CHAPTER 26

Animal Systems II

26.1 Response

26.2 Movement and Support

26.3 Reproduction

26.4 Homeostasis

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The wings of birds, such as this African fish eagle, served as an inspiration for airplanes.

HS-LS1-1, HS-LS1-2, HS-LS1-3, HS-LS1-4, HS-LS4-2, HS-ETS1-1, HS-ETS1-2

CASE STUDY

How can engineers learn from animal systems?

Dreams of imitating animals' abilities are as old as the human imagination. More than 2000 years ago, Greek myths told of an inventor who used bird wings as models for artificial wings that could allow him to fly with his son, Icarus. Centuries later, in the real world, artist and inventor Leonardo Da Vinci used birds as inspiration in his efforts to design and build "flying machines." And a little more than 100 years ago, two bicycle mechanics observed how the structure and shape of pigeons' wings enabled them to fly. After testing lots of prototypes, Wilbur and Orville Wright actually did build a successful "flying machine"—their first airplane—in 1903.

Today collaborations between biology and engineering design have a name: biomimicry, or "mimicking life." Translating that concept into engineering solutions that work requires tackling design challenges from two approaches at once.

Approach 1: Engineers identify a human need and create what is called a "design brief" that describes and defines a design challenge.

Approach 2: Biologists search for a living system in which evolution has "solved" that challenge. They ask, "What structures in nature enable organisms to fly? Or run quickly? Or swim through water with minimal drag? Or climb walls?"

Then biologists and engineers combine approaches 1 and 2. First, they work together to identify how those biological structures perform the desired function. Then they figure out how to apply what they've learned in designing an engineering solution.

Natural selection has produced some animal structures we can adapt for our purposes and other structures we can't use so well. So bird wings, for example, have served as useful models for airplane wings. Bee and dragonfly wings, not so much.

But insect wings offer different inspiration for engineers designing more efficient blades for wind turbines. Insect wings are sturdy, yet flexible. Studies of insect flight show that slightly elastic wings can adapt to changing wind conditions in ways that improve performance. Early trials of "insect-wing" prototypes suggest that turbine blades of the right flexibility could generate 35 percent more power than rigid blades!

There are hundreds of examples. Engineers trying to boost the speed of Japan's "bullet trains" hit a challenge. The trains were moving so quickly that when they entered tunnels, they created shock waves strong enough to damage tunnel structures! Solution? Engineers modeled the "nose" of the train after the beaks of kingfishers—birds that nose-dive into water to snag their prey ... and do so with very little splash. Trains with kingfisher-inspired noses create no shock waves, but also run faster, and use less energy!

What else can inventors learn from studying animals? Can you think of a useful design patterned after an animal body part or activity?

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

LESSON 26.1 Response

KEY QUESTIONS

- *How do animals respond to their environment?*
- *What are some trends in nervous system evolution?*
- *What are some types of sensory systems in animals?*

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.

VOCABULARY

neuron
stimulus
sensory neuron
interneuron
response
motor neuron
ganglion
cerebrum
cerebellum

READING TOOL

As you read your textbook, identify the main ideas and details or evidence that supports the main ideas. Use the lesson headings to help you. Record your work on the table in your **Biology Foundations Workbook.**

INTERACTIVITY

Explore the structure and function of neurons and how they send signals around the body.

Imagine that you are at a favorite place—a beach, a volleyball court … wherever. Think about how the sun and wind feel on your face. Or how you should judge the distance and location of other players as you prepare for the perfect spike. Now think about the way you experience that place. You gather information about your surroundings through senses such as vision and hearing. Your brain decides how to respond to that information. Then your muscles transform that decision into action. All animals do pretty much these same things, but the sensory world of a dog, cat, or mosquito is different from yours. Let's examine why.

How Animals Respond

Animals must often respond to events or environmental conditions within seconds, or even fractions of a second. Sometimes they need to catch food. Other times, they need to avoid being caught by other animals that want to make them into food! Most animals have evolved nervous systems that enable them to respond to events around them. Nervous systems are composed of different kinds of nerve cells, or **neurons**. Neurons are connected to one another in ways that enable them to pass information from one cell to the next. In this way, neurons acquire information from their surroundings, interpret that information, and then "decide" what to do about it.

Detecting Stimuli Information in the environment that causes an organism to react is called a **stimulus**. Chemicals in air or water can serve as stimuli. Light or heat can also stimulate the nervous system. The sound of your phone buzzing or vibrating on a Friday night is a stimulus that might prompt you to answer it. Animals' ability to detect stimuli depends on specialized cells called **sensory neurons**. Each type of sensory neuron responds to a particular stimulus such as light, heat, or a chemical.

Humans have many types of sensory cells similar to those in other animals. For that reason, many animals react to stimuli that humans notice, too, including light, taste, odor, temperature, sound, water, gravity, and pressure. But many animals have types of sensory cells that humans don't have. That's one reason that some animals respond to stimuli that humans can't detect, such as weak electric currents or Earth's magnetic field.

Processing Information Does a particular odor indicate food or danger? Is the immediate environment too hot, too cold, or just right? When sensory neurons detect a stimulus, they pass information about it to other nerve cells. Those neurons, which typically pass information to yet more neurons, are called **interneurons**, shown in **Figure 26-1**. Interneurons process information and determine how an animal responds. The number of interneurons an animal has, and the ways those interneurons process information, determine how flexible and complex an animal's behavior can be.

Some invertebrates, such as cnidarians and worms, have few interneurons. These animals are capable of only simple responses to stimuli. They may swim toward light or toward a chemical stimulus that signals food. Vertebrates, such as this leopard, have more highly developed nervous systems with greater numbers of interneurons, especially in the brain. This is the reason that vertebrate behaviors can be more complex than behaviors of most invertebrates.

Responding A specific reaction to a stimulus is called a **response**. For example, waking up when you hear your alarm clock go off is a response. ***When an animal responds to a stimulus, body systems—including the nervous system and the muscular system—work together to generate the response.*** Responses to many stimuli are directed by the nervous system. However, those responses are usually carried out by other types of cells or tissues, such as muscle tissue. Nerve cells called **motor neurons** carry "directions" from interneurons to muscles. Other responses to environmental conditions may be carried out by other body systems, such as respiratory or circulatory systems.

READING CHECK Classify What type of nerves do animals use when they respond to loud noises?

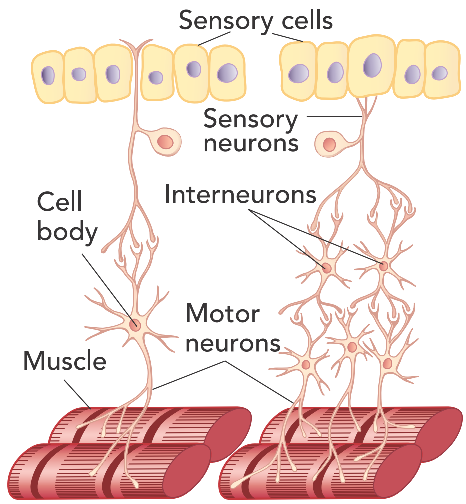
BUILD VOCABULARY

Prefixes The prefix *inter-* means "between" or "among." An **interneuron** is located between two other neurons.

Figure 26-1

Neural Circuits

In some neural circuits, sensory neurons connect to motor neurons in ways that enable fast but simple responses. In others, specialized sensory cells connect to sensory neurons, which connect to interneurons, which connect to motor neurons. Mammals, such as the leopard shown, have complex neural circuits, and therefore can process and respond to information in complex ways.



Trends in Nervous System Evolution

Nervous systems vary greatly in organization and complexity across the animal kingdom. ***Animal nervous systems exhibit different degrees of cephalization and specialization.***

Invertebrates Invertebrate nervous systems range from simple collections of nerve cells to complex organizations that include many interneurons. You can see some examples in **Figure 26-2**.

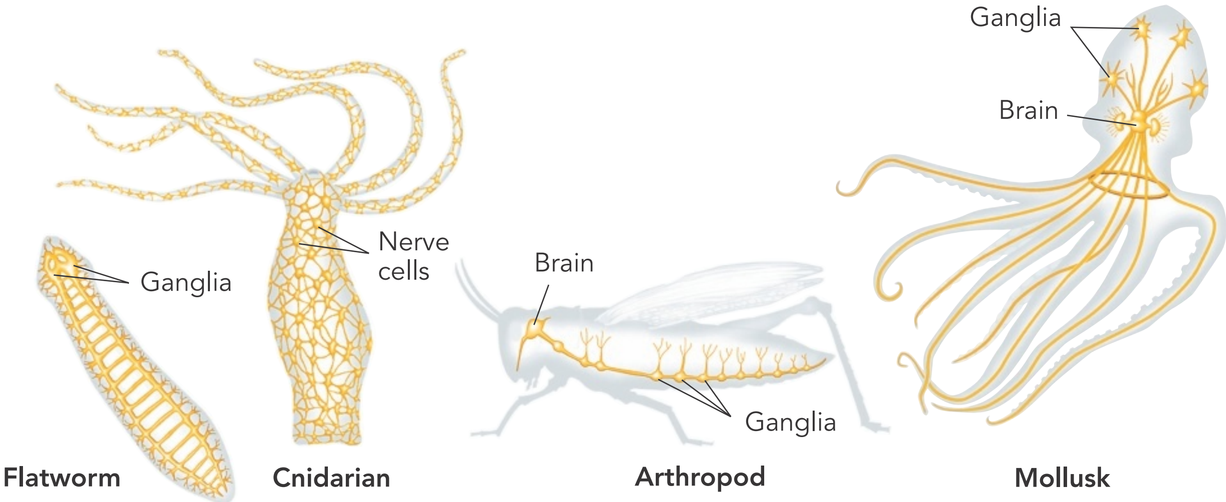


Figure 26-2

Invertebrate Nervous Systems

Invertebrate nervous systems have different degrees of cephalization and complexity. Flatworms have centralized nervous systems with small ganglia in their heads. Cnidarians have a nerve net that despite its simplicity, enables them to be successful predators. Arthropods and cephalopod mollusks have a brain and specialized sensory organs.

Nerve Nets, Nerve Cords, and Ganglia Cnidarians, such as jellyfishes, have simple nervous systems called nerve nets. As the name implies, nerve nets consist of neurons connected into a net-like arrangement with few specializations. In echinoderms such as sea stars, some interneurons are grouped together into nerves or nerve cords that form a ring around the animals' mouths and stretch out along their appendages. In other invertebrates, interneurons are grouped together into small structures called **ganglia** (singular: ganglion), where interneurons connect with one another.

"Heads" As you learned in Chapter 24, bilaterally symmetric animals often exhibit cephalization, the concentration of sensory neurons and interneurons into a "head." Certain flatworms and roundworms show some cephalization. Some cephalopod mollusks and many arthropods show higher degrees of cephalization. In these animals, interneurons form ganglia in several places. Typically, the largest ganglia are located in the head region and are called cerebral ganglia.

Brains In some species, cerebral ganglia are further organized into a structure called a brain. The brains of some cephalopods, such as octopuses, enable complex behavior, including several kinds of learning. In fact, some cephalopod mollusks, such as this octopus, can be trained to complete tasks such as opening a jar!

Chordates Some very simple chordates have nothing you would recognize as a "head" as adults, but still have a cerebral ganglion. Most vertebrates show a high degree of cephalization and have highly developed nervous systems. Vertebrate brains are formed from many interneurons within the skull. These interneurons are connected with each other and with sensory neurons and motor neurons in the head and elsewhere in the body. The human brain contains more than 100 billion nerve cells, each of which sends signals to as many as 1000 other nerve cells and receives signals from up to 10,000 more.

Parts of the Vertebrate Brain Regions of the vertebrate brain include the cerebrum, cerebellum, medulla oblongata, optic lobes, and olfactory bulbs. The **cerebrum** is the "thinking" region of the brain. It receives and interprets sensory information and determines a response. The cerebrum is also involved in learning, memory, and conscious thought. The **cerebellum** coordinates movement and controls balance, while the medulla oblongata controls the functioning of many internal organs. Optic lobes are involved in vision, and olfactory bulbs are involved in the sense of smell. Vertebrate brains are connected to the rest of the body by a thick collection of nerves called a spinal cord, which runs through a tube in the vertebral column.

Vertebrate Brain Evolution Brain evolution in vertebrates follows a general trend of increasing size and complexity from fishes, through amphibians and reptiles, to birds and mammals. **Figure 26-3** shows how the size and complexity of the cerebrum and cerebellum increase.

READING CHECK **Infer** How do the folds of the mammalian cerebellum increase its surface area?

READING TOOL

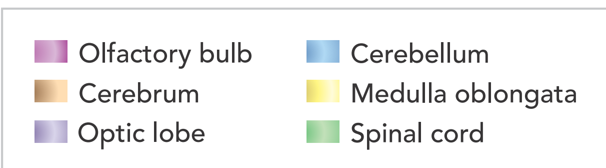
The main idea of this section is that evolution has lead to increasing cephalization and specialization in animal nervous systems. Look for and identify the details that support this idea.

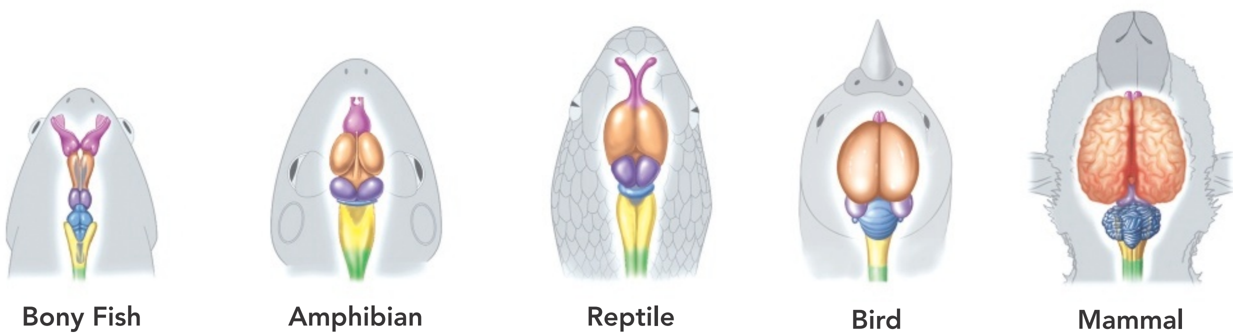
INTERACTIVITY

Figure 26-3

Vertebrate Brains

The cerebrum and cerebellum increase in size from fish to mammal. In fishes, amphibians, and reptiles, the cerebrum, or "thinking" region, is relatively small. In birds and mammals, and especially in primates, the cerebrum is much larger and may contain folds that increase its surface area. The cerebellum is also most highly developed in birds and mammals.





Quick Lab

Guided Inquiry

Does a Planarian Have a Head?

1. Cover half of the outside of a petri dish with black paper.
2. Place a white sheet of paper under the other half.
3. Place a planarian in the center of the dish, and add spring water to keep it moist.
4. Observe the planarian for 2 minutes. Record how many times it moves from one side of the dish to the other.

ANALYZE AND CONCLUDE

1. **Form a Hypothesis** When the planarian moved, did one end always lead the way? Form a hypothesis that explains your observation.

INTERACTIVITY

Learn how different sense organs are adapted to the their needs.

Sensory Systems

The more complex an animal's nervous system is, the more developed its sensory systems tend to be. ***Sensory systems range from individual sensory neurons to sense organs that contain both sensory neurons and other cells that help gather information.***

Invertebrate Sense Organs Many invertebrates have sense organs that detect light, sound, vibrations, movement, body orientation, and chemicals in air or water. Invertebrate sense organs vary widely in complexity. Flatworms, for example, have simple eyespots that detect only the presence and direction of light. More cephalized invertebrates have specialized sensory tissues and well-developed sense organs. Some cephalopods and arthropods have complex eyes that detect motion and color and form images. **Figure 26-4** shows a variety of invertebrate sensory systems.

Chordate Sense Organs The simplest chordates have few specialized sense organs. In tunicates, sensory cells in and on the siphons and other internal surfaces help control the amount of water passing through the pharynx. Lancelets have a cerebral ganglion with a pair of eyespots that detect light.

Most vertebrates have highly evolved sense organs, as you can see in **Figure 26-5**. Many have very sensitive organs of taste, smell, and hearing. Some sharks, for example, can sense 1 drop of blood in 100 liters of water! And although all mammalian ears have the same basic parts, they differ in their ability to detect sound. Bats and dolphins can find objects in their environment using echoes of their own high-frequency sounds. A great many species of fishes, amphibians, reptiles, birds, and mammals have color vision that is as good as, or better than, that of humans.

Figure 26-4

Invertebrate Sense Organs

The compound eye of this insect is made up of many lenses that detect minute changes in movement.

The antennae of this male midge can sense sound waves and air motion.

The garden spider can detect vibrations in its web through its legs.

CASE STUDY

Figure 26-5

Vertebrate Sense Organs

The senses and sense organs of vertebrates can inspire inventors. For example, the ability of bats and dolphins to sense objects through reflected sound inspired naval sonar and medical sonograms. The rattlesnake can detect infrared (heat) radiation from other animals using an organ in its face, similar to motion detectors in alarm systems. The eagle has extremely sharp eyesight. The eye helped inspire the invention of the camera.

Some species, including certain fishes and duck-billed platypuses, can detect weak electric currents in water. Some sharks use this "electric sense" to navigate by detecting electric currents in seawater caused by ocean currents moving through Earth's magnetic field. Other "electric fish" create their own electric currents. These fishes use electric pulses to communicate with one another in much the same way that other animals communicate using sound. Many species that can detect electric currents use that ability to track down prey in dark, murky water. Some birds can detect Earth's magnetic field directly, and they use that ability to navigate during their long-distance migrations.

HS-LS1-1, HS-LS1-2

LESSON 26.1 Review

KEY QUESTIONS

1. What is the role of motor neurons in the response to stimuli?
2. Describe three examples of specialization in the nervous systems of animals.
3. Give an example of an animal with a very simple sensory system and an example of one with a complex sensory system.

CRITICAL THINKING

4. **Construct an Explanation** An eagle sees a mouse on the ground and then swoops down to catch it. Describe the events that occur in the nervous system of the eagle as it completes this activity.
5. **Interpret Visuals** Study the vertebrate brains shown in **Figure 26-3**. Compare the brain of the mammal with other brains. How do brain structures help explain the abilities of mammals?

LESSON 26.2

Movement and Support

KEY QUESTIONS

- *What are the three types of skeletons?*
- *How do muscles enable movement?*

HS-LS1-2: Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms.

VOCABULARY
hydrostatic skeleton
exoskeleton
endoskeleton
joint

READING TOOL

As you read through this lesson, take notes on the different types of skeletons that protect and support organisms. Fill in the graphic organizer in your **Biology Foundations Workbook.**

As a fly hovers over a stream, a frog leaps out of the water to catch it. An earthworm wriggles through leaf litter nearby. A falcon streaks overhead, hunting a mouse scampering across a field. All these organisms are responding to external factors by moving. Their movement depends on interactions among the nervous, muscular, and skeletal systems.

Types of Skeletons

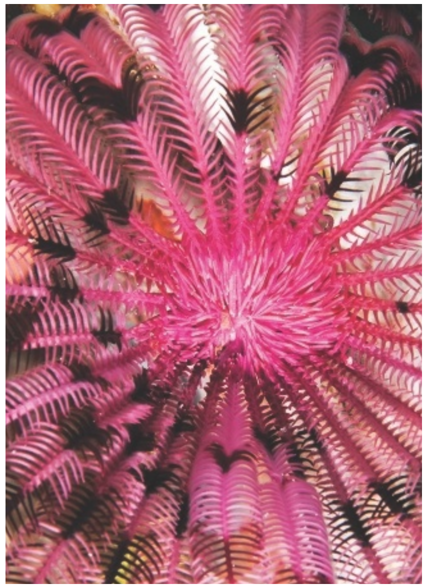
To move efficiently, all animals must generate physical force and somehow apply that force against air, water, or land in order to push or pull themselves around.

Skeletal Support Animals can move most efficiently if they have some kind of rigid body parts. Why? Because rigid body parts help apply the force generated by muscles. Legs push against the ground. Bird wings push against air. Fins or flippers apply force against water. Each of these body parts is rigid because each is supported by some sort of skeleton. ***Animals have three main kinds of skeletal systems: hydrostatic skeletons, exoskeletons, and endoskeletons.*** The three types of skeletons are shown in **Figure 26-6**.

Hydrostatic Skeletons Some invertebrates, such as cnidarians and annelids, have hydrostatic skeletons. The **hydrostatic skeleton** of an earthworm, for example, consists of fluids held in a body cavity that can alter the earthworm's body shape by working with contractile cells in its body wall. Earthworms have two major groups of body muscles. Longitudinal muscles run from the front of the worm to the rear and can contract to make the worm shorter and fatter. Circular muscles wrap around each body segment and can contract to make the worm longer and thinner. The earthworm moves by alternately contracting these two sets of muscles.

Earthworm: Hydrostatic Skeleton

Cicada: Exoskeleton



Crinoid: Endoskeleton

Figure 26-6

Invertebrate Skeletons

Some invertebrates, such as this earthworm, have hydrostatic skeletons. Many arthropods, such as cicadas, periodically outgrow their exoskeleton and must literally break out of them, and grow a new exoskeleton, in order to increase in size. Some invertebrates (including this crinoid) and all chordates have an endoskeleton.

Exoskeletons Many arthropods have **exoskeletons**, or external skeletons, as do most mollusks, such as snails and clams. Arthropod exoskeletons, which typically cover their bodies, are made of a complex carbohydrate called chitin. Most mollusks have hard shells made of calcium carbonate. Arthropods' exoskeletons enable them to swim, fly, burrow, walk, crawl, and leap. They can also provide watertight coverings that enable some species to live in Earth's driest places. An exoskeleton can also provide physical protection from predators—as you know if you have ever tried to crack a crab shell. Mollusks with two-part shells can also close their shells to avoid drying out.

But exoskeletons have disadvantages. An external skeleton poses a problem when the animal it belongs to needs to grow. To increase in size, arthropods break out of their exoskeleton and grow a new one in a process called molting. Exoskeletons are also relatively heavy. The larger arthropods get, the heavier their skeletons become in proportion to their body weight. This is one reason that some science fiction monsters could never exist in the real world. The legs of a spider the size of an elephant would collapse under the spider's weight!

BUILD VOCABULARY

Prefixes The prefix *exo-* means "outside," so an **exoskeleton** is outside the animal. The prefix *endo-* means "within," so an **endoskeleton** is within, or inside, the animal.

Endoskeletons Echinoderms and vertebrates have **endoskeletons**, which are any kind of structural support system that is inside the body. Crinoids and other echinoderms have an endoskeleton made of calcified plates. These skeletal plates support and protect echinoderms, and also give them a bumpy texture.

As an internal skeleton does not surround the body, it cannot protect an animal the way that an exoskeleton can. On the other hand, an internal skeleton can grow as an animal grows, so the animal does not need to molt. Because endoskeletons are lightweight in proportion to the bodies they support, even land-dwelling vertebrates can grow very large.

INTERACTIVITY

Learn how skeletons, muscles, and joints are all related.

INTERACTIVITY

Learn how bones and muscles relate to body mass.

Joints If any kind of rigid skeleton were made of one piece, or if its parts were rigidly attached to each other, the animal couldn't move. Arthropods and vertebrates can move because their skeletons are divided into many parts that are connected by **joints**. In vertebrates, bones are connected at joints by strong connective tissues called ligaments.

READING CHECK **Describe** What features of an endoskeleton provide support and movement?

Muscles and Movements

The muscular structure of an animal, such as the sloth shown in **Figure 26-7**, helps determine how it lives and moves. Muscles are specialized tissues that produce physical force by contracting, or shortening, when they are stimulated by the nervous system. Muscles can relax when they aren't being stimulated, but they cannot actively get longer. That presents a problem. Think about the way you move. You walk by swinging your legs forward and then backward, pushing against the ground as you walk. But how do you get your legs to move backward and forward if your muscles can generate force in only one direction? The answer involves interactions between the muscular system and the skeletal system. ***In many animals, muscles work together in pairs or groups that are attached to different parts of a skeleton.*** Muscles are attached to bones around the joints by tough connective tissue called tendons. Tendons are attached in such a way that they pull on bones when muscles contract. Typically, muscles are arranged in groups that pull parts of the skeleton in opposite directions.

READING TOOL

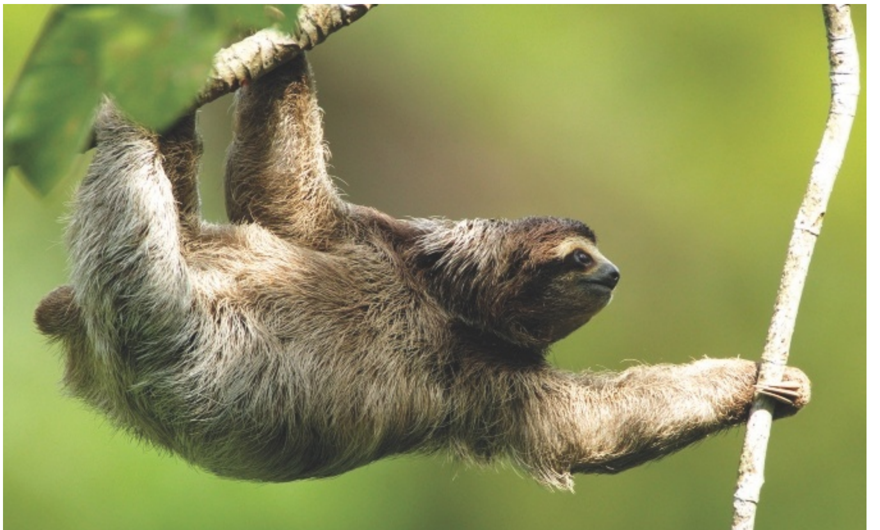
Refer to **Figure 26-8** as you read about muscles and movement. Use the diagram to explain why muscles generally work in pairs to create movement.

Movement Arthropod muscles are attached to the inside of the exoskeleton. Vertebrate muscles are attached around the outside of bones. In both cases, different pairs or groups of muscles pull across joints in different directions. As you can see in **Figure 26-8**, when one muscle group contracts and the other is relaxed, it bends the joint. When the first group relaxes and the second group contracts, the joint straightens and the first muscle group is stretched. Muscles can only contract, so they must be stretched back into position by the opposing muscle group.

Figure 26-7

Vertebrate Musculoskeletal Systems

A great variety of bones, muscle groups, and joints have evolved in vertebrates. For instance, a sloth's muscles and bones are well suited for climbing through trees.



Vertebrate Muscular and Skeletal Systems An amazing variety of complex combinations of bones, muscle groups, and joints have evolved in vertebrates. In many fishes and snakes, muscles are arranged in blocks on opposite sides of the backbone. These muscle blocks contract in waves that travel down the body, bending it first to one side and then to the other. These waves of movement generate thrust. The limbs of many modern amphibians and reptiles stick out sideways, as though the animals were doing push-ups. Sideways movements of their backbone move their limbs forward and backward.

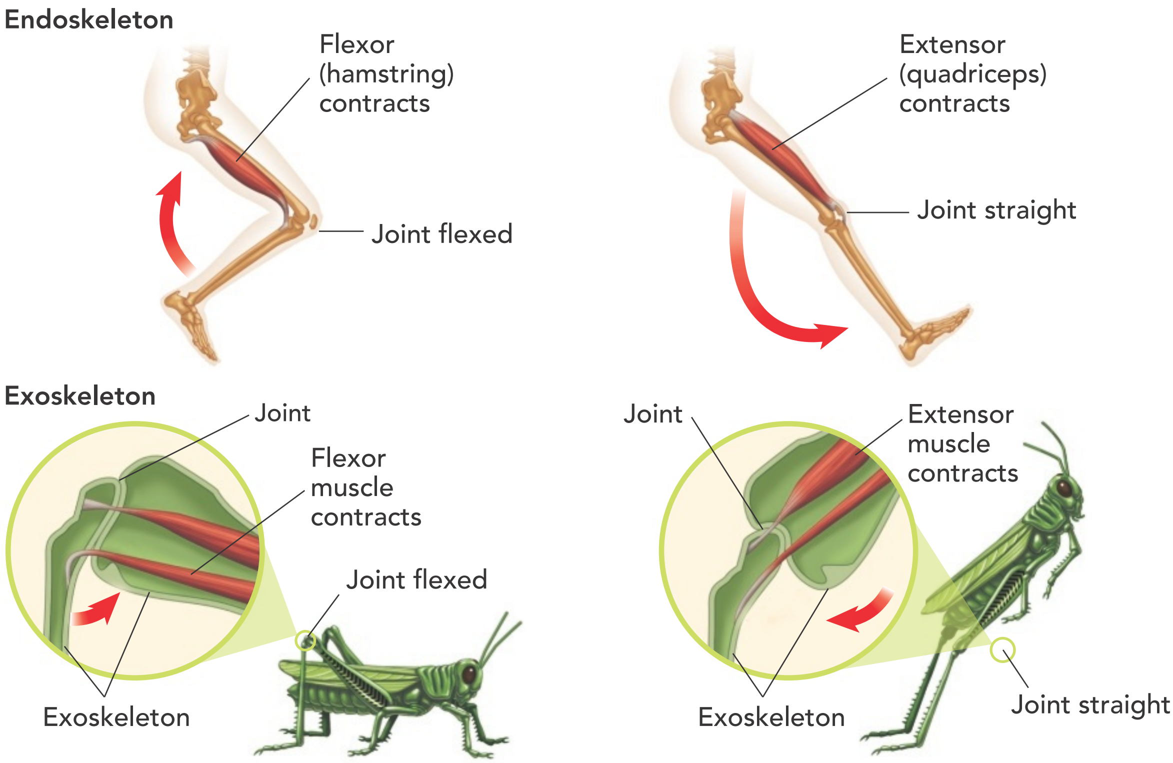
Most mammals stand with their legs straight under them, whether they walk on two legs or four. The shapes and relative positions of bones, muscles, and joints are linked closely to the functions they perform. Limbs may be specialized for high-speed running, flying, swimming, manipulating objects, or climbing. Paleontologists can reconstruct the habits of extinct animals by studying the joints of fossil bones and the places where tendons and ligaments once attached.

ANIMATION

Figure 26-8

Muscles and Joints

The diagrams show how muscles work with a vertebrate endoskeleton and an arthropod exoskeleton to bend and straighten joints.



HS-LS1-2

LESSON 26.2 Review

KEY QUESTIONS

1. Describe the three main types of skeletons.
2. How does the organization of muscles allow animals a variety of movements?

CRITICAL THINKING

3. **Predict** When is an animal with an exoskeleton most vulnerable to attack from predators? Explain your prediction.
4. **Construct an Explanation** Why are spiders unable to grow to large sizes, as they are sometimes depicted in science fiction movies?
5. **Use Models** Create a model of a vertebrate or invertebrate joint. Make sure the muscles are attached to the same skeletal structures they would be attached to in a real animal and that the muscles and skeletal structure allow the joint to bend and flex.

LESSON 26.3 Reproduction

KEY QUESTIONS

- *How do asexual and sexual reproduction in animals compare?*
- *How do internal and external fertilization differ?*
- *Where do embryos develop?*
- *How are terrestrial vertebrates adapted to reproduction on land?*

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-LS1-4: Use a model to illustrate the role of cellular division (mitosis) and differentiation in producing and maintaining complex organisms.

HS-LS4-2: Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment.

VOCABULARY

placenta
metamorphosis
amniotic egg
mammary gland

READING TOOL

Keep track of the similarities and differences between sexual and asexual reproduction. Fill in the Venn diagram in your **Biology Foundations Workbook.**

Sexual reproduction can be dangerous. Just ask a male praying mantis, who may be devoured by a female shortly after they mate or even *while* they are mating! Sexual reproduction can also require lots of effort. Just ask a male peacock, whose success in courting a female depends on growing and lugging around a huge tail that makes it harder for him to escape predators. Or a female elephant, who carries the ever-increasing weight of her developing young for twenty-two months! Yet most animal species engage in sexual reproduction during at least part of their life cycles. Why do they take the risk?

Asexual and Sexual Reproduction

All animals must reproduce, or their populations and species become extinct. This vital function is made possible by interactions among virtually all body systems.

Asexual Reproduction Many invertebrates and a few chordates can reproduce asexually in various ways. Some cnidarians divide in two. Some animals reproduce through budding, which produces new individuals as outgrowths of the body wall. Females of some species can reproduce asexually by producing eggs that develop without being fertilized. This kind of asexual reproduction occurs in some crustaceans and insects but very rarely in vertebrates.

Asexual reproduction requires only one parent, so individuals in favorable environmental conditions can reproduce rapidly. Offspring produced asexually carry only a single parent's DNA, so they have less genetic diversity than offspring produced sexually. Lack of genetic diversity can be a disadvantage to a population if its environment changes.

Sexual Reproduction Recall that sexual reproduction in animals involves meiosis, the process that produces haploid reproductive cells, or gametes. Gametes carry half the number of chromosomes found in body cells. Typically, male animals produce small gametes, called sperm, that can "swim" using flagellum. Females produce larger gametes called eggs, which do not swim. When haploid gametes join during fertilization, they produce a zygote that contains the diploid number of chromosomes.

Sexual reproduction maintains genetic diversity in a population by creating individuals with new combinations of genes. Because genetic diversity is the raw material on which natural selection operates, sexually reproducing populations are better able to evolve and adapt to changing environmental conditions. On the other hand, sexual reproduction requires two individuals of different sexes. So the density of a population must be high enough to allow mates to find each other.

In most animal species that reproduce sexually, every individual is either male or female. Among annelids, mollusks, and fishes, however, some species are hermaphrodites (hur MAF roh dyts), which means that some individuals can function as both male and female. Some hermaphrodites, such as the nudibranch in **Figure 26-9**, can produce eggs and sperm at the same time. Usually these animals don't fertilize their own eggs but rather exchange sperm with another individual. Other hermaphroditic species change from one sex to the other as they mature.

VIDEO

Watch some of the different ways that animals are born.

Figure 26-9

Hermaphrodites

Although nudibranchs are hermaphrodites, they must mate in order to reproduce.

Reproductive Cycles A number of invertebrates have life cycles that alternate back and forth between sexual and asexual reproduction. Parasitic worms and cnidarians alternate between forms that reproduce sexually and forms that reproduce asexually.

Parasitic worms, such as blood flukes, mature in the body of an infected person, reproduce sexually, and release embryos that pass out of the body in feces. If the embryos reach fresh water, they develop into larvae and infect snails, in which they reproduce asexually. Then the larvae are released, ready to infect another person.

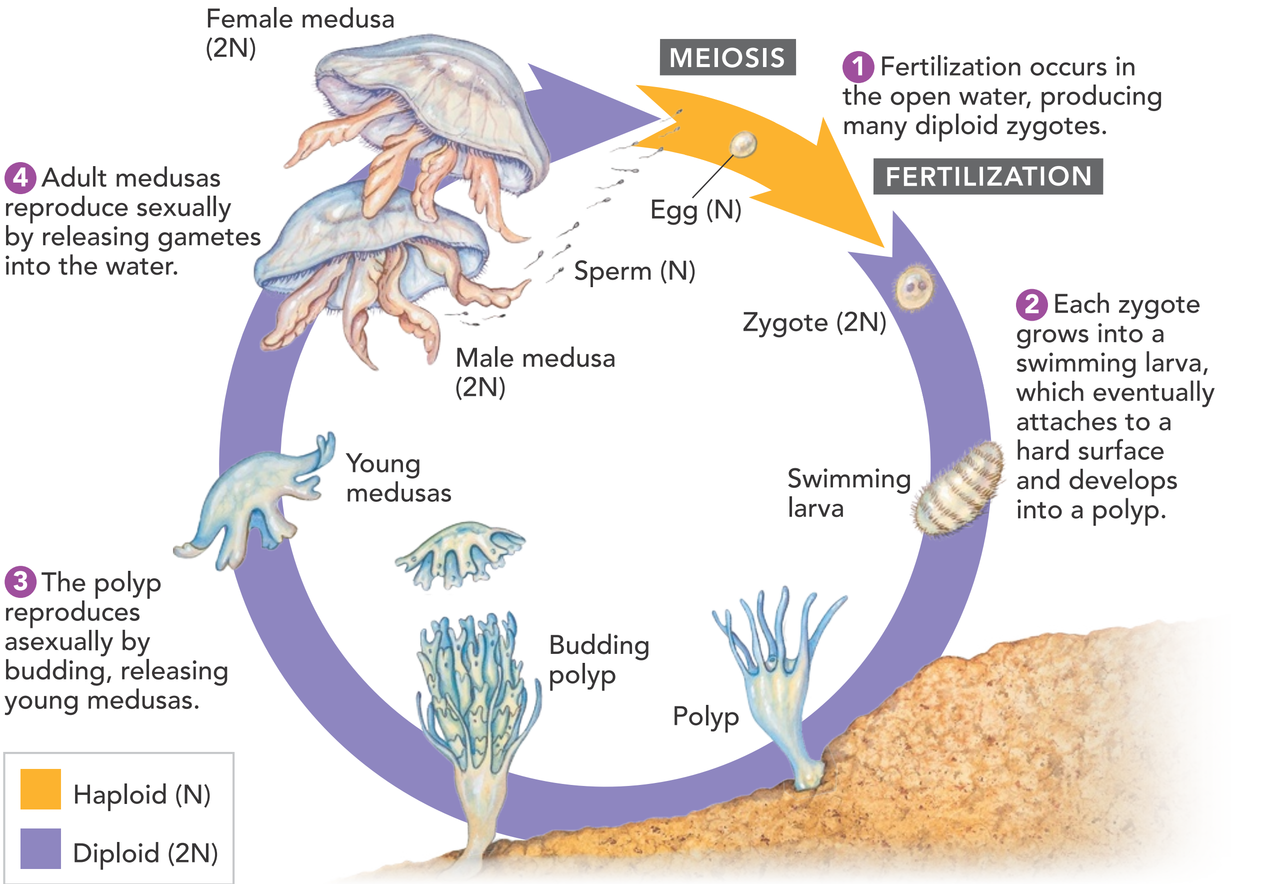


Figure 26-10

Alternating Reproductive Cycles

The reproductive cycle of *Aurelia*, a jellyfish, alternates between asexual and sexual reproduction.

Many cnidarians alternate between two body forms: polyps that grow singly or in colonies, and medusas that swim freely in the water. The life cycle of a common jellyfish, *Aurelia*, is shown in **Figure 26-10**. In these jellyfish, polyps produce medusas asexually by budding. Those medusas then reproduce sexually by producing eggs and sperm they release into the water. After fertilization, the resulting zygote grows into a free-swimming larva that eventually attaches to a hard surface and develops into a polyp.

READING CHECK **Interpret Diagrams** Refer to **Figure 26-10**. Which part of the life cycle includes sexual reproduction?

Internal and External Fertilization

In sexual reproduction, eggs and sperm may meet either inside or outside the body of the egg-producing individual. These methods are called internal and external fertilization, respectively.

INTERACTIVITY

Learn about some of the different reproductive strategies in the animal kingdom.

Internal Fertilization

Many aquatic animals and nearly all terrestrial animals reproduce by internal fertilization. ***During internal fertilization, eggs are fertilized inside the body of the egg-producing individual.***

Invertebrates Many different kinds of invertebrates reproduce by internal fertilization. The eggs of sponges and some other aquatic animals are fertilized by sperm released by others of their species and taken in from the surrounding water. In many arthropod species, males deposit sperm inside the female's body during mating. The crab in **Figure 26-11** carried fertilized eggs until they hatched.

Chordates Some fishes and amphibians, and all reptiles, birds, and mammals, reproduce by internal fertilization. In some amphibian species, males deposit "sperm packets" into their environment. Later, females will pick up these packets and put them inside their own body. In many other chordate species, males have an external sexual organ that deposits sperm inside the female during mating.

Figure 26-11

Internal Fertilization

Many female arthropods, like this crab, carry fertilized eggs until they hatch.

External Fertilization

Many aquatic invertebrates and vertebrates reproduce by external fertilization. ***In external fertilization, eggs are fertilized outside the body of the egg-producing individual.***

Invertebrates Invertebrates with external fertilization include corals, worms, and mollusks. These animals release large numbers of eggs and sperm into the water. Gamete release is usually synchronized with tides, phases of the moon, or seasons, so that eggs and sperm are present at the same time. Fertilized eggs develop into free-swimming larvae that typically grow for a time before changing into adult form.

Chordates Chordates with external fertilization include most nonvertebrate chordates and many fishes and amphibians. In some fish species, males and females spawn in a school, releasing large numbers of eggs and sperm into the water. Other fishes and many amphibians spawn in pairs. In these cases, the female usually releases eggs onto which the male deposits sperm.

Development and Growth

After eggs are fertilized, the zygote divides through mitosis and the cells undergo differentiation. In this process, the cells develop into the specialized tissues needed for a multicellular organism to function. This development occurs under different circumstances in different species.

Oviparous: Loggerhead sea turtle

Ovoviviparous: Cat shark

Viviparous: Thomson's gazelle

Where Embryos Develop

Embryos develop either inside or outside the body of a parent in various ways. ***Animals may be oviparous, ovoviviparous, or viviparous.***

Oviparous Species Embryos develop in eggs outside of the parental body in an oviparous (oh VIP uh rus) species. Most invertebrates, many fishes and amphibians, most reptiles, all birds, and a few odd mammals are oviparous.

Ovoviviparous Species In species that are ovoviviparous (oh voh vy VIP uh rus), embryos develop within the mother's body, but they depend entirely on the yolk sac of their eggs, and receive no additional nutrients from the mother. The eggs either hatch within the mother's body or are released immediately before hatching. The young swim freely shortly after hatching. Guppies and other fishes in their family, along with some shark species, are ovoviviparous.

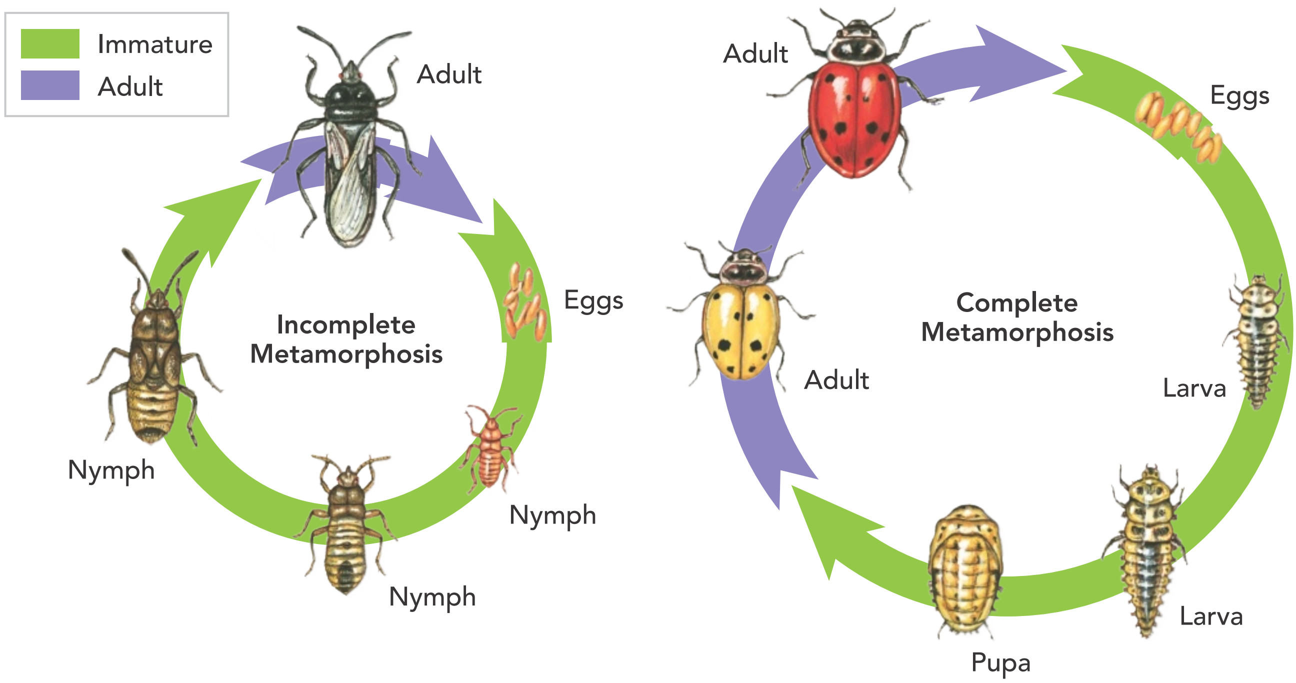
Viviparous Species Embryos that obtain nutrients from the mother's body during development belong to a viviparous (vy VIP uh rus) species. Viviparity occurs in most mammals and in some insects, sharks, bony fishes, amphibians, and reptiles. In viviparous insects, and in some sharks and amphibians, the young are nourished by secretions produced in the mother's reproductive tract. In placental mammals, the young are nourished by a **placenta**—a specialized organ that enables exchange of respiratory gases, nutrients, and wastes between the mother and her developing young.

How Young Develop

Most newborn mammals and newly hatched birds and reptiles look a lot like miniature adults. Infant body proportions are different from those of adults, and newborns have less hair, fur, or feathers than adults have, but it is pretty clear that a newly hatched snake is not going to grow up to be an eagle!

The young of many groups of invertebrates, fishes, and amphibians, however, can look very different from adults. As they develop, they undergo **metamorphosis**—a developmental process that involves dramatic changes in shape and form.

Aquatic Invertebrates Many aquatic invertebrates have a larval stage that looks nothing like an adult. These larvae often swim or drift in open water before undergoing metamorphosis and assuming adult form. Members of some groups, such as cnidarians, have a single larval stage. Other groups, such as crustaceans, may pass through several larval stages before they look like miniature adults.



Terrestrial Invertebrates Insects may undergo one of two types of metamorphosis, as shown in **Figure 26-12**. Some insects, such as grasshoppers, undergo gradual or incomplete metamorphosis. Immature forms, or nymphs, resemble adults, but lack functional sexual organs and some adult structures such as wings. As they molt several times and grow, nymphs gradually acquire adult structures.

Other insects, such as butterflies, undergo complete metamorphosis. Larvae of these animals look nothing like their parents, and they feed in different ways as well. Larvae molt and grow but change little in appearance. Then they undergo a final molt and change into a pupa (PYOO puh; plural: pupae), the stage in which an insect larva develops into an adult. During the pupal stage, the entire body is remodeled inside and out! The adult that emerges looks like a completely different animal. Don't let your familiarity with caterpillars and butterflies dull your wonder at this change. If land vertebrates underwent this kind of metamorphosis, a larva that looks like a snake could grow up into an eagle.

Hormones control metamorphosis in arthropods. Recall that hormones are chemicals produced in one organ of an organism that affect that organism's other tissues and organs. In insects that undergo complete metamorphosis, high levels of a juvenile hormone keep an insect in its larval form. As the insect matures, its production of juvenile hormone decreases. Eventually, the concentration of juvenile hormone drops below a certain threshold. The next time the insect molts, it becomes a pupa. When no juvenile hormone is produced, the insect undergoes a pupa-to-adult molt.

Amphibians Like insects, most amphibians undergo metamorphosis that is controlled by hormones. This metamorphosis changes amphibians from aquatic young into terrestrial adults. Tadpoles are the larvae of a frog or toad.

INTERACTIVITY

Figure 26-12

Insect Metamorphosis

Some insects will undergo metamorphosis during growth. The chinch bug undergoes incomplete metamorphosis, in which the nymphs look similar to adults. The ladybug undergoes complete metamorphosis. The developing larva and the pupa look completely different from the adult.

INTERACTIVITY

Explore the commonalities that exist in many species during development.

READING TOOL

Relate an animal's reproductive system and strategy to its ability to care for offspring.

Care of Offspring

Animals' care of their offspring varies from no care at all to years of nurturing. Most aquatic invertebrates and many fishes and amphibians release large numbers of eggs that they completely ignore. This reproductive strategy succeeds in circumstances favoring populations that disperse and grow rapidly.

But other animals care for their offspring. Some amphibians incubate their young in their mouth, on their back, or even in their stomach! Birds and mammals generally care for their young. Maternal care is an important mammalian characteristic. Males of many species also help care for the young. Parental care helps the young survive in crowded, competitive environments. Typically, species that provide intensive or long-term parental care give birth to fewer young than species that offer no parental care.

READING CHECK **Summarize** How is parental care related to the number of offspring that the animal produces?

Reproductive Diversity in Chordates

Chordates first evolved in water, so early chordate reproduction was suited to aquatic life. The eggs of most modern fishes and amphibians still need to develop in water, or at least in very moist places. As some vertebrate lineages left the water to live on land, they evolved new reproductive strategies. ***In many terrestrial chordates, reproductive strategies enable the fertilized eggs to develop somewhere other than in a body of water.***

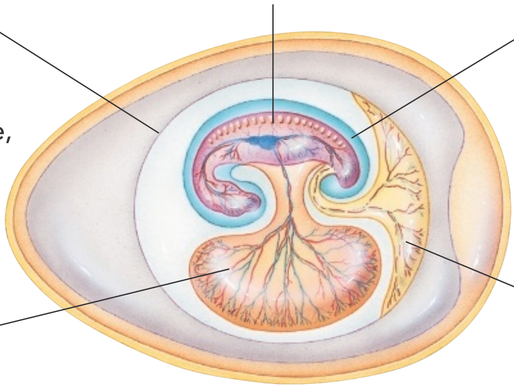
The Amniotic Egg

Reptiles, birds, and a few mammals have evolved amniotic eggs in which an embryo can develop outside its mother's body, and out of water, without drying out. The **amniotic egg** is named after the amnion, one of four membranes that surround the developing embryo. You can learn about the functions of the membranes in **Figure 26-13**. The amniotic egg is one of the most important vertebrate adaptations to life on land.

Figure 26-13

Amniotic Egg

An amniotic egg contains several membranes and an external shell. Although it is waterproof, the eggshell is porous, allowing gases to pass through. The shell of a reptile egg is usually soft and leathery, while the shell of a bird egg is hard and brittle.



Mammalian Reproductive Strategies

Mammalian Reproductive Strategies The three groups of mammals—monotremes, marsupials, and placentals—differ greatly in their means of reproduction and development, but all nourish their young with mother's milk.

Monotremes Reproduction in monotremes is a bizarre combination of reptilian and mammalian traits. Like a reptile, a female monotreme lays soft-shelled amniotic eggs that are incubated outside her body. The eggs hatch in about ten days. But like other mammals, young monotremes are nourished by milk produced by the mother's **mammary glands**. Female monotremes secrete milk through pores on the surface of the abdomen. The duck-billed platypus and four species of echidna are examples of monotremes.

Marsupials Little more than embryos when they emerge, marsupial infants crawl across their mother's fur and attach to a nipple in her pouch. They spend several months drinking milk and completing their development. Kangaroos are marsupial mammals.

Placentals Placental mammals are named for the placenta, a specialized organ that transfers nutrients and oxygen to the embryo. It is also the means of removing carbon dioxide and other wastes from the embryo. The placenta allows the embryo to develop for a long time inside the mother and allows the offspring to be born at a fairly advanced stage of development.

Analyzing Data

Gestational Period

In placental mammals, the time from fertilization to birth is called the gestational period. The table lists gestational periods and typical weights of several adult female mammals.

Gestation Time and Weight

Species	Gestation (days)	Female Weight (kg)
Mouse	20	0.02
Rabbit	33	1
Goat	150	15
Chimpanzee	227	40
Human	226	50
Bison	270	600
Elephant (African)	640	5000

1. **Compare** How does the gestational period of humans compare with that of the other species listed in the table?
2. **Identify Patterns** What trend is shown by the data?
3. **Ask Questions** What questions could you ask, and then investigate, to help explain the trend you identified?

HS-LS1-1, HS-LS1-2, HS-LS1-4, HS-LS4-2

LESSON 26.3 Review

KEY QUESTIONS

1. Compare the advantages of sexual reproduction and asexual reproduction.
2. Describe the two main ways that animal eggs are fertilized.
3. Describe the three main ways that animal embryos develop.
4. How did the evolution of the amniotic egg provide an advantage to terrestrial chordates?

CRITICAL THINKING

5. **Compare and Contrast** How are complete and incomplete metamorphosis alike? How are they different?
6. **Construct an Explanation** How are sperm and egg cells specialized for reproduction? Why is the specialization necessary?

LESSON 26.4

Homeostasis

A kangaroo rat conserves water so well, it can survive without drinking.

KEY QUESTIONS

- *Why are interactions among body systems essential?*
- *How do animals control their body temperature?*

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.

VOCABULARY

endocrine gland
ectotherm
endotherm

READING TOOL

As you read about ectotherms and endotherms, take notes listing the differences between these types of animals. Fill in the Venn Diagram in your **Biology Foundations Workbook.**

A herd of wildebeests plods across Africa's Serengeti Plain. The land is parched, so they move toward greener pastures. They walk slowly, their steps using as little energy as possible. With no food in their guts, their bodies mobilize energy stored in fat deposits, and distribute it to body tissues. Between watering holes, their bodies conserve water by producing as little urine as possible. Survival requires interactions among body systems that perform the functions of regulation, nutrient absorption, reproduction, and defense from injury or illness.

Interrelationship of Body Systems

Homeostasis, the control of internal conditions, is vital to survival. Kangaroo rats can survive without ever drinking any water, getting all the moisture they need from the other foods they eat. Yet their brain cells, like those of humans, require a stable temperature and a steady stream of glucose for energy—even when the animal is under stress. Brain cells must be bathed in fluid with a constant concentration of water. Metabolic wastes must be eliminated. These conditions must not dramatically change during droughts, floods, famines, heat, or cold. Failure of homeostasis, even for a few minutes, would lead to permanent brain injury or death.

You've learned about the digestive, respiratory, circulatory, excretory, nervous, muscular, and skeletal systems separately. Yet these systems are tightly interconnected. ***All body systems interact to maintain homeostasis.*** In most animals, respiratory and digestive systems would be useless without circulatory systems to distribute oxygen and nutrients. Excretory systems require a circulatory system that collects carbon dioxide and nitrogenous wastes from tissues and delivers them to the lungs and excretory organs. Muscles wouldn't work without a nervous system to direct them and a skeletal system to support them.

In addition to the organ systems you've already learned about, you will now learn about other body systems: those that defend against illness, regulate body temperature, and produce and release hormones that regulate many body systems—all to help ensure homeostasis.

INTERACTIVITY

Learn about the various regulatory systems in animals.

Fighting Disease

The environment within an animal's body is a comfortable place for disease-causing microorganisms, or pathogens, that may "steal" oxygen and nutrients. If pathogens enter the body and grow, they can disrupt homeostasis in ways that disrupt the health of an organism, causing disease.

Most animals have an immune system that can distinguish between "self" and "other." Once the immune system discovers "others" in the body, it attacks the invaders and works to restore homeostasis. An example is the macrophage attack shown in **Figure 26-14**. You experience this process whenever you catch a cold or fight off other infections. During the process, you may develop a fever and feel other effects of the battle going on within your body.

SEM 2600×

Figure 26-14
Macrophages

The immune system uses white blood cells called macrophages to defend against invaders, such as the tuberculosis bacterium (pink).

Chemical Controls

Most vertebrates and many invertebrates regulate body functions using a system of chemical controls. Endocrine glands are part of that regulatory system. **Endocrine glands** interact with other body systems by releasing hormones into the blood that are carried throughout the body.

In insects, several hormones interact with other body systems to regulate growth, development, and metamorphosis. In vertebrates, several endocrine glands make up an endocrine system that interacts with other body systems. Some endocrine glands receive information about environmental changes from the nervous system. If danger threatens, endocrine glands release hormones that help the body respond rapidly. Other endocrine glands respond to concentrations of water and other molecules in the blood by regulating the amount of water in the body and the amount of calcium in bones.

READING CHECK **Summarize** How do endocrine glands help maintain homeostasis?

HS-LS1-3

Modeling Lab Guided Inquiry

The Role of Endocrine Glands

Problem How do endocrine glands help humans maintain homeostasis?

In this lab, you will use a model to demonstrate the role of the endocrine system in maintaining blood glucose levels. You will use the model to explain the function of the endocrine system and its importance for maintaining homeostasis.

You can find this lab in your digital course.

INTERACTIVITY

Explore how endothermic animals are able to maintain their rates of metabolism.

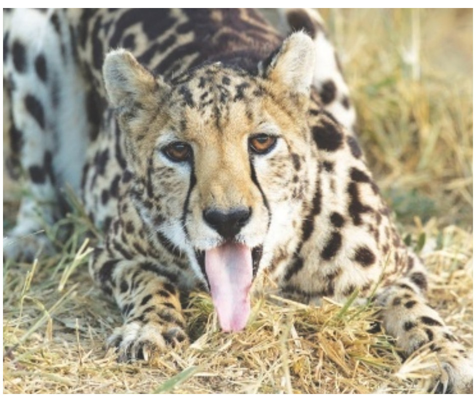
BUILD VOCABULARY

Word Origins The words **ectotherm** and **endotherm** are both derived from the Greek word *therme*, meaning "heat." The prefix *endo-* is a Greek word meaning "within." Therefore, the word *endotherm* literally means "heat from within."

Figure 26-15

Regulating Body Temperature

This shovel-snouted lizard, an ectotherm, lives in the Namib Desert in Africa, one of the hottest places on Earth. It is regulating its body temperature by stilting—raising its body off the hot sand by performing a sort of push-up. Many endotherms, such as this cheetah, pant when they are very warm. Panting allows air to evaporate some of the moisture in the blood-vessel rich mouth and respiratory tract, cooling the blood.



Body Temperature Control

Every organism must respond to environmental temperature, because control of body temperature is essential to homeostasis. Why? Many body functions are influenced by temperature. For example, muscles cannot operate if they are too cold or too hot. Cold muscles contract slowly, making an animal slow to react. If muscles get too hot, on the other hand, they may tire easily.

Body temperature control requires three components: a source of heat, a way to conserve heat, and a method of eliminating excess heat. An animal may be described as an ectotherm or endotherm based on the structures and behaviors that enable it to control its body temperature. Two examples are shown in **Figure 26-15**.

Ectotherms On cool, sunny mornings, lizards bask in the sun. This doesn't mean that they are lazy! A lizard is an **ectotherm**—an animal whose regulation of body temperature depends mostly on its relationship to sources of heat outside its body. ***Most reptiles, invertebrates, fishes, and amphibians are ectotherms that regulate body temperature primarily by absorbing heat from, or losing heat to, their environment.***

Ectotherms have relatively low metabolic rates when resting, so their bodies don't generate much heat. When active, their muscles generate heat, just as your muscles do. However, most ectotherms lack effective body insulation, so their body heat is easily lost to the environment. That's why ectotherms warm up by basking in the sun. But they also have to regulate body temperature when it is hot. Ectotherms also often use underground burrows, where there are fewer temperature extremes. On hot, sunny days, they might seek shelter in a burrow that is cooler than the land surface. On chilly nights, those same burrows are warmer than the surface, enabling the animal to conserve some body heat.

Endotherms An **endotherm** is an animal that regulates body temperature, at least in part, with the heat that its body generates. ***Endotherms, such as birds and mammals, have high metabolic rates that generate heat, even when they are resting.*** Birds conserve body heat primarily with insulating feathers, such as fluffy down. Mammals use combinations of body fat and hair for insulation. Some birds and most mammals can get rid of excess heat by panting. Humans sweat when overheated. As sweat evaporates, it removes heat from the skin and the blood in capillaries just under the surface of the skin. Thus, as warm blood flows through the cooled capillaries, it loses heat.

Comparing Ectotherms and Endotherms

Ectothermy and endothermy each have advantages and disadvantages in different situations. Endotherms move around easily during cool nights or in cold weather because they generate and conserve their own body heat. That's how musk oxen live in the tundra and killer whales swim through freezing polar seas. But the high metabolic rate that generates this heat requires a lot of fuel. The amount of food needed to keep a single cow alive would be enough to feed ten cow-sized lizards!

Ectothermic animals need much less food than similarly sized endotherms. In environments where temperatures stay warm and fairly constant, ectothermy is a more energy-efficient strategy. But large ectotherms run into trouble if it gets very cold at night or stays cold for long periods. It takes a long time for a large animal to warm up in the sun after a cold night. That's one reason that most large lizards and amphibians live in tropical or subtropical areas.

Evolution of Temperature Control There is little doubt that the first land vertebrates were ectotherms. But questions remain about when and how often endothermy evolved. Although modern reptiles are ectotherms, a great deal of evidence suggests that some dinosaurs were endotherms. Many feathered dinosaur fossils have been discovered recently, suggesting that these animals, like modern birds such as the one in **Figure 26-16**, used feathers for insulation. Current evidence suggests that endothermy has evolved at least twice among vertebrates. Endothermy evolved once along the lineage of ancient reptiles that led to birds, and once along the lineage of ancient reptiles that led to mammals.

INTERACTIVITY

Figure 26-16

Temperature Regulation

Like some of their dinosaur ancestors, modern birds use feathers to stay warm. When a bird gets cold, its dense, fluffy undercoat of down feathers stands up and creates spaces next to the bird's skin in which body heat is trapped.

HS-LS1-2, HS-LS1-3

LESSON 26.4 Review

KEY QUESTIONS

1. How does the body maintain homeostasis? Describe an example.
2. Compare how ectotherms and endotherms maintain body temperature.

CRITICAL THINKING

3. **Predict** You are touring several ecosystems, including an icy coastline in the Arctic, and a dry desert in the southwest United States. Do you predict that you will observe equal numbers of ectotherms and endotherms in all ecosystems? Explain your prediction.
4. **Construct an Explanation** Why is maintaining homeostasis important when the body is fighting an infection?
5. **Synthesize Information** How does a high metabolic rate help a bird or mammal regulate its body temperature?

CASE STUDY WRAP-UP

How can engineers learn from animal systems?

Biomimicry informs and inspires engineering design.

HS-ETS1-1, CCSS.ELA-LITERACY.RST.9-10.1, CCSS.ELA-LITERACY.WHST.9-10.1

Make Your Case

Animals body systems accomplish a range of essential functions—from running, digging, flying, or swimming to maintaining homeostasis. Use your imagination and online research to produce a design brief for a function whose design you think could be inspired by an animal system or structure.

Produce a Design Brief

1. **Conduct Research** After reviewing the chapter, go online to search for important and potentially useful animal adaptations that could solve the challenge posed by your design brief. Learn more about how this adaptation works for the animal, and describe how you could put that function to use.
2. **Construct an Argument** Describe a way to fulfill the requirements of your design based on the animal adaptation you researched. Investigate some of the challenges and opportunities involved in applying biologically inspired design to your project.

The beak of the kingfisher (inset) inspired the design of the nose of high-speed trains.

Careers on the Case

Work Toward a Solution

A successful inventor needs to understand science and engineering, as well as the needs of society for new technology.

Biomechanical Engineer

This career combines biology and engineering to develop new products. The work of biomechanical engineers has led to powerful artificial limbs, efficient and safe exercise equipment, and plastic bags that break apart in landfills. Biomedical engineers work in manufacturing, hospitals, universities, and research facilities.

VIDEO

Watch this video to learn about other careers in biology.

hhmi | BioInteractive

Technology on the Case

Research and Engineering in Action

What do X-ray movies of kangaroos on treadmills, the design of athletic shoes, and the engineering of artificial knee joints have in common? They involve the way muscles, skeletons, and joints work. And data from studies like those can inform the design of things ranging from artificial knee joints to athletic shoes optimized for running or other sports.

If you've never injured yourself, you may take the way your body works for granted. You don't think about what your knees or ankles do when you walk. But if you have ever pulled a major body muscle or injured a joint, you KNOW how each of those structures affects your ability to function. Knee and ankle joints, in particular, handle lots of stress, and move in several different ways. And ask your family how long it took you to learn to walk!

That complexity makes designing prostheses—artificial body parts—very difficult. Fifty years ago, most prosthetic limbs were very simplistic, and could barely do anything close to natural body function. Biomechanical studies of human and animal muscular and skeletal systems are informing the designs of ever-more-sophisticated prosthetics.

By studying how natural joints react to stress and impact, engineers are learning to design prostheses that may not look much like the body parts they replace, but function in ways that allow their wearers to compete in the Paralympic Games. And, excitingly, engineers and surgeons are learning to connect nerves to prosthetic limbs, in ways that will soon enable wearers to control them.

CHAPTER 26
STUDY GUIDE

Lesson Review

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

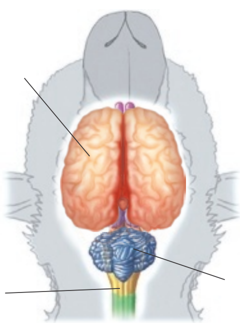
26.1 Response

When an animal responds to a stimulus, body systems—including the nervous system and the muscular system—work together to generate a response. The nervous system acts to control body movements and responses to the environment. The system is made up of a variety of nerve cells, or neurons. Sensory neurons detect stimuli, such as an odor, a touch, or a change in temperature. Interneurons help process stimuli. Motor neurons act to move muscles. A muscular movement is often the body's response to a stimulus.

A nerve net is a relatively simple nervous system found in some invertebrates consisting of a few neurons in a netlike arrangement. In other invertebrates, interneurons gather in structures called ganglia. A brain is a complex structure of many ganglia.

Sensory systems range from individual sensory neurons to sense organs that contain both sensory neurons and other cells that help gather information.

- neuron
- stimulus
- sensory neuron
- interneuron
- response
- motor neuron
- ganglion
- cerebrum
- cerebellum



Use Diagrams Label the cerebrum, the cerebellum, and the medulla oblongata.

26.2 Movement and Support

Animals have three main kinds of skeletal systems: hydrostatic skeletons, exoskeletons, and endoskeletons. A hydrostatic skeleton is a skeleton made of fluid-filled body segments that work with muscles to allow the animal to move. An exoskeleton is an external skeleton, and an endoskeleton is an internal skeleton. Exoskeletons are hard outer coverings, and are found in insects and mollusks. Endoskeletons are inside the body and made of bone and cartilage.

In many animals, muscles work together in pairs or groups that are attached to different parts of a skeleton.

- hydrostatic skeleton
- exoskeleton
- endoskeleton
- joint

26.3 Reproduction

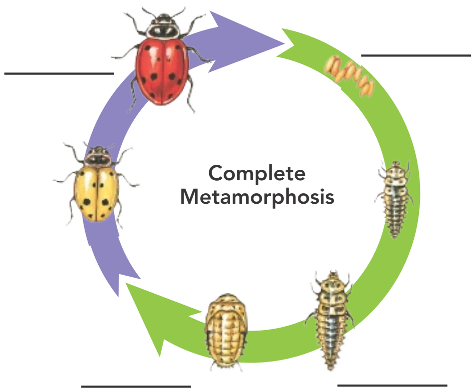
All animals must reproduce, or their populations and species will become extinct. Asexual reproduction requires only one parent, so individuals in favorable environmental conditions can reproduce rapidly. But since offspring produced asexually carry only a single parent's DNA, they have less genetic diversity than offspring produced sexually. On the other hand, sexual reproduction requires two parents, and maintains genetic diversity in a population by creating individuals with new combinations of genes.

During internal fertilization, eggs are fertilized inside the body of the egg-producing individual. In external fertilization, eggs are fertilized outside the body of the egg-producing individual.

Embryos develop either inside or outside of the body of the parent. The pattern of development may be oviparous, ovoviviparous, or viviparous.

Reptiles, birds, and a few mammals have evolved amniotic eggs in which an embryo can develop outside its mother's body, and out of water, without drying out. The amniotic egg is one of the most important vertebrate adaptations to life on land.

- placenta
- metamorphosis
- amniotic egg
- mammary gland



Interpret Diagrams Add labels to show the stages of complete metamorphosis.

26.4 Homeostasis

Homeostasis refers to the control of the internal conditions of the body. Homeostasis allows an organism to withstand changes in environmental conditions, such as a change in temperature, as well as changes in internal conditions, such as a decrease in available energy or an infection.

Processes of homeostasis involve all body systems working together. Endocrine glands help coordinate body systems by releasing hormones. Homeostasis also involves the regulation of growth and development.

Ectotherms, such as fishes and reptiles, lack mechanisms for conserving body heat. Endotherms, which include mammals and birds, are able to keep heat inside their bodies and maintain a constant internal temperature.

- endocrine gland
- ectotherm
- endotherm

Interpret Visuals What can you infer about temperature regulation in the bird shown here?

Organize Information

Complete the chart to show examples of the body systems discussed in this chapter. Some examples are entered for you.

Purpose	Example (Invertebrate)	Example (Vertebrate)
Response	Nerve net in jellyfish	1.
Movement and Support	2.	3.
Reproduction	4.	5.
Homeostasis	6.	Endocrine glands

PERFORMANCE-BASED ASSESSMENT

Design a model of Interacting Systems

Design a Solution

HS-LS1-2, HS-ETS1-2, CCSS.ELA-LITERACY.RST.9-10.3

STEM As you learned in this chapter, every animal has a group of body systems that work together to perform specific functions for the organism. A nervous system senses the environment and controls movement. A skeletal system supports the body, while the muscular system pulls on the skeleton to move it. The circulatory, digestive, and respiratory systems work together to deliver food and oxygen to cells, and work with the excretory system to remove wastes. Homeostasis is maintained by many systems working together. Perhaps most remarkably of all, a reproductive system allows animals to make more of their own kind.

No one has succeeded in developing an artificial, robotic clone of even the simplest animal. However, engineers have designed and built devices that mimic many animal functions. Robotic arms, for example, can pivot, bend, and grasp, much as a human arm can. Robots now work in factories and assembly lines. Tirelessly and ceaselessly, they perform repetitive tasks without complaint.

You can use ordinary materials to make a very simple model of the bones and muscles at the elbow. Use a brad (stationery fastener) to join two strips of cardboard. The strips should rotate freely about the brad, which represents the elbow joint. Attach strings on either side of the model arm to represent the muscles that bend and flex the elbow.

Construct the model arm. Then follow the steps to develop a model of other interactions between body systems.

ENGINEERING PROJECT

1. **Identify Criteria** You will develop and use a model of another interaction between body systems. Your teacher will assign your group one of the interactions shown below.
   - the nervous and muscular systems working together to control movement
   - the circulatory and respiratory systems working together to take in oxygen, and to remove carbon dioxide
   - the circulatory and digestive systems working together to take in food
   - the endocrine system working to control another body system or organ.
2. **Develop Models** With your group members, discuss ways to represent the interaction between body systems. Draw sketches and share your ideas, and conduct research as necessary. Your model could be a physical model, such as the model of the elbow discussed earlier. Or it could be a diagram with labels and captions, or an interactive computer model.
3. **Construct Models** Decide on a plan for your model, and make a detailed diagram to show your plan. With your teacher's approval, follow your plan and diagram to construct the model. You may revise your plan as necessary for the model to be useful and accurate.
4. **Use Models** Show the model to your teacher or a classmate. Use the model to explain how the systems interact to provide a specific function for the organism.
5. **Communicate** Share your plans or completed model with classmates. In your presentation, respond to these questions.
   - What challenges did you face in developing the model? How did you meet these challenges?
   - How does the model illustrate an interaction between body systems? What is the function of this interaction?
   - How do you think you could improve your model, or revise it to illustrate other functions?

CHAPTER 26

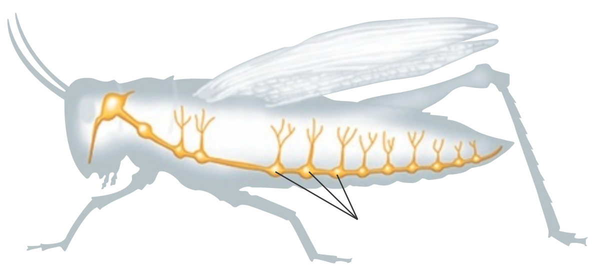
ASSESSMENT

KEY QUESTIONS AND TERMS

26.1 Response

HS-LS1-1, HS-LS1-2

1. Information received from the environment that causes an organism to respond is called a
   a. response.
   b. stimulus.
   c. reaction.
   d. trigger.
2. The simplest nervous systems are called
   a. cephalopods.
   b. motor neurons.
   c. nerve nets.
   d. sensory neurons.
3. In vertebrates, the part of the brain that coordinates body movements is the
   a. olfactory lobe.
   b. optic lobe.
   c. cerebrum.
   d. cerebellum.
4. The arrows in this diagram are pointing to which structures?



   a. ganglia
   b. brains
   c. nerve nets
   d. motor neurons
5. What two major trends in the evolution of the nervous system do invertebrates exhibit?
6. In general, how do the brains of mammals compare with the brains of other vertebrates? What is the significance of that difference?
7. What kinds of environmental stimuli are some animals capable of sensing that humans cannot?

26.2 Movement and Support

HS-LS1-2

8. Which of the following animals uses a hydrostatic skeleton?
   a. arthropod
   b. sponge
   c. fish
   d. annelid
9. Vertebrates have endoskeletons made of
   a. chitin.
   b. calcium carbonate.
   c. cartilage and/or bone.
   d. bone only.
10. Muscles generate force
   a. only when they lengthen.
   b. only when they shorten.
   c. when they lengthen or shorten.
   d. all the time.
11. Describe how a fish uses its muscles to swim.
12. What is the function of joints in a skeleton?
13. Describe how muscles work together to bend and straighten the knee.

26.3 Reproduction

HS-LS1-1, HS-LS1-2, HS-LS1-4, HS-LS4-2

14. Which reproductive strategy is rarely used in vertebrates?
   a. internal fertilization
   b. asexual reproduction
   c. budding
   d. amniotic eggs
15. A species that lays eggs that develop outside the mother's body is
   a. oviparous.
   b. viviparous.
   c. ovoviviparous.
   d. nonviparous.
16. Which structure in female mammals produces milk to nourish young?
   a. kidney
   b. pupa
   c. mammary gland
   d. placenta
17. Describe the life cycle of a typical cnidarian. Be sure to include the alternation of the polyp form with the medusa form.
18. Compare and contrast internal and external fertilization.
19. What survival advantages does the placenta confer on mammals?

26.4 Homeostasis

HS-LS1-2, HS-LS1-3

20. Stable internal conditions are called
   a. homeostasis.
   b. ectothermy.
   c. endothermy.
   d. reactivity.

21. The main source of heat for an ectotherm is
   a. its high rate of metabolism.
   b. the environment.
   c. its own body.
   d. its food.

22. What do all endotherms do?
   a. control body temperature through behavior.
   b. control body temperature from within.
   c. obtain heat from outside their bodies.
   d. maintain relatively low rates of metabolism.

23. How do endocrine glands help regulate body activities?

24. What is the function of the endocrine system with regards to homeostasis?

25. Explain the advantages and disadvantages of ectothermy and endothermy.

26. What does current evidence suggest about the evolution of endothermy?

CRITICAL THINKING

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

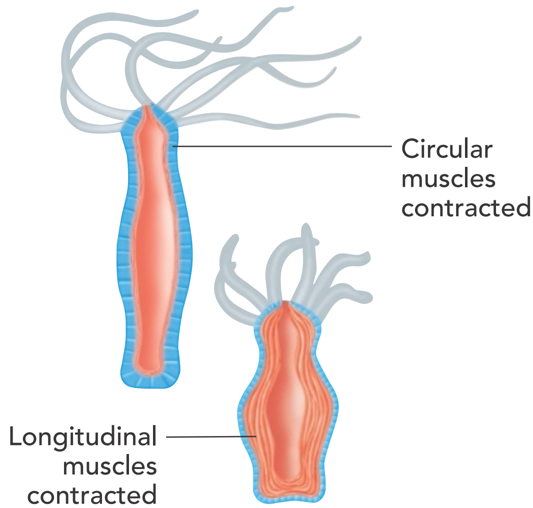
27. **Construct an Explanation** How is it useful for animals to have paired muscles across a joint, instead of only one muscle?

28. **Compare** Describe and compare the three major types of neurons.

29. **Evaluate Reasoning** A pet dog is walking with poor coordination. The veterinarian decides to take a CT scan of the dog's brain. What does the veterinarian suspect might be wrong with the dog? Cite evidence from the chapter to support your answer.

30. **Compare and Contrast** List two advantages and two disadvantages of exoskeletons and endoskeletons.

31. **Compare and Contrast** Describe the differences between a newborn placental mammal and a newborn marsupial.



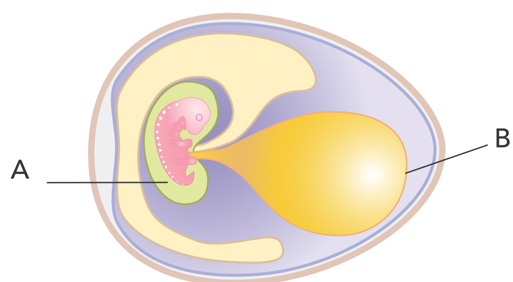
32. **Apply Concepts** The diagrams show a type of skeletal system found in invertebrates. What is the name for this type of skeleton? Describe how it functions.

33. **Infer** Many mammals care for their young for extended periods of time. This parental behavior does not help the parent survive. Why might extended parental care have been naturally selected for in these species?

34. **Apply Concepts** What two body systems interact to deliver hormones to the organs they affect? Describe how this interaction takes place.

35. **Form a Hypothesis** Birds and mammals live in both warm and cold biomes, but most reptiles and amphibians live in relatively warm biomes. Form a hypothesis that would explain this difference.

Use the diagram to answer questions 36 and 37.



36. **Interpret Visuals** What is the function of the membrane labeled A?

37. **Infer** What is membrane B? What is the function of the structure it surrounds?

CROSSCUTTING CONCEPTS

38. **Structure and Function** How does an insect's exoskeleton help the insect survive? What are the drawbacks or limitations of the exoskeleton?
39. **Systems and System Models** The nervous system of an animal can be compared to the network of noncellular telephones and the wires that connect them in a city. Describe how a telephone network acts as a model of the nervous system.
40. **Cause and Effect** Describe an example of a cause-and-effect relationship that involves homeostasis.

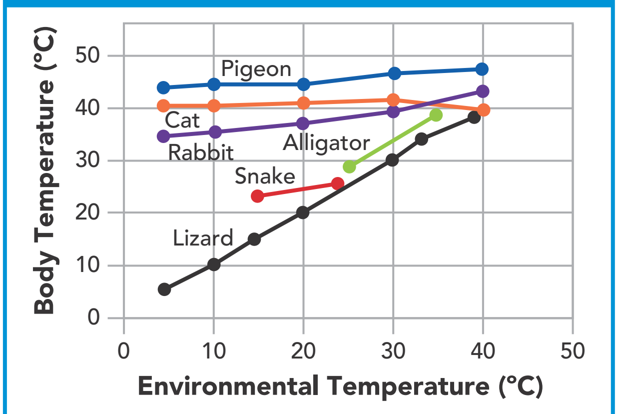
MATH CONNECTIONS

Analyze and Interpret Data

CCSS.MATH.CONTENT.HSN.Q.A.1

The line graph plots the internal body temperature of various animals against the environmental temperature, or temperature of the air or water outside their bodies. For the alligator and snake, the short lines show the limited temperature range over which the animals survive. Use the graph to answer questions 41 to 43.

Temperature Control in Chordates



41. **Interpret Graphs** How does temperature control compare between the pigeon and the lizard?
42. **Classify** Based on the line graph, classify the six animals represented as ectotherms or endotherms. Explain how you classified them.
43. **Fit a Function to Data** Write a linear equation to relate the body temperature of the lizard to its environmental temperature. Identify the range at which the equation models the situation.

The table lists the hearing range for several animals. The hearing range is measured in hertz (Hz), where the two numbers indicate the lowest and highest frequency sounds that the animal can hear. Use the table to answer questions 44 and 45.

Animal	Hearing Range (Hz)
Tree frog	50–4000
Canary	250–8000
Dog	67–45,000
Bat	2000–110,000
Human	30–23,000
Elephant	16–12,000
Bottlenose dolphin	75–150,000

44. **Interpret Data** How does human hearing range compare with the ranges of the animals listed in the table?
45. **Infer** Bats and dolphins are two of the few types of animals that navigate by echolocation. In this process they emit sounds and then listen for the echoes. What do the data in the table suggest about echolocation?

LANGUAGE ARTS CONNECTION

Write About Science

CCSS.ELA-LITERACY.WHST.9-10.2

46. **Write Procedures** Write a procedure for classifying animals according to their skeletons.
47. **Write Informative Texts** Write a paragraph that describes the advantages and disadvantages offered by the two different types of reproduction.

Read About Science

CCSS.ELA-LITERACY.RST.9-10.2

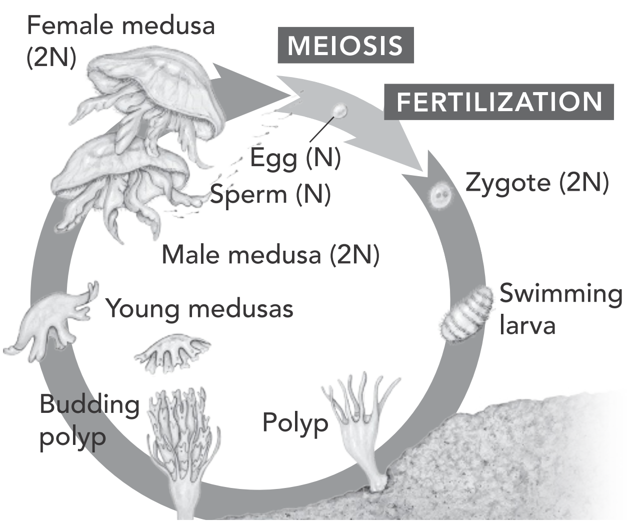
48. **Summarize Text** Describe the importance of homeostasis in an animal.

CHAPTER 26

END-OF-COURSE TEST PRACTICE

1. Vertebrate brain evolution follows a trend of increased size in which part(s) of the brain?
   I. cerebrum
   II. cerebellum
   III. medulla
   A. I only
   B. II only
   C. III only
   D. I and II only
   E. I, II, and III
2. Keshawn is constructing models to show the differences between various animal nervous systems. Which of the following would NOT be in a model of any invertebrate nervous system?
   A. ganglia
   B. interneurons
   C. brain
   D. cerebellum
   E. sensory organs
3. Animal movement is made possible by the interaction of which two systems?
   A. endoskeleton and exoskeleton
   B. nervous and endocrine
   C. skeletal and muscle
   D. cerebrum and cerebellum
   E. cartilage and bone

Use the figure of the reproductive cycle of the *Aurelia* jellyfish to answer question 4.



4. Which process is necessary for a jellyfish zygote to develop into a polyp?
   A. meiosis
   B. fertilization
   C. mitosis
   D. budding
   E. mutation
5. What is an advantage of asexual reproduction?
   A. increased genetic diversity
   B. requires only one parent
   C. one organism can produce both eggs and sperm
   D. fewer mutations
   E. more offspring survived
6. A function of both the immune system and the endocrine system is to
   A. restore homeostasis.
   B. control body temperature.
   C. regulate the amount of water in the body.
   D. stimulate growth and development.
   E. regulate gamete production.

ASSESSMENT

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

If You Have Trouble With...						
Question	1	2	3	4	5	6
See Lesson	26.1	26.1	26.2	26.3	26.3	26.4
Performance Expectation	HS-LS1-2	HS-LS1-2	HS-LS1-2	HS-LS1-4	HS-LS4-2	HS-LS1-3