He searched for holes or cracks like the ones made by his captive crabs. He found that more than 50 percent of these shells had telltale signs of predator breakage.

Dr. Vermeij also took note of scars on the shells. When he was a child collecting shells, he hated finding these raised, jagged lines intruding on a shell's smooth surface. Now he learned to recognize these scars as sites of *unsuccessful* attacks. The scars were like arrows pointing to strong defensive features.The scars provided evidence that the snail's predators sometimes fail. When predators fail, the snail's defensive traits can be passed down to the next generation. This is how stronger defenses evolve.

Hermit crab helpers

Next, Dr. Vermeij wanted to compare the ability of Guam snails to resist predator breakage with the ability of other tropical snails.

Dr. Vermeij traveled to Jamaica to sample shells there. He found that less than 25 percent of Jamaican shells showed signs of breakage by predators. He took a bunch of empty Jamaican shells back to Guam. He wanted to see how successful Guam's crabs would be at breaking these shells.

There was one problem. Crabs don't go around breaking empty shells. They're looking for food.

Dr. Vermeij realized that luckily, crabs aren't very picky eaters. So he collected a bunch of hermit crabs from Guam and offered them new housing in Jamaican shells. Then he put these shells in tanks holding Guam's *Carpilius* crabs.

Photo - courtesy of Mary Graziose

Most of these Jamaican shells couldn't stand up to the predators from Guam. They offered larger openings, a thinner outer lip, and a groove on the underside that provided a nice place for a crab to grip. Similar snails from Guam had evolved much better defenses.

The crushing power of crabs

Why then, were Jamaican snails so much less likely to die from breakage by predators? Dr. Vermeij suspected that perhaps Jamaican crabs were less powerful.

To test this idea, Dr. Vermeij figured out a way to calculate the mechanical advantage of a crab claw's moveable finger based on its size and shape. He measured hundreds of crab specimens in the Smithsonian collection. He found that the two species of *Carpilius* found around Guam had thicker, more powerful claws than the single Jamaican species. Other types of crabs showed similar patterns.

The evidence was mounting. Where stronger crabs inhabit the waters, snails develop more elaborate structures to defend themselves. Where crabs are less of a threat, snails are not as well fortified.

Dr. Vermeij shared his research in several journal articles. After further study of predator-prey patterns in fossils, Dr. Vermeij wrote a book called *Evolution and Escalation: An Ecological History of Life*. He is now considered one of the world's leading experts on mollusks, both ancient and modern.

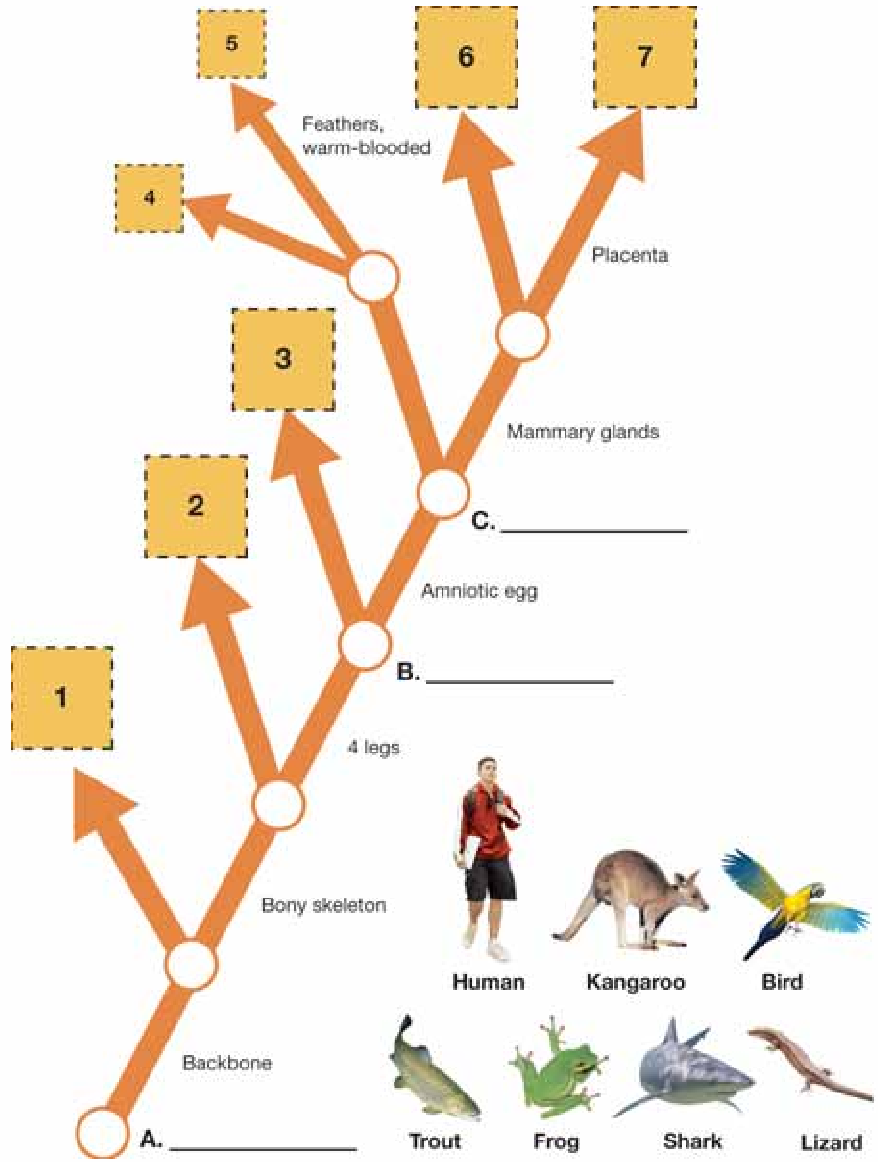
Questions:

1. What question was Dr. Vermeij trying to answer in Guam?
2. Dr. Vermeij has said that if you want to be a scientist, some of the qualities you need are boundless curiosity, a willingness to risk being wrong sometimes, creative thinking, and a passion for doing the hard work. How does Dr. Vermeij demonstrate each of these qualities?
3. Dr. Vermeij said that scarred and broken shells became "mines of information." What did he learn from them?

CHAPTER ACTIVITY Making an Evolutionary Tree

You have learned how evolutionary relationships among living organisms and their ancestors can be displayed on a branching diagram called an evolutionary tree. In this activity, you will create an evolutionary tree showing evolutionary relationships among vertebrates and their ancestors.

For this activity you will need a large sheet of newsprint or poster board, markers, pencils, glue, and magazine pictures of the following animals: shark, trout, frog, lizard, snake, turtle, crocodile, bird, kangaroo, mouse, and human.



What you will do

1. Use the diagram to the right as a template for your evolutionary tree.
2. Use the information in the diagram to place the organisms listed above at the correct numbers on the diagram.
3. Draw your tree on newsprint or poster board. Use a pencil first, then use markers to add color.
4. Find pictures of the different vertebrates in magazines or using the Internet. Cut out your pictures and glue them on your tree.
5. Answer the questions below and present your evolutionary tree to your class for discussion.

Applying your knowledge

a. Mammals evolved from an extinct group of organisms called therapsids. Where would therapsids be placed on your diagram (node A, B, or C)?

b. Early reptiles gave rise to all vertebrates except for fish and amphibians. Where would early reptiles be placed on your diagram (node A, B, or C)?

c. Sea squirts are chordates but do not have a backbone. Where would sea squirts be placed on your diagram (node A, B, or C)?

Chapter 15 Assessment

Vocabulary

Select the correct term to complete the sentences.

amniotic egg	circulatory system	ectotherm
bilateral symmetry	connective tissue	endotherm
external fertilization	cornea	epithelial tissue
hermaphrodite	digestive system	gills
lateral line system	internal fertilization	muscle tissue
muscular system	lung	nervous system
notochord	mammary glands	nervous tissue
optic nerve	placenta	pupil
retina	therapsids	radial symmetry
skeletal system	invertebrate	vertebrae

Section 15.1

1. One characteristic of animals is that they have tissues like _____ for movement and _____ for response.
2. Jellyfish, clams, and grasshoppers are _____ - animals without backbones.
3. Earthworms are _____ because they have both male and female reproductive parts.
4. The _____ provides support, while the _____ allows for movement.
5. Animals that are organized around a central point have _____, while animals that have two similar halves have _____.
6. The _____ of an animal helps to get nutrients and energy from food that the _____ then transports around the body along with oxygen and wastes.
7. The brain, spinal cord, and nerves make up the _____ of a human.

Section 15.3

8. Parts of the mammalian eye include: _____, _____, _____, and _____.
9. Most fish, amphibians, and reptiles are _____s, whereas birds and mammals are _____s.
10. All members of Phylum Chordata have a _____ - a flexible rod-shaped structure found in embryos.
11. Vertebrate organs are made of four types of tissues: muscle tissue for movement, nerve tissue for transmission of signals, _____ for support and protection of soft areas, and _____ for a protective outside layer.
12. The _____ is the most important adaptation for life on land since it keeps the embryo from drying out.
13. The backbone is made up of a set of joining bones called _____.
14. The male drops sperm onto eggs that the female has already laid in _____, whereas the male deposits the sperm inside the female in _____.
15. Mammals evolved from a now extinct group of reptiles called the _____.
16. Mammals feed their young with _____, which are organs that produce milk.
17. Fish have _____ for getting oxygen from water and amphibians have _____s for getting oxygen from the air.
18. The developing embryo of most mammals gets food and oxygen through the _____ that attaches it to the mother's uterus.
19. Most fish have a _____ for sensing vibrations.

Concepts

Section 15.1

1. What are the two major groups of animals? Describe each group and give an example.
2. Describe seven major characteristics of animals.
3. What are the three types of symmetry? Describe each type and give an example.
4. Describe the range of types of guts in animals from the most simple to the most complex.
5. List an organ that belongs to each of these organ systems:
   a. skeletal
   b. muscular
   c. digestive
   d. circulatory
   e. respiratory
   f. nervous
   g. reproductive
6. What organ systems help you to do these activities: run, do your homework, eat lunch, and watch television?
7. What is the advantage of having more than one type of reproduction for simple animals?

Section 15.2

8. Why is a sponge considered an animal?
9. How is a jellyfish more complex than a sponge?
10. What are the three types of worms? Which is the most simple? Which is the most complex?
11. What do a snail and a clam have in common?
12. Draw and label a mollusk body.
13. Why do you think there are more fossils of mollusks than worms?
14. What are two advantages and one disadvantage of having an exoskeleton?
15. Why is it advantageous for a butterfly larva and an adult butterfly to rely on different sources of food? What would happen if they both ate the same food?
16. If sea stars get stuck on the beach out of the water, they cannot make their way back to the ocean. Explain why not.

Section 15.3

17. Which of these is not a characteristic of vertebrates?
    a. a backbone and a skull
    b. an internal skeleton
    c. radial symmetry
    d. well developed organ systems
18. Match each of these tissue types to the correct description.

a. epithelial	1. three types including smooth, muscle, and cardiac
b. connective	2. transmits signals
c. nerve	3. provides strength, support, and protection
d. muscle	4. protects from dehydration, damage, and invasion from bacteria

19. Do you believe that an endothermic or an ectothermic animal would be more active on a cold night? Why?
20. Why do the largest reptiles live where it is warm year round?
21. Predict if ectothermic animals perspire. Explain your guess.
22. Why does external fertilization require water?
23. What are the five classes of vertebrates? Describe their major characteristics and give an example for each.
24. What are the three classes of fish? Which is most simple? Which is most complex?
25. Do you think gills have a lot of blood vessels? Why or why not?
26. If female fish lay thousands of eggs, why is the water not overcrowded with fish?
27. How are amphibians dependent on water?
28. How are birds' eggs more protected than the eggs of reptiles, amphibians, and fish?
29. Both birds and bats fly. Explain two major differences between these two types of animals.
30. Explain the difference between these pairs of terms:
    a. endoskeleton, exoskeleton
    b. gills, lung
    c. ectotherm, endotherm
    d. internal fertilization, external fertilization
    e. vertebrate, invertebrate
    f. radial symmetry, bilateral symmetry

Math and Writing Skills

Section 15.1

1. Make a wanted poster for animals that describes the key features of this kingdom.
2. Write help wanted advertisements for three of the organ systems found in animals. Describe what the important functions of the system are in your ad.
3. Write a creative story that includes the major organ systems discussed in this chapter.
4. Pretend that you are an animal that either has bilateral or radial symmetry. Write a persuasive paragraph that explains why your particular type of symmetry is advantageous.
5. Surveys show that the most popular pets in the United States today are (in order): cats, dogs, parakeets, small rodents (rabbits, gerbils, hamsters), and fish. Take a survey in your class to find out what pets your fellow classmates own. Create a graph to display your results.
6. The largest mammal (and animal overall) is the blue whale, which can be 110 feet long. The largest insect is a stick insect, which can measure 15 inches. How many stick insects would it take to equal the length of one blue whale?

Section 15.2

7. Write a news story about the discovery of a giant squid on a local beach. Include features of the squid and other mollusks in your story.
8. Some sponges live on the shells of crabs. Write a conversation that might occur between the sponge and the crab thanking each other for their help. Explain the advantages of this relationship for both the sponge and the crab in your script.

9. One particular sponge can filter water at the rate of 22.4 L / day. How much water does this sponge filter in one hour?
10. There are 150,000 species of mollusks. If 27% of mollusks are gastropods, what is the combined total number of species of bivalves and cephalopods?
11. You can figure out the temperature in summer by listening to cricket chirps. Count the chirps you hear in 15 seconds. Add 39 to the number of chirps to find the temperature in Fahrenheit within a few degrees. What would the temperature outside be if you counted 44 chirps in 30 seconds?
12. Compare and contrast two major phyla of invertebrates in terms of: symmetry, body structure, nutrition, locomotion, and reproduction.
13. Choose one major phyla of invertebrates to create a descriptive acrostic for its common name.
14. Design your own invertebrate. Draw a picture of your creation and answer these questions in a paragraph. What will it be called? What phyla would it belong to? What does it look like? How big will it be? What type of habitat does it live in? Describe what and how it eats. How does this invertebrate move? What are the predators of this new invertebrate? Describe how it defends itself.

Section 15.3

15. If there are 45 species of jawless fish, 275 species of cartilaginous fish, and 25,000 species of bony fish, how many total species of fish are there? What percent of the total number of fish does each class represent?
16. Write a guidebook that will help a tadpole adjust to life on land.
17. There are fewer species of amphibians than any other vertebrate group. Why do you believe that this is true? Explain your reasoning.
18. Your friend just got a job at the pet store. He is having trouble distinguishing the salamanders from the lizards. Give your friend advice about how to easily tell the difference between these two types of animals.
19. A frog might lay between 500 to 5,000 eggs at one time. A turtle could lay 100 eggs at a time. Explain these numbers in terms of fertilization and chance of survival.
20. Choose three different habitats and describe the types of birds that live there.
21. Explain the features of mammals that allow them to live successfully in colder environments than reptiles.
22. Pick two familiar vertebrates and describe their adaptations for getting food.
23. A box turtle lives five times as long as a gorilla. A gorilla lives twice as long as a giraffe. A giraffe lives twice as long as a rabbit. A rabbit lives five times as long as an opossum, which only lives for one year. How long do the other animals usually live for?
24. Nearly a quarter of all mammals can fly! 985 species of bats make up 23.1% of all known mammal species. Use this number to estimate the total number of mammal species scientists have discovered.