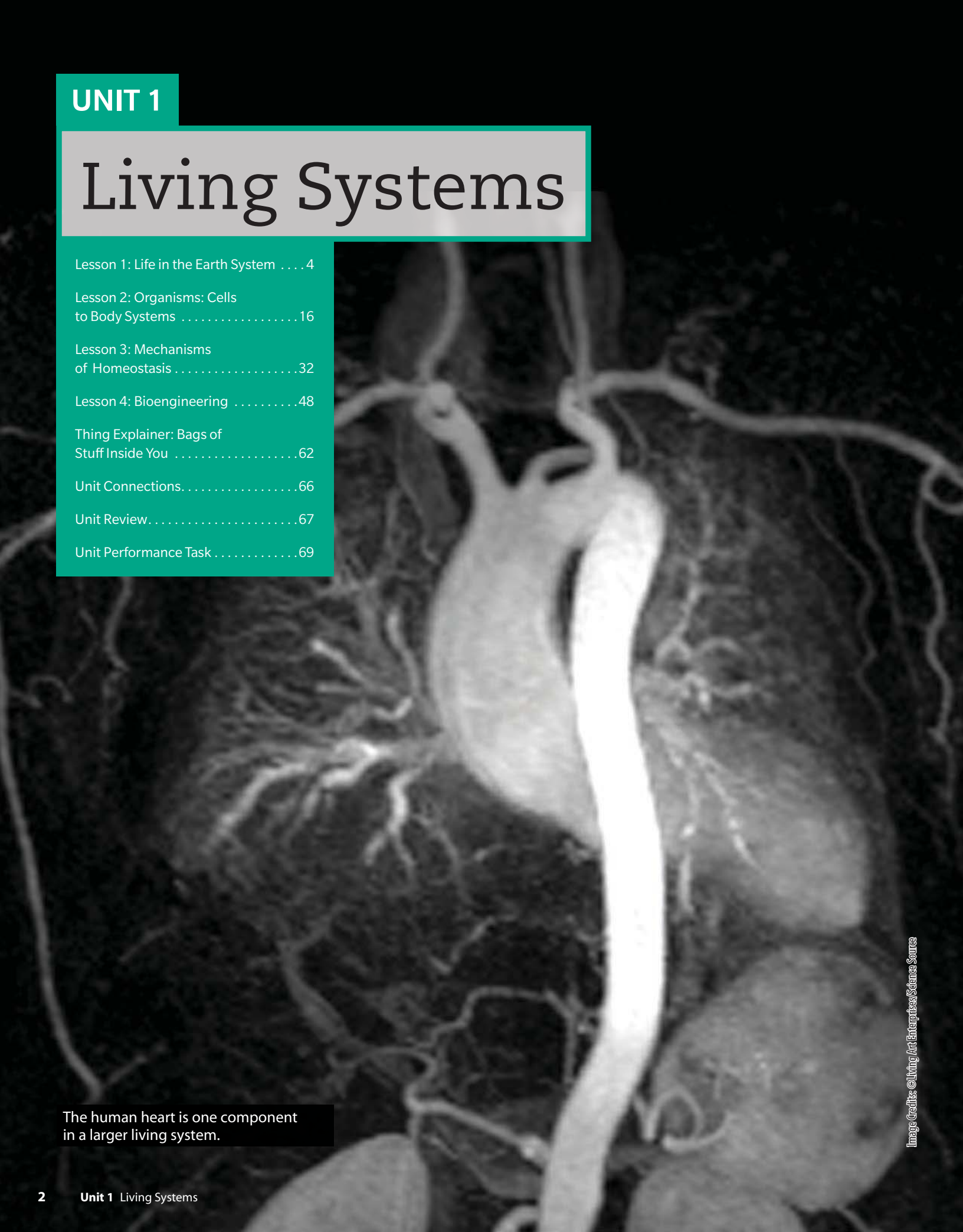
UNIT 1

Living Systems



The human heart is one component in a larger living system.

FIGURE 1: Each bat is a living system.

Living and nonliving systems are all around you. Nonliving systems help you complete many tasks, such as cars and buses to travel to school or cell phones to make a call. Organisms, such as bats, are examples of living systems. Cells in bats work together to perform all of the functions necessary for life. For example, structures in bats' wings help them maintain water balance in their bodies. Bats and other living and nonliving things are part of larger systems on Earth.

Predict How do you think living systems such as bats carry out life functions and respond to changes in the environment?

DRIVING QUESTIONS

As you move through the unit, gather evidence to help you answer the following questions. In your Evidence Notebook, record what you already know about these topics and any questions you have about them.

1. What are the levels of organization within the Earth system?
2. How do systems in living things interact to maintain the organism?
3. How does the structure of cells relate to different functions and specialization?
4. How have advances in technology influenced human health and society?

UNIT PROJECT

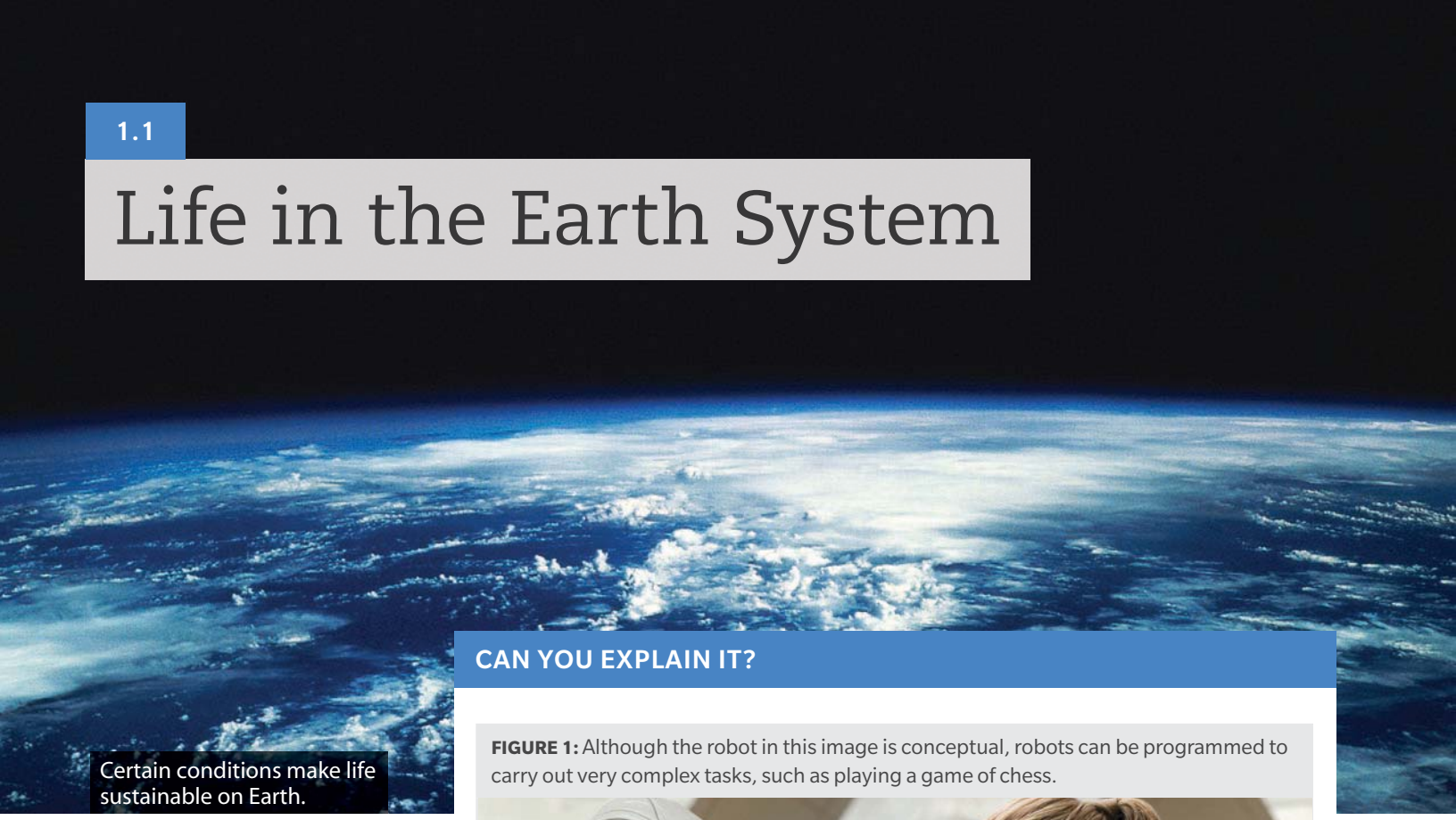
Investigating Plant Systems

A seedling is a living system made up of different components. Grow seedlings and investigate how they interact with other systems to survive and grow in changing conditions. Can you explain the levels of organization within your seedlings and the environment, from cells to ecosystem?

Go online to download the Unit Project Worksheet to help plan your project.

1.1

Life in the Earth System



Certain conditions make life sustainable on Earth.

CAN YOU EXPLAIN IT?

FIGURE 1: Although the robot in this image is conceptual, robots can be programmed to carry out very complex tasks, such as playing a game of chess.

Gather Evidence As you explore the lesson, gather evidence to make a claim about what defines a living system.

Humans have used technology since early times. Today we may be quick to name cellular phones and computers as examples. However, technology includes even simple things, such as a fork or a pen, basically any tool, process, or system that is designed to solve a problem.

Robotic technology has advanced to human-like form. Robots can perform work, including tasks that are difficult or dangerous, but they also can provide companionship and health care. Consider the players in this chess game. The robot and the human have parts that perform similar functions and have a control center to guide their actions. They are both systems that can perform many of the same tasks.

Predict Imagine a company that sells robots like the one shown in Figure 1. The company makes the claim: "This living machine is the perfect companion." Make a case to either support or refute this claim. How similar are living and nonliving systems?

Systems and System Models

Throughout history, humans have strived to understand the world around us. To help make sense of the observed phenomena, we organize information and identify patterns. One approach to understanding natural phenomena is called systems thinking. This way of thinking examines links and interactions between components, or parts of a system, to understand how the overall system works.

Properties of Systems

A system is a set of interacting components considered to be a distinct entity for the purpose of study or understanding. The robot and human at the beginning of the lesson are both systems.

FIGURE 2: To send a text message, a cellular phone requires components, such as a signal receiver and transmitter, a battery, a circuit board, and a screen.

Collaborate Discuss this question with a partner: What systems could you define in the world around you?

Boundaries and Components

Boundaries define the space of the system to separate that system from the rest of the universe. A cellular phone is a system of electronics contained in a protective covering. The components are all the parts of the system that interact to help the system carry out specific functions. For example, a cellular phone needs the parts described in Figure 2 to function properly. Together, the components send and receive radio signals and transform them into useful communication, such as text messages.

Analyze What is the boundary of the human body? What is the boundary of a robot? Compare the inputs and outputs of humans and robots in terms of matter and energy.

Inputs and Outputs

The inputs and outputs of different types of systems include energy, matter, and information. Outputs are generated when the inputs are processed in some way. In the case of a cellular phone, a radio signal (an input) is converted to vibrations (an output) that you detect as sound.

Open and Closed Systems

Systems can be categorized according to the flow of inputs and outputs. In an open system, the inputs and outputs flow into and out of the system. In a closed system, the flow of one or more inputs and outputs is limited in some way. An isolated system is a system in which all of the inputs and outputs are contained within the system.

Analyze Is the human body an open, closed, or isolated system? What about a robot? Explain your answer.

Controls

The components of a system include the controls that help keep the system working properly by monitoring and managing the inputs and outputs. Controls can be automatic, manually set, or a combination of both. An important system control is feedback. Feedback is information from one step of a cycle that acts to change the behavior of a previous step of a cycle. So, feedback is output that becomes input. A feedback loop is formed when an output returns to become an input in the same system that generated the output.

Systems and System Models

Model Draw a simple diagram showing how a thermostat would respond when the temperature in a room rises above the set point.

FIGURE 3: A thermostat can be used to control the heating and cooling systems in a home.

Some air conditioners and heaters have a control system called a thermostat, such as the one shown in Figure 3. A thermometer inside the thermostat continually measures the temperature in the room. If the air temperature in the room rises above a preset temperature, the thermostat signals the air conditioner to turn on. If the air temperature in the room falls below the preset temperature, the thermostat signals the air conditioner to turn off.

System Organization

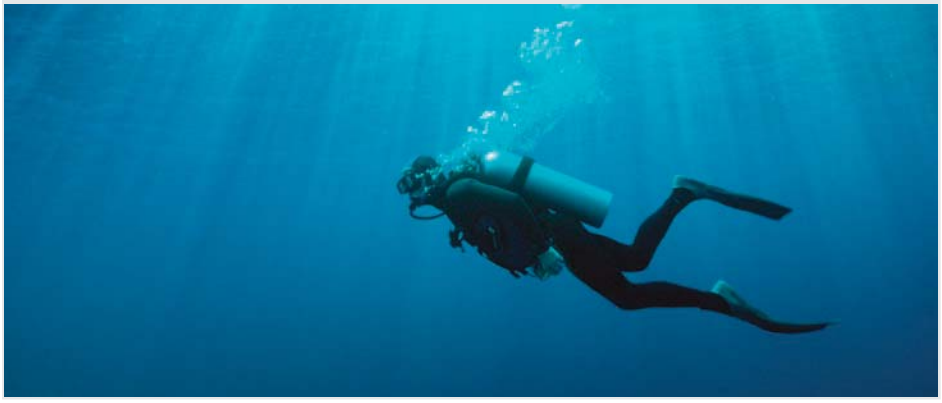
Systems can range in size and in complexity. For example, a thermostat is a small, relatively simple system. The chess-playing robot is a larger, very complex system. The Earth system is larger still and is itself a part of the solar system, the Milky Way galaxy, and the universe.

More complex systems generally have more levels of organization than simpler systems. For example, organisms, or living things, are systems made up of smaller systems, such as organs, tissues, and cells. Two organisms that interact also can make up a system, such as a bird that pollinates a plant. On a larger scale, you are a system that is part of an ecosystem, or community of organisms, and their physical environment. You also are part of the larger Earth system.

FIGURE 4: Both the hummingbird and the thistle plant are systems that interact with one another. They are part of an ecosystem, such as a city park.

As mentioned earlier, an output of a system can feed back into the system, changing how the system may respond. Similarly, an output of one system can act as an input to a completely different, perhaps even unrelated, system. Think about walking into an air-conditioned building on a hot day. The cool air becomes an input to your body system as receptors in your skin detect the change in air temperature. You may even begin to shiver slightly: the body's response when it senses cold temperatures.

FIGURE 5: A scuba diver and the *scuba* gear she wears are two systems interacting.



Explain The scuba diver is a living system. The *scuba* gear, or *self-contained underwater breathing apparatus,* is a system of air exchange. How are these two systems interacting?

Gather Evidence
How do your interactions with nonliving systems affect your environment?

System Models

Model Develop a short list of systems that you think biologists would want to model. Choose one system from your list and develop a plan for how you would model it.

Suppose that an engineering team is designing a new airplane. If they were to build a full-sized airplane for a performance test of each different design, the cost and the time would be impractical. A more practical option would be to use a smaller scale model of the airplane to study and analyze the various components of the system. A model is a pattern, plan, representation, or description designed to show the structure or workings of an object, system, or concept. You might think of a model simply as a smaller scale physical representation of a larger system. However, models are not limited to physical objects. Other types of models include computer simulations, conceptual diagrams, and mathematical equations, as shown in Figure 6.

FIGURE 6: Types of Models

a Physical Model
A smaller or larger copy of an object. Physical models also can be built to scale. Scale is the proportional relationship between a model's measurements and the real object's measurements.

Protein Synthesis

DNA ⟶ RNA ⟶ Proteins

b Conceptual Model
A diagram or flow chart that shows how parts of a system are related or how a process works.

$y = a(1 + r)^x$

y = final population
a = initial population
r = growth rate
x = number of time intervals passed

c Mathematical Model
An equation or set of equations that generate data related to how a system or process works.

d Simulation
Often in the form of a computer model. Can be used to test variables and observe outcomes. Mathematical models play a significant role in computer models.

Systems Biology

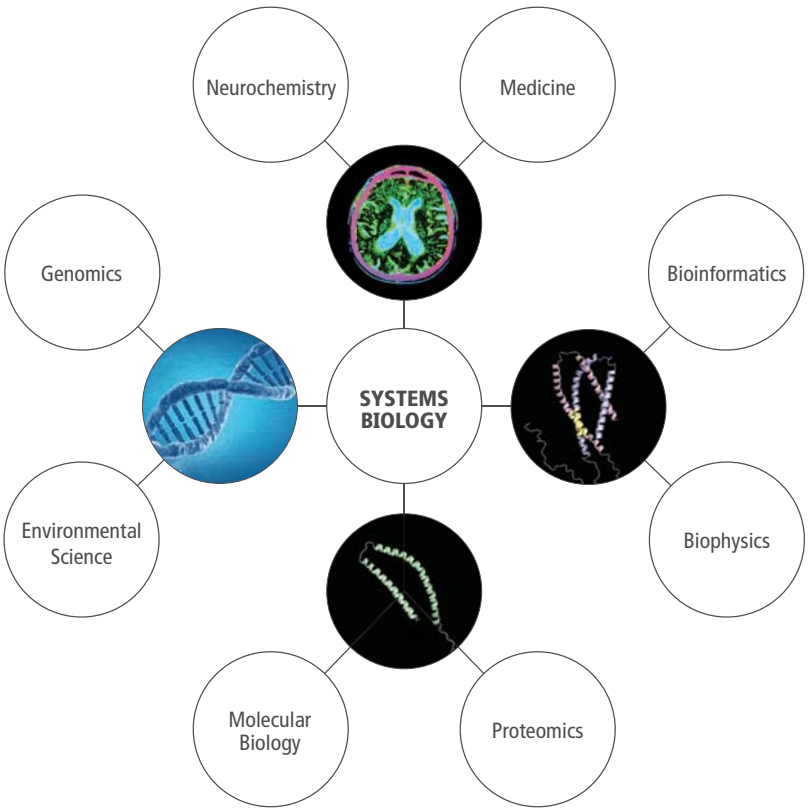
We can apply systems thinking to biology. Systems biology studies biological systems as a whole. This approach allows scientists to consider biological phenomena at different scales and examine how the components of a biological system interact. By considering the larger picture, biologists are better able to identify emergent properties of the system. An emergent property is a property that a system has but that its component parts do not have. For example, cells are self-contained systems that can function independently. However, when combined, similar cells form tissue, which can perform unique functions that the individual cells could not.

Language is a more recognizable example of a system with emergent properties. Its basic components are the sounds that combine to form words. The emergent properties are the meanings of the words made from these sounds when placed into sentences. The sentences and paragraphs convey meaning the words and sounds making up the words cannot individually.

Similarly, DNA is a molecule that carries the genetic code of all organisms. The code consists of just four bases represented with the letters A, T, G, and C. The sequence of these bases in DNA provides coded instructions for making thousands of different proteins. Each protein is made of a specific arrangement of amino acids coded for by DNA. The emergent property of DNA is the information that codes for proteins.

FIGURE 7: A systems approach in scientific research of diseases, such as Parkinson's disease, requires collaboration among many different areas of science.

Explore Online



Parkinson's disease (PD) is an aging-related degeneration of nerve cells in the brain that causes progressive slowness of movement. Many factors can contribute to PD. For example, PD often involves proteins that become misfolded, which interferes with the protein performing its normal function within the cell. The build up of these misfolded proteins causes additional damage.

Many different scientific and mathematical disciplines contribute to PD research with the goal of coming to a complete understanding of the disease. For example, biophysics applies laws of physics to biological phenomena. Some biophysicists study the structural changes of a brain protein called alpha-synuclein and its influence on PD. Typically, alpha-synuclein is unfolded, but in certain conditions it becomes highly folded, contributing to PD. Understanding why a protein misfolds may involve investigating how the DNA transmitted the code when building that protein. Was there a mistake in the code? Or does something happen to the protein after coding occurs? Genomics research helps to answer these kinds of questions.

Language Arts Connection Work with a group to research one of these fields and its contribution to PD research. Share your research with other groups in your class.

Explain Describe how different types of models could be used to research a disease. Make a list of questions you would ask. Categorize your questions into different fields of science that might be involved in the research.

The Earth System

System Models

FIGURE 8: Model of the Earth system.

Explain Is Earth an open, closed, or isolated system? Explain.

To understand living things better, we can study the systems in which they exist. One of these systems is our home planet—Earth. The Earth system is all of the matter, energy, and processes within Earth's boundary. Earth is made up of smaller systems, such as the biosphere, where all living things exist and interact. The biosphere in turn includes many smaller subsystems of living things in both aquatic and land environments. Earth itself exists within larger systems, such as the solar system and the Milky Way galaxy.

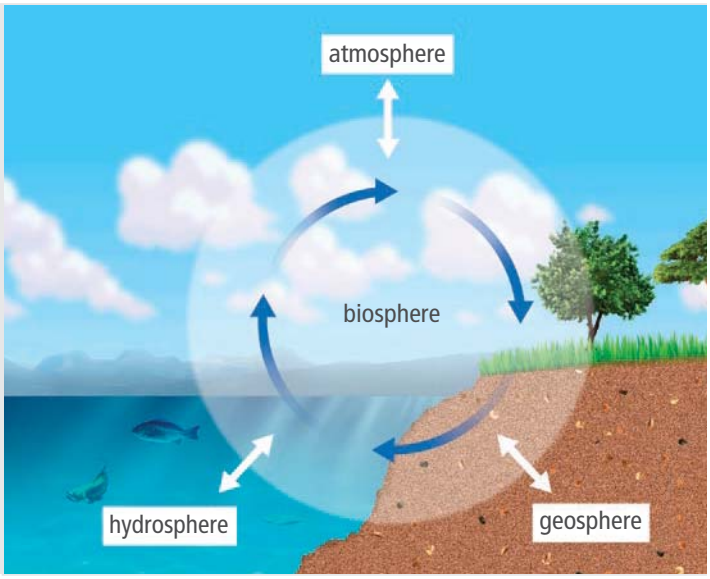
As Figure 8 shows, matter stays within the Earth system, but energy enters the system in the form of sunlight and exits in the form of heat. Within the system itself, light energy is converted into other forms of energy that drive transformations of matter from one form to another as it cycles through the system.

Organization of the Earth System

Scientists use a system model to better understand interactions within the Earth system. The system model, shown in Figure 9, organizes the Earth system into four interconnected systems, or spheres: geosphere, hydrosphere, biosphere, and atmosphere.

The geosphere is all the solid features of Earth's surface, such as mountains, continents, and the sea floor, as well as everything below Earth's surface. The hydrosphere is all of Earth's water, including water in the form of liquid water, ice, and water vapor. The biosphere is the area of Earth where life exists. The atmosphere is all of the air that envelops Earth's solid and liquid surface.

FIGURE 9: Scientists organize the Earth system into four spheres.

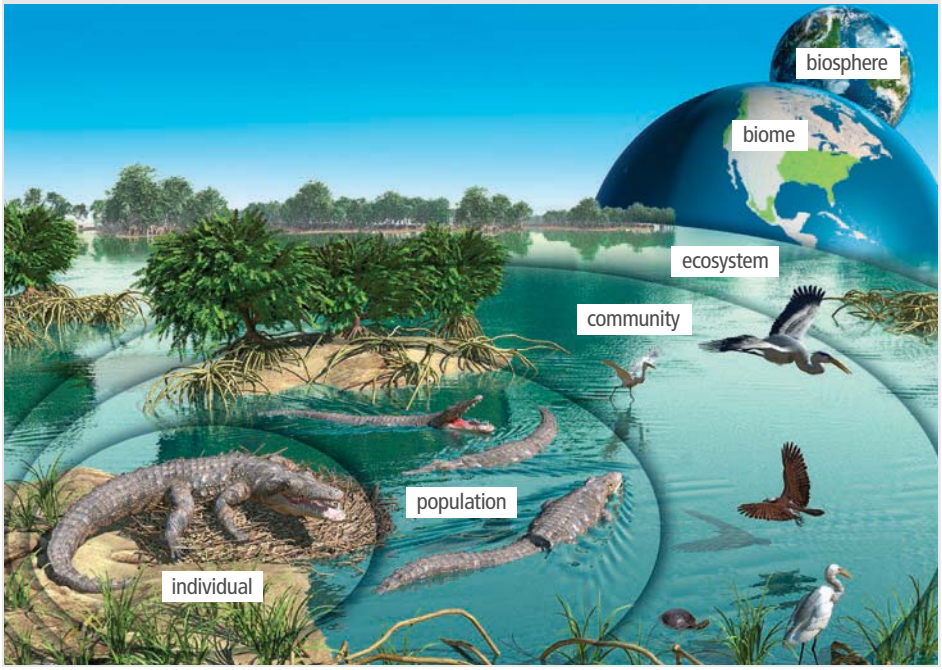


Explain This model shows the biosphere in the middle of the diagram with arrows connecting it to the other spheres. Why is the biosphere depicted this way?

Organization of the Biosphere

Earth's biosphere is made up of ecosystems. An ecosystem includes all of the nonliving and living things, or organisms, in a given area. Nonliving things include the climate, soil, water, and rocks that organisms rely on for survival. The relationships among organisms can be further categorized. Organisms of the same species that live in the same area make up a population. The collection of the different populations in an area make up a community. Communities exist within larger systems called biomes. Biomes are major regional or global areas characterized by their climate and vegetation. Examples of biomes include deserts, tropical rain forests, tundra, and grasslands.

FIGURE 10: The Florida Everglades is an example of an aquatic ecosystem.



The living components in an ecosystem are called biotic factors. The nonliving components of ecosystems are abiotic factors. The biotic and abiotic components in an ecosystem interact and are interdependent.

FIGURE 11: Taiga is a biome characterized by long, cold winters and short, mild, and rainy summers.

Model Place these terms in order to illustrate the levels of scale from an organism to the solar system: *population, biosphere, solar system, ecosystem, organism, biome, Earth, community.*

Explore Online

Hands-On Lab

Life Under a Microscope
Observe pond water under a microscope and determine whether items are living or nonliving based on their observable characteristics.

Model Identify the biotic and abiotic factors in Figure 11. Make a model to illustrate how these factors interact in this ecosystem.

Characteristics of Living Things

Scientists use a set of characteristics to define living things. In general, all living things are made up of one or more cells, require an energy source, grow and change over time, reproduce by making copies of themselves or by having offspring, and respond to changes in their environment. Homeostasis is the maintenance of constant internal conditions in an organism. Although temperature and other environmental conditions are always changing, the conditions inside organisms usually stay quite stable. Maintaining stable internal conditions is critical to an organism's survival.

FIGURE 12: Most plants get nitrogen from the soil. Venus flytraps grow in nitrogen-poor soil and must rely on the insects they catch as their source of nitrogen.

Explore Online

Analyze Describe at least two biological systems. Explain how these systems are independent from and interconnected with each other.

The Venus flytrap in Figure 12 is a living thing. It is a plant made up of individual cells that work together to perform the functions it needs to survive. It gets its energy from the sun and the nutrients it needs from the insects it digests. A Venus flytrap reproduces both sexually through pollination and asexually by spreading its rhizomes—rootlike stems—underground in the soil.

How scientists think about the characteristics of living things has undergone revision as new evidence comes to light. For example, there is disagreement about whether or not viruses are alive. Viruses do not maintain homeostasis and cannot reproduce without a host organism.

Another way to think about life is as an emergent property of a collection of certain nonliving things. As an example, proteins are chemical building blocks in all organisms, but proteins by themselves are nonliving things. However, proteins in combination with other molecules and a complex set of reactions make up living things. This argument applies to viruses, which are made only of a strand of genetic material surrounded by a protein coat. As a result, some scientists claim viruses are not living things, because they are not made of cells. However, there are some membrane-bound viruses. Are viruses living things or not? The debate continues.

Explore Online

Hands-On Lab

The Study of Life Plan and conduct an investigation to determine how different factors affect the number of living things found in a soil sample.

Explain Record evidence for whether the robot at the beginning of this lesson meets the criteria for a living system. Which criteria does it meet, and which does it not? Does a robot have emergent properties? Explain your answer.

Engineering

Modeling a System

Identify the System

Whether you think about it or not, you interact with systems every day. A school, a classroom, or an athletic team could be modeled as a system. In this activity, you will model a system that you are familiar with, and then use your model to suggest improvements to that system. You can choose one of the following school-related systems or come up with one of your own:

- getting food in the cafeteria
- visitors checking in at the front office
- students getting on buses to go home
- cars leaving the parking lot when school is over

You may work on your system model on your own or in collaboration with one or more students.

Make a Model

Make a model of the system you have chosen. Your model should illustrate the following:

- the components of the system
- how the components interact
- the inputs and outputs of the system
- the system boundaries
- system controls and feedback loops

Identify a Problem

Identify a problem with this system for which you could suggest solutions. For example, is there congestion in this system when too many people try to get to a location at the same time?

Suggest a Solution

Brainstorm some solutions to this problem. How could the efficiency of this system be improved in terms of the following items?

- time
- costs
- materials
- inputs and outputs

FIGURE 13: Your school cafeteria can be modeled as a system.

Consider Tradeoffs

Choose one of the solutions you suggested, and answer this question: How would this proposed solution affect the other parts of the system?

Are there any social, cultural, or environmental impacts of your solution? Explain your answer.

Revise the Model

Revise your original model to show how the solution you suggested would be integrated into the system.

Language Arts Connection Prepare a multimedia presentation to persuade people to implement your solution. A multimedia presentation should use graphics, text, music, video, and sound. Include your final model, an explanation of the solution you are proposing, and a discussion of tradeoffs you considered.

VIRUSES: ARE THEY ALIVE? LIFE UNDER A MICROSCOPE Go online to choose one of these other paths.

Lesson Self-Check

CAN YOU EXPLAIN IT?

FIGURE 14: Both robots and humans are complex systems.

Robots have many of the capabilities of humans, including taking in and processing information and completing many of the same tasks as humans. Robots can be used to complete tasks that are too dangerous or difficult for humans to complete.

Some robots are built to perform a specific task and do not resemble any sort of organism. Other robots, though, may have human-like forms and could be used to provide companionship or health care. When promoting one of their humanoid robots, similar to the one in Figure 14, an imaginary robotics company claims, "This living machine is the perfect companion."

Explain Refer to the notes in your Evidence Notebook to explain whether or not a robot fits the criteria of a living system. Consider the following questions when developing your explanation:

1. Which properties of systems does the robot have, and which does it not?
2. Which properties of living things does the robot have, and which does it not?
3. What potential emergent properties could this robot have?

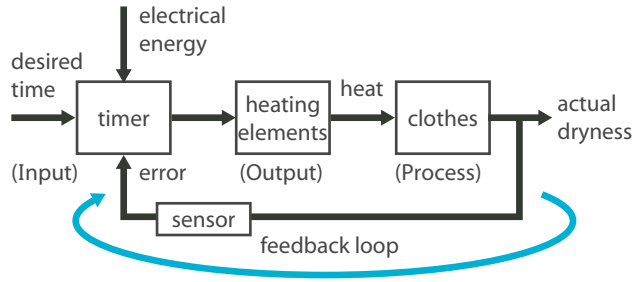
For each of the above questions, include specific examples and evidence to support your claims.

CHECKPOINTS

Check Your Understanding

Use the diagram to answer Questions 1–5.

FIGURE 15: This conceptual model shows the basics of how a dryer works.



1. How does the sensor interact with the other components of this system?
   - **a.** The sensor detects the heat of the clothes and makes the timer generate more heat.
   - **b.** The sensor detects the dryness of the clothes and then sends information to the timer.
   - **c.** The sensor detects whether the heating element is functioning properly and then sends input to the timer.
   - **d.** The sensor detects how much time is left and sends input to the heating element to increase or decrease the heat.

2. Which of these is not a direct input for the timer in this system?
   - **a.** time manually entered by the user
   - **b.** electrical signals from the sensor
   - **c.** dryness of the clothes
   - **d.** heat from the heating element
   - **e.** electricity from the wall outlet

3. Given the model, would you say this system is a closed system or an open system? Explain your answer.

4. Explain how the feedback loop works in this model.

5. Would a small load of laundry take longer to dry than a larger load? Use the diagram to explain your answer.

6. What is an emergent property?
   - **a.** a property that a system has but that its individual component parts do not have
   - **b.** a new property exhibited by a component of a system
   - **c.** a property of an individual component but not the system as a whole
   - **d.** a property that is not always exhibited by a system

7. Pick two of Earth's spheres (biosphere, atmosphere, geosphere, hydrosphere), and draw a model showing how these two systems interact. Your model should show components of these systems, at least one way these components interact, and inputs and outputs that move from one system to another.

8. Is movement a characteristic of living things? Explain why this characteristic should or should not be considered a characteristic of living things, giving specific examples to support your claim.

9. Explain what a feedback loop is using the terms *input, output*, and *homeostasis*.

MAKE YOUR OWN STUDY GUIDE

In your Evidence Notebook, design a study guide that supports the main idea from this lesson:

Models can be used to illustrate the relationships between components of living and nonliving systems.

Remember to include the following information in your study guide:

- Use examples that model main ideas.
- Record explanations for the phenomena you investigated.
- Use evidence to support your explanations. Your support can include drawings, data, graphs, laboratory conclusions, and other evidence recorded throughout the lesson.

Consider the properties of systems and system models and how systems can be used to model the levels of organization within living organisms.

1.2

Organisms: Cells to Body Systems

Muscle cells have a specialized structure that allows them to contract.

CAN YOU EXPLAIN IT?

FIGURE 1: A ballerina awaits her cue backstage.

If you have ever performed in front of an audience, you may have experienced the feeling of having "butterflies" in your stomach. When you have a feeling about something going a certain way, you might describe it as a "gut feeling." Where do these sensations come from? Do they come from your stomach, your brain, or both?

Systems within your body interact to help you take in information, make decisions, and carry out tasks. Sometimes these systems carry out tasks without your even knowing it, such as pumping your blood, helping you breathe, and breaking down your food.

Predict How do you think systems within your body interact to produce sensations like "butterflies" in your stomach?

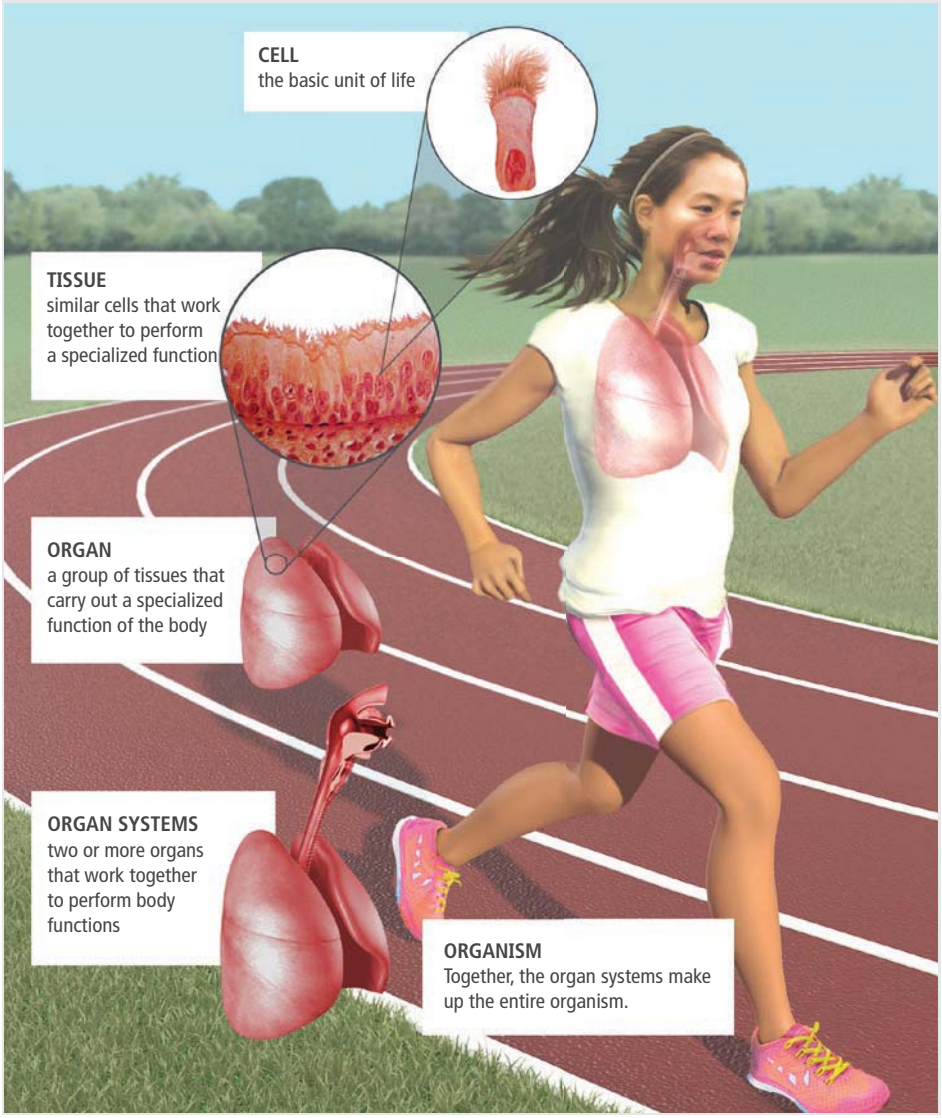
Gather Evidence
As you explore this lesson, gather evidence to explain how systems within your body interact to regulate overall body functions.

Interacting Systems in Organisms

Over the course of a day, you complete many different tasks. Whether you are eating, sleeping, or talking to a friend, systems within your body are interacting at different levels. Scientists organize multicelluar organisms into five basic levels beginning with cells and moving to increasingly complex structures. These five levels of organization are shown in the human respiratory system in Figure 2.

A tissue is a group of similar cells that work together to carry out a specific function. For example, cells in the epithelial tissue of your lungs have tiny hair-like extensions called cilia. Together, these ciliated cells act like a conveyer belt to sweep foreign particles and pathogens out of the lungs. Groups of tissues form organs such as the lungs, sinuses, and nose. Each of these organs has a specialized function in the body. Multiple organs interact to carry out whole-body functions. In the respiratory system, the nose and sinuses filter, moisten, and warm the air before it enters the lungs.

FIGURE 2: Multicellular organisms have a hierarchical structural organization. Each system, such as the respiratory system, is made up of interacting components.



Collaborate Describe a task you perform each day that requires different systems within your body to interact.

Analyze How do structures in the respiratory system interact to protect the lungs? How might a sinus infection affect the rest of the respiratory system?

Organ Systems

An organ system is two or more organs that work together to perform body functions. Organ systems interact to help the organism maintain internal stability, or homeostasis. For example, the muscular system interacts with the circulatory system to help pump your blood and deliver oxygen and nutrients to cells. Some of the components and functions of organ systems in the human body are shown in Figure 3.

FIGURE 3: Organ Systems in the Human Body

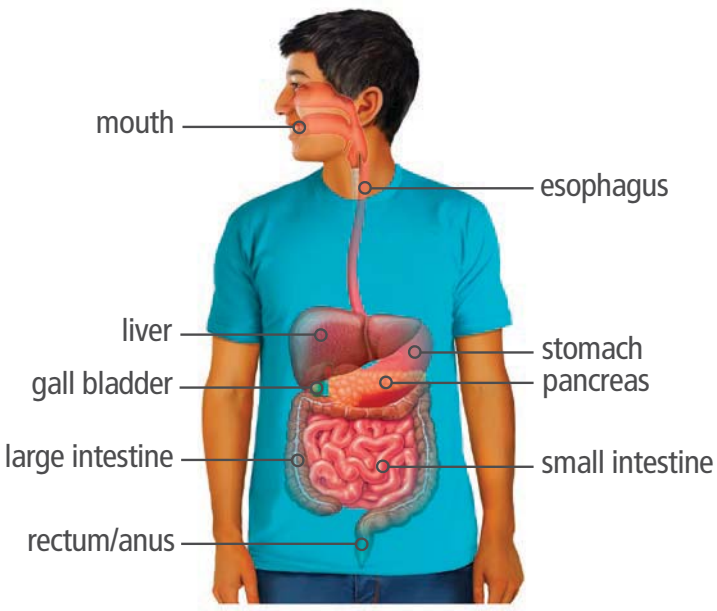
System	Organs and Other Components	Primary Functions
Circulatory	heart, blood vessels, blood, lymph nodes, lymphatic vessels	transports oxygen, nutrients, hormones, and wastes; helps regulate body temperature; collects fluid lost from blood vessels and returns it to the circulatory system
Digestive	mouth, pharynx, esophagus, stomach, small and large intestines, pancreas, gall bladder, liver	breaks down and absorbs nutrients, salts, and water; transfers digested materials to the blood; eliminates some wastes
Endocrine	hypothalamus, pituitary, thyroid, parathyroids, adrenal glands, pancreas, ovaries, testes	produces hormones that act on target tissues in other organs to influence growth, development, and metabolism; helps maintain homeostasis
Excretory	skin, kidneys, bladder	filters blood and eliminates waste products; helps maintain homeostasis
Immune	white blood cells, thymus, spleen	protects against disease; stores and generates white blood cells
Integumentary	skin, hair, nails, sweat and oil glands	protects against infection, UV radiation; regulates body temperature
Muscular	skeletal, smooth and cardiac muscles	produces voluntary and involuntary movements; helps to circulate blood and move food through the digestive system
Nervous	brain, spinal cord, peripheral nerves	regulates body's response to changes in internal and external environment; processes information
Reproductive	*male*: testes, penis, associated ducts and glands *female*: ovaries, fallopian tubes, uterus, vagina	produces and transports reproductive cells; provides the environment for embryonic development in females
Respiratory	nose, nasal cavity, pharynx, trachea, lungs	brings in oxygen for cells, expels carbon dioxide and water vapor
Skeletal	bones, cartilage, ligaments, tendons	supports and protects vital organs; allows movement; stores minerals; bone marrow is site of red blood cell production

Analyze Many organ systems interact with the circulatory system. If a person's circulatory system did not function properly, how might other systems, such as the respiratory and digestive systems, be affected? How would homeostasis, or internal stabilty, be affected by these system imbalances?

Organs

Organ systems can carry out complex functions, because they are made up of organs that work together within the system. An organ is a group of tissues that carry out a specialized function of the body. Figure 4 shows the organs in the digestive system.

FIGURE 4: Organs are components that make up a body system, such as the digestive system. In general, an organ system is made up of organs specific to the function of that system.



The digestive system is a collection of organs that breaks down food into nutrients and energy that can be used by cells. When you eat, the mouth breaks down food mechanically by chewing, and proteins called enzymes in your saliva break down food chemically. Muscles in the esophagus contract to move the chewed food to the stomach. The stomach then uses both mechanical and chemical digestion to break down food into nutrient components that the body absorbs and uses. As muscles in the stomach churn food, it continues to be broken down by gastric juice, which consists of mucus, enzymes, and acid.

The partly digested food passes into the small intestine, where additional digestion takes place. Organs such as the liver and pancreas secrete chemicals into the upper small intestine. These chemicals break food particles into individual nutrients, which are absorbed through the walls of the small intestine and pass into the blood. Any food that remains undigested passes into the large intestine where excess water is absorbed before the solid waste is excreted from the body.

Systems and System Models Make a simple flow chart to illustrate how the organs of the digestive system interact to help you digest food.

Explore Online

Hands-On Lab

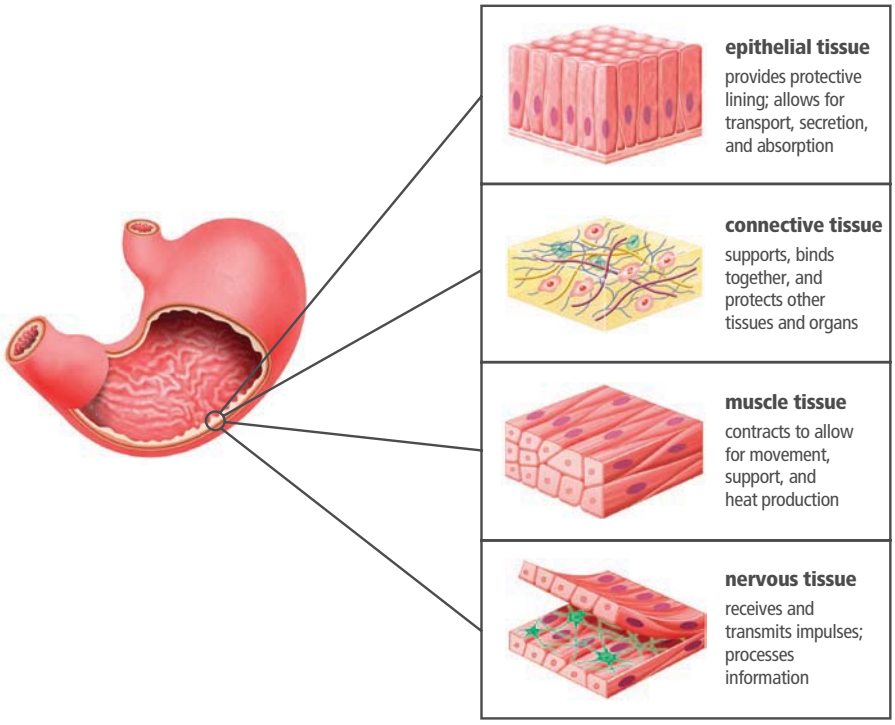
Connecting Form to Function Examine a slice of the roots, stems, and leaves of a plant to explain how their structures relate to their functions.

Predict How might the digestive system and the immune system interact to help protect the body?

Tissues

For an organ such as the stomach to carry out its function of breaking down food, different tissues must work together. A tissue is a group of similar cells that work together to perform a specialized function, usually as part of an organ. In the human body, organs are made up of four general types of tissues—epithelial, connective, muscle, and nervous tissue.

FIGURE 5: Organs such as the stomach are made up of four main types of tissues.



Gather Evidence A tendon is a band of tissue that attaches a muscle to another body part such as a bone. Which type of tissue would tendons most likely contain?

Tissues in the stomach help it carry out its function in the body. Signals from nervous tissue stimulate muscle tissue in the stomach to contract. The walls of the stomach contain three layers of muscle tissue that contract about every 20 seconds. The muscle tissue in the stomach contracts involuntarily, without you having to think about it. The epithelial lining of the stomach is made up of cells that secrete stomach acid and absorb nutrients. The type of epithelial tissue that lines the stomach has column-shaped cells. This type of tissue provides a large amount of surface area for absorption and secretion.

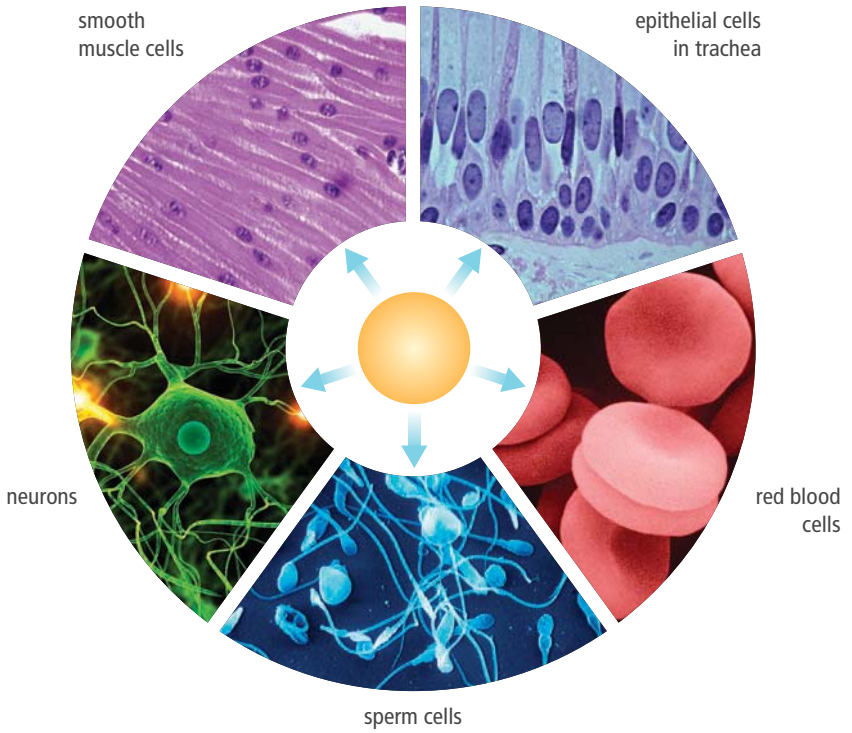
Connective tissue provides support and protection for structures in the body. Some types of connective tissue are fibrous and tough. Other types, such as loose connective tissue, provide support to internal organs and the surrounding blood vessels. The connective tissue that surrounds blood vessels has the property of elasticity. This is important, because as blood pumps through the circulatory system, the vessels within this system must stretch to accommodate blood flow.

Analyze How does nervous tissue interact with muscular tissue in the stomach to break down food? Why is it important for the nervous and digestive systems to work together?

Cells and Cell Differentiation

Humans, like other multicellular organisms, are collections of specialized cells that work together. A cell is the most basic unit of life. The cells that make up an organism arise from a single cell that goes through successive divisions to make new cells. Cell differentiation is the process by which cells become specialized in structure and function.

FIGURE 6: All cells in a multicellular organism arise from a single cell. As the organism develops, cells take on unique structures that help them carry out specialized functions.



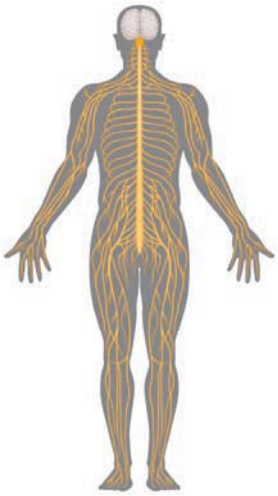
The specialization enabled by differentiation is what allows different types of cells to have different functions. For example, sperm cells have a long tail called a flagellum that allows for movement. Some epithelial cells in the trachea have hair-like extensions called cilia. These structures provide a sweeping motion that helps clear small particles out of the trachea. Neurons have extensions that allow the cell to communicate with many other cells. This allows for the formation of complex, interconnected networks of neurons, such as those in the human brain. Your brain contains billions of neurons with trillions of connections. This allows for communication between the cells of your body, as well as higher functions such as memory and learning.

Language Arts Connection Red blood cells carry oxygen and nutrients to cells. To carry out their function, these cells must bind oxygen and travel through small blood vessels in the circulatory system called capillaries. Capillaries are so narrow that red blood cells must move through them "single file." Write an explanation for how the structure of red blood cells allows them to carry out their function.

Engineering

Nanobots are microscopic robots built on the scale of a nanometer. Engineers are designing nanobots that can help deliver medicine, move through the bloodstream to hard-to-reach areas, and even destory cancer cells. Research a type of nanobot currently under development. How did the purpose of the nanobot affect its design? List some structural features the design has or could have to complete its purpose.

FIGURE 7: The nervous system is made up of the brain, spinal cord, and nerves.



Neurons

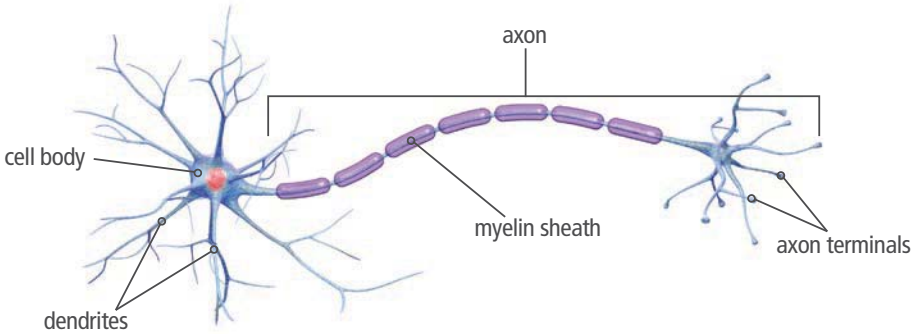
The nervous system is a network of nerves and sensory organs that work together to process information and respond to the environment. The basic unit of the nervous system is the neuron. Neurons are specialized cells that are able to send electrical and chemical signals to help the organism sense information, coordinate a response, and carry out that response.

Humans and other organisms have three types of neurons: sensory neurons, interneurons, and motor neurons. Sensory neurons detect stimuli and send signals to the brain and the spinal cord. Interneurons in the brain and spinal cord receive and process the information from the sensory neurons and send response signals to motor neurons. Motor neurons act on the signal by stimulating muscles to contract.

Systems and System Models Draw a flow chart illustrating how the three types of neurons would interact to help a person pick up an object.

Most neurons have three main parts: the cell body, one or more dendrites, and an axon, shown in Figure 8. The short, branchlike extensions that extend from the cell body are called dendrites. Dendrites receive electrochemical messages from other cells. The axon is a long extension of the cell that carries electrochemical signals away from the cell body and passes them to other cells. The branched endings of the axon are specialized to transmit electrochemical signals to other cells.

FIGURE 8: The neuron is a specialized cell within the nervous system.



Just as most electric wires are wrapped in an insulating material, many axons are wrapped in a protective covering called a myelin sheath. This covering is formed from a collection of cells that are wrapped around the axon. The myelin sheath protects the axon and helps speed transmission of nerve impulses.

Analyze Diseases such as multiple sclerosis cause the myelin sheath to break down. How would the breakdown of myelin affect the functioning of a neuron?

The nervous system interacts with all the other systems in the body. For example, when you eat, your brain signals your digestive system to start making chemicals and churning your food. Neurons also stimulate muscle tissue in the digestive system to contract, which helps the digestive system move and break down food.

Muscle Cells

Muscles consist of bundles of muscle cells that contract when they are stimulated by the nervous system. A contraction shortens the muscle, causing the bone or tissue to which the muscle is attached to move. Some muscles, such as those in Figure 9, are under voluntary control, so you can choose to move this type of muscle tissue. This type of muscle is called skeletal muscle. Some muscles are under involuntary control, meaning they move in response to nerve signals or hormones, but you do not choose to move them. Smooth muscle in internal organs and cardiac muscle in the heart are under involuntary control.

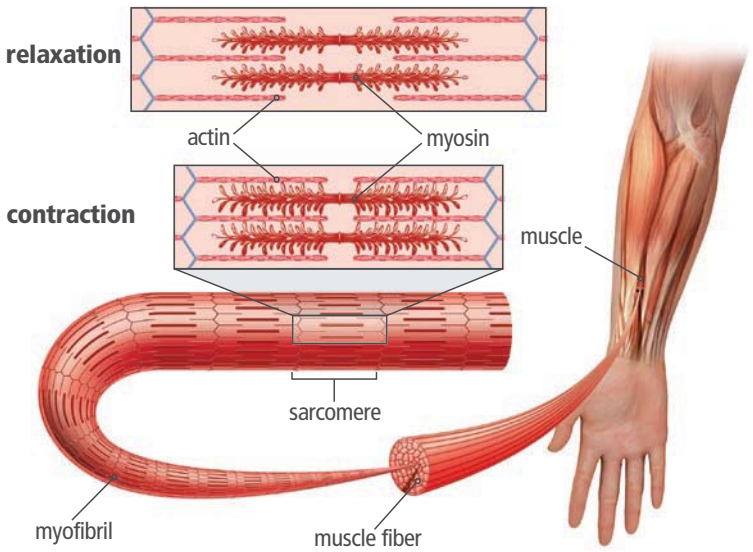
Collaborate With a partner, describe an activity that would require muscles that are under voluntary control and another activity that would require muscles that are under involuntary control.

The specialized structure of muscle cells allows them to contract. Skeletal muscles are made up of long cylindrical bundles that contain muscle fibers. Muscle fibers are bundles of single, thin muscle cells called myofibrils. Each myofibril is made up of several sarcomeres. A sarcomere is the contractile unit of the muscle cell. Sarcomeres contain thin filaments made of actin and thick filaments made of myosin. When a muscle cell is relaxed, actin and myosin are not connected to each other. In contraction, the myosin attaches to the actin and pulls the actin toward the center of the sarcomere. This in turn shortens the sarcomere, and the muscle cell contracts. The contraction of many muscle cells at once shortens the entire muscle.

FIGURE 9: Skeletal Muscles

FIGURE 10: Actin and myosin work together to help a muscle move. During contraction, myosin filaments pull actin filaments toward the center of the sarcomere.

Explore Online



Explain How does the structure of the muscle cell help it carry out its function?

Model Construct a model to illustrate how the nervous and digestive systems might interact to produce the sensation of "butterflies in your stomach." Which organs are most likely involved, and how do they interact when you have this feeling?

The Cell System

Gather Evidence Make a table to record the name of each organelle or cell structure, its role in the cell system, and a simple visual or analogy representing that organelle. As you read each section, complete the table.

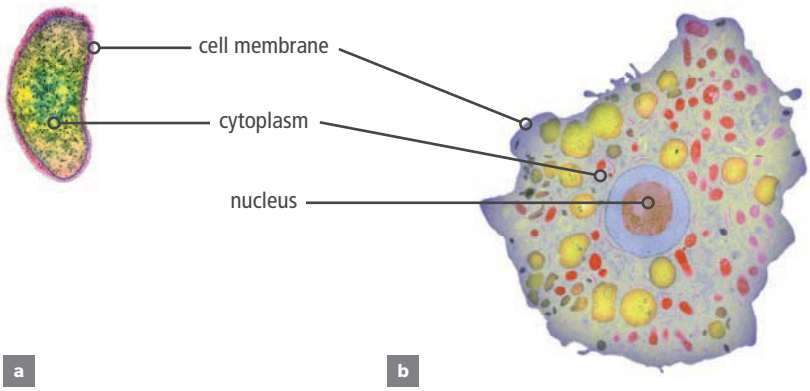
The most basic level of organization in living things is the cell. Organisms may be made up of just one cell, or they may be multicellular. Cells in multicellular organisms are specialized to perform different functions. Your body is made of trillions of cells of many different shapes, sizes, and functions, including long, thin, nerve cells that transmit information as well as short, blocky, skin cells that cover and protect the body. Despite this variety, the cells in your body share many characteristics with one another and with the cells that make up other organisms.

Cell Structure

All cells are enclosed by a cell membrane that controls the movement of materials into and out of the cell. Inside the membrane, a cell is filled with cytoplasm. Cytoplasm is a jelly-like substance that contains dissolved materials such as proteins and sugars. These building blocks are used to make cell structures and can be broken down to release energy used by the cell to do work. Some types of cells also have organelles, which are specialized structures that perform distinct processes within a cell. Most organelles are surrounded by a membrane. In many cells, the largest and most visible organelle is the nucleus, which stores genetic information.

Analyze What is the boundary that separates the cell system from the surrounding environment? Explain the function of this boundary.

FIGURE 11: Basic Cell Structure



Prokaryotic and Eukaryotic Cells

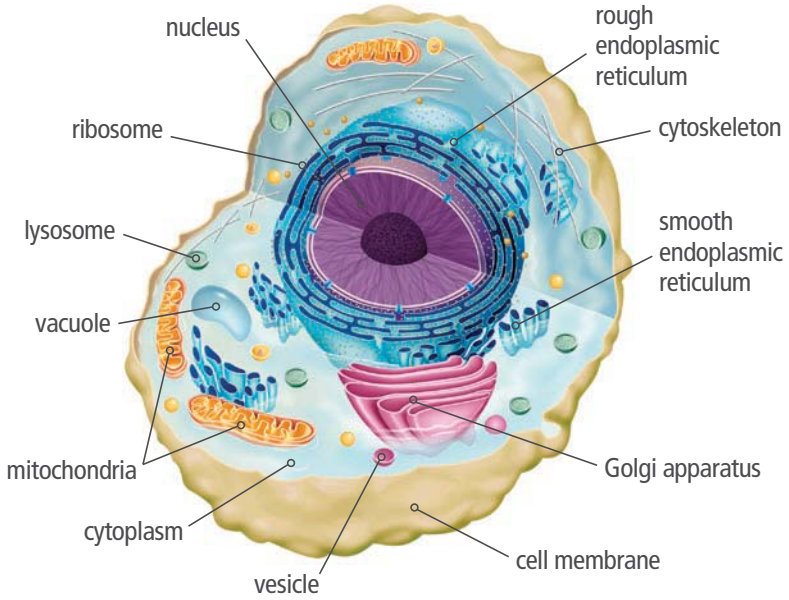
Scientists classify cells into two broad categories based on their internal structures: prokaryotic cells and eukaryotic cells. Prokaryotic cells do not have a nucleus or other membrane-bound organelles. Instead, the cell's DNA is suspended in the cytoplasm. Most prokaryotes are microscopic, single-celled organisms. Eukaryotic cells have a nucleus and other membrane-bound organelles. Eukaryotes may be multicellular or single-celled organisms.

Explain Which of the cells in Figure 11 is a prokaryotic cell, and which is a eukaryotic cell? Cite evidence to support your claim.

Animal Cell Structure

Like your body, eukaryotic cells are highly organized structures. They are surrounded by a protective membrane that receives messages from other cells. They have membrane-bound organelles that perform specific cellular processes, divide certain molecules into compartments, and help regulate the timing of key events.

FIGURE 12: Organelles in the animal cell interact to help the cell carry out functions.



Analyze Describe how the endoplasmic reticulum, mitochondrion, and Golgi apparatus are structurally similar.

The cell is not a random jumble of suspended organelles and molecules. Rather, certain organelles and molecules are anchored to specific sites, depending on the cell type. If the membrane were removed from the cell, the contents would not collapse and ooze out in a puddle. The cytoskeleton gives a cell its shape while at the same time maintaining its flexibility. It is made of small subunits that form long threads, or fibers, that crisscross the entire cell.

Cytoplasm is itself an important contributor to cell structure. In eukaryotes, it fills the space between the nucleus and the cell membrane. The fluid portion, excluding the organelles, consists mostly of water. Water helps maintain the structure of the cell and provides a medium in which chemical reactions can occur.

Nucleus

The nucleus is the storehouse for most of the genetic information, or DNA, in your cells. DNA is like a blueprint with instructions for making proteins, which carry out most of the work in the cell. DNA must be carefully protected, but DNA also must be available for use at the proper times. Molecules that would damage DNA need to be kept out of the nucleus. But many molecules are involved in making proteins from the DNA code, and they need to access the DNA at certain times. The membrane, or nuclear envelope, that surrounds the nucleus has pores that allow only certain molecules to pass between the nucleus and cytoplasm.

Structure and Function What purpose is served by controlled openings in the nuclear membrane?

FIGURE 13: The nucleus has openings called pores.

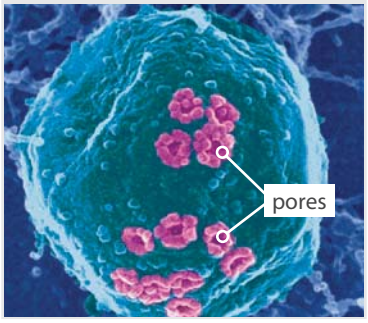
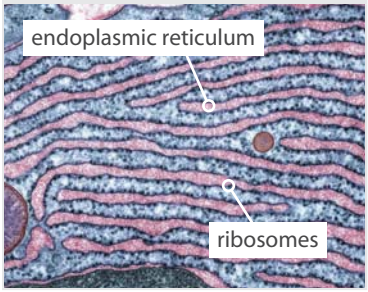


FIGURE 14: Rough ER is so named because it has ribosomes on the surface.



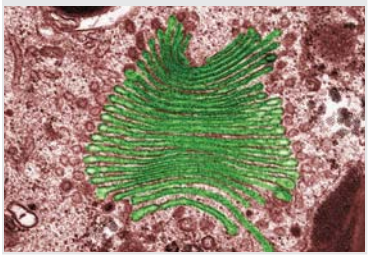
Endoplasmic Reticulum and Ribosomes

A large part of the cytoplasm of most eukaryotic cells is filled by the endoplasmic reticulum. The endoplasmic reticulum, or ER, is an interconnected network of thin, folded membranes. Numerous processes, including the production of proteins, occur both on the surface of the ER and inside the ER. In some regions, the ER is studded with ribosomes, tiny organelles that help make proteins.

Surfaces of the ER that are covered with ribosomes are called rough ER, because they look bumpy when viewed with an electron microscope. Not all ribosomes are bound to the ER; some are suspended in the cytoplasm. In general, proteins made on the ER are either incorporated into the cell membrane or secreted. In contrast, proteins made on suspended ribosomes are typically used in chemical reactions occurring within the cytoplasm. ER that does not have ribosomes on the surface is called smooth ER. Smooth ER performs a variety of specialized functions, such as breaking down drugs and alcohol.

Explain Neurons have special proteins in their cell membranes that allow them to generate electrical current. Are these proteins most likely produced by ribosomes on the rough ER or ribosomes suspended in the cytoplasm? Explain your answer.

FIGURE 15: The Golgi apparatus processes and delivers proteins.

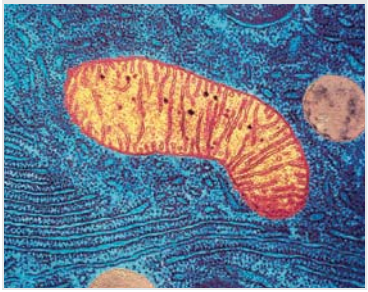


Golgi Apparatus

After a protein has been made, part of the ER pinches off to form a vesicle surrounding the protein. Protected by the vesicle, the protein can be safely transported to the Golgi apparatus. The Golgi apparatus consists of stacks of membrane-enclosed spaces that process, sort, and deliver proteins. Its membranes contain structures called enzymes that make additional changes to proteins. The Golgi apparatus also packages proteins. Some of the packaged proteins are stored within the Golgi apparatus for later use. Some are transported to other organelles within the cell. Still others are carried to the membrane and secreted outside the cell.

Collaborate Discuss this question with a partner: If the cell were compared to a nonliving system, such as a warehouse that ships products to customers, what would be an appropriate analogy for the Golgi apparatus?

FIGURE 16: Mitochondria provide energy to the cell.



Mitochondria

Mitochondria supply energy to the cell. Mitochondria are bean shaped and have a double membrane, similar to nuclei. Within the inner membrane, a series of chemical reactions converts molecules from the food you eat into usable energy. Unlike most organelles, mitochondria have their own ribosomes and DNA. This fact suggests that mitochondria were originally free-living prokaryotes that were taken in by larger cells.

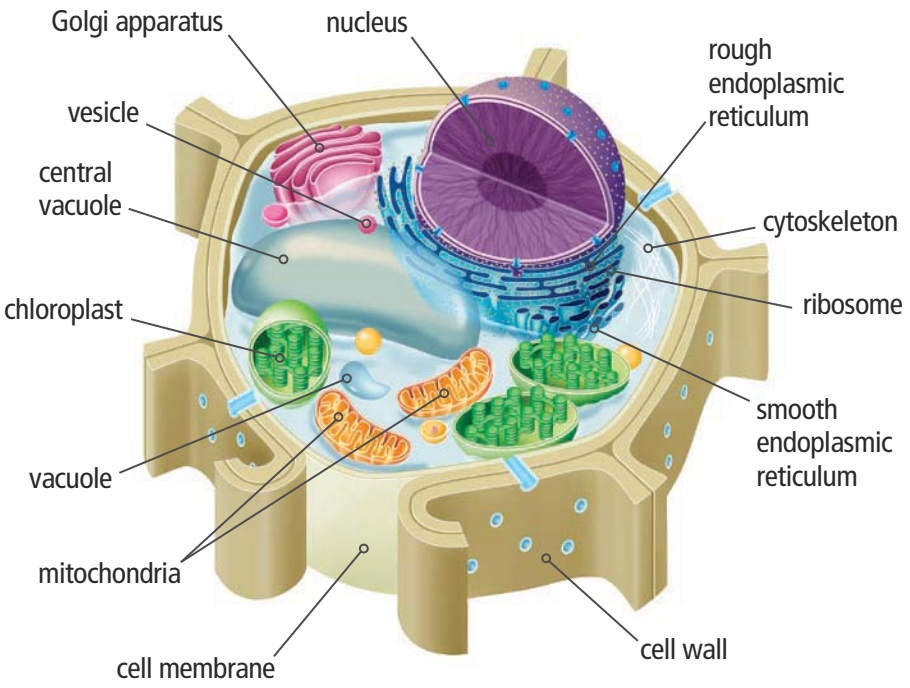
Predict Which would you predict would have more mitochondria–a muscle cell or a skin cell? Explain your answer.

Other structures in the animal cell include lysosomes and centrioles. Lysosomes are membrane-bound organelles that contain special proteins called enzymes. These enzymes break down and recycle old, worn-out cell parts. Centrioles are involved in cell division, and they will be discussed in further detail in another lesson.

Plant Cell Structure

Plant cells have many of the same organelles as animal cells, but they also have some distinct differences. Two important differences are structures that enable plant cells to capture light energy from the sun and to have a more rigid support structure.

FIGURE 17: Plant cells have specialized structures that carry out specific functions, such as protecting the cell and capturing energy.



Explain What organelles do plant cells have that animal cells do not have? What do you think is the function of each of these organelles?

Explore Online

Hands-On Lab

Comparing Cells Use a microscope to investigate the similarities and differences between plant and animal cells.

Cell Wall

Plants, algae, fungi, and most bacteria have a cell wall that surrounds the cell membrane. The cell wall is a rigid layer that gives protection, support, and shape to the cell. The cell walls of multiple cells can adhere to each other to help support an entire organism. For instance, much of the wood in a tree trunk consists of dead cells whose cell walls continue to support the entire tree.

Analyze The cell walls of plant cells have openings, or channels. How is this structure most likely related to the proper functioning of the plant system?

FIGURE 18: The cell wall provides protection and support for the cell.

FIGURE 19: Chloroplasts carry out photosynthesis.

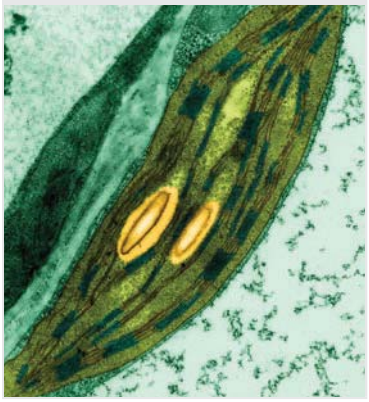
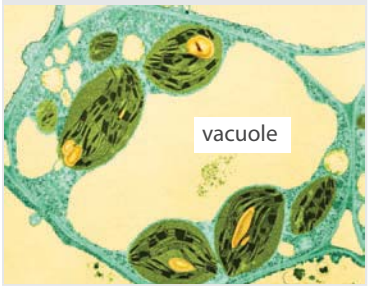


FIGURE 20: The vacuole stores materials needed by the cell.



Chloroplast

Chloroplasts are organelles that carry out photosynthesis, a series of complex chemical reactions that convert light energy from the sun into energy-rich molecules the cell can use. Like mitochondria, chloroplasts are highly compartmentalized. They have both an outer membrane and an inner membrane. Also like mitochondria, chloroplasts have their own ribosomes and DNA. Scientists have hypothesized that they, too, were originally free-living prokaryotes that were taken in by larger cells.

Collaborate Where do you think the most chloroplasts are found in the plant system–in leaves, the stem, or the root? Use evidence to support your answer.

Vacuole

A vacuole is a fluid-filled sac used for the storage of materials needed by a cell. These materials may include water, nutrients, and salts. Most animal cells have many small vacuoles. The central vacuole, shown in Figure 20, is a structure unique to plant cells. It is filled with a watery fluid that strengthens the cell and helps to support the entire plant. The central vacuole also may contain other substances, including toxins that would harm predators, waste products that would harm the cell itself, and pigments that give color to cells, such as those in the petal of a flower.

Analyze When a plant wilts, its leaves shrivel. How is this phenomenon related to the function of the vacuole in the plant system?

Explaining the Cell System Boundary

Predict How do you think the structure of the cell membrane allows for some materials to move into the cell, while other materials are kept out?

The cell membrane is an important structure for cell function. The cell membrane, or plasma membrane, forms a boundary that separates the organelles within the cell from the environment outside of the cell. The cell membrane also controls the passage of materials into and out of a cell. The complex, double-layer structure of the membrane makes it possible for the cell to selectively pass materials, such as nutrients, water, and waste, in and out of the cell. In this way, the cell membrane maintains stable conditions within the cell, even when conditions in the surrounding environment change.

In addition, the structure of the cell membrane allows the cell to communicate with other cells. For example, a neuron has specialized structures in its cell membrane that help it send and receive chemical and electrical signals. The membrane's structure helps the cell carry out its function within the nervous system, and the nervous system helps the organism interpret information from their environment and respond accordingly.

Explain Make a claim for how the organization in eukaryotic cells allows these cells to perform specialized functions within an organism. How do the components of the cell system interact to help it carry out specific tasks and interact with other systems in the body? Use evidence and examples to support your claim.

Engineering

Modeling Interacting Body Systems

In this lesson, you have learned about body systems and how they interact in organisms. Now it is your turn to model interacting body systems within an organism. In this activity, you will create a model to show how systems within an organism interact to carry out a task of your choice.

FIGURE 21: Body systems interact to help keep you healthy.

Define the Systems

Decide on a task that interests you, such as running, playing video games, or talking to a friend. Think about the body systems that are likely involved in completing that task. For example, the man in Figure 21 is drinking water to rehydrate after being in the sun. His integumentary system, or skin, sweats to keep him from overheating. As he loses water through sweat, his nervous system processes information from the body and sends signals that make the man feel thirsty. To quench his thirst, the man drinks water, which eventually reaches his digestive system. Water passes across cell membranes and eventually into his blood, which transports it to his cells.

Select an Appropriate Model

Select the type of model you would like to use to illustrate the interactions among your systems. Types of models include conceptual models, physical models, mathematical models, and computer models. Your model should use media and materials effectively. It should show that you understand the concepts that you are illustrating and capture the audience's interest.

Conduct Research

Research to learn more about how the body systems interact to carry out the task that you chose. As you search for information, keep track of your sources to submit with your final model. Be sure to use sources that are reliable. For example, government and educational institutions are more reliable than personal websites. With your final model, submit a list of resources in the format specified by your teacher.

Make a Model

Your model should include text and media that illustrate how systems interact at different levels to help an organism carry out a task. Consider the levels of organization involved, such as cells, tissues, organs, and organ systems. The model should also demonstrate how energy, materials, and information flow within and between systems in the organism.

Language Arts Connection Present your model to your peers. Explain how it illustrates interactions between systems required to carry out the task you chose. Consider using illustrations, simulations, or demonstrations to explain the processes involved clearly.

A multimedia presentation combines text, sounds, and images. A successful multimedia presentation includes:

- a clear and consistent focus;
- ideas that are presented clearly and logically;
- graphics, text, music, video, and sounds that support key points; and
- an organization that is appropriate to its purpose and audience.

PLANT TISSUES AND CELLS | COMPARING PROKARYOTES AND EUKARYOTES | Go online to choose one of these other paths.

Lesson Self-Check

CAN YOU EXPLAIN IT?

FIGURE 22: A ballerina awaits her cue backstage.

Recent research has shown that the nervous system and digestive system are very closely connected. Nerves not only send signals to the digestive system to function when needed, but the digestive system sends signals to the nervous system. In fact, scientists refer to the portion of the nervous system associated with the gut as our "second brain," because it can operate without any input from the brain to continue the digestive process. The second brain contains around 100 million neurons, more than the spinal cord or the peripheral nervous system. Thus, part of our emotions may be tied to the nerves in our digestive system.

Explain Use your model of the nervous and digestive systems and the evidence you have gathered in your Evidence Notebook to construct an explanation of how sensations, such as "butterflies" in the stomach, might arise. Which organs do you think are communicating, how are they communicating, and what is the function of this communication?

1. State your claim.
2. Summarize the evidence you have gathered to support your claim, and explain your reasoning.
3. Use your model to illustrate your claim. Revise the model as needed based on new evidence you gathered.

CHECKPOINTS

Check Your Understanding

1. Which of the following correctly describes the relationship between tissues and organs?

- **a.** Several organs interact to help a tissue carry out a specialized function.
- **b.** One type of specialized tissue is found in each organ.
- **c.** Organs are made up of different types of tissue that work together.
- **d.** Tissues compete with each other to carry out the main function of the organ.

2. Which of the following organ systems must work together to bring oxygen to the body's cells? Select all correct answers.

- **a.** digestive system
- **b.** skeletal system
- **c.** immune system
- **d.** respiratory system
- **e.** circulatory system

3. The word *organ* comes from the Latin word *organum*, meaning "instrument" or "implement." Describe how this meaning relates to the definition of a living organ.

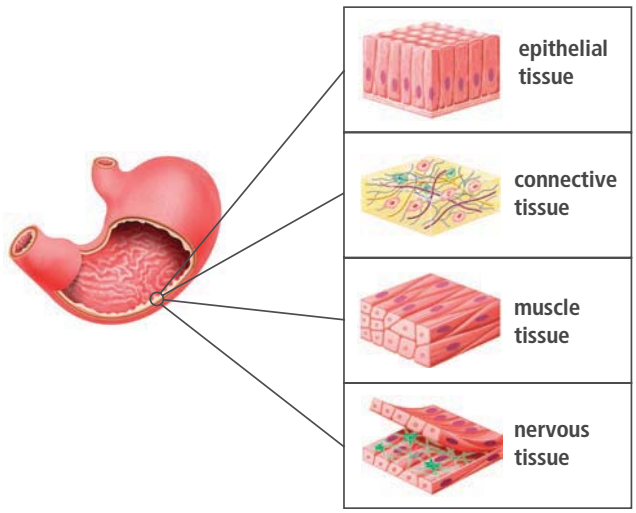
4. Draw a diagram to show the relationship between cells, organs, tissues, organ systems, and organisms. Include media and text in your diagram.

5. Explain how the structure of a plant cell helps the plant system maintain its shape.

6. Which organelles are found in plant cells but not animal cells? How are these structures related to functions at the organism level?

7. List the main organ systems that would interact to help a person play the violin, and explain how they would work together to help the person complete this task.

FIGURE 23: Organs such as the stomach are made up of four main types of tissues.



8. How do the four types of tissue shown in Figure 23 interact to help the stomach carry out its function of breaking down food?

MAKE YOUR OWN STUDY GUIDE

In your Evidence Notebook, design a study guide that supports the main idea from this lesson:

Systems in organisms interact at different levels to carry out functions necessary for life.

Remember to include the following information in your study guide:

- Use examples that model main ideas.
- Record explanations for the phenomena you investigated.
- Use evidence to support your explanations. Your support can include drawings, data, graphs, laboratory conclusions, and other evidence recorded throughout the lesson.

Consider how the information in this lesson can help you model interactions within and between systems at different levels.

1.3

Mechanisms of Homeostasis

Your circulatory system responds to an increase in cellular metabolism by increasing the flow of oxygen-carrying red blood cells to your tissues.

CAN YOU EXPLAIN IT?

The complex tissues, organs, and organ systems in your body must respond to a wide variety of conditions. For example, you might walk out of a warm building into the cold outside and feel the drastic change of temperature. Your body temperature must remain the same in both conditions for you to survive.

Gather Evidence
As you explore this lesson, gather evidence about the ways your body responds to changing environmental conditions.

FIGURE 1: Your body has control systems that keep its internal environment stable.

When it is cold outside, you likely wear warm clothing and you might drink a hot beverage to stay warm. However, if you become too cold, your body's temperature control center jumps into action. Receptors in your skin send signals to the brain, which sets into motion warming tactics, such as shivering. When you shiver, your muscles contract and expand in quick bursts, which releases energy and helps you to warm back up.

Predict Many people shiver when they have a fever, even though their body temperature is higher than normal. Why would your body respond to the increased internal temperature as though you were cold?

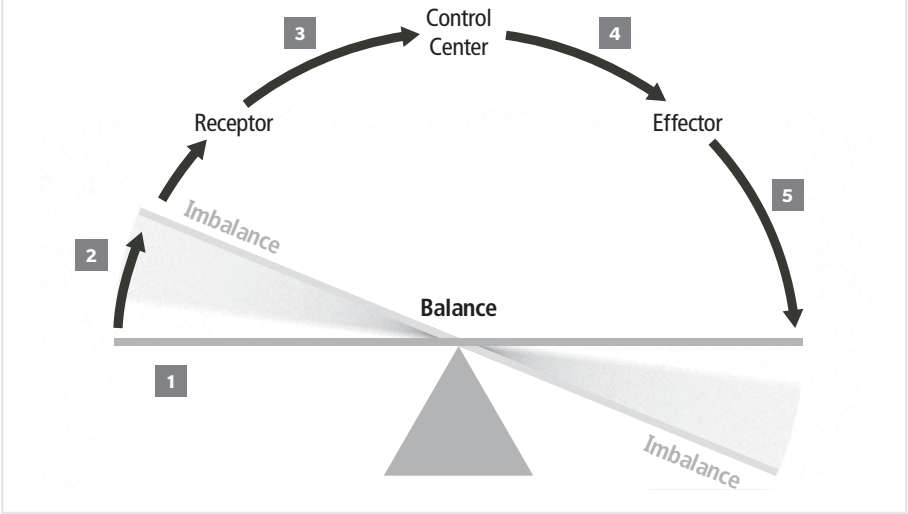
Control Systems in Organisms

External and internal factors such as temperature changes, infection, stress, and pollution challenge the stability of an organism. In the same way that a cell must maintain stable conditions, an organism must maintain stability despite changes in its internal state or within the environment in which it lives.

Control Systems

Fortunately, the body has many control systems that keep its internal environment stable. Together, these control systems are responsible for maintaining homeostasis. Homeostasis is the regulation and maintenance of the internal environment within the narrow ranges that are necessary to support life at the cellular level.

FIGURE 2: Control systems maintain homeostasis.



As shown in Figure 2, homeostasis is maintained through the following steps:

1. A stimulus is anything from the internal or external environment that causes an imbalance in the internal conditions of a cell, organ, organ system, or organism.
2. Stimuli are detected by receptors. There are thousands of internal receptors, as well as specialized receptors that detect information about changes in the organism's external environment.
3. The receptor sends information to a control center, often in the central nervous system. The control center compares the information to set points. Set points are ideal values for the conditions at which the body functions best.
4. If the control center detects movement away from the set point, it responds by sending messages through one of the organism's communication systems. Messages sent by the control center are carried to effectors that carry out the response.
5. The response restores balance by returning internal conditions to their set points.

Gather Evidence
Identify a change in your environment that might affect homeostasis. Explain using the terms *stimulus, control center, set point, receptors, effectors,* and *imbalance* in your answer.

Homeostasis depends on communication between the receptors, the control center, and the effectors. In the human body, communication is the joint responsibility of the nervous system and the endocrine system.

Model Use the homeostatic control systems diagram in Figure 2 to explain how shivering can help body temperature return to normal.

The nervous system sends messages along a direct route between the receptor and the control center, or between the control center and the effector. The control center in the human body is the central nervous system, which consists of the brain and the spinal cord. Some responses, such as shivering, are generated by the spinal cord and are called reflex responses. Information that requires more interpretation, such as visual and auditory input, is routed through the brain.

Unlike the nervous system, the endocrine system uses a more indirect—but still rapid—method of communication. Hormones are chemicals secreted into the bloodstream by ductless endocrine glands. The hormones then travel throughout the body, acting only on cells that have receptors for those particular hormones.

In order to maintain homeostasis, receptors throughout the organism must constantly compare current conditions to the appropriate set points. Set points are actually narrow ranges of acceptable conditions in a cell or organism. If receptors detect a change in an internal condition causing it to stray outside the set point, the control center communicates instructions to the effector. The effector acts to restore the internal environment to its set point. This interaction between the receptor, the control center, and the effector is known as a feedback loop.

Hands-On Activity

Modeling Feedback

Have you ever lost and recovered your balance? If so, you've experienced a feedback loop between your center of balance and your skeletal muscles. In this activity, you will balance a book on your head while walking.

Predict How would you need to adjust your balance to keep a book balanced on your head?

FIGURE 3: Feedback will help you balance a book on your head.

MATERIALS

- Hardcover book, at least 6" × 8"

PROCEDURE

1. Balance the hardcover book on your head.
2. Walk 3 meters forward and backward—once with your eyes open, then with your eyes closed.
3. Always walk with a partner when your eyes are closed and clear any objects from your path.

ANALYZE

1. What type of receptors provided information about the position of the book while you walked?
2. How did you respond whenever the book changed position? Did you find it more or less difficult to maintain balance with your eyes closed? Explain your answer.

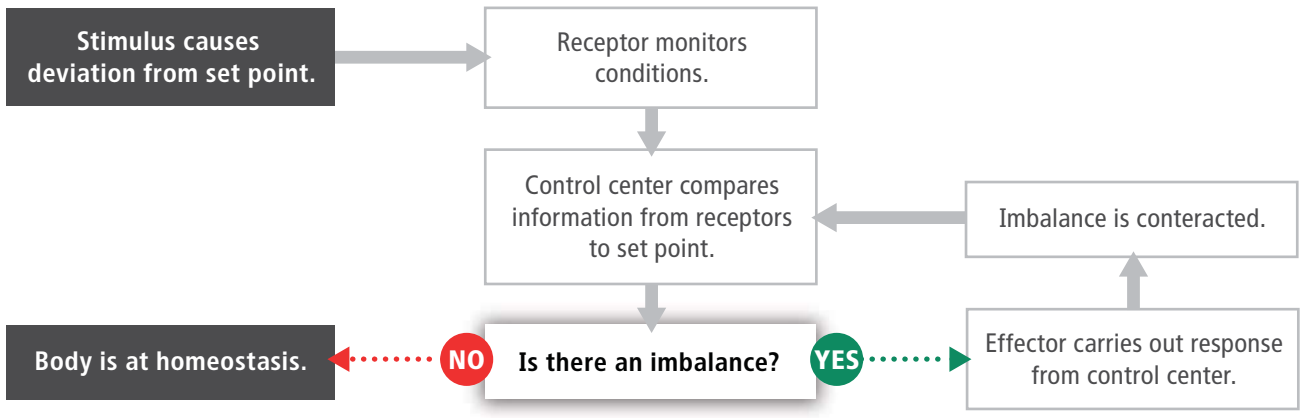
Negative Feedback Loops

Consider what happened in the book-balancing activity. You responded to a change in the book's position by changing your speed or moving your body in the opposite direction until the book returned to balance. You continued to make adjustments to maintain that balance until you removed the book from your head.

What you experienced was the result of a negative feedback loop. In a negative feedback loop, a stimulus causes an imbalance in one direction. This imbalance is detected by receptors that send information to the control center. The control center evaluates the information and sends a signal to the effectors to make an adjustment that is in the opposite direction from the stimulus, returning the system to balance.

Why is this process called a loop? The receptors also check the new conditions that result from the actions of the effector and then update the control center. The control center then signals any additional actions that the effector needs to take. These small changes cause conditions to hover around the set point and maintain homeostasis.

FIGURE 4: Negative Feedback Loop Flow Chart



The thermostat of a furnace is a nonliving example of a negative feedback loop. The thermostat contains a receptor (thermometer), a control center (microprocessor), and an effector (switch). The set point is the programmed temperature. When the thermometer detects that the air temperature is lower than the set point, it signals the thermostat's microprocessor, which responds by turning on the switch of the furnace.

While the heating system is running, the thermometer continues to measure air temperature and send updates to the microprocessor, which compares it to the desired temperature. Once the air temperature reaches the set point or just slightly above it, the control center turns off the furnace until the room temperature once again drops below the set point. As a result, the room temperature remains within a couple of degrees of the set point.

Your body has its own internal thermostat. Humans need to maintain a body temperature between 36.7 °C and 37.1 °C (98.2 °F and 98.8 °F). This narrow range is maintained by several mechanisms. Two of these mechanisms are sweating to cool down when the temperature exceeds 37.1 °C and shivering to warm up when it drops below 36.7 °C.

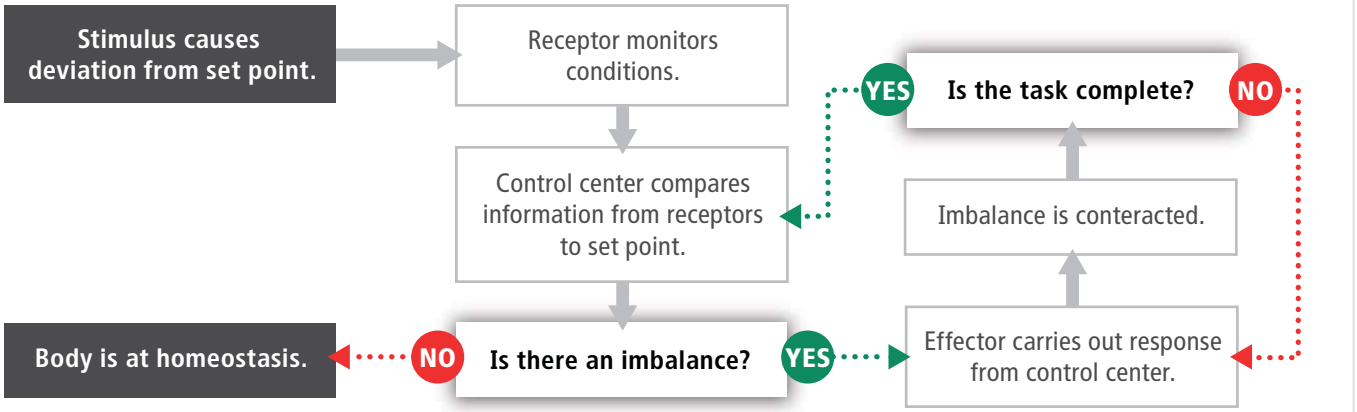
Analyze Based on Figure 4, explain how the body uses a negative feedback loop to regulate body temperature. Use the terms *control center, stimulus, set point, receptors, effectors,* and *imbalance* in your answer.

Positive Feedback Loops

Just as there are negative feedback loops in living systems, there are also positive feedback loops. A negative feedback loop makes adjustments in the opposite direction of a stimulus, but a positive feedback loop makes adjustments in the same direction as the stimulus. Scientists sometimes refer to positive feedback loops as reinforcing loops, because they amplify the stimulus instead of counteracting it.

Have you ever experienced a loud screech coming from a loudspeaker in an auditorium or at a show? This is an example of a positive feedback loop. The sound from the microphone is amplified and sent through the loudspeaker. Sometimes, the microphone will pick up that sound again, it is amplified, and sent through the speaker again. This loop continues again and again. Eventually, you hear the high-pitched screech from the loudspeaker.

FIGURE 5: Positive Feedback Loop Flow Chart



Collaborate Oxytocin is a pituitary hormone that stimulates the muscles in the uterus to contract during birth. It also stimulates the release of prostaglandins from the placenta, causing more uterine contractions. With a partner, explain how this process is a positive feedback loop.

Positive feedback is important when rapid change is needed, such as when you cut your finger. Your body depends on maintaining blood volume and blood pressure. A cut results in blood loss, so the body depends on a positive feedback loop to quickly generate a clot to stop the bleeding. This occurs as platelets and clotting factors stimulate the activation of more platelets and clotting factors at the wound. Once the cut has healed, a clot is no longer needed (and could be dangerous if it gets into the bloodstream). The body then uses another positive feedback loop to dissolve the clot.

Positive feedback loops are not as common in the body as negative feedback loops, but they are important for maintaining homeostasis. For example, some hormones are regulated by positive feedback loops. The release of one hormone may stimulate the release or production of other hormones or substances, which stimulate further release of the initial hormone.

Explain The body relies on positive and negative feedback loops to maintain homeostasis. One such feedback loop is used to maintain water balance in the body. What type of feedback loop returns the body to homeostasis when it becomes dehydrated? Use evidence from this lesson to support your answer.

Homeostasis in the Human Body

Homeostasis regulates many different things in organisms, such as temperature, water balance, salt levels, pH, nutrients, and gases. Because all of these things have set points, the body requires feedback loops for each one in order to maintain homeostasis. Remember that at its most basic level, the body is composed of many groups of specialized cells. These cells are further organized into organs, which in turn are organized into systems. Whatever affects one organ system affects the body as a whole. This means that whenever an imbalance occurs in one organ system, the imbalance affects the entire organism.

Explore Online

Hands-On Lab

Negative and Positive Feedback
Analyze data and generate graphs to determine whether a process is an example of a negative or positive feedback loop.

Interacting Organ Systems

All of your body systems interact to maintain homeostasis, much like a group of dancers interact to perform a highly choreographed ballet. If one dancer misses a cue, it throws the rest of the dancers out of step and time. Consider the importance of a healthy blood pressure to the body. Blood pressure is the force with which blood pushes against the walls of blood vessels. Receptors in the blood vessels and heart detect changes in blood pressure, then signal the brain. The brain stimulates the heart to beat faster or slower to help restore the blood pressure to its correct level.

Arteries are a type of blood vessel in the circulatory system that carry oxygen-rich blood throughout the body. If blood pressure is too low, the brain tells the heart to beat faster to increase the amount of blood in the arteries, which increases the pressure exerted by the blood on the walls of the arteries. If the pressure is too high, the heart beats slower, reducing the amount of blood in the arteries and so lowering the blood pressure. In this case, the systems working together to maintain blood pressure homeostasis are the nervous system and the circulatory system.

Cause and Effect

Blood pressure depends on how elastic and unblocked the arteries are and on the strength of the heart contraction. The less elastic the arteries and the more blockages that reduce blood flow, the harder the heart must pump. As a result, blood pressure rises. Blood pressure also rises naturally with activity, stress, and strong emotions, but it should drop again with rest. If the pressure remains high, there could be a problem in the circulatory system.

Predict If a person's blood pressure is too high or too low, how might the other organ systems in their body be affected?

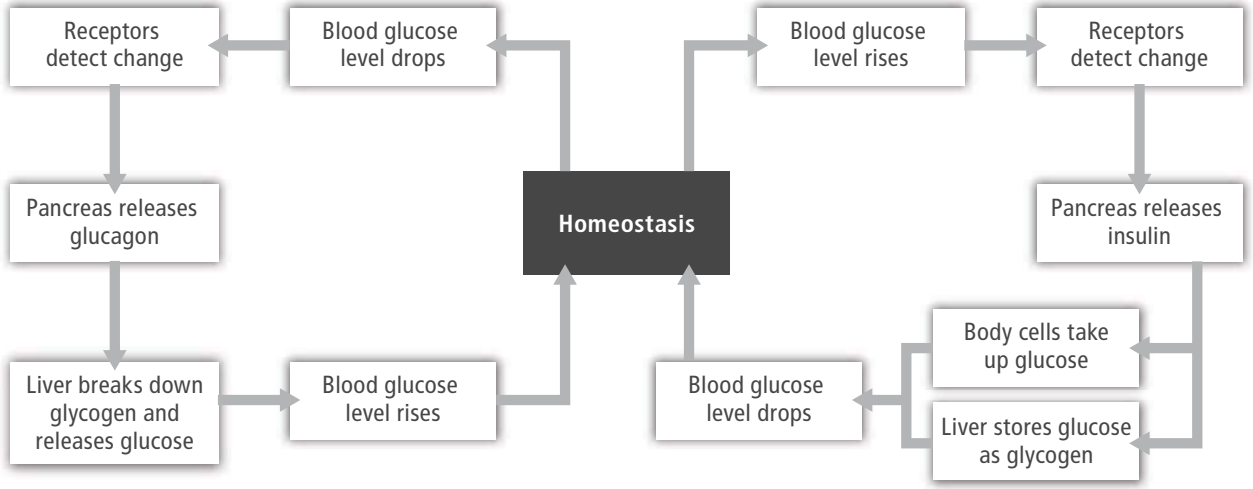
FIGURE 6: Blocked Artery

Image Credits: ©Colorization by: Mary Martin/Science Source

Maintaining Glucose Concentrations

The cells in the human body rely heavily on glucose to supply the energy needed to survive and grow. However, glucose concentrations in the blood must be maintained within a very narrow range for good health. Glucose needs can vary widely depending on what activities the body is performing. A person's activity levels are always changing, so the body must work constantly to maintain homeostasis.

FIGURE 7: Glucose levels are regulated by a negative feedback loop.



Blood glucose levels are controlled by two feedback loops, shown in Figure 7. Each loop relies on the endocrine system to respond to changing levels. When blood glucose levels rise, such as when you eat a meal, the increase is detected by beta cells in the pancreas. The beta cells respond by releasing insulin, which stimulates cells to absorb glucose from the blood stream. It also causes the liver to store excess glucose in the form of glycogen. Once levels return to the set point, insulin secretion subsides. This feedback keeps blood glucose levels from exceeding the maximum set point.

The body has a second feedback loop that maintains a minimum blood glucose level. Blood glucose levels can drop after a long time passes without eating or during prolonged exercise. When the brain detects levels below the minimum set point, it signals pancreatic alpha cells to produce glucagon. Glucagon stimulates the liver to convert glycogen to glucose and release it into the blood stream. If the liver is unable to release glucose rapidly enough, the brain signals a feeling of hunger in order to obtain additional glucose.

Analyze Why are the insulin and glucagon feedback loops examples of negative feedback loops?

Maintaining Carbon Dioxide Concentrations

Every time you exercise, lie down to rest, or simply stand up, your needs for oxygen and nutrients change. Your heart speeds up or slows down and you breathe faster or slower, depending on your level of activity. The respiratory system interacts with the nervous system to maintain homeostasis. Control centers in the brain monitor dissolved gases in the blood, particularly carbon dioxide (CO_2) and oxygen (O_2) concentrations.

Explore Online

Hands-On Lab

Investigating Homeostasis and Exercise Investigate how the circulatory system, respiratory system, and perspiration levels are affected by exercise.

As you become more active, CO_2 levels increase and the blood becomes more acidic. Sensors signal this change to the brain. The brain sends messages through the nervous and endocrine systems that stimulate the diaphragm and rib cage muscles to work more rapidly. This allows you to take in more O_2 and release CO_2, returning levels in your body to homeostasis.

In humans, gas exchange is a cooperative effort of the circulatory and respiratory systems. The circulatory system distributes blood and other materials throughout the body, supplying cells with nutrients and oxygen, and carrying away wastes. Blood vessels are organized so that oxygen-poor blood and oxygen-rich blood do not mix.

The circulatory system has three types of blood vessels: arteries, veins, and capillaries. Arteries carry oxygen-rich, or oxygenated, blood away from the heart. Veins are blood vessels that carry oxygen-poor, or deoxygenated, blood back to the heart. Capillaries are responsible for delivering O_2 directly to cells and removing CO_2 and waste. With a wall only one cell thick, it is easy for materials to diffuse easily into and out of capillaries. The capillary system serves as a connection between arteries and veins, ensuring a continuous path for blood flow throughout the body.

Once the veins deliver deoxygenated blood to the heart, it is immediately transported to the lungs, where gases can be exchanged with the air. As shown in Figure 8, when you inhale, the air flows from your nose or mouth through the trachea to the bronchi (*sing.* bronchus). The air continues into smaller branches called bronchioles and finally into small, thin-walled air sacs called alveoli. A network of capillaries surrounds each alveolus, taking in O_2 and releasing CO_2. When you exhale, the CO_2 exits through your nose or mouth.

FIGURE 8: Circulatory System

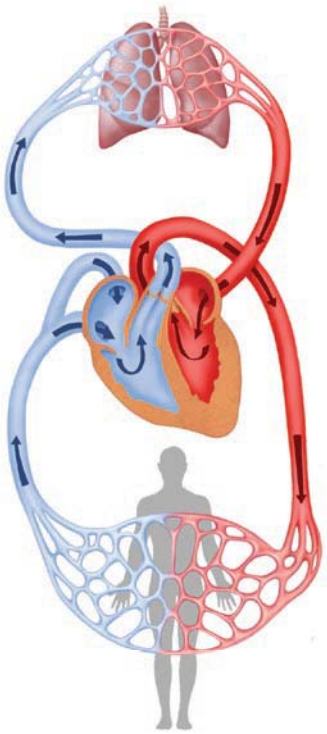
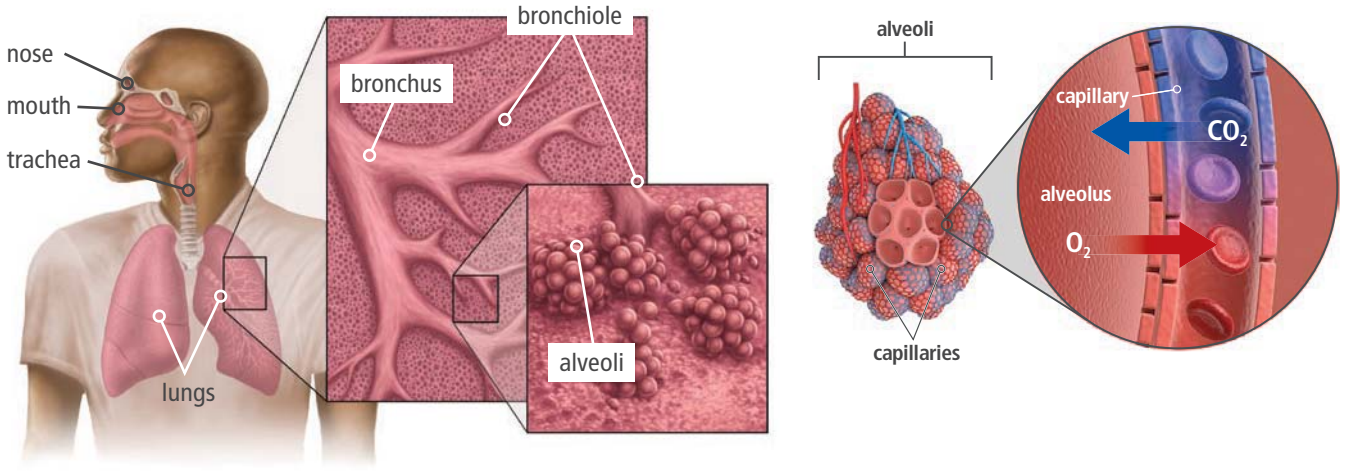


FIGURE 9: Diffusion of gases into and out of the alveoli maintains oxygen and carbon dioxide homeostasis.



Gas homeostasis in the blood is maintained through diffusion. When you inhale, the air has a higher concentration of O_2 than the blood in the capillaries surrounding the alveoli. This allows O_2 to diffuse down a concentration gradient into the blood. From there, the blood is taken to the heart and pumped through the body. The concentration of O_2 in the blood is higher than in the cells, so it diffuses out of the blood. Carbon dioxide diffuses in the opposite direction—from the cells into the blood. The concentration of CO_2 is higher in the cells than in the blood because cells produce CO_2 as a waste product. Once in the blood, it travels back to the heart and then into the lungs, where it diffuses into the alveoli and is exhaled out of the lungs.

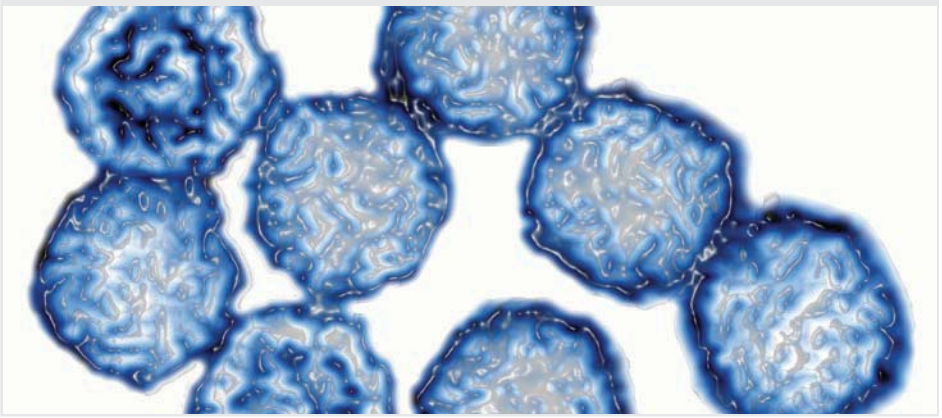
Model Create a flow Make a flow chart explaining how homeostasis is maintained when you become more active. How do the respiratory and nervous systems interact to maintain appropriate CO_2 and O_2 levels and prevent the blood from becoming too acidic?

Disrupting Homeostasis

Homeostatic mechanisms usually work quickly, but sometimes a change in the environment can occur too rapidly or be of too great a magnitude to be controlled through feedback mechanisms. When this happens, homeostasis is disrupted. Disruptions can happen for several reasons including the failure of sensors to detect a change in the internal or external environment, sending or receiving the wrong message, serious injury, or disease-causing agents, such as bacteria or viruses.

A rhinovirus, shown in Figure 10, can change the body's internal chemistry to cause the common cold. This results in disruption of one or more homeostatic mechanisms. One commonly disrupted mechanism is body temperature, resulting in fever. A fever occurs when the hypothalamus raises the set point for internal temperature. This makes you feel cold, because your internal temperature is below the set point. Your body may shiver to raise your internal temperature closer to the new set point.

FIGURE 10: The common cold is caused by a rhinovirus.



Short-Term Effects

Collaborate With a partner, discuss whether your body's response to the common cold is an example of negative or positive feedback. Use evidence to support your claim.

Many disruptions in homeostasis are temporary. A cold is an excellent example of a short-term disruption in homeostasis. When the virus first enters your body, it may multiply too rapidly for your immune system to destroy it. When that happens, you may experience cold symptoms, such as a sore throat or runny nose. In only a few days, however, your immune system develops antibodies that can mark the virus for destruction, restoring homeostasis. Lasting damage from the common cold is very rare.

Recall that shivering is the body's response to decreased body temperature. Shivering occurs when you are sick not because you are experiencing cold environmental temperatures, but because your body is trying to adjust to a new—higher—set point for body temperature. In other words, your body is shivering to produce a fever.

Long-Term Effects

Long-term disruptions of homeostasis can cause more damage than short-term disruptions. One form of long-term disruption is Cushing's syndrome. This disorder is caused by a long-term elevation of the hormone cortisol. Cushing's can result from tumors of the adrenal or pituitary gland, or from long-term cortisone treatment. Cortisol is one of the body's stress hormones. When it remains elevated for long periods of time, it disrupts glucose and fat metabolism, immune response, and sleep, and causes blood pressure to increase. Each of these disruptions can lead to other disorders, such as hypertension, diabetes, strokes, and heart attacks.

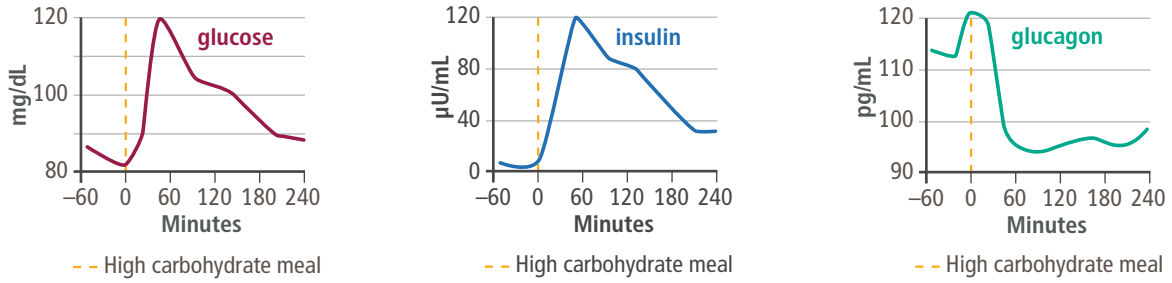
Data Analysis

Understanding Diabetes

Recall that the regulation of blood glucose levels occurs through negative feedback loops. The insulin loop is stimulated by elevated blood glucose levels, and the glucagon loop is stimulated by lowered blood glucose levels.

Diabetes mellitus is a long-term disruption of the insulin feedback loop. Type 1 occurs when the body's immune system destroys the ability of beta cells in the pancreas to produce insulin. Type 2 is caused when pancreatic insulin production decreases or when insulin cannot move glucose from the blood into cells.

FIGURE 11: Blood glucose, insulin, and glucagon responses to a high-carbohydrate meal.



Two variables are inversely related if an increase in the value of one variable is associated with a decrease in the value of the other variable. For example, the levels of insulin and glucose increase and glucagon decreases when a person eats. Therefore, insulin and glucose levels have an inverse relationship to glucagon. This relationship can be seen in Figure 11.

Analyze Answer the following questions in your Evidence Notebook:

1. What is the relationship between blood glucose levels, insulin levels, and glucagon levels in the blood stream?
2. Type 1 Diabetes occurs when the body's immune system destroys the ability of the pancreas to produce insulin. How would these graphs look different in a person with Type 1 diabetes?

Homeostasis is critical for the health of any organism and requires various systems to interact. To maintain some homeostasis some organisms may use methods similar to those in humans, and others may require different methods specific to their environment.

Explain Choose an example of a homeostatic variable from this lesson. Explain the feedback loop responsible for maintaining homeostasis for this variable. Then describe how homeostasis for this variable can be disrupted.

Homeostasis in Other Organisms

Many of the homeostatic processes you have learned about in humans are the same in other organisms as well. However, some organisms use different mechanisms to maintain homeostasis. For example, not all mammals have sweat glands all over their skin and so are unable to rely on sweating to cool off. As sweat evaporates, heat is removed with it, cooling the skin. Dogs make up for the lack of sweat glands by panting. When they pant, the short, shallow breaths direct air flow over the moist linings of their upper respiratory tract. This has the same evaporative cooling effect as a breeze passing over your sweaty skin.

Predict What other organisms do you think would have different homeostasis mechanisms from humans? Why would this be an advantage in their environment?

Gas Exchange in Plants

Plants take in carbon dioxide for photosynthesis and give off oxygen as a waste product. In plants, like in humans, homeostatic mechanisms regulate gas exchange. Gases are exchanged through structures called stomata (singular, *stoma*). Stomata are small openings, or pores, on the underside of leaves that are surrounded by cells called guard cells. Stomata can be open or closed, depending on the needs of the plant.

FIGURE 12: Stomata help a plant maintain homeostasis.

When the sun is out, certain wavelengths of light are absorbed by a protein called phototropin, stimulating a series of reactions that causes the guard cells to fill with water. The guard cells become more rigid, causing the stomata to open. While the stomata are open for photosynthesis, water vapor is given off. Giving off water vapor is not necessarily bad for the plant. In fact, it helps draw water into the plant at the roots. It also allows the plant to eliminate the oxygen produced during photosynthesis.

Water vapor loss is not a problem for plants in moist environments. However, plants in dry or drought environments may struggle to maintain water balance because they lose water faster than they can replace it. This causes the plant to wilt and disrupts other homeostatic mechanisms that rely on nutrients that are drawn into the roots with water. To counteract this, many types of plants release a hormone called abscisic acid, or ABA, from the roots in response to decreased soil water levels. The accumulation of ABA in leaves triggers the transport of water out of the guard cells. This causes the cells to relax, closing the stomata.

Analyze Determine the stimulus, receptor, control center response, and effector for gas exchange for plants.

Plant Response to Drought

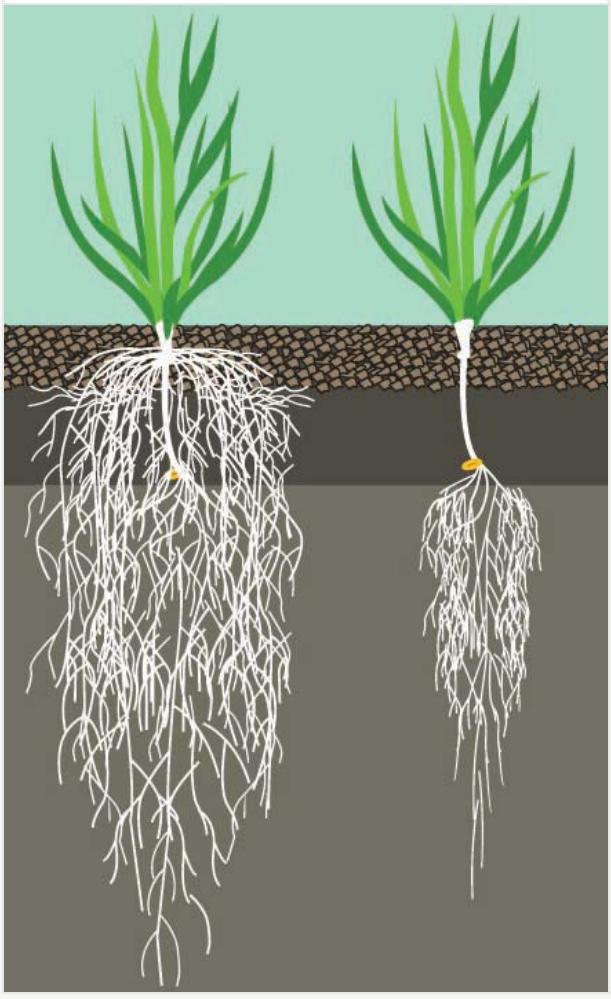
How does a plant cope with long-term or recurring water stress? Again, the homeostatic mechanism begins with the roots. One of the effects of drought is to alter the way roots grow in various plants. For example, when the plant maidenstears (*Silene vulgaris*) experiences moderate drought-stress, its roots grow deeper into the soil in search of water. A larger percentage of the roots are thin, allowing them to reach into tiny pores in the soil in search of every drop of water. In other plant species, such as myrtle (*Myrtus communis*), the percentage of thicker roots is greater in drought conditions. Scientists also discovered that roots in drought-stressed maidenstears have more branches than those grown under normal conditions.

Normal roots are relatively white and flexible. Drought stress tends to make roots become harder and turn brown. This is due to the presence of a waxy substance called suberin, the main component of cork. This forms a protective cap on the root tip as it enters a resting phase while soil moisture remains low.

Another change observed in drought-stressed plants is an increase in the thickness of the root cortex—the outer layer of root tissue. This helps protect the root from dehydration.

Model Create a model demonstrating how this feedback mechanism helps a plant maintain homeostasis during a drought.

FIGURE 13: The root growth of the plant on the right has been affected by drought.



Thermoregulation

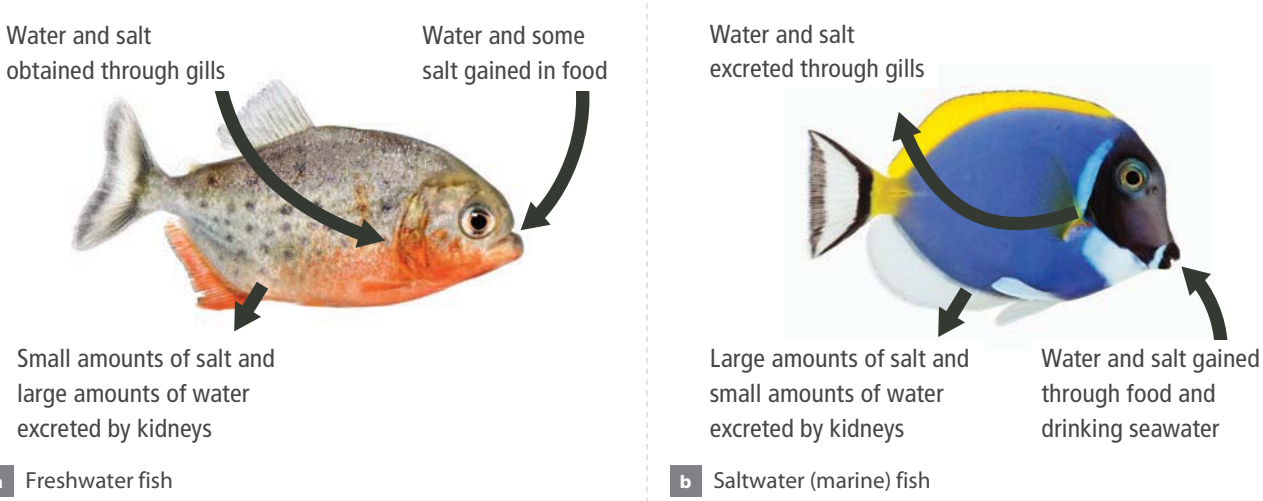
Not all feedback loops involve nerve impulses or hormones. Thermoregulation maintains a stable body temperature under a variety of conditions. Sometimes, the response to a temperature imbalance is a change in behavior. This type of feedback response is how cold-blooded animals, or ectotherms, manage their body temperature. Unlike warm-blooded animals, or endotherms, that use metabolic processes to manage internal body temperature, ectotherms do not have physiological mechanisms to maintain a constant body temperature. Instead, their body temperature is determined by their surrounding environment. When ectotherms become too cold, they move to a warmer environment. When they become too hot, they move to a cooler environment. This behavior helps them maintain homeostasis.

Explain Is thermoregulation an example of negative or positive feedback? Use evidence to support your answer.

Osmoregulation

When you live in a watery environment, you must have a strategy to maintain water and salt balances. If you live in salt water, your environment is constantly trying to dehydrate you. If you live in fresh water, your body acts like a permanently thirsty sponge. Saltwater and freshwater fish have developed strategies to cope with these problems. As part of those prevention strategies, both types of fish undergo a homeostatic process called osmoregulation, which balances fluid and salt levels.

FIGURE 14: The type of water environment determines the osmoregulation strategy of fish.



a Freshwater fish

b Saltwater (marine) fish

Collaborate
A saltwater fish swims into a river delta, where the salt concentration is lower than in normal saltwater. This would disrupt its osmotic balance. With a partner, explain how the fish's body will restore homeostasis.

Fish in freshwater environments (Figure 14a) must retain as much salt as possible in order to maintain osmotic balance. Their kidneys reabsorb salt and excrete very dilute urine to rid themselves of as much excess water as they can. At the same time, they take in salt through the gills and in food, and drink very little water.

In contrast, when marine fish ingest salt water (Figure 14b), their bodies attempt to excrete, or get rid of, as much of the salt as possible in order to maintain osmotic balance. The kidneys help extract salt from the body and concentrate it into very salty urine, which is then excreted from the body. The fish's gills actively excrete salt as well.

Land animals, on the other hand, must maintain osmotic balance in a dry environment. Their primary goal for osmotic regulation is water conservation. The kidneys of land animals work more like those of a saltwater fish. That is, the necessary water is reabsorbed and excess salt ions are excreted. The drier the climate and the more difficult it is to obtain water, the more concentrated the urine will be.

The type of nitrogenous waste that land animals excrete also affects their ability to maintain osmotic balance. Fish excrete this waste as urea, which is water-soluble. Most mammals also excrete urea. This means they must take in enough water to maintain osmotic balance while excreting enough to flush the urea from their bodies. Reptiles, amphibians, birds, and insects excrete these wastes as insoluble uric acid. This allows them to conserve water by producing highly concentrated urine.

Explain Make a flow chart modeling a homeostatic mechanism in an animal and how it can be disrupted. In your flow chart, note the stimulus, receptor, control center response, and effector for the feedback loop.

Hands-On Lab

Investigating Homeostasis and Exercise

Your body's temperature, heart rate, and blood pressure need to remain within certain set ranges. An increase in activity level will shift these values, and your body will use feedback loops to bring levels back to the target set points. Exercise particularly affects the circulatory and respiratory systems as well as perspiration levels. In this lab, you will develop an experiment to test the effect of exercise on homeostasis and then create graphs to analyze your results.

Predict How will the circulatory and respiratory systems and perspiration levels change in response to exercise? How will the body return to homeostasis?

FIGURE 15: Increased activity can affect homeostasis.

PROCEDURE

Develop a procedure to test how the circulatory and respiratory systems and perspiration levels change in response to exercise and how the body returns to ideal conditions after exercise. Consider the following questions for your procedure:

- What will be the role of each team member? Not everyone will exercise.
- What materials will you need for the experiment?
- How will you measure the response to increased activity?
- How will you you know whether the body systems are in a stable state?
- How many experimental trials will you need? How long will each trial last?
- Which variable will you change, and which variables will be kept constant?
- How will you record your data?

Your teacher must approve your materials list and procedure before you begin.

SAFETY

If the person exercising feels discomfort at any time, stop the experiment and inform your teacher immediately.

ANALYZE

1. Graph the measurements you took of changes in the circulatory and respiratory systems and perspiration levels as a function of how long a person has exercised.
2. Using your data and graphs, determine the effects of exercise over time on the circulatory and respiratory systems and on perspiration levels.
3. How would you improve your procedure to better collect data for the question asked in this activity? Did you make any errors that affected your results? What other measurements could you collect to learn about the effect of exercise?
4. How are perspiration levels related to body temperature and homeostasis?
5. Develop a feedback loop to model the relationship between exercise and either the circulatory system or respiratory system.

DISORDERS OF THE ENDOCRINE SYSTEM | EXPLAINING HOMEOSTASIS | Go online to choose one of these other paths.

Lesson Self-Check

CAN YOU EXPLAIN IT?

FIGURE 16: Control systems in the skin help conserve body heat.

In the winter, you take steps to help your body maintain its internal temperature by wearing warm clothes and drinking hot beverages or eating hot soup. Your body also has its own ways of maintaining its internal temperature in cold weather. When your body temperature drops below a set point, your brain signals your muscles to contract and expand rapidly. These contractions, or shivering, generate heat, which helps increase your body temperature.

Many viruses and bacteria that cause illnesses reproduce best around 37 °C, which is normal body temperature. To fight off these agents, the body increases its internal temperature above the normal range. This makes it harder for the virus or bacteria to reproduce and your immune system can fight it off more quickly. By shivering, your body is trying to raise its internal temperature to meet the new set point. When the infection is cleared, your body returns to the set point, and the fever breaks.

Explain Refer to the notes in your Evidence Notebook to explain each of the following questions. Use evidence from the lesson to support your claims.

1. Why do you shiver when you have a fever?
2. Is this response an example of positive or negative feedback? Why?
3. How does a fever disrupt homeostasis? Use the terms *stimulus*, *control center*, *set point*, *receptors*, *effectors*, and *imbalance* in your answer.

CHECKPOINTS

Check Your Understanding

1. How do stomata function in most plants relative to gas exchange?
   - **a.** Stomata close to prevent nitrogen from escaping.
   - **b.** Stomata close to allow photosynthesis to occur.
   - **c.** Stomata open to allow carbon dioxide in and oxygen and water out.
   - **d.** Stomata open to allow water to build up in the plant.

2. The circulatory and respiratory systems work together to provide cells with oxygen and nutrients and remove waste products such as carbon dioxide. When you need *more* oxygen, how does the circulatory system respond?
   - **a.** More blood is sent to the lungs and less to the rest of the body.
   - **b.** The blood vessels to the arms and legs constrict to conserve oxygen.
   - **c.** The heart beats at a faster rate to match the rise in breathing rate.
   - **d.** Blood moves more slowly through the organs to carry away more wastes.

3. What would happen on a hot day if your brain did not receive input that your body was starting to heat up?
   - **a.** You would start to sweat.
   - **b.** You would start to overheat.
   - **c.** You would start to shiver.
   - **d.** You would not feel any effect at all.

4. Flatworms are invertebrates with soft bodies, and some live in freshwater environments. Based on this information, what can you predict about how a freshwater flatworm's body handles osmoregulation? Select all correct answers.
   - **a.** Excretes dilute urine
   - **b.** Excretes concentrated urine
   - **c.** Absorbs as much salt as possible from surroundings
   - **d.** Excretes as much salt as possible from its body

5. When a newborn baby nurses, the mother's body is stimulated to produce milk. What would happen to the milk supply if the mother chose to bottle-feed rather than breastfeed? Why?

6. People who experience severe blood loss go into a condition known as hemorrhagic shock. Shock occurs when the blood volume returning to the heart is reduced. The heart responds by trying to increase output, which can result in the patient bleeding to death if they are not treated in time. Is this an example of negative feedback or positive feedback? Explain your answer.

7. Many desert animals are nocturnal, waiting to forage when temperatures are cooler and humidity is greater. How does this behavior help these animals regulate water balance?

8. What would happen to glucose homeostasis if the pancreas could no longer produce glucagon?

9. Exercise increases carbon dioxide levels in the blood. This affects homeostasis by decreasing blood pH, which is detected by receptors in the brain stem. The brain stem is the control center for gas exchange. Based on this information, what message would the brain stem send to the muscles of the diaphragm and rib cage to restore blood pH homeostasis?

MAKE YOUR OWN STUDY GUIDE

In your Evidence Notebook, design a study guide that supports the main idea from this lesson:

Homeostasis is the regulation and maintenance of the internal environment within a set range that is necessary to support life at the cellular level.

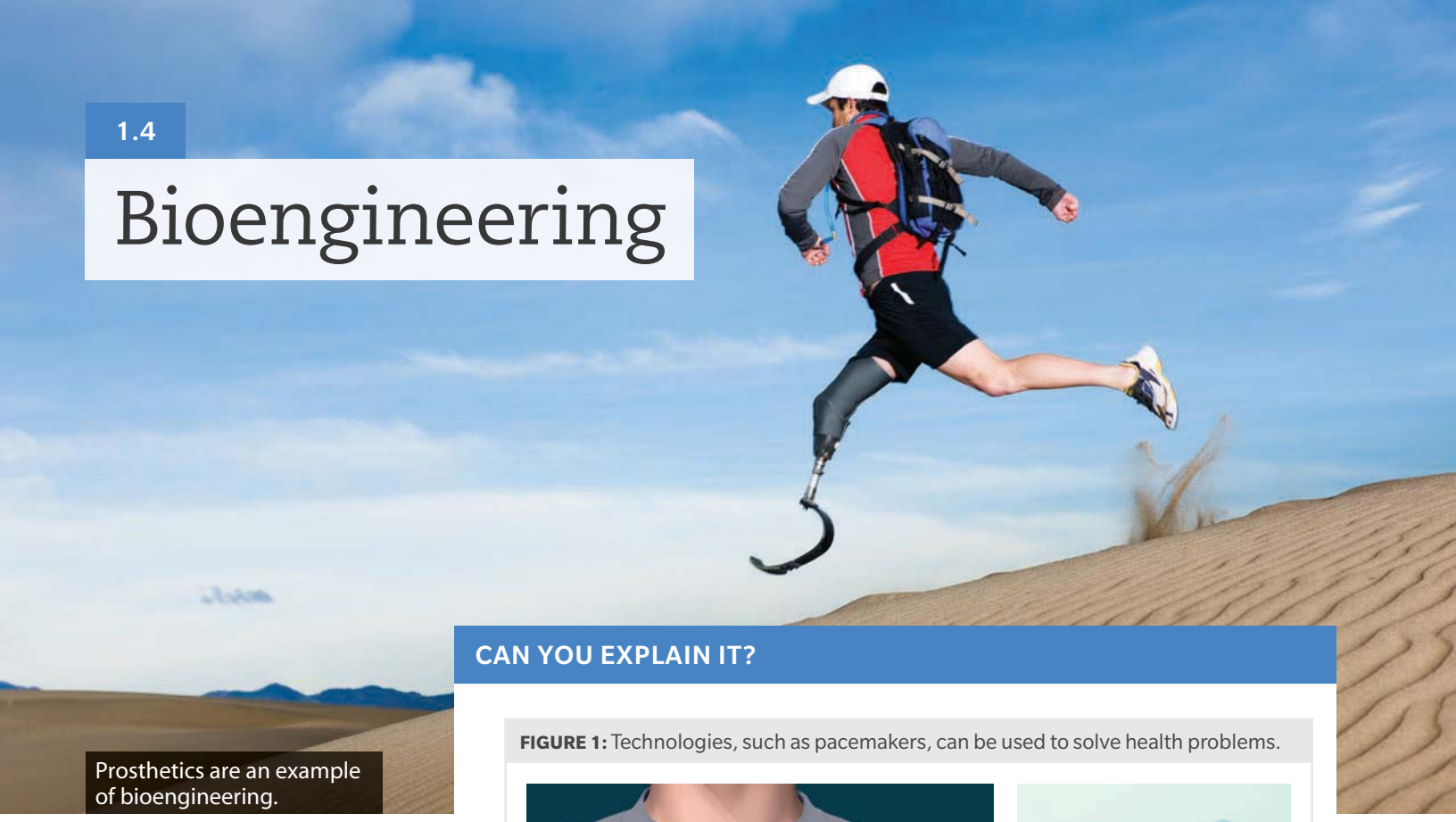
Remember to include the following information in your study guide:

- Use examples that model main ideas.
- Record explanations for the phenomena you investigated.
- Use evidence to support your explanations. Your support can include drawings, data, graphs, laboratory conclusions, and other evidence recorded throughout the lesson.

Consider the role positive and negative feedback loops play in maintaining homeostasis in an organism.

1.4

Bioengineering

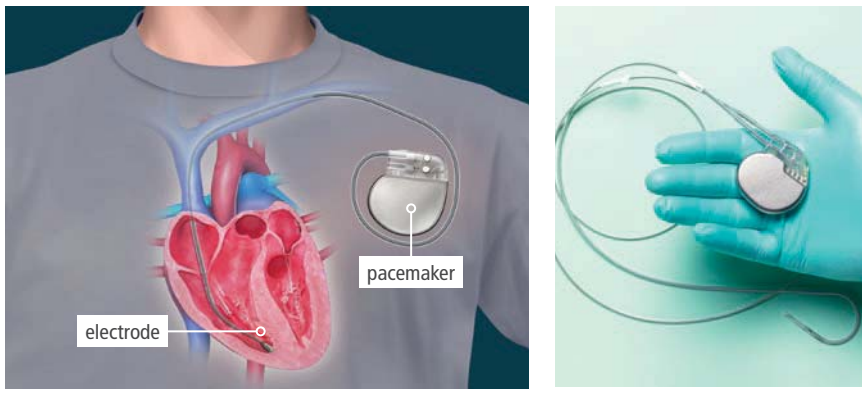


Prosthetics are an example of bioengineering.

Gather Evidence
As you explore the lesson, gather evidence to explain how a nonliving system can be designed to work together with a living system.

CAN YOU EXPLAIN IT?

FIGURE 1: Technologies, such as pacemakers, can be used to solve health problems.



In a healthy heart, the rhythmic beating is the result of carefully timed nerve signals that spread throughout the cardiac muscle. These signals cause the muscle to contract in a specific sequence that forces blood to travel through the atria and ventricles of the heart. When these signals fail to fire correctly, the heart may beat slowly or erratically, or one or more chambers may not contract properly. If this occurs, a medical professional may fit a patient with a pacemaker.

Pacemakers are designed to take over or assist the nerve signals that occur naturally in the heart. The first battery-operated, portable pacemakers were developed in the 1950s. A modern pacemaker, shown in Figure 1, consists of a battery and computer in the casing with electrodes entering the heart. The electrodes and computer work together to monitor the heart's activity and send electric impulses when the heart's rhythm is abnormal. The battery provides the power for the electrodes to stimulate the cardiac muscle.

Predict The batteries in pacemakers do not last forever and eventually need to be recharged or replaced. What types of features would you need to consider when designing a better battery for a pacemaker?

Technology and Living Systems

When you think about the term *technology*, you probably think of a cell phone or a tablet computer. Technology is the application of scientific knowledge for practical purposes. Technology does include advanced machines, such as computers and robotic equipment. It also includes simpler items you may not have thought of, such as sunglasses, scissors, and pencils.

Collaborate Discuss with a partner three technologies that you used as you prepared for school today.

Technology and the Human Body

Over the course of human history, advancements in science and technology arose through the process of engineering. Bioengineering applies the concepts of engineering to living things. Through bioengineering and scientific advancements, biotechnology has developed that allows people to live longer, healthier lives.

Analyzing Benefits, Risks, and Costs

Every new technology has benefits, risks, and costs. Bioengineers must analyze these tradeoffs when considering how new or improved technologies can impact living systems. Decisions must be made about whether a new technology's benefits outweigh the associated costs and risks. Benefits are the favorable effects of the solution, while the costs and risks are the unfavorable effects. A cost might include the impact on the environment. A risk could be the side effects from using a medical device. Engineers must balance the benefits, risks, and costs of each design solution.

FIGURE 2: A cochlear implant sends audio signals to the brain.

For example, cochlear implants increase the hearing ability for people with damaged inner ears. In a normal ear, the pinna (the ear's outer portion) funnels sound waves into the auditory canal. The sound waves then hit the eardrum, causing it to vibrate. These vibrations are then applified by the middle ear. Hair cells in the cochlea convert the waves into impulses that are transmitted to the brain by the auditory nerve.

A cochlear implant, shown in Figure 2, has a microphone and speech processor, which pick up sounds from the environment. A transmitter and stimulator convert signals from the processor into electrical signals. An electrode array implanted into the cochlea collects the electrical signals and sends them to the auditory nerve.

Analyze How does a cochlear implant's process of transmitting sound to the brain mimic the process used by the ear?

Scientists and engineers continue to modify technology to meet the needs and demands of society. This often involves increasing the benefits of technology while reducing the costs and risks. For the cochlear implant, engineers could increase the benefits by improving the speech recognition ability. They also may work with scientists to decrease the likelihood of infection, reducing the risk. Engineers may find new materials that reduce the cost on the environment and reduce the cost of the implant. A replacement for precious metals in computers could reduce the environmental impact from mining and make an implant less expensive.

Research and Development

Scientists ask questions to learn more about a phenomenon, and engineers design solutions to problems related to that phenomenon. This back-and-forth between scientists and engineers is part of a process known as research and development. The studies and testing performed during this process often lead to the development and improvement of technologies.

Explain How are technology and life sciences related in the field of bioengineering?

In the case of the cochlear implant, scientists asked questions to learn more about the phenomena of hearing. Scientists might have asked, "How do the ear and brain interact to detect sound?" or "Which structures are affected in patients with hearing loss?" Engineers designed the cochlear implant using information on the mechanics of hearing that arose from scientific research.

Technology and Society

Technology has greatly influenced society, and society has influenced progress in technology. New technologies change our lifestyles, diets, and living spaces. Likewise, as social trends, economic forces, and cultural values change, new technologies emerge that support these changes. These new technologies also may propel society toward new changes in culture, health, and the environment.

Consider the advances in emergency medical treatment and technology. Prior to the 1950s, many ambulances were simply a way to deliver a patient to the hospital. Ambulances only had enough room for a patient in the back, so no medical care could be given during transport. Changes in societal expectations led to vehicles with enough room for emergency responders to work on patients, as well as new technologies to save lives. Modern ambulances continue to undergo design changes as new medical needs arise.

FIGURE 3: With technological improvements, emergency response time is faster.

Science as a Human Endeavor How have improvements in emergency medical technology changed our society?

Image Credits: (r) ©A. Y. Owen/Time Life Pictures/Getty Images; (l) ©Zero Creatives/Cultura/Getty Images

All new technologies come with risks and costs to people and society, no matter how great the benefits. For example, many vaccines are refrigerated, allowing them to remain effective for longer periods of time. Refrigeration is rare in some parts of the world, though, making it difficult for people to access these vaccines. Refrigerants also add to the greenhouse gas effect. In response, some researchers are turning their attention to producing vaccines that do not require refrigeration.

Engineering

Clean Drinking Water

FIGURE 4: Societies around the world gain access to clean drinking water through new engineering designs, such as improved devices to transport water and new wells.

Many people in the world do not have access to clean drinking water. They must walk miles to and from wells to bring water to their homes. Once they carry the water home, it often needs to be filtered to avoid water-borne diseases, such as cholera. In response, bioengineers developed better water filtration systems in wells, making the water cleaner and safer. Engineers also developed devices to make it easier to transport water over long distances, as shown in the left image in Figure 4. Getting water can be a full day's work and is often the job of women and young girls. By decreasing the time spent focusing on water, women and girls have more time to devote to other tasks, such as education.

Collaborate If you were asked to design a device to transport water, such as the rollers shown in Figure 4, what societal, cultural, and environmental impacts would you need to consider?

In some cases, by solving one problem, advances in technology can cause new social and economic problems. Medical technology has enabled many humans to live longer lives. In some countries, longer life spans mean that the proportion of older individuals continues to grow, and more resources are needed to support these people.

The environment also is a concern when it comes to new technologies. Disposable medical supplies make it possible to use sterile equipment on each new patient. Once used, though, the material needs to be disposed of properly to prevent biohazardous waste from potentially affecting others.

Explain During the next 50 years, what biotechnology would you like to see developed or improved? Describe the potential benefits, risks, and costs of the technology and how it would impact society.

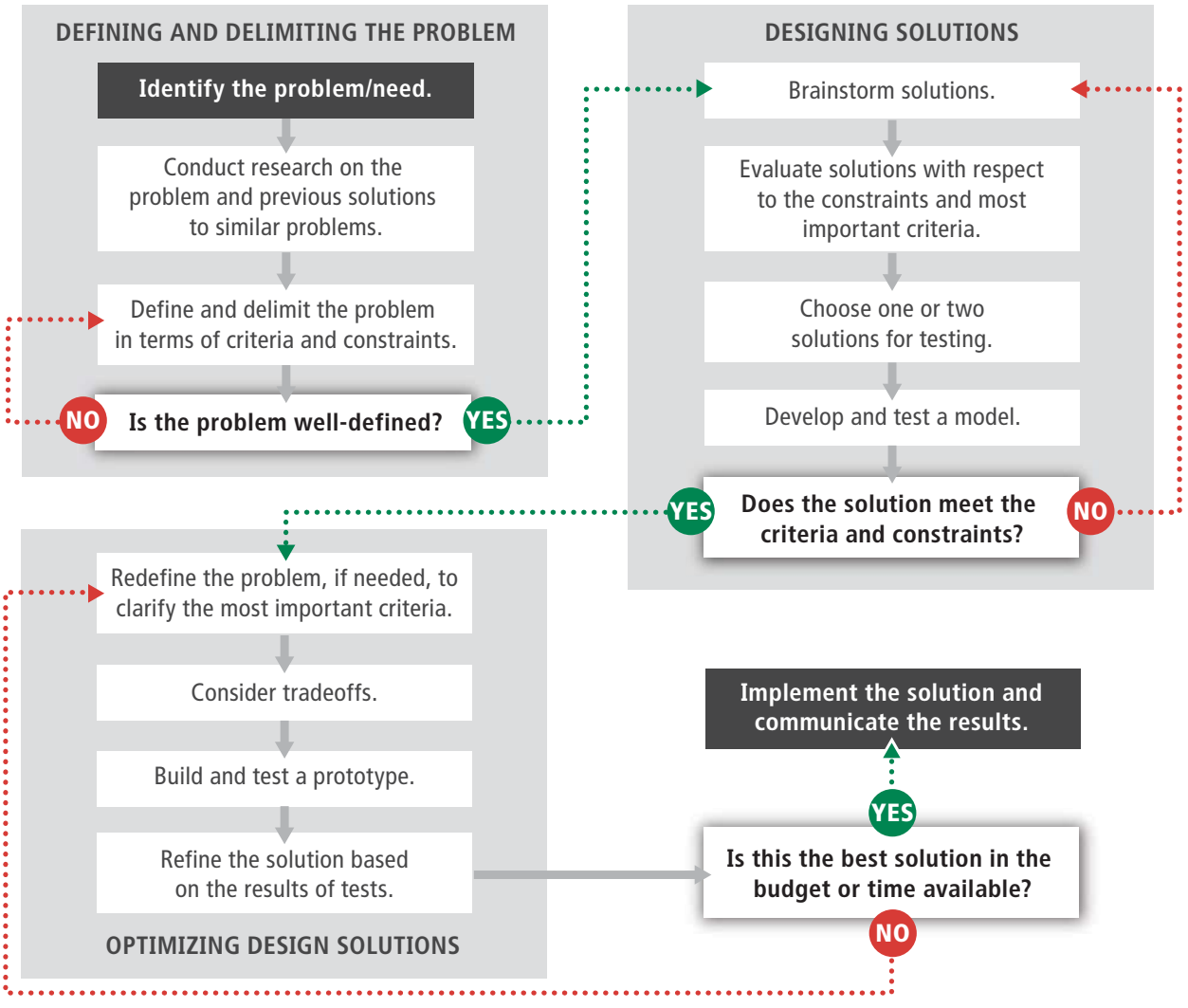
Engineering in Life Science

Engineering and scientific inquiry both involve a set of principles and a general sequence of events. Scientific investigations often include steps such as asking questions, making predictions, and investigating the effects of changing variables. The engineering design process includes steps, such as defining a problem, developing possible solutions, and optimizing a solution.

The Engineering Design Process

The engineering design process is a method used to develop or improve technology. The process is iterative, meaning it uses repeating steps. Engineers do not always apply these steps in the same order. They may skip some on occasion or perform other steps more than once.

FIGURE 5: The engineering design process is a set of steps that lead to designing or improving a solution to a problem.



Following a well-defined set of steps ensures that engineers take a thoughtful and complete approach when designing a solution to a problem. In this process, engineers must first identify and define the problem or need. In doing so, they may need to perform research or analyze data to learn more about the problem. They must identify aspects that are desired in a final solution as well as the limits on the solution. Next, engineers will begin to design solutions. During this stage, they will evaluate several different solutions and choose only one or two options to begin testing. In the testing, or optimizing, stage, designs are tested using computer simulations and prototypes. Based on the results of these tests, the designs may be accepted or refined. The engineers may even decide to choose a different solution and start the process over.

Imagine that bioengineers are designing a new type of artificial hip. They will need to research how a normal hip functions and what types of materials are safe to use. The client that hired the engineers may ask the team to consider using 3D printing to custom fit the product to each patient. They may also say the design can cost no more than $10,000. The engineers will come up with many different design solutions, but only those that cost less than $10,000 will be considered. The final design may not be 3D printed, but it may have other aspects that make it better. Engineers must consider these types of tradeoffs before presenting their final design.

Collaborate With a partner, discuss why it is necessary for scientific and engineering processes to be iterative, instead of following a fixed sequence of steps.

Defining and Delimiting the Problem

The first step in the engineering design process is to ask questions that help specifically define the problem. These questions help an engineer understand the criteria for the design. Criteria make clear what a successful solution must accomplish and how efficient and economical that solution should be. These are the "wants" for the solution. Criteria can include many different aspects of a design, but often cost, safety, reliability, and aesthetics are considered.

Then, engineers delimit the problem. Delimiting is the process of defining the limitations, or constraints, of the solution. Constraints are the limitations of a design and are usually given by the client. These constraints can include things like cost, weight, dimensions, available resources, and time. Any solution that does not meet the constraints of the design is not considered.

Engineers often must balance criteria and constraints. They may accept some risks in tradeoffs, or compromises, for greater benefits. Engineers also may give up one benefit in favor of another to avoid a potential risk. Consider the artificial hip example again. Any design that exceeds the $10,000 constraint is not approved. The manufacturer may consider a design using more typical materials if that reduces a risk or increases a benefit over using different materials. The benefit of the tradeoff will depend on the problem defined by the engineer.

Analyze A company is designing an electric wheelchair and hires you as the engineer. They tell you the wheelchair must not cost more than $5,000. The design must be usable by people with limited hand movement and should not require a battery replacement very often. In your Evidence Notebook, define the problem and then list criteria and constraints for possible solutions.

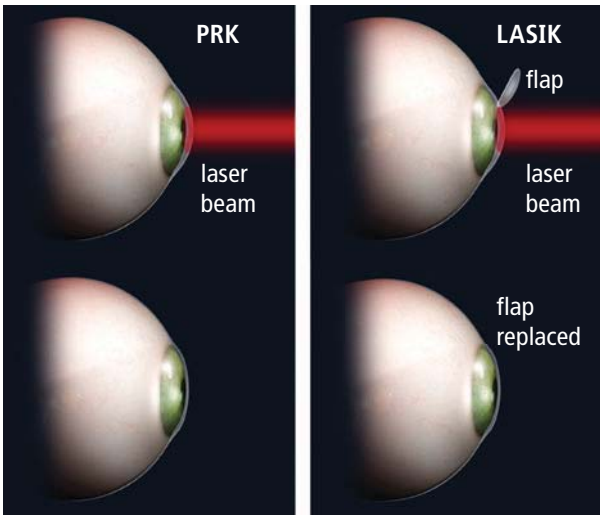
Explore Online

Hands-On Lab

Modeling Joint Movement
Use the engineering design process to develop models of the joints in the skeletal system and test their ranges of motion.

Vision Correction Technology

FIGURE 6: PRK and LASIK both correct a person's vision using a laser, but the technique used will depend on the needs of the patient.



Vision correction has undergone many changes since glasses were first developed in Italy in the 13th century. In addition to modern glasses, people with impaired vision also can buy contact lenses or undergo surgery to fix their eyesight. LASIK and PRK are two of the more recognizable technologies developed to address vision problems. In LASIK surgery, a blade or laser forms a flap on the outer surface of the cornea. Then, another laser reshapes the cornea. In PRK, the surface layer of the cornea is removed and the corneal bed is reshaped. Doctors and patients must weigh the criteria and constraints before choosing a solution. Figure 7 lists several of the criteria for each of these vision correction technologies.

Analyze Analyze the tradeoffs between each of the engineering solutions for vision correction technologies in Figure 7. How would a doctor explain the tradeoffs of each choice to a patient? What questions might a doctor ask to help a patient pick the technology that best addresses their needs and wants?

FIGURE 7: Vision correction technologies have tradeoffs including safety, reliability, cost, and aesthetics.

Technology	Eyeglasses	Contact Lenses	LASIK	PRK
Safety	Provides sun protection and physical protection for the eyes.	Provides sun protection but not physical protection. Infections are possible if lenses are not cleaned often.	Cannot provide sun or physical protection. Procedure is generally safe. Relatively short recovery time.	Cannot provide sun or physical protection. Procedure is generally safe. Longer recovery time.
Reliability	Can be lost or broken. Lenses or frames can be replaced as needed.	Can be lost or torn. Can be replaced as needed.	Results are relatively permanent. Glasses may become necessary.	Results are relatively permanent. Glasses may become necessary.
Cost	Prices range from tens to hundreds of dollars.	Prices range from tens to hundreds of dollars.	Prices are typically in the thousands of dollars.	Prices are typically in the thousands of dollars.
Aesthetics	Come in many colors and shapes. May obscure some facial features.	Come in many colors. Do not obscure facial features.	Does not obscure facial features. Eye color cannot be altered.	Does not obscure facial features. Eye color cannot be altered.

Engineers prioritize criteria by deciding which ones are most important for a given problem. They make tradeoffs between them to begin brainstorming solutions to the problem. Engineers may even redefine the problem to clarify the most important criteria before beginning to design and test a solution. Remember, if a proposed solution does not meet the constraints of the problem, it will not move forward in the engineering design process.

Designing Solutions

After engineers have identified the constraints and criteria for solving a problem, the next step is to brainstorm design ideas for a solution. Usually, engineers and other specialists work in teams when brainstorming. The group leader presents the problem to be solved and encourages all ideas to be suggested, even if they seem outrageous.

Once the team has brainstormed several ideas, they may use a decision matrix, or Pugh chart, to evaluate each solution against the criteria of the problem. In a decision matrix, each criteria is given a number, or weight, based on how important that criteria is. The more important the criteria, the greater the weight assigned to it. Then, each design is rated based on how well it meets those criteria. The scores for each design are multiplied by their respective weights, and the products are totaled so engineers can determine how well the design is meeting the criteria. They may choose to take the design with the highest score to the next phase, or they may choose to brainstorm new ideas if no designs meet the requirements.

FIGURE 8: An example decision matrix for three water filtration system designs, weighted on a scale from 0 to 5

Design Criteria	Weight	Design 1	Design 2	Design 3
Safety	5	4	1	5
Reliability	4	2	3	4
Cost	2	1	2	1
Aesthetics	1	1	1	0
Total Points		31	22	43

Figure 8 shows how a decision matrix can be filled out for three designs. In this example, each column represents a different design for a new water filtration system people can use in their homes. Safety is weighted a 5, meaning it is extremely important. Aesthetics, though, are weighted very low, meaning they are not as important. To determine how to weight each design, engineers may choose to make a model or run computer simulations to see how each design would work in a typical situation.

A bioengineer may use a decision matrix to evaluate a technology, such as a new design for a Continuous Positive Airway Pressure (CPAP) machine. These machines are worn by people who suffer from sleep apnea, a condition where breathing starts and stops during sleep. CPAP machines are worn while a person is sleeping and supply a constant source of pressure to help keep their airways open. The criteria for a machine like this would likely include safety and reliability but also may include comfort, ease of use, and noise level.

Engineering Make a decision matrix for the three CPAP machines shown in Figure 9. What criteria do you think are important for this machine? How would you weight them?

Once a number of solutions are proposed, they are evaluated against the criteria and constraints set out for the desired solution. Solutions that do not meet the constraints must be redesigned if they are to be considered. In general, one or two ideas that best meet the criteria and all constraints are selected, and these ideas enter the optimization phase of the design process.

FIGURE 9: Examples of different CPAP designs

Optimizing Design Solutions

When one or two solutions have been chosen, engineers may build a prototype of the technology to further test the capabilities and effectiveness of the design. A prototype is the first build of a design and may not be built to scale or with the final materials. Since the results from testing the prototype may result in design changes, prototypes are often built with cheaper materials than the final version. This way, engineers can run many tests and build many versions of their designs. As the design becomes more refined and finalized, engineers may begin to use the final materials to ensure the solution will work as expected.

Analyze What types of information can be gained from building a prototype that is not an exact model of the final product?

Engineering

Optimizing Prosthetics

One of the biggest challenges often facing designers is the need to think creatively and to seriously consider new designs. While not traditional, these new designs may be what are required to solve a problem or improve an existing product. Van Phillips engineered the "blade" prosthetic leg/foot now preferred by runners. His design abandoned the traditional clunky prosthetic, favoring lightweight materials tailored to athletes, as shown in Figure 10.

FIGURE 10: Prosthetic leg designs have changed over time. As new materials are developed, new ideas are generated.

Collaborate Discuss this question with a partner: How have advances in the different fields of science and engineering influenced prosthetic limb technology?

Testing is an important part of the engineering design process, allowing engineers to get feedback on the design. Data collected from tests will tell engineers if their design is working as expected. The data also may show design problems that were not seen in early stages of the process. Engineers will review these issues and determine which ones need to be fixed. Considering tradeoffs is an important part of the optimization process. Issues that do not seriously impact important criteria or constraints may not be corrected if the tradeoff is undesirable, such as increasing the cost of the design. However, if the problem is important enough, engineers may need to change the design or brainstorm new designs to address the concern.

FIGURE 11: Engineers may return to a design or a prototype during the optimization process.

Life cycle analyses are another way to evaluate a design. A life cycle analysis attempts to evaluate the real cost of a new technology or design. It takes into account the materials and energy used to manufacture, transport, use, and dispose of a product. Perhaps one design has several benefits over another. If the design is much more expensive to produce, manufacturers might abandon it in favor of another, less expensive design. If it wears out quickly and needs to be replaced often, the design might be abandoned in favor of a more durable alternative.

Life cycle analysis also considers the environmental impact of the materials and wastes from producing the design. Engineers might consider an alternative if manufacturing a design produces pollution. If the product cannot be thrown away safely, a biodegradable or recyclable option may be considered.

Engineers may also run a cost-benefit analysis to further evaluate their design solution. A cost-benefit analysis is a method of identifying the strengths and weakness of a design. The cost could be the monetary cost to produce the design. If the device costs too much to make and the benefits are not great enough, the design solution may be disregarded in favor of a less expensive design. A cost also could be related to environmental factors. If a design uses a very rare metal and will result in large-scale mining, the environmental impact may outweigh the benefits, especially if a different material could be used.

When a final design has been chosen and fully tested, engineers will communicate their results. This may just involve presenting the final solution to the client to begin production. If the design is new or groundbreaking or has important implications, the engineering team may publish a journal article detailing the design to the scientific community.

Explain How do you think the engineering design process differs for biotechnologies, like pacemakers, used in the medical field compared with that used in other fields of technology, like in developing a cell phone?

Language Arts Connection

Research the life cycle of different cell phones. How long are they built to last? What are the energy requirements to manufacture a phone? Develop your own life cycle analysis of a phone to determine the true cost of the technology.

Careers in Science

Careers in Bioengineering

Bioengineering includes a variety of fields, such as biomedical engineering, cellular engineering, molecular engineering, and others. Bioengineers use engineering methods and biological science to design and manufacture equipment, computer systems, and new materials used in the field of biology.

Biomedical Engineering

Devices made by biomedical engineers include artificial joints and organs, prosthetics, corrective lenses, and dental implants. Biomedical engineers still use the engineering design process to help them develop and optimize medical technologies. In this field, engineers must always consider how a design will interact with the different systems of the human body.

FIGURE 12: Biomedical engineers design devices, such as prosthetic limbs. This prosthetic limb is designed to interpret messages from the user's nervous system.

A bionic hand, as shown in Figure 12, might interact with the nervous system to interpret signals to grasp an item. However, implanting such a device could cause a stress on the immune system, causing the body to reject the device. Biomedical engineers must consider all potential health risks when designing solutions.

Imagine that a company wants to develop prosthetics for competitive swimmers who have had one of their legs amputated at the knee. The company needs a working design within six months and wants each prosthetic to cost less than $30,000. The prosthetic must last a swimmer at least five years before any parts need to be replaced. How would an engineering team solve this problem?

First, the engineering team must define and delimit the problem. The constraints were given by the company: The design must cost less than $30,000; it needs to be completed in half a year; and all components need to last at least five years. The criteria for this problem may include weight, hydrodynamics in the water, and safety of use.

Once the problem is defined, engineers will begin brainstorming possible designs. Each proposed design will be evaluated, and the solutions that meet all constraints and the most important criteria will be chosen for testing. When developing prosthetics, engineers may run computer simulations and use other types of models to help evaluate each solution. The team may realize that traditional prosthetic materials are too heavy to be used for an aquatic prosthetic. Instead, they may research more lightweight materials.

The engineering team will then begin testing and optimizing their designs. They will build prototypes and may even fit their prototype to swimmers to get feedback and data on the design. At this stage, engineers may realize their design generates too much drag in the water and needs to be redesigned to be more streamlined.

Even when the client approves a solution, engineering teams may continue to review designs and make improvements. As technology changes, there are new opportunities for improved design concepts.

Working with a team, develop your own design of an aquatic prosthetic leg. Imagine you are working with the same constraints outlined in this example. With your group:

Define and delimit the problem In your group, outline the criteria and constraints and then clearly define the problem.

Design a solution Each individual in your group should propose a potential solution. Assign weights to the criteria your group outlined, and make a decision matrix to evaluate each design. Choose the highest-rated design, or brainstorm additional ideas until you find a solution that solves the problem your group outlined. Remember, you may need to redefine the problem if the design solutions do not meet the criteria or constraints. When your final design has been chosen, make a model, such as a drawing, of that design and have your teacher approve it before moving to the next stage of the process.

Develop a prototype Using common household and classroom items, develop a prototype of your approved design. You may use items such as paper towel rolls, PVC tubing, cardboard, tape, and any other items you may need. Remember, a prototype does not need to be a replica of the final product. Your prototype may not be made to scale or it may not be waterproof. The prototype should be able to demonstrate how the design will work, but it does not need to function completely.

Optimize the design After building your prototype, review your design and identify areas where the design could be improved. Review the criteria and constraints again to ensure your design is solving the problem. If you feel your design did not work, brainstorm new designs or ways to change aspects of your designs. You may wish to build an additional prototype to test your modifications.

Language Arts Connection With your group, research other designs for prosthetics that help people swim. Then, make a presentation to share with the class. In your presentation:

- Include a summary of your research and the prosthetic designs you discovered.
- Present a diagram of your final design to the class.
- Explain the most important criteria considered in designing your solution.
- Finally, present your prototype and explain how your design will solve the problem.

Cellular Engineering

Cellular engineering is a field of bioengineering that combines an understanding of cellular functions, biological systems, and engineering practices to develop technologies that help improve people's lives. For example, cellular engineers may study ways that stem cells can be used to improve the lives of people with medical conditions, such as Parkinson's disease or diabetes.

Tissue engineering uses aspects of cellular engineering to develop biological tissues. Whole tissues or portions of tissues can be made from cells and then used to repair damaged areas of the body. Scientists in this field are even trying to make entire organs using their understanding of cellular function, engineering, and biological systems.

FIGURE 13: Bioengineers develop technologies, like MRI machines, to help scientists learn more about living systems.

Molecular Engineering

Molecular engineering is a highly integrated field of study combining knowledge from biology, chemistry, mechanics, and materials science. Molecular engineers study ways to build better materials and systems by studying the molecular properties of those materials.

In the field of biology, molecular engineers are studying immunotherapy. Immunotherapy is the treatment of disease by amplifying or minimizing the body's immune response. Molecular engineers are developing vaccines to increase patients' immune responses.

Molecular engineers also are researching ways to edit and manipulate an organism's genetic material. This may allow them to treat or cure genetic disorders, modify metabolic rates, and modify the structure of proteins to make new functions. To make changes to the genetic material of an organism, molecular engineers are developing new technologies to help further their research.

Language Arts Connection Write a short newspaper-style article comparing and contrasting the different fields of bioengineering.

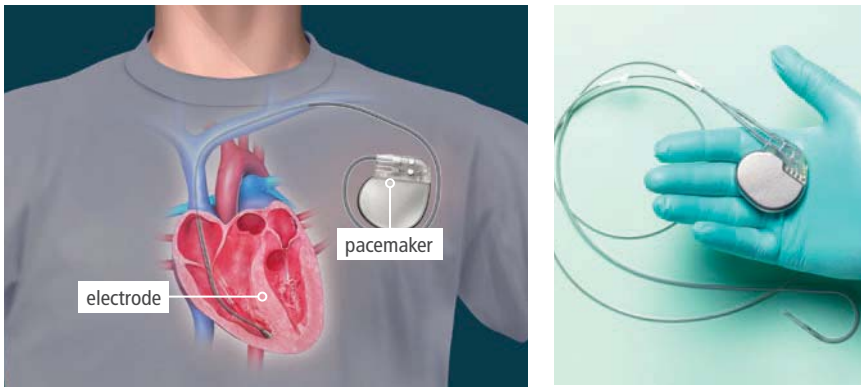
3D BIOPRINTING | NANOTECHNOLOGY

Go online to choose one of these other paths.

Lesson Self-Check

CAN YOU EXPLAIN IT?

FIGURE 14: A pacemaker is a nonliving system that functions inside a living system, the human heart.



Pacemakers generate electrical signals that stimulate the heart when cardiac activity is abnormal. The pacemaker has gone through many design changes based on improved technology and medical knowledge since its initial conception. As technologies improved, designs became smaller. As scientific understanding of anatomy, heart conditions, and biological systems progressed, so did the efficiency of pacemakers. Scientists and engineers continually work together to improve upon this design and many others in the medical field.

Explain The batteries in pacemakers eventually need to be recharged or replaced. What types of features would you consider when designing a better battery for a pacemaker?

When designing a new component for a device, engineers will still use the engineering design process. The process is iterative, so the steps may not be applied in the same order. For example, when designing a new battery for a pacemaker, engineers may start by testing pacemakers and existing batteries. The data gathered in these tests may help them brainstorm new ideas for how to improve the previous design.

The engineering team also will have different constraints when improving a design than when creating a new design. For example, engineers will only be able to develop batteries that fit inside the existing pacemaker and work with the components already in the design. They also may be working within a shorter timeframe and a smaller budget than if they were developing a new pacemaker design.

By working with patients, doctors, and manufacturers, engineers can identify the most important criteria to incorporate into their design. Perhaps patients would rather have a battery that is easier to recharge than one that lasts a few years longer and needs to be replaced. Once engineers understand the limitations in the current design, the constraints, and the important criteria, they can begin developing new designs.

CHECKPOINTS

Check Your Understanding

1. Imagine that you are an engineer who designed a prototype for a client. After testing the prototype, you discover it does not address the client's needs. What might be a possible next step in the process?

2. You and a partner have brainstormed a design for an implanted device to help keep insulin levels in check for a person who is diabetic. What should be the next step in the design process?
   - **a.** test on a patient
   - **b.** build a prototype
   - **c.** revise the design
   - **d.** evaluate the design

3. Which of the following technologies would likely involve a bioengineer to design and build? Select all correct answers.
   - **a.** artificial heart valve
   - **b.** tablet computer
   - **c.** artificial hip joint
   - **d.** global positioning system
   - **e.** automobile engine
   - **f.** surgical robot

4. A biomedical engineer is developing a portable medical imaging machine designed to be used in remote areas or in situations where a natural disaster has made access to local imaging facilities difficult. She made a list of criteria and constraints for the new device. Which of these should be classified as criteria? Select all correct answers.
   - **a.** transmits information wirelessly to base medical facility
   - **b.** one person can carry it without assistance
   - **c.** uses a rechargeable battery
   - **d.** case made of high-impact plastic
   - **e.** generates high-definition CT scans
   - **f.** completes scans rapidly

5. One of the ways in which society impacts technology is through government regulation. Describe how government regulation can have both positive and negative impacts on technology.

6. Make a decision matrix to compare three models of a device, perhaps personal tablet devices or phones. Use the following questions to build the matrix and evaluate the results:
   - **a.** What design criteria are most important?
   - **b.** How would you weight these criteria?
   - **c.** How would the competing designs score on each criterion?
   - **d.** Which design(s) should move to the next stage of the process and why?

MAKE YOUR OWN STUDY GUIDE

In your Evidence Notebook, design a study guide that supports the main ideas from this lesson:

Bioengineering is the application of engineering processes and practices to living things.

Engineering develops and modifies technological solutions for the needs of society.

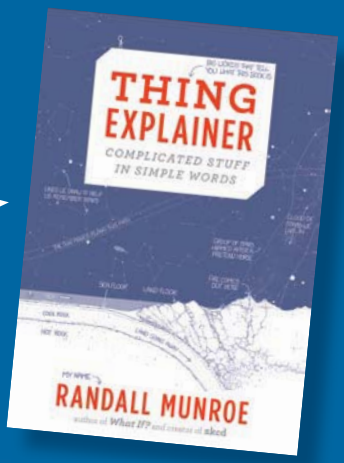
Remember to include the following information in your study guide:

- Use examples that model main ideas.
- Record explanations for the phenomena you investigated.
- Use evidence to support your explanations. Your support can include drawings, data, graphs, laboratory conclusions, and other evidence recorded throughout the lesson.

Consider how bioengineering solutions influence the environment while addressing the wants of society.

THING EXPLAINER BY RANDALL MUNROE

A BOOK EXPLAINING COMPLEX IDEAS USING ONLY THE 1,000 MOST COMMON WORDS

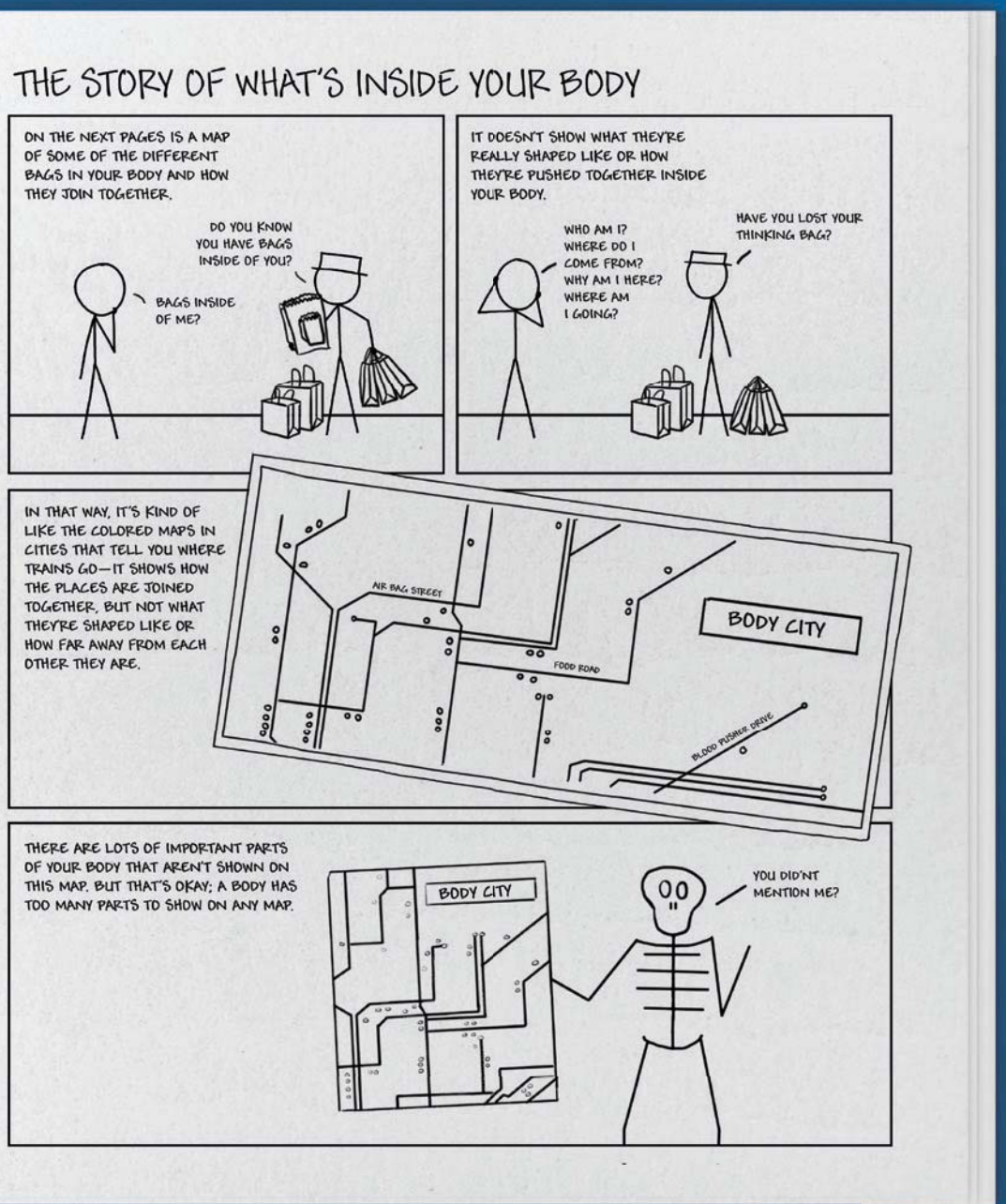


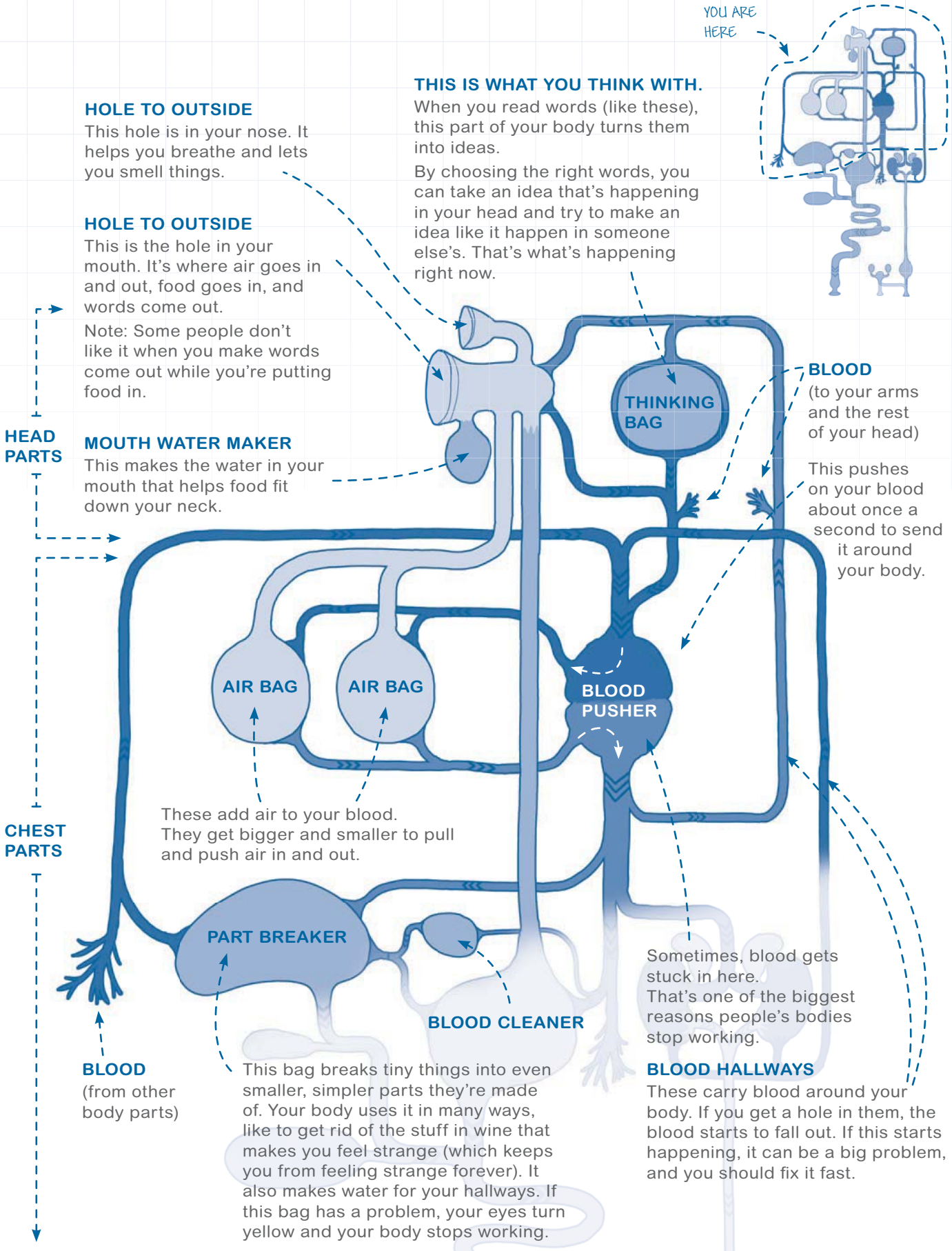
RANDALL MUNROE
XKCD.COM

BAGS OF STUFF INSIDE YOU

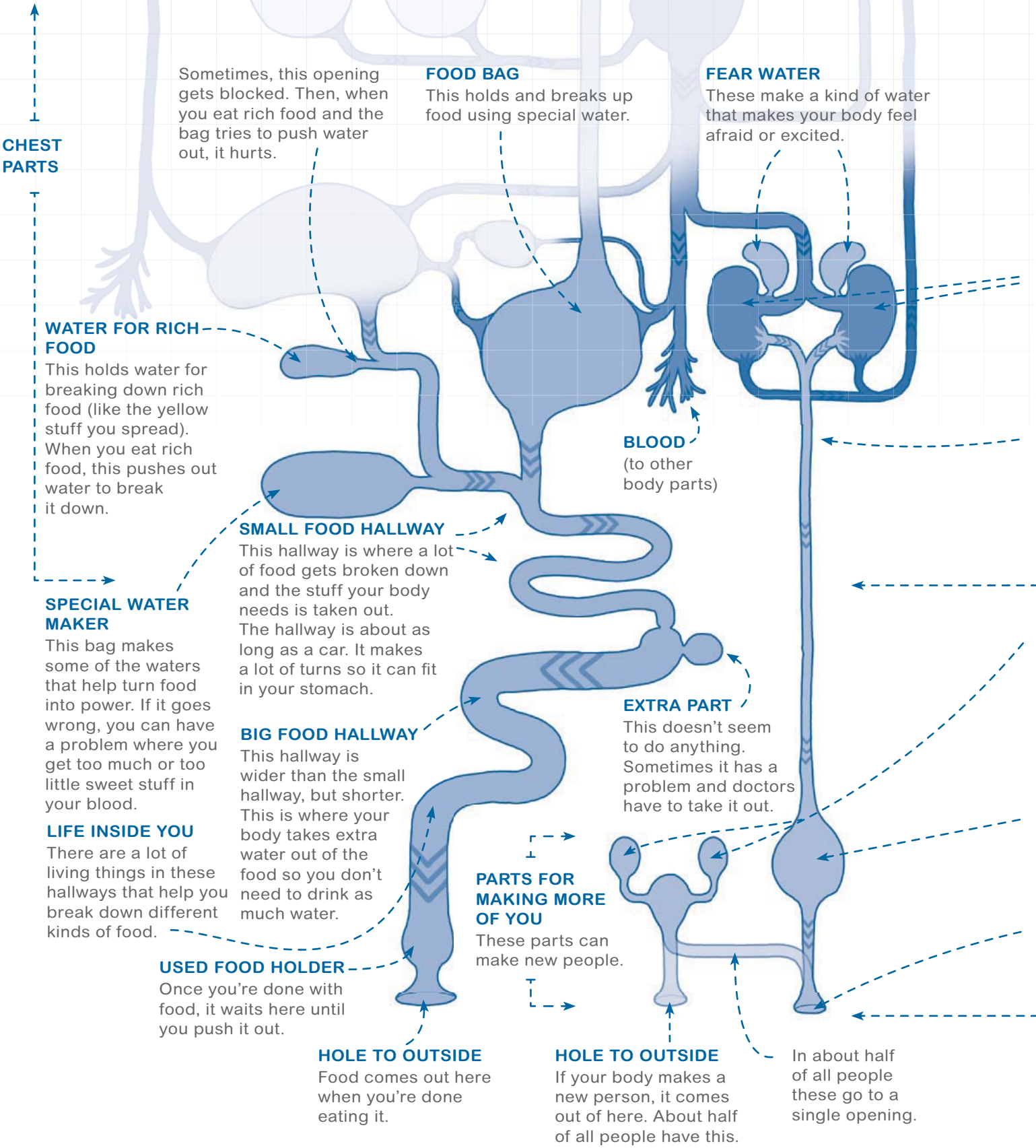
Parts of your body and how they work together

You know that an organ system is two or more organs working together to perform body functions. Here's a look at several organ systems in the human torso.




YOU ARE HERE
THIS IS WHAT YOU THINK WITH.
When you read words (like these), this part of your body turns them into ideas.
By choosing the right words, you can take an idea that's happening in your head and try to make an idea like it happen in someone else's. That's what's happening right now.
HOLE TO OUTSIDE
This hole is in your nose. It helps you breathe and lets you smell things.
HOLE TO OUTSIDE
This is the hole in your mouth. It's where air goes in and out, food goes in, and words come out.
Note: Some people don't like it when you make words come out while you're putting food in.
HEAD PARTS
MOUTH WATER MAKER
This makes the water in your mouth that helps food fit down your neck.
THINKING BAG
BLOOD
(to your arms and the rest of your head)
This pushes on your blood about once a second to send it around your body.
AIR BAG
AIR BAG
BLOOD PUSHER
CHEST PARTS
These add air to your blood. They get bigger and smaller to pull and push air in and out.
PART BREAKER
BLOOD CLEANER
Sometimes, blood gets stuck in here. That's one of the biggest reasons people's bodies stop working.
BLOOD
(from other body parts)
This bag breaks tiny things into even smaller, simpler parts they're made of. Your body uses it in many ways, like to get rid of the stuff in wine that makes you feel strange (which keeps you from feeling strange forever). It also makes water for your hallways. If this bag has a problem, your eyes turn yellow and your body stops working.
BLOOD HALLWAYS
These carry blood around your body. If you get a hole in them, the blood starts to fall out. If this starts happening, it can be a big problem, and you should fix it fast.

BAGS OF STUFF INSIDE YOU



CHEST PARTS

Sometimes, this opening gets blocked. Then, when you eat rich food and the bag tries to push water out, it hurts.

FOOD BAG
This holds and breaks up food using special water.

FEAR WATER
These make a kind of water that makes your body feel afraid or excited.

WATER FOR RICH FOOD
This holds water for breaking down rich food (like the yellow stuff you spread). When you eat rich food, this pushes out water to break it down.

BLOOD
(to other body parts)

SMALL FOOD HALLWAY
This hallway is where a lot of food gets broken down and the stuff your body needs is taken out. The hallway is about as long as a car. It makes a lot of turns so it can fit in your stomach.

SPECIAL WATER MAKER
This bag makes some of the waters that help turn food into power. If it goes wrong, you can have a problem where you get too much or too little sweet stuff in your blood.

EXTRA PART
This doesn't seem to do anything. Sometimes it has a problem and doctors have to take it out.

BIG FOOD HALLWAY
This hallway is wider than the small hallway, but shorter. This is where your body takes extra water out of the food so you don't need to drink as much water.

LIFE INSIDE YOU
There are a lot of living things in these hallways that help you break down different kinds of food.

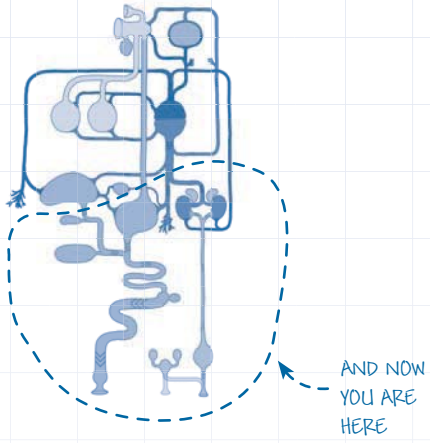
PARTS FOR MAKING MORE OF YOU
These parts can make new people.

USED FOOD HOLDER
Once you're done with food, it waits here until you push it out.

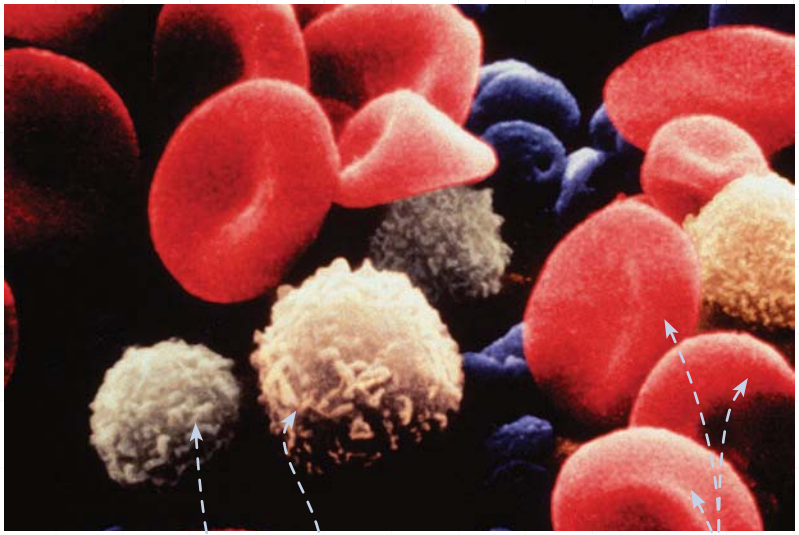
HOLE TO OUTSIDE
Food comes out here when you're done eating it.

HOLE TO OUTSIDE
If your body makes a new person, it comes out of here. About half of all people have this.

In about half of all people these go to a single opening.



Go online for more about *Thing Explainer*.



BLOOD CLEANERS

These look for stuff in your blood that you're done with or have too much of—like extra sweet stuff, or stuff from the doctor that you ate to feel better—and send it to be pushed out of your body.

YELLOW WATER HALLWAY

Most of the time, the water from your blood cleaners is yellow, but eating certain colorful foods can make it change color for a while.

(If it turns dark or red, it may mean you're sick.)

BODY PLAN HOLDERS

These parts hold lots of plans for new people. Each plan is made from pieces of the plans used to make you.

These parts also control how your voice, hair, and body grow.

LOWER PARTS

YELLOW WATER HOLDER

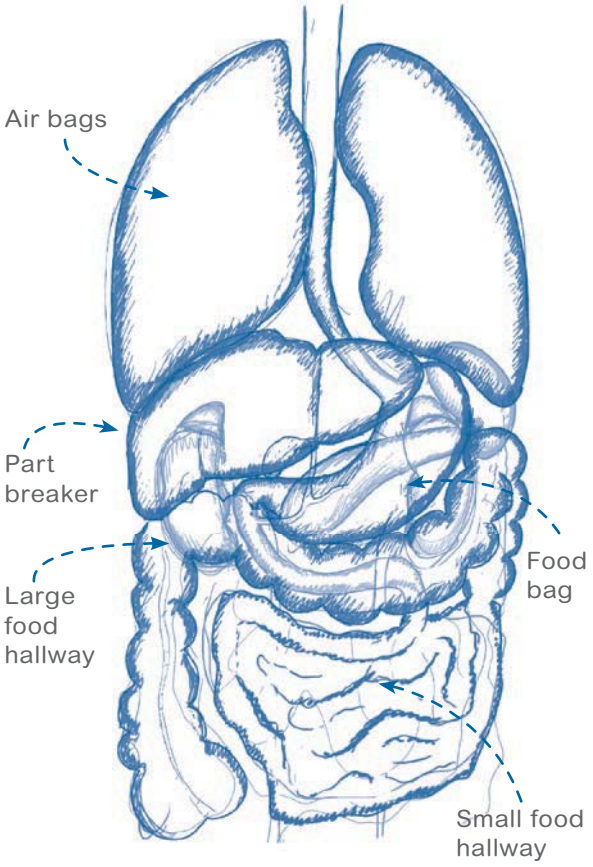
This holds yellow water until you push it out.

HOLE TO OUTSIDE

The yellow water from your blood comes out here.

PUSHED TOGETHER

In real life, these parts are all pushed together inside your chest like this.



Technology Connection

Computer Systems Computers and people have more in common than you might think. Computers are systems that use hardware and software to store, manipulate, and analyze data. People are living systems that use smaller systems to survive and reproduce. Computers have many components that have a similar function to human structures or other living systems. For example, a processor is a computer's control center, much like a brain is a person's control center. Computers can be part of a larger system, or network, just as people are part of larger systems like populations and ecosystems.

Using library and Internet resources, research computer systems. Create and label a diagram of a computer system that describes how the computer is made up of smaller systems, how it links to other larger systems, and how information and energy flows among systems. Make a list of questions you would ask about the relationship between people and computers based on the diagram you develop.

FIGURE 1: Computers, like this laptop, are made up of components.

Music Connection

Your Body on Music Have you ever felt calm, excited, or sad while listening to music? This is because music can affect your mood. Multiple studies have shown that music has other effects on the human body, such as increasing cognitive abilities and lowering blood pressure. Music can even be used as a therapy to decrease the symptoms of heart disease.

Using library or Internet resources, research the effects playing and listening to music can have on the human body. Evaluate the claims and evidence provided, then construct an argument either for or against using music as a medical therapy. Write a blog entry to convince others of your argument. Support your argument with specific text evidence from reliable, scientific sources.

FIGURE 2: Listening to and playing music has been linked to health and medical benefits.

Earth Science Connection

Humans in Space Living in space is tough on the human body. Zero gravity environments negatively affect balance, coordination, muscle strength, and bone density. Isolation in confined spaces can lead to sleep and mood disorders and poor nutrition. The radiation levels in space are more than ten times the levels found on Earth. All of these problems must be solved for humans to safely live away from Earth for long periods of time.

The effects of space on the human body can be reduced through engineering. For example, some astronauts use specialized machines to exercise in space. Collaborate with a group to develop a prioritized list of criteria and constraints that an engineer might consider when designing an apparatus to combat the effects of space on the human body.

FIGURE 3: Exercise in space slows muscle loss and mineral loss in bones.

SYNTHESIZE THE UNIT

In your Evidence Notebook, make a concept map, graphic organizer, or outline using the Study Guides you made for each lesson in this unit. Be sure to use evidence to support your claims.

When synthesizing individual information, remember to follow these general steps:

- Find the central idea of each piece of information.
- Think about the relationships between the central ideas.
- Combine the ideas to come up with a new understanding.

DRIVING QUESTIONS

Look back to the Driving Questions from the opening section of this unit. In your Evidence Notebook, review and revise your previous answers to those questions. Use the evidence you gathered and other observations you made throughout the unit to support your claims.

PRACTICE AND REVIEW

1. How does organization make it possible for the human body to carry out the wide range of interactions necessary for survival?

a. Cells are the foundation of the human body and each cell can carry out all interactions necessary for survival.

b. Tissues are the highest level of organization in the human body and tissues are capable of carrying out specialized tasks necessary for survival.

c. Levels of organization make it possible for cells, tissues, organs, and organ systems to specialize and take on specific functions.

d. There is no overlap in the organization and interaction of organ systems, making it possible for the body to fulfill a wide range of life functions.

2. Select a relationship that is similar to the following relationship: neuron : send electrical signal

a. cardiac cell : muscle cell

b. muscle cell : contraction

c. circulatory system : blood cell

d. homeostasis : endocrine system

3. A newly discovered organism has cells with large fluid-filled sacs in the middle. Considering current scientific knowledge about the structure and function of cell organelles, what is a likely function of these structures in the new organism? Select all correct answers.

a. store water and waste

b. store genetic information

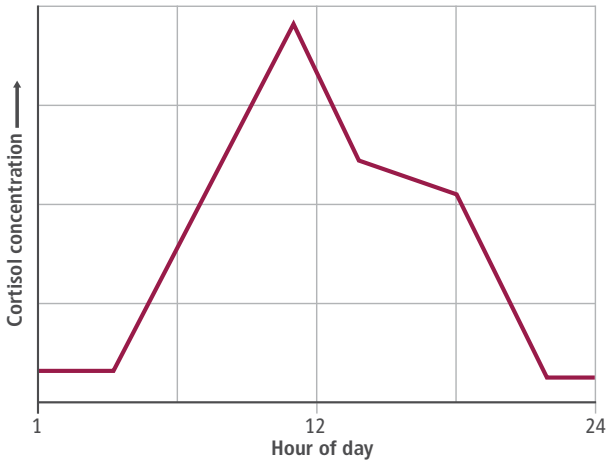
c. produce sugar

d. strengthen the cell

Use the information from Figure 4 to answer Question 4.

Cortisol Concentrations over a 24-Hour Period

FIGURE 4: Cortisol concentrations change throughout the day.



4. Cortisol is produced at certain times of the day, as shown in the graph. Cortisol has a positive feedback on Process A, which outputs Substance Z. At what time of day will the concentration of Substance Z be at its highest if there is no other feedback on Substance Z?

a. morning

b. afternoon

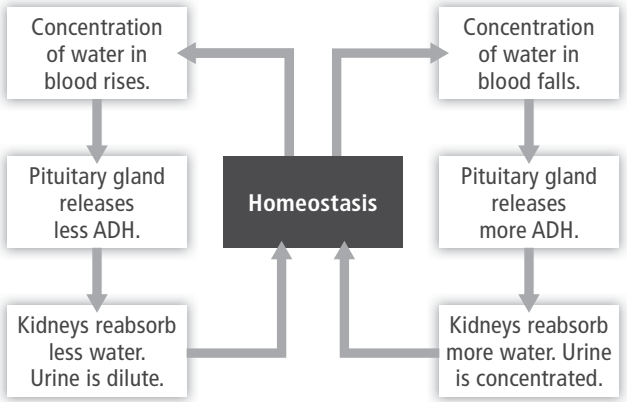
c. evening

d. late night

Use the following information and the diagram to answer Questions 5–8.

The pituitary gland regulates the concentration of water in blood by releasing higher or lower levels of the antidiuretic hormone (ADH). ADH increases the amount of water reabsorbed from urine by tubules in the kidneys.

FIGURE 5: The pituitary gland controls the concentration of water in blood.



5. Which sequence models the correct flow of information in this feedback loop?

a. pituitary gland ⟶ kidney tubules ⟶ pituitary gland

b. kidney tubules ⟶ pituitary gland ⟶ water concentration in blood

c. water concentration in blood ⟶ kidney tubules ⟶ pituitary gland

d. water concentration in blood ⟶ pituitary gland ⟶ kidney tubules

6. How does this feedback loop demonstrate multiple body systems working together to maintain homeostasis?

a. The pituitary gland works with the kidneys to regulate the water concentration in blood.

b. The pituitary gland is part of the endocrine system, which interacts with the excretory and circulatory systems to regulate water concentration in blood.

c. The pituitary gland is part of the nervous system, which interacts with the digestive and immune systems to regulate water concentration in blood.

d. The pituitary gland maintains homeostasis, the kidneys regulate the water concentration in blood, and blood circulates to deliver water to cells.

7. Imagine a disorder that prevented kidney tubules from reabsorbing water from urine. Draw a model that explains how this change would affect this feedback loop.

8. What evidence supports your model and your claim for Question 7? Provide evidence and explain your reasoning.

9. Imagine a solution for a problem scores high for all criteria but violates one of the constraints. What is the relationship between the solution and the problem?

a. The solution will work for the problem because it does not have to satisfy every constraint.

b. The solution may work for the problem if there is a trade-off between criteria and constraints.

c. The solution is not viable for the problem as it is currently defined and delimited.

d. The solution will never be successful and should be abandoned.

10. Imagine your team is developing technology to perform less invasive angioplasty, a surgery typically used to unblock arteries in the heart. You have two solutions. Both solutions are equally effective and safe. Solution 1 costs less than Solution 2. Solution 2 is made from recycled materials and has a lower environmental impact than Solution 1. What is a likely next step to help you choose between the two solutions?

a. Prioritize cost and environmental impact to decide which solution is best for this problem.

b. Redefine the problem and optimize the two solutions to solve the new problem.

c. Design a solution that is cheaper and has a lower environmental impact than both Solution 1 and Solution 2.

d. Add constraints until one solution is no longer viable.

UNIT PROJECT

Return to your unit project. Prepare your research and materials into a presentation to share with the class. In your final presentation, evaluate the strength of your hypothesis, data, analysis, and conclusions.

Remember these tips while evaluating:

- Look at the empirical evidence—evidence based on observations and data. Does the evidence support the explanation?
- Consider if the explanation is logical. Does it contradict any evidence you have seen?
- Think of tests you could do to support and contradict the ideas.

Analyzing a Disease Outbreak

Greenfield, a small town in south Texas, has seen a recent outbreak of sickness involving unexplained high fevers. All symptoms reported are shown in Figure 6. The town lacks the medical expertise and laboratory resources to properly diagnose the medical cause of the high fevers. Town residents need information about what is causing the outbreak, why the symptoms are occurring, and how further cases can be prevented. The only other thing that seems out of place in Greenfield is the large flea population. What information can you provide to the residents of Greenfield?

FIGURE 6: Clinical symptoms presented in the twenty-five undiagnosed high-fever cases, Greenfield, TX, 2016

Symptoms	Number of Affected Individuals
Fever (body temperature > 38.5 °C)	25
Discomfort	19
Headache	17
Muscle ache	16
Chills	16
Rash	11
Light sensitivity	7
Confusion	3

1. DEFINE THE PROBLEM

With your team, write a statement outlining the problem you've been asked to solve. Record any questions you have on the problem and the information you need to solve it.

2. CONDUCT RESEARCH

With your team, investigate all of the information you've been given about the outbreak in Greenfield. What is the most likely disease causing the outbreak?

3. DEVELOP A MODEL

On your own, analyze the problem you've defined along with your research. Make a model that demonstrates how the disease is transmitted and how the body systems are working together to combat the infection. Your model should also show why the symptoms are occurring and how homeostasis is involved in the immune response.

4. IDENTIFY A SOLUTION

Provide a range of solutions for how the town can avoid further outbreaks of this disease.

5. COMMUNICATE

Present your findings to the town residents, explaining the most likely cause of the disease, why the symptoms are occurring in relation to the immune response and homeostasis, and your proposed solutions for preventing further outbreaks. Your presentation should include images and data to support your claims.

CHECK YOUR WORK

A complete presentation should include the following information:

- a clearly defined problem with supporting questions that are answered in the final presentation
- a model of disease transmission and immune response in humans
- a recommendation that explains how to solve the problem and uses evidence to support the solution
- images and data that further support your solution