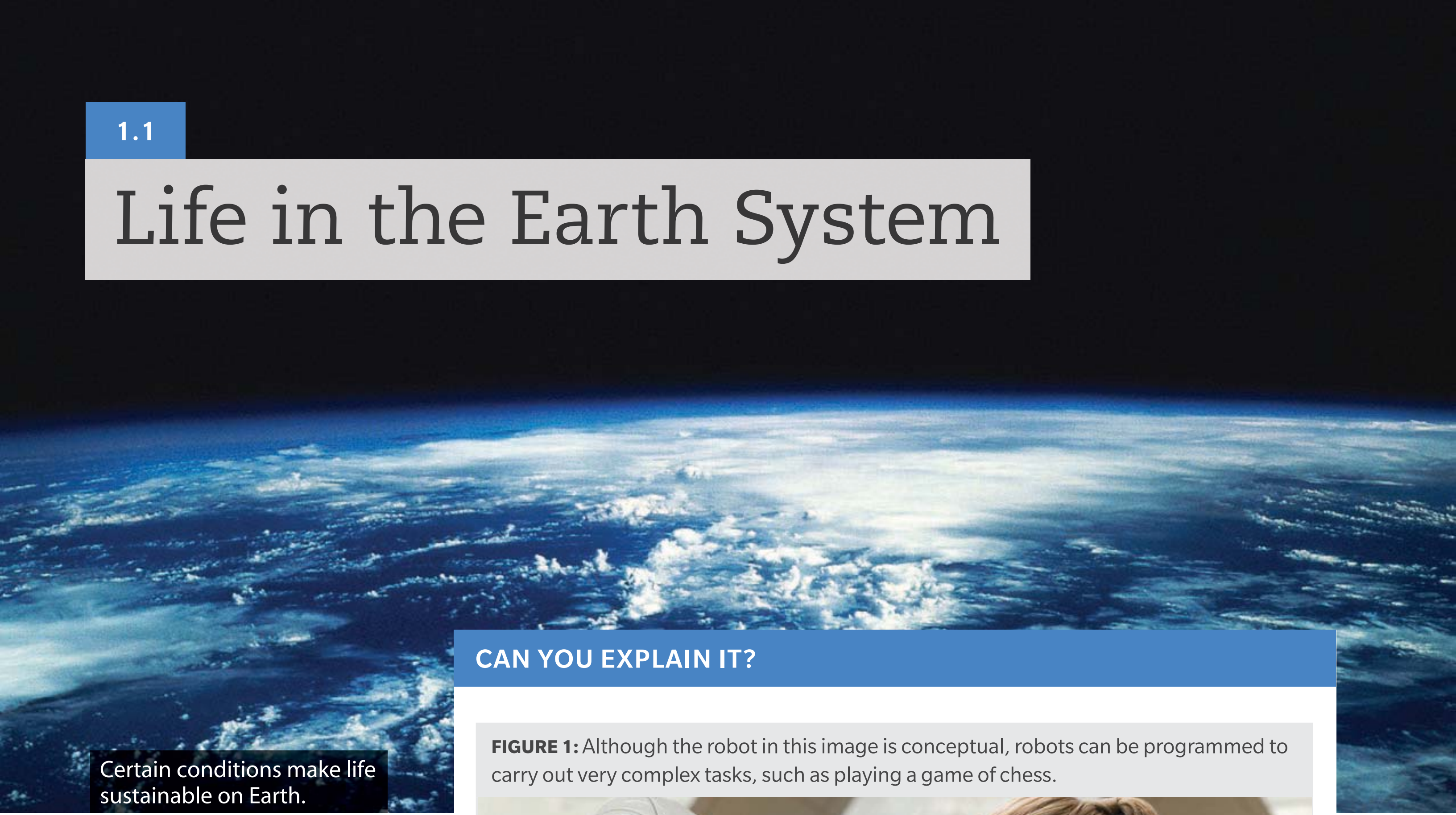

1.1

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?

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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.

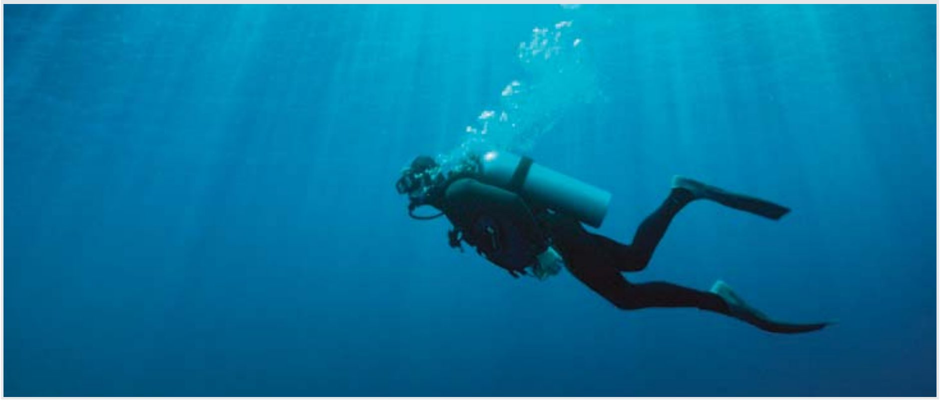
More complex systems generally have more levels of organization than simpler systems. For example, organisms, or living things, are systems made up of smaller systems, such as organs, tissues, and cells. Two organisms that interact also can make up a system, such as a bird that pollinates a plant. On 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.

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

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?

Image Credits: (tl) ©Don Mammoser/Shutterstock; (tr) ©Ben Blankenburg/Fotolia; (b) ©Photographer's Choice RF/Georgette Douwma/Getty Images

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

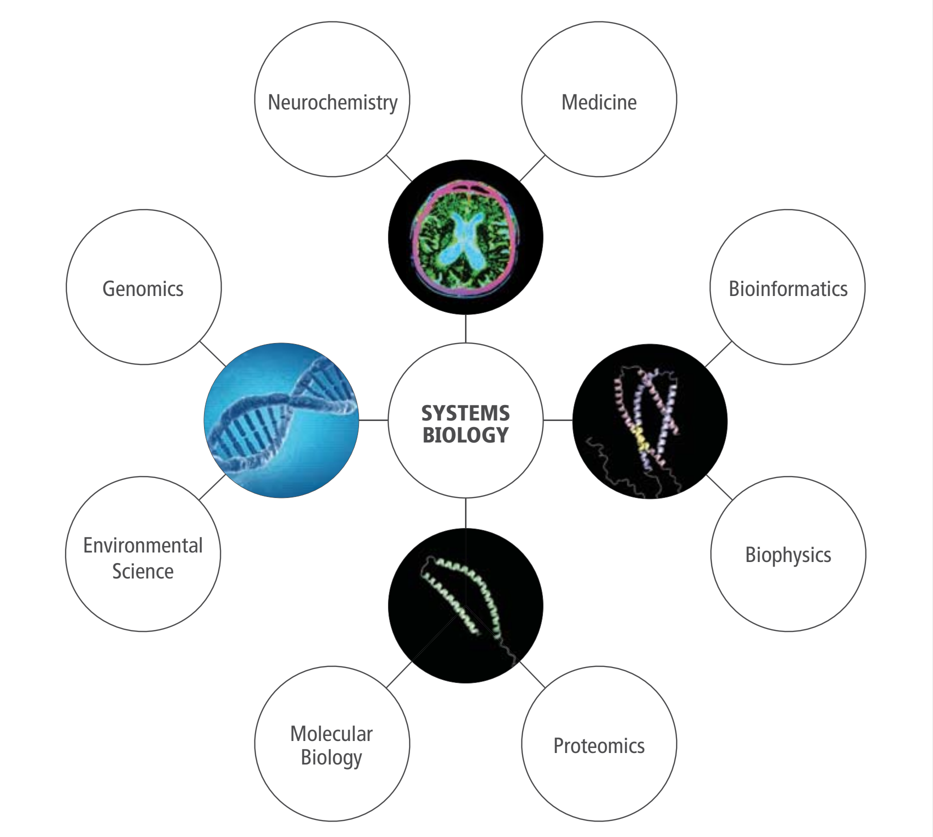
We can apply systems thinking to biology. Systems biology studies biological systems as a whole. This approach allows scientists to consider biological phenomena at different scales and examine how the components of a biological system interact. By considering the larger picture, biologists are better 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.

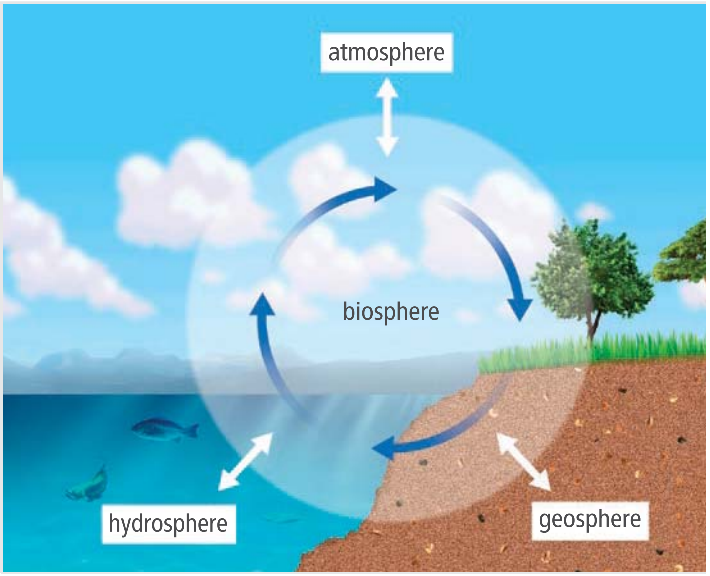
As Figure 8 shows, matter stays within the Earth system, but energy enters the system in the form of sunlight and exits in the form of heat. Within the system itself, light energy is converted into other forms of energy that drive transformations of matter from one form to another as it cycles through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

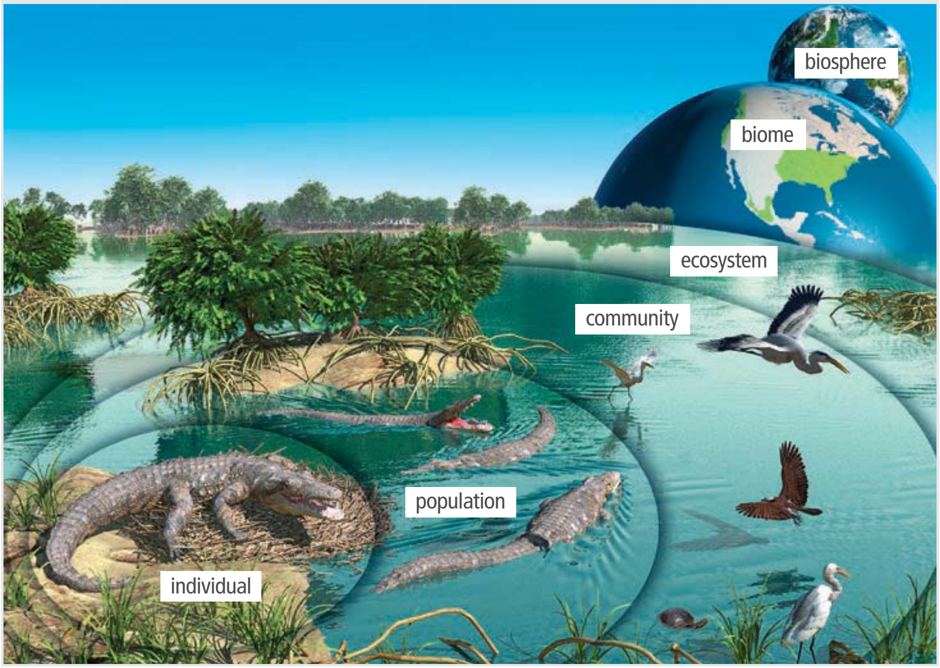


Explain This model shows the biosphere in the middle of the diagram with arrows connecting it to the other spheres. Why is the biosphere depicted this way?

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.



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.

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 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.

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

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

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.

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.

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.

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.

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

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

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?

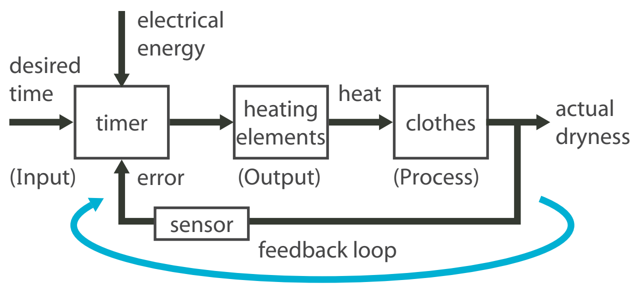
For each of the above questions, include specific examples and evidence to support your claims.

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.