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.

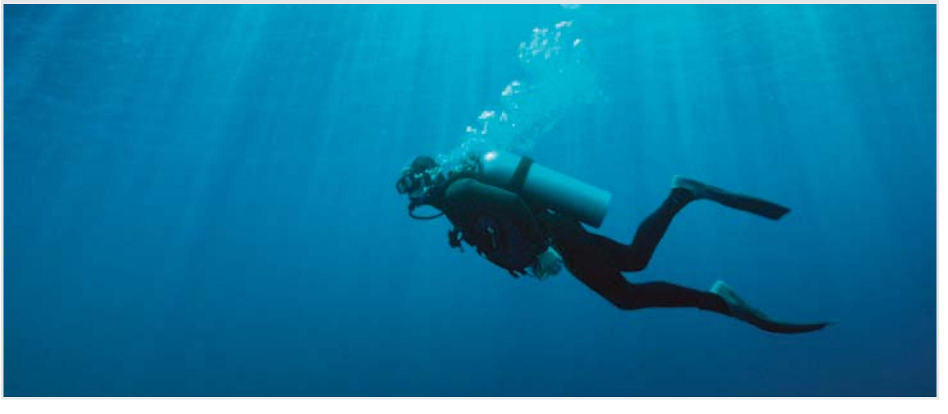
More complex systems generally have more levels of organization than simpler systems. For example, organisms, or living things, are systems made up of smaller systems, such as organs, tissues, and cells. Two organisms that interact also can make up a system, such as a bird that pollinates a plant. On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

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.

System Models

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

Protein Synthesis

DNA ⟶ RNA ⟶ Proteins

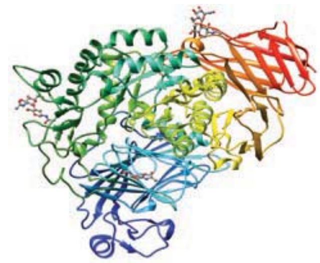
$y = a(1 + r)^x$

y = final population

a = initial population

r = growth rate

x = number of time intervals passed



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.

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

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.

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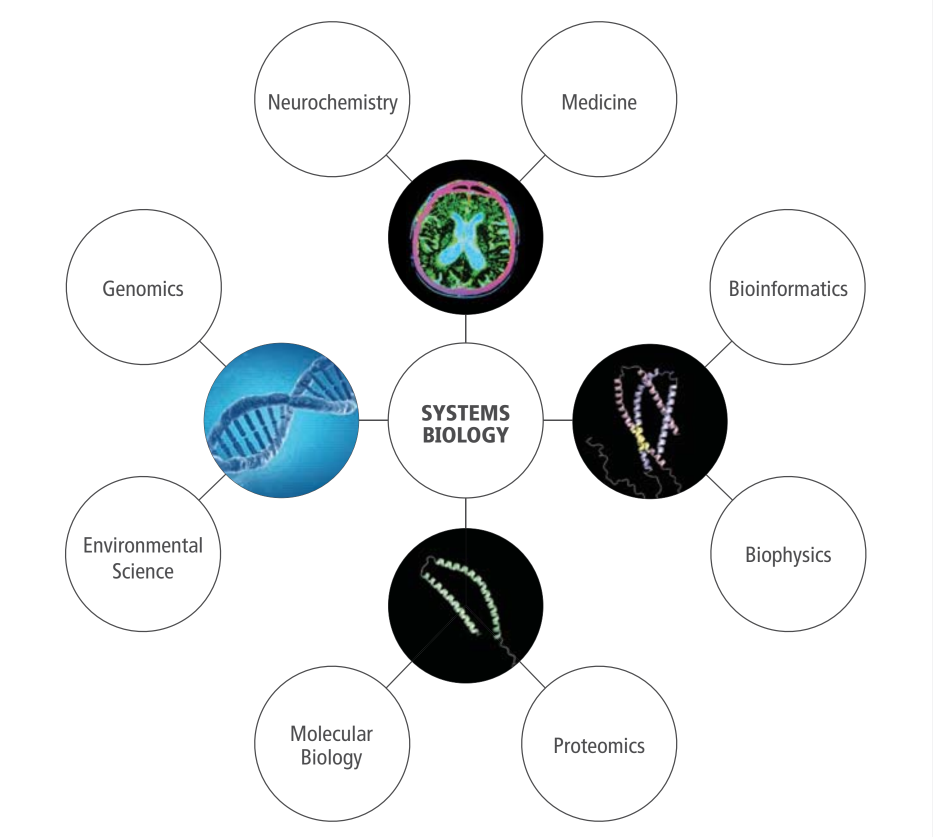
Similarly, DNA is a molecule that carries the genetic code of all organisms. The code consists of just four bases represented with the letters A, T, G, and C. The sequence of these bases in DNA provides coded instructions for making thousands of different proteins. Each protein is made of a specific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