Unit 1 Living Systems

The learning experiences in this unit prepare students for the mastery of

Performance Expectations

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

LS1-3 Plan and conduct an investigation to provide evidence that feedback mechanisms maintain homeostasis.

ETS1-2 Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

ETS1-3 Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.

Explore Online

In addition to the print resources, the following resources are available online to support this unit.

Lesson 1 Life in the Earth System
- Online Student Edition
- Lesson Quiz

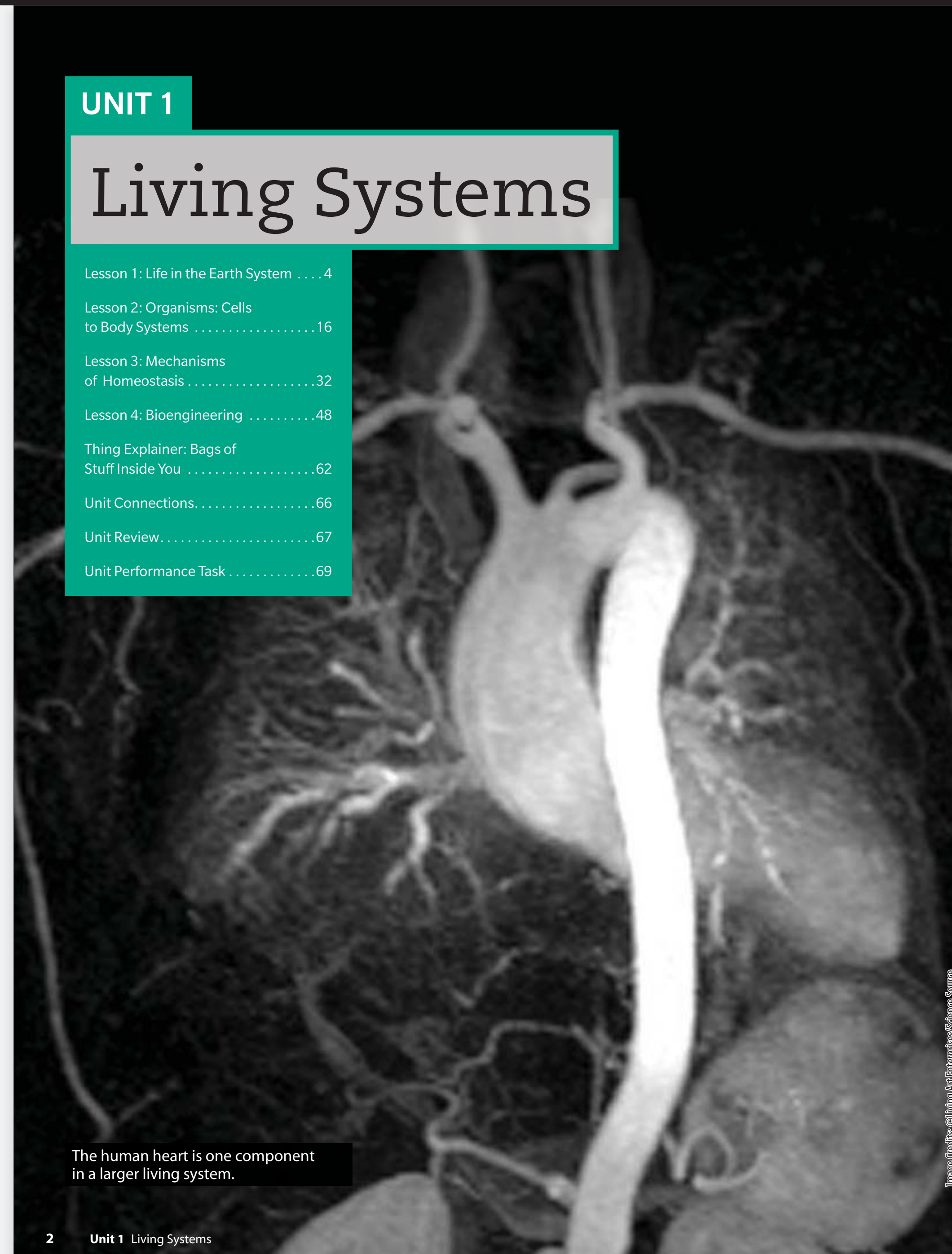
Lesson 2 Organisms: Cells to Body Systems
- Online Student Edition
- Lesson Quiz

Lesson 3 Mechanisms of Homeostasis
- Online Student Edition
- Lesson Quiz

Lesson 4 Bioengineering
- Online Student Edition
- Lesson Quiz

Unit Performance Task

Unit Test


UNIT 1

Living Systems

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

Image Credits: ©Living Art Enterprises/Science Source

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.

1 **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.

Unit Prerequisite Knowledge

Students should understand these concepts before starting the unit:

- Multicellular organisms are made up of many kinds of cells that together function as an organism.
- Living organisms respond to their environment.
- Systems are often composed of subsystems.

EVIDENCE NOTEBOOK

1 Prompt students to think about what functions bats need to perform and how their bodies are organized to perform these functions. For example, bats would need sturdy but light skeletal systems in order to fly. Bats also must be able to navigate at night.

Collaboration

Driving Questions You may wish to have the whole class discuss their initial thoughts about the Driving Questions for this unit. Tell students that at this point in the course, they should have many questions about what they will be learning in this unit. Encourage students to record questions and their initial responses in their Evidence Notebooks, where they can revise and add to their answers as they move through the unit.

UNIT PROJECT

Investigating Plant Systems See pages 3K–3L for more support in planning and supporting your students through their projects.

Integrating the NGSS* Three Dimensions of Learning

Building to the Performance Expectations

The learning experiences in this unit prepare students for mastery of

From Molecules to Organisms: Structures and Processes

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

LS1-3 Plan and conduct an investigation to provide evidence that feedback mechanisms maintain homeostasis.

Engineering Design

ETS1-2 Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

ETS1-3 Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.

Assessing Student Progress

The **Unit Project: Investigating Plant Systems,** in which students track the growth and development of seedlings, allows students to make connections to show how systems in the plant interact and provides students with opportunities to practice aspects of the Performance Expectations. In addition, students can further practice or be assessed on aspects of the Performance Expectations in the **Unit Performance Task: Analyzing a Disease Outbreak.**

Lesson 1
Life in the Earth System

In Lesson 1, students explore properties of systems and system models and determine whether something is an open or closed system **(SEP Developing and Using Models, CCC Systems and System Models).** Students develop and use a model based on evidence to illustrate the organization of the Earth system **(SEP Developing and Using Models, CCC Systems and System Models).** They learn about the characteristics of living things and develop a claim for whether something is a living system **(DCI LS1.A, SEP Constructing Explanations and Designing Solutions).**

Lesson 2
Organisms: Cells to Body Systems

In Lesson 2, students develop and use models **(SEP Developing and Using Models)** to illustrate how multicellular organisms have a hierarchical structural organization **(DCI.HS-LS1.A)** and use system models **(CCC Systems and System Models)** to illustrate the relationships between components of a system, such as cells, tissues, organs, and organ systems.

Lesson 3
Mechanisms and Homeostasis

In Lesson 3, students learn about various positive and negative feedback mechanisms that maintain homeostasis in living organisms **(DCI LS1.A).** They model disruptions to homeostasis **(CCC Stability and Change)** to understand how the human body responds. Students design and conduct an investigation measuring the effects of exercise on the body **(SEP Planning and Carrying Out Investigations).**

Lesson 4
Bioengineering

In Lesson 4, students analyze technologies that have influenced human health to define benefits and risks, predict ways in which technology influences society and society influences technology, and define a bioengineering problem and outline criteria and constraints for the solution **(DCI ETS1.B).** They explain how the engineering design process could be used to evaluate a solution to a human health problem **(SEP Scientific Investigations Use a Variety of Methods, CCC Influence of Science, Engineering, and Technology on Society and the Natural World).** They design their own biotechnology solution to a problem **(SEP Constructing Explanations and Designing Solutions)** and create a model to test their solution **(SEP Developing and Using Models, CCC Systems and System Models).**

You Solve It Go online to access an interactive simulation.

*Next Generation Science Standards and logo are registered trademarks of Achieve. Neither Achieve nor the lead states and partners that developed the Next Generation Science Standards was involved in the production of, and does not endorse, these products.

NGSS Across This Unit

Explore Online

Next Generation Science Standards	Unit Project	Lesson 1	Lesson 2	Lesson 3	Lesson 4	Unit Performance Task	You Solve It
SEP Developing and Using Models	•	•	•		•	•	
SEP Constructing Explanations and Designing Solutions		•			•	•	
SEP Planning and Carrying Out Investigations				•			
SEP Scientific Investigations Use a Variety of Methods				•	•		
DCI **LS1.A** Structure and Function		•	•	•	•	•	
DCI **ETS1.B** Developing Possible Solutions		•			•		
DCI **ETS1.C** Optimizing the Design Solution		•			•		
CCC Systems and System Models	•	•	•		•	•	
CCC Stability and Change				•			
CCC Influence of Science, Engineering, and Technology on Society and the Natural World					•		

NGSS Across the Grades

Middle School

MS-LS1-1 Conduct an investigation to provide evidence that living things are made of cells; either one cell or many different numbers and types of cells.

MS-LS1-2 Develop and use a model to describe the function of a cell as a whole and ways parts of cells contribute to the function.

MS-LS1-3 Use argument supported by evidence for how the body is a system of interacting subsystems composed of groups of cells.

MS-ETS1-2 Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.

MS-ETS1-3 Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.

High School

HS-LS1-2
HS-LS1-3
HS-ETS1-2
HS-ETS1-3

Trace Tool to the NGSS Go online to view the complete coverage of standards across lessons, units, and grade spans.

3D Unit Planning

Lesson 1 Life in the Earth System pp. 4–15

Overview

Objective Use models to illustrate the relationships between components of living and nonliving systems.

SEP Developing and Using Models
SEP Constructing Explanations and Designing Solutions
DCI **LS1.A** Structure and Function
DCI **ETS1.C** Optimizing the Design Solution
DCI **ETS1.B** Developing Possible Solutions
CCC Systems and System Models
CCC Influence of Science, Engineering, and Technology on Society and the Natural World

Math and **English Language Arts** standards and features are detailed on lesson planner pages.

	Print and Online Student Editions	Explore Online
ENGAGE	**Lesson Phenomenon** p. 4 **Can You Explain It?** Imagine a company that sells human-like robots making 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?	**ELA Handbook**
EXPLORE/ EXPLAIN	**Systems and System Models** pp. 5–9 **The Earth System** pp. 10–12 The Study of Life	**Video** Protein folding and Parkinson's Disease **Video** Venus Flytrap
ELABORATE	**Continue Your Exploration** p. 13 **Engineering:** Modeling a System	**Continue Your Exploration** Viruses: Are They Alive? Life Under a Microscope **Hands-On Lab Worksheet** **Hands-On Lab Teacher Support** **Lab Safety Handbook**
EVALUATE	**Lesson Self-Check** pp. 14–15	**Lesson Quiz** Make Your Own Study Guide

Hands-On Lab Planning

Additional Downloadable Lab Options

Life Under a Microscope

30 minutes Small Groups	**Objective** Students observe pond water under a microscope and determine whether items are living or nonliving based on their observable characteristics.

The Study of Life

90 minutes Small Groups	**Objective** Students plan and conduct an investigation to determine how different factors affect the number of living things found in a soil sample.

Lesson 2 Organisms: Cells to Body Systems pp. 16–31

Overview

Objective Use models to explain how systems within an organism interact at different levels to carry out functions necessary for life.

SEP Developing and Using Models
DCI **LS1.A** Structure and Function
CCC Systems and System Models
CCC Influence of Science, Engineering, and Technology on Society and the Natural World

Math and **English Language Arts** standards and features are detailed on lesson planner pages.

	Print and Online Student Editions	Explore Online
ENGAGE	**Lesson Phenomenon** pp. 16 **Can You Explain It?** How do systems within your body interact to produce sensations like "butterflies" in your stomach?	**ELA Handbook**
EXPLORE/ EXPLAIN	**Interacting Systems in Organisms** pp. 17–23 Connecting Form to Function **The Cell System** pp. 24–28 Comparing Cells	**Animation** Muscle Contraction **Hands-On Lab Worksheet** **Hands-On Lab Teacher Support** **Lab Safety Handbook**
ELABORATE	**Continue Your Exploration** p. 29 **Engineering:** Modeling Interacting Body Systems	**Continue Your Exploration** Plant Tissues and Cells Comparing Prokaryotes and Eukaryotes
EVALUATE	**Lesson Self-Check** pp. 30–31	**Lesson Quiz** Make Your Own Study Guide

Hands-On Lab Planning

Additional Downloadable Lab Options

Connecting Form to Function

45 minutes
Small Groups

Objective Students examine a slice of the roots, stems, and leaves of a plant and explain how their structures relate to their functions.

Comparing Cells

45 minutes
Small Groups

Objective Students use a microscope to investigate the similarities and differences between plant and animal cells.

3D Unit Planning

Lesson 3 Mechanisms of Homeostasis pp. 32–47

Overview

Objective Explain how positive and negative feedback loops help an organism to maintain homeostasis.

SEP Planning and Carrying Out Investigations
DCI **LS1.A** Structure and Function
CCC Stability and Change

Math and **English Language Arts** standards and features are detailed on lesson planner pages.

	Print and Online Student Editions	Explore Online
ENGAGE	**Lesson Phenomenon** p. 32 **Can You Explain It?** 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?	**ELA Handbook**
EXPLORE/ EXPLAIN	**Control Systems in Organisms** pp. 33–36 Modeling Feedback **Homeostasis in the Human Body** pp. 37–41 Negative and Positive Feedback **Homeostasis in Other Organisms** pp. 42–44	**Hands-On Lab Worksheet** **Hands-On Lab Teacher Support** **Lab Safety Handbook**
ELABORATE	**Continue Your Exploration** p. 45 Investigating Homeostasis and Exercise	**Hands-On Lab Worksheet** **Hands-On Lab Teacher Support** **Lab Safety Handbook** **Continue Your Exploration** Disorders of the Endocrine System Explaining Homeostasis
EVALUATE	**Lesson Self-Check** pp. 46–47	**Lesson Quiz**

Hands-On Lab Planning

Modeling Feedback

20 minutes
Small Groups

Objective Students explain feedback mechanisms involved in balancing a book on their head while they walk.

Materials
- hardcover book, at least 6″ x 8″

Investigating Homeostasis and Exercise

45 minutes
Small Groups

Objective Students investigate how the circulatory system, respiratory system, and perspiration levels are affected by exercise.

Materials
- stopwatch

Advance Preparation Students participating should wear appropriate clothing for exercising.

Additional Downloadable Lab Options

Negative and Positive Feedback

45 minutes
Small Groups

Objective Students analyze data and generate graphs to determine whether a process is an example of a negative or positive feedback loop.

Lesson 4 Bioengineering pp. 48–61

Overview

Objective Explain how bioengineers design and evaluate solutions to human health problems.

SEP Developing and Using Models
SEP Constructing Explanations and Designing Solutions
DCI **LS1.A** Structure and Function
DCI **LS1.A** Developing Possible Solutions
DCI **ETS1.C** Optimizing the Design Solution
CCC Systems and System Models
CCC Influence of Science, Engineering, and Technology on Society and the Natural World

	Print and Online Student Editions	Explore Online
ENGAGE	**Lesson Phenomenon** p. 48 **Can You Explain It?** The batteries in pacemakers don't 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?	**ELA Handbook**
EXPLORE/ EXPLAIN	**Technology and Living Systems** pp. 49–51 Clean Drinking Water **Engineering in Life Science** pp. 52–57 Modeling Joint Movement Vision Correction Technology Optimizing Prosthetics	**Hands-On Lab Worksheet** **Hands-On Lab Teacher Support** **Lab Safety Handbook**
ELABORATE	**Continue Your Exploration** pp. 58–59 **Careers in Science:** Careers in Bioengineering	**Continue Your Exploration** 3-D Bioprinting Nanotechnology
EVALUATE	**Lesson Self-Check** pp. 60–61	**Lesson Quiz**

Hands-On Lab Planning

Additional Downloadable Lab Options

Modeling Joint Movement

Three 45-minute class periods
Small Groups

Objective Students use the engineering design process to develop models of the joints in the skeletal system and test their ranges of motion.

3D Unit Planning, continued

Assessment Planning

Pre-Assessment

Assessment Guide, Unit Pretest
The Unit Pretest focuses on prerequisite knowledge and is composed of items that evaluate student's preparedness for the content covered within this unit.

Formative Assessment

Student Edition: Explorations, Lesson Self-Check

Summative Assessment

Assessment Guide, Lesson Quiz
The Lesson Quiz provides a quick assessment of each lesson objective and of the portion of the Performance Expectation aligned to the lesson.

Student Edition: Unit 1 Review, pp. 67–68

Student Edition: Unit Performance Task, pp. 69
The Performance Task provides students with an opportunity to collaborate with classmates in order to practice or be assessed on aspects of the Performance Expectations aligned to the unit.

Assessment Guide, Unit Test and Modified Unit Test
The Unit Test provides an in-depth assessment of the Performance Expectations aligned to the unit.
The Modified Unit Test can be used to assess students who need extra support.

HMH Field Trips
powered by
Google Expeditions

Go to **hmhco.com/fieldtrips** for 3D, 360-degree experiences to share with your students. A Teacher Guide is also available to help you customize the experience.

Teacher Notes

Teacher Notes

UNIT 1 Living Systems

Differentiate Instruction

Differentiate with Technology

Robots

Some interactive, browser-based online games give students the opportunity to design their own robots. National Geographic's Challenge Robots has a series of fast-paced activities to teach students about the engineering process used to design robots for specific tasks.

3-D Visualizations

3-D visualizations of the human body are a good way to learn about body systems. 3-D visualization software such as BioDigital Human—Anatomy and Health Conditions in 3D!—are available for free on smart phones and tablets. These programs allow students to explore body systems and see how they work.

Designing Systems

Students can build a device that functions like a body system. For example, encourage students to build a pump that could be used to replace a heart or a filter system that could be used to replace a kidney.

Vocabulary Support

Unit Vocabulary

system *Lesson 1*
feedback *Lesson 1*
model *Lesson 1*
emergent property *Lesson 1*
ecosystem *Lesson 1*
organism *Lesson 1*
biotic factor *Lesson 1*
abiotic factor *Lesson 1*
homeostasis *Lesson 1*
organ system *Lesson 2*
organ *Lesson 2*
tissue *Lesson 2*
cell *Lesson 2*
cell differentiation *Lesson 2*
cell membrane *Lesson 2*
nucleus *Lesson 2*
mitochondrion *Lesson 2*
chloroplast *Lesson 2*
homeostasis *Lesson 3*
stimulus *Lesson 3*
hormone *Lesson 3*
feedback loop *Lesson 3*
negative feedback loop *Lesson 3*
positive feedback loop *Lesson 3*
technology *Lesson 4*
bioengineering *Lesson 4*
biotechnology *Lesson 4*
engineering design process *Lesson 4*

Reinforcing Vocabulary

To help students build vocabulary knowledge for this unit, have them make vocabulary flashcards. Begin by writing each vocabulary term on one side of an index card. Then, as they encounter a vocabulary term, they write a definition in their own words.

Academic Vocabulary

The word *systems* is used throughout this unit. The scientific concept of a system is important to understanding its use as a technical term. Have students work in small groups and come up with their own definitions of a system as it applies to science. Encourage students to use different sources to find information for their definitions. Have each group make a poster that describes their view of the scientific definition of a system.

Biology Vocabulary

Point out to students that biologists use terms that have a very specific scientific meaning. This is done deliberately to make sure that every scientist is talking about the same thing. Ask students to come up with alternate definitions for the word *system* that do not have a scientific meaning.

ELL

ELL teaching strategies in this unit:

Lesson 1 pp. 4B, 8
Lesson 2 p. 16B
Lesson 3 p. 32B
Lesson 4 p. 48B

RTI/Extra Support

Strategies for students needing extra support in this unit:

Lesson 1 pp. 7, 8, 12
Lesson 2 pp. 18, 19
Lesson 3 pp. 39, 47
Lesson 4 pp. 52, 54, 59, 61

Extension

Strategies for students who have mastered core content in this unit:

Lesson 1 p. 13
Lesson 2 pp. 19, 25
Lesson 3 pp. 35, 37
Lesson 4 pp. 52, 59, 61

UNIT 1 Living Systems

Making Connections

Connections to Community

Use these opportunities for informal science learning to provide local context and to extend and enhance unit concepts.

At Home

HEATING OR COOLING SYSTEM Almost every home has some type of heating or cooling system. Encourage students to make a diagram of their home's heating or cooling system. Their diagram should show the energy input and the output of the system. Encourage students to think about how the system creates a homeostasis of conditions inside the house compared to the outside. *Use with Lesson 3.*

In the Community

LINGUISTIC DIVERSITY Language is a systematic form of communication with rules for combining sounds, words, and sentences. The relationship between language and culture is a profound one; as language is passed along from one generation to the next, it carries with it ideas, beliefs, and customs. Linguistic diversity is a measure of unique languages in a place, such as a country. Challenge students to choose a system (your school, your city, your state) and investigate the linguistic diversity represented within that system. Invite students to share their own language history, including languages they speak besides English. *Use with Lesson 1.*

LIKE A CELL Ask students to look at the city they live in or a city near to them. Compare the functioning of the city with that of a cell. Compare different cities within their state and ask them to find ways cities in a state work together. Finally, compare how states work together as part of the country. Ask students to compare this to the levels of organization in the body. Encourage students to make a poster that illustrates their findings. *Use with Lesson 2.*

GLASSES Ask students to interview friends, family members, or neighbors who wear glasses about the vision problem the glasses correct. Based on their interviews, have students make a chart that shows the numbers of people with different types of vision correct ions. *Use with Lesson 4.*

Home Letters Use these letters to engage family members with unit concepts.

Collaboration

Opportunities for students to work collaboratively in this unit:

Group Discussion pp. 4, 5, 14, 17, 21, 24, 33, 35, 42, 46, 49, 51, 56, 60

Partners p. 38

Think-Pair-Share pp. 26, 36, 44

Research pp. 30, 43

Activity pp. 23, 28

Connections to Other Disciplines

Opportunities to connect to other content areas in this unit:

Evolutionary Biology Connection p. 40

Physical Science Connection pp. 32, 39

Engineering Connection p. 25

Chemistry Connection p. 37

Environmental Science Connection p. 38

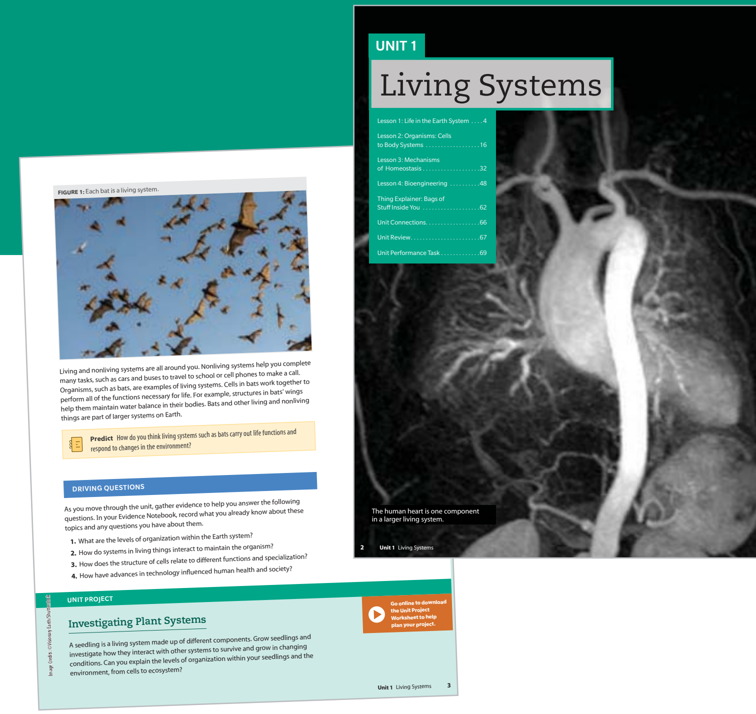
Physics Connection pp. 48, 54

Technology Connection p. 66

Music Connection p. 66

Earth Science Connection p. 66

Unit Project



UNIT 1

Living Systems

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

2 Unit 1 Living Systems

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.

Image Credits: ©Visionary Earth/Shutterstock

Unit 1 Living Systems 3

Overview and Planning

Investigating Plant Systems

3D Learning Objective

Students plan and carry out an investigation in which they grow seedlings under different conditions and use evidence from their study to construct an explanation of how different systems interact inside the seedling.

Students write their own procedures and select the conditions that will serve as variables in the study. In each lesson, students are asked a series of questions or asked to draw models that deal with the lesson topic. As students compile their results, they will consider how the environment affects the seedlings; the role homeostasis plays in growth, development, and maintenance; and how engineering can provide solutions to problems that make it difficult for plants to grow.

NGSS Focus	Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
This project supports building student mastery of **Performance Expectations HS-LS1-2, HS-LS1-3, and ETS1-2.** Students will plan and conduct an investigation to provide evidence that feedback mechanisms maintain homeostasis. The students will use models to describe solutions to problems that make plant growth difficult.	• Developing and Using Models • Constructing Explanations and Designing Solutions • Planning and Carrying Out Investigations • Scientific Investigations Use a Variety of Methods	• **LS1.A** Structure and Function • **ETS1.B** Developing Possible Solutions • **ETS1.C** Optimizing the Design Solution	• Systems and System Models • Stability and Change • Influences of Science, Engineering, and Technology on Society and the Natural World

Classroom Management	Suggested Materials	Safety
Individual or small groups 4–5 class periods	• See the procedure for a detailed materials list for the lab. • Seeds from any plant in the cabbage family (bok choi, broccoli, kale, cauliflower, and lettuce) sprout quickly, usually within one to three days.	• Students should wash their hands after handling any seeds, soil, or fertilizer.

Getting Started

Introducing the Project

Prepare students for their investigation by asking the following questions:

- **What conditions do plants need in order to grow?**
- **How does changing conditions, such as too much or too little sunlight, affect plants?**
- **What role do nutrients and minerals play in growing healthy plants?**
- **How does homeostasis play a role in keeping plants healthy?**

Student Deliverables

A **student worksheet** is available to help students in planning and completing the project. Students can turn in their worksheets, or they can be assessed on a final lab report, their models, and/or final presentations explaining their project.

In addition to the worksheet, students should document the changes in their seedlings by either taking a daily picture of the plants or drawing a picture every day to note the changes. Students will then review these images at the end of the project and explain the changes they observed.

Scoring Rubric for Unit Project	
	The worksheet, lab write-up, and/or presentation states a claim supported with detailed evidence to show how plants grow under different conditions.
	Each model created accurately shows how different conditions affect plant growth.
	The worksheet, lab write-up, and/or presentation presents work in a well-organized format that is logical, easy to understand, and informative.
	The worksheet, lab write-up, and/or presentation uses photos or art pieces as evidence to show how different conditions affect plant growth over the course of the project.

Differentiate Instruction

Extra Support Have groups exchange plan designs for their respective investigations. Each group should review and comment on the other group's plan and offer suggestions for improving the investigation. The two groups could work collaboratively to design more effective investigations.

Suggested Resources

- **U.S. Department of Agriculture:** contains detailed information about conditions and requirements that different plants need for optimal growth
- **Environmental Protection Agency:** contains detailed information about soil and climate conditions that affect plant growth
- Local department of natural resources, department of agriculture, state institutions, and university resources

Guiding Students on Project Planning

Once students understand the project goals and their deliverables, the next step is for students to plan and carry out their investigation. To help student think about planning and carrying out their investigations, consider asking:

- **Which conditions do you plan to investigate to study the effects on plant growth?**
  Conditions for plant growth include sunlight, water, temperature, and soil nutrients and minerals. When choosing conditions, students should consider how these will be manipulated for the experimental group.
- **How will you collect data?**
  Students should consider how they will measure or quantify the effects of the specific factors they have selected in terms of effect on plant growth. For example, how will they measure temperature, and how often will they measure it?
- **How will you record your data?**
  Explain that data should be recorded in a data table. The data collections should be consistent among the control and experimental groups. Having a good control is essential when looking at how changing conditions affect a plant.

Be sure to review and approve project plans before students begin.
The Unit Project Worksheet can be used for formal approval.

Go Online

Go online to download the Teacher's Edition of the student worksheet for this unit project to access additional questions, sample answers, and additional scaffolding to help students plan and carry out their investigations.

LESSON 1

Life in the Earth System

Building to Performance Expectation

The learning experiences in this lesson prepare students for mastery of:

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

HS-ETS1-2 Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

HS-ETS1-3 Evaluate a solution to a complex real-world problem based on prioritized criteria and tradeoffs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.

Trace Tool to the NGSS

Go online to view the complete coverage of standards across lessons, units, and grade levels.

SEP Science & Engineering Practices

Developing and Using Models
Develop and use a model based on evidence to illustrate the relationships between systems or between components of a system.

Constructing Explanations and Designing Solutions
Design and evaluate a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.

DCI Disciplinary Core Ideas

LS1.A Structure and Function
Multicellular organisms have a hierarchical structural organization, in which any one system is made up of numerous parts and is itself a component of the next level. (HS-LS1-2)

ETS1.C Optimizing the Design Solution
Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (tradeoffs) may be needed. (HS-ETS 1-2)

ETS1.B Developing Possible Solutions
When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. (HS-ETS 1-3)

CCC Crosscutting Concepts

Systems and System Models
Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows—within and between systems at different scales.

CONNECTIONS TO MATH

MP.4 Model with mathematics.

CONNECTIONS TO ENGLISH LANGUAGE ARTS

SL.11-12.5 Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest.

RST.11-12.8 Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information.

RST.11-12.9 Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.

Supporting All Students, All Standards

Integrating the Three Dimensions of Learning

In this lesson, students will explore properties of systems and system models and determine whether something is an open or closed system **(SEP Developing and Using Models, CCC Systems and System Models).** Students develop and use a model based on evidence to illustrate the organization of the Earth system **(DCI LS1.A, SEP Developing and Using Models, CCC Systems and System Models).** They describe biological systems based on the structure and function **(DCI LS1.A).** Students identify a problem with a system and design a solution to it **(SEP Constructing Explanations and Designing Solutions)**. They then consider tradeoffs to optimize their solution **(DCI ETS1.C).**

Preassessment

Have students complete the unit pretest online or see the Assessment Guide.

Building on Prior Knowledge

Introduce the term *system* to students. Have each student generate a list of what they think of when they hear that term. Then have students form small groups to share their ideas and produce a combined list. Finally, have groups share their combined lists to create a class list.

You may want to review the following concepts:

- All living things are organisms composed of one or more cells.
- Earth is composed of both living and nonliving systems that constantly interact and influence each other.
- You can choose any boundary you wish to define a system, but the boundary you choose determines which parts are in the system and which are its surroundings.

Professional Development Go online to view **Professional Development videos** with strategies to integrate CCCs and SEPs, including the ones used in this lesson.

Content Background

A system is composed of parts that work together to perform a function. Each part can influence the behavior or properties of other parts. For example, parts can interact by exerting forces on each other or by causing physical or chemical changes. Parts can also interact through feedback loops in which the influence of one part on another feeds back to the original to maintain a balance. A boundary separates a system from the rest of the universe. Some boundaries are obvious, such as the ocean's surface, but different boundaries can be defined to describe or emphasize different interactions.

Earth is an example of a complex system. Smaller systems that make up Earth include the hydrosphere (water), the biosphere (living things), the atmosphere (air), and the geosphere (land). The stability of the Earth system depends on the constant interactions among these four parts. The hydrosphere, for example, is the source of water in the atmosphere that falls as rain needed by plants in the geosphere for survival.

Different models can be useful for describing a system. Models help identify a system's inputs and outputs, such as energy, matter, and data. Models are limited because identifying all of a system's parts and interactions is difficult. Models can, however, evolve over time to become more accurate as understanding of the system increases.

Differentiate Instruction

Lesson Vocabulary

- system
- feedback
- model
- emergent property
- ecosystem
- organism
- biotic factor
- abiotic factor
- homeostasis

Reinforcing Vocabulary As students encounter each vocabulary term in the lesson, engage them in discussing how it relates to previous terms they have learned in the lesson.

ELL Support

Graphic Organizers As students work through the lesson, have them pause after each section and work in pairs to draw a graphic organizer that relates concepts in the section. Use the opportunity to reinforce vocabulary by asking questions that students can answer with new or difficult words from the section. You might ask, *What forms when output becomes input in the same system?* (feedback loop) Students could make a T-chart listing types of models in one column and examples in the other.

ENGAGE: Lesson Phenomenon

Lesson Objective

To use models to illustrate the relationships between components of living and nonliving systems.

Can You Explain It?

Students are asked to record their initial thoughts about how living and nonliving systems are similar and how they differ, using robots and humans as examples. Students will collect evidence related to this phenomenon throughout the lesson and revisit the question at the end of the lesson to use what they have learned to make a claim about what defines a living system.

Engineering Connection

Robots The robot in Figure 1 is not a typical example of most robots. A robot is any machine designed to accomplish a variety of tasks, usually by receiving inputs from a human or computer. Robots are often designed to perform a certain function, such as assembling parts in a manufacturing plant.

Collaboration

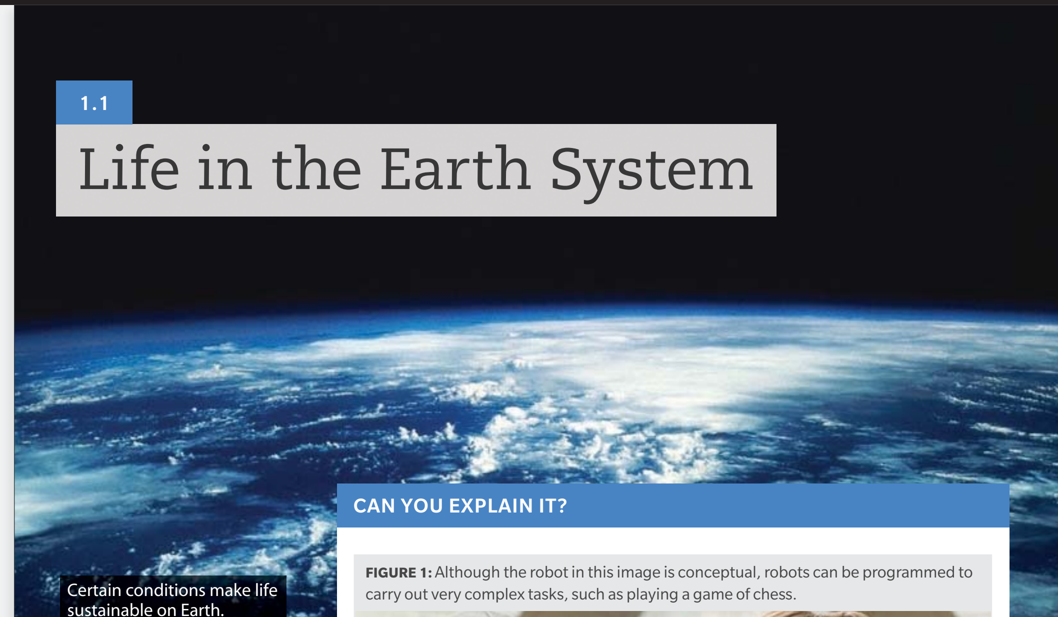
Discussion Have students make lists of living things and nonliving things and then compare and contrast them. As a class, discuss the items and generate a list of criteria for living and nonliving systems. Ask students to consider where robots belong on the lists.

EVIDENCE NOTEBOOK

1. Evidence should show an understanding that a living system must be made up of cells, must obtain and use energy, must grow and develop, must respond to the environment, and must reproduce.
2. Suggest that students think about properties of familiar living and nonliving systems and consider which are requirements for a system to be classified as living. Then have them decide whether the robot has those properties.

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.

1 **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.

2 **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?

EXPLORATION 1 Systems and System Models

EXPLORATION 1

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.

3 **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.

3D Learning Objective

Students explore properties of open and closed systems. Students learn how to **use models to simulate systems and interactions.** Students learn that **a system is made up of numerous parts,** and they use **system models** to explain interactions within and between systems at different scales.

Collaboration

Group Discussion Divide the class into pairs of students to discuss the question. Remind students that systems can be large or small, and they can be either produced by people or found in nature. After pairs have finished their discussions, allow class time for them to share and explain their ideas.

Misconception Alert

Students may think that the boundary of a system is predetermined. Explain that any boundary can be assigned to a system. The boundary that is used for a model does not necessarily have to correspond to a physical boundary. For example, explain that when describing the Earth system, you could choose Earth's surface or Earth's atmosphere as the boundary. You could even choose a much greater area around Earth to be part of the system when analyzing inputs and outputs of the system.

EVIDENCE NOTEBOOK

3 The boundary of the human body is the skin, or epidermis. The boundary of a robot is the outer layer of its structure. Matter and energy inputs of the human body include air, food, and water. Outputs of the human body include energy released as heat and bodily waste. Matter and energy inputs of a robot include the materials used to construct the robot and the electrical energy used to power the robot. Outputs include any forces the robot exerts on objects outside its boundary.

Claims, Evidence, and Reasoning

Help students understand how to analyze systems by walking them through the process for a thermos.

Ask: *What is a claim you can make about whether a thermos is an open system or a closed system?* **Sample answer:** A thermos is a closed system.

Ask: *What evidence do you have to support your claim?* **Sample answer:** A thermos, when sealed, can have an input and output of neither energy nor mass.

Ask: *What reasoning explains how your evidence supports your claim?* **Sample answer:** In a closed system, the flow of one or more inputs and outputs is limited in some way. Since both are restricted in a thermos, it may be considered an isolated system.

CCC Systems and System Models

A digital thermostat like the one in Figure 3 contains a component called a *thermistor* that changes its electrical resistance in response to temperature changes. The input to the system is thermal energy from the surrounding air, and the electrical current from the thermistor is the output.

EVIDENCE NOTEBOOK

1. The human body is an open system because both matter and energy are inputs and outputs. A robot is a closed system because energy is an input and an output, but matter is not.
2. Diagrams could represent the thermostat as a system with an input of thermal energy and an output of electrical current. When the input rises above a certain level, a sensor (the control of the system) switches an electrical circuit on or off to turn the heating or cooling system on or off.

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.

1 **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

2 **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.

3 **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.

4 **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

Differentiate Instruction

Extra Support Emphasize to students that a feedback loop occurs within a single system, not between one system and another. Use the hummingbird in Figure 4 as an example. The hummingbird is taking nectar from the flower. The nectar is an output of the flower and input for the hummingbird. The energy enables the hummingbird to continue taking nectar from flowers. The input and output of nectar is not an example of a feedback loop, however, because it occurs between two systems.

DCI LS1.A Structure and Function

Use the picture of the city park to identify interactions between systems and the components of a system.

Ask: *From what you already know, can you identify some examples of systems interacting in the park shown in the photo? These may not be obvious.* **Sample answer:** Water from the river is evaporating into the air. The trees and bushes are taking in water from the ground. Solar energy is transferred from the sun to the plants.

EVIDENCE NOTEBOOK

3 Students might explain that driving an automobile can release pollutants into the air, washing clothes removes water from a well or reservoir, and planting a garden changes the land.

4 The output of the *scuba* gear is air that is used as input that the scuba diver needs to survive underwater.

SEP Developing and Using Models

As students develop their models, remind them that the point of the activity is not just to show what the biological system looks like. Their models should also show how the parts of the system interact. Students can watch the short online simulation of the folded protein for a more complex example of a model they may wish to pursue.

Math Connection

Use examples to demonstrate for the class how the equation $y = a(1 + r)^x$ can be used to describe or predict population changes and how different factors affect them. Begin with an initial population of 600 and solve the equation for different values of r and x. For example, demonstrate how the value of y changes when either r or x doubles.

MP.4 Model with mathematics.

Differentiate Instruction

English Language Learners Write the word *emergent* on the board. Say the word aloud, and have students repeat it after you. Point out that the word is similar to *emerge*, which means to rise or come out of, such as a seedling emerging from the ground. Help students relate this to an emergent property that arises from the components of a system working together but that each individual component does not have.

EVIDENCE NOTEBOOK

1 Examples of systems that students might choose to model include an animal cell, the body's digestive system, or a human hand and arm. Students should describe the type of model they would make, the components of the system, inputs and outputs, and the interactions among the different components.

System Models

1 **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.

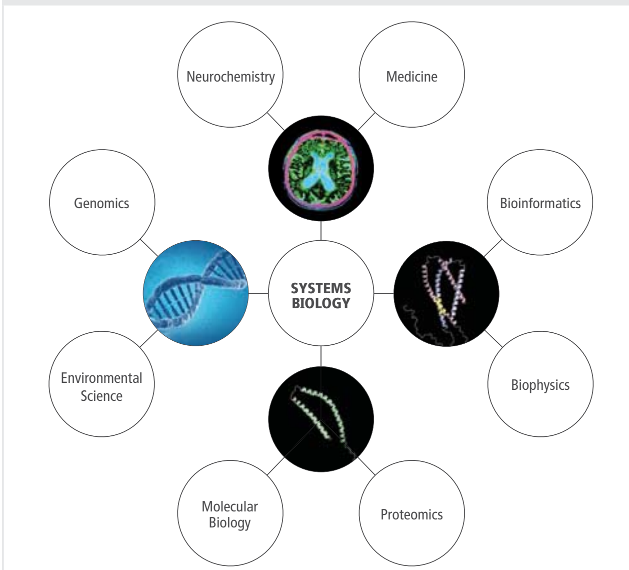
Systems Biology

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.

Image Credits: (t) ©GJLP/Science Source; (r, b) ©Wesley Peng; (l) ©iStock/Getty Images Plus/Svisio

2 **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.

Language Arts Connection

Multimedia Presentation As groups research Parkinson's disease, have them make a computer presentation that shows key points explaining how the field they researched relates to the disease. Suggest that groups include interactive elements if possible.

Explore Online

Exploring Visuals

Systems Biology Use Figure 7 to emphasize the importance of a collaborative approach when researching treatments or cures for diseases. For each of the eight branches of science shown in the figure, have a small group of students briefly research its contribution to the study of Parkinson's disease. Then have groups share what they have learned with the class and discuss how the parts of the system work together. Have students watch the short online video from Figure 6 showing the alpha-synuclein protein folding that is thought to contribute to PD.

EVIDENCE NOTEBOOK

2 Students should provide a list of questions that could be asked about a disease, a type of model that could be used to answer each question, and different fields of science that might be involved. For example, when researching a blood-related disease, a study of the circulatory system might include the biophysics question, *How do the sizes of the parts of the system compare?* and use a physical model to answer the question. A pharmaceutical researcher might ask, *What is the flow rate of a certain medicine in the blood?* and use a mathematical model to answer the question.

FORMATIVE ASSESSMENT

3-2-1 Have students write three things they found out in the lesson, two things from the lesson that they found interesting, and one question that they still have about the concepts presented in the lesson.

EXPLORATION 2 The Earth System

3D Learning Objective

Students **use system models** to explore the **hierarchical organization of multicellular organisms** and their place in the Earth system. Students **use a model to simulate a system** and interactions in order to **illustrate the relationship between systems and components of a system**.

CCC Systems and System Models

Students should recognize that the model of the Earth system could be constructed in various ways, depending on the interaction intended to be the focus of the model.

Misconception Alert

Students may think that because different spheres are defined on Earth, that the biosphere, the atmosphere, the hydrosphere, and the geosphere are independent of each other. Use Figure 9 to emphasize that energy and matter are continually moving throughout the four spheres. Guide students in a discussion of various ways that the transfer of energy and the movement of matter occur.

Ask: *What is one way that matter moves from the geosphere to the hydrosphere?* **Sample answer:** Minerals dissolve in a river and are washed into large bodies of water. Wind can blow small particles of dust into the water.

Ask: *What is a way that matter moves from the atmosphere to the geosphere?* **Sample answer:** Through photosynthesis, plants absorb carbon dioxide and release oxygen.

EVIDENCE NOTEBOOK

1. Earth is a closed system because energy can enter or leave the system, but matter generally cannot.
2. The model focuses on how the biosphere interacts with each of the other three spheres and also how the biosphere serves as a connection point between each of the other spheres.

EXPLORATION 2

The Earth System

System Models

FIGURE 8: Model of the Earth system.

1 **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.

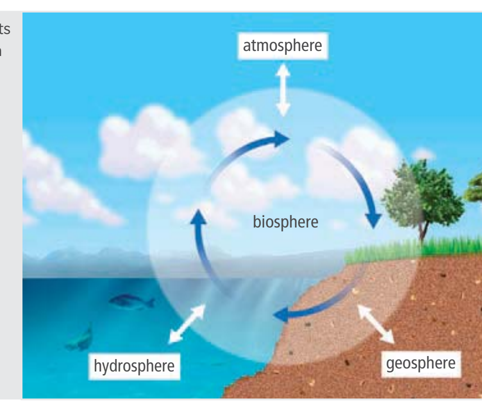
As Figure 8 shows, matter stays within the Earth system, but energy enters the system in the form of sunlight and exits in the form of heat. Within the system itself, light energy is converted into other forms of energy that drive transformations of matter from one form to another as it cycles through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

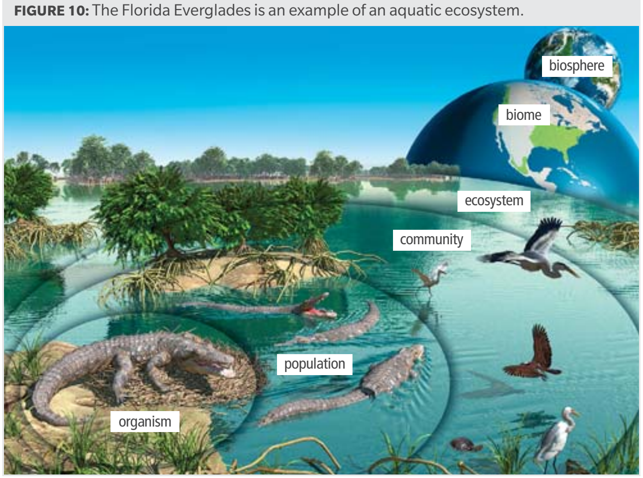


2 **Explain** This model shows the biosphere in the middle of the diagram with arrows connecting it to the other spheres. Why is the biosphere depicted this way?

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.



3 **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.

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

Explore Online

Hands-On Lab
Life Under a Microscope

DCI **LS1.A Structure and Function**

Students learn about the hierarchical structural organization among individuals in an ecosystem and make connections to the biotic and abiotic components that function in that system.

Exploring Visuals

System Relationships Be sure students understand that the model shown in Figure 10 is a simplification.

Ask: *How does a biome compare to an ecosystem?* **Answer:** A biome includes many ecosystems.

Ask: *How does a population compare to a community?* **Answer:** There can be many populations in a community.

Ask: *Why is this an effective type of model for showing the different components of the system?* **Answer:** The model shows the hierarchy of the components of the system. It also shows how the size of the components increases in the hierarchy.

EVIDENCE NOTEBOOK

3 organism → population → community → ecosystem → biome → biosphere → Earth → solar system

4 Biotic factors include plants, elk, and insects. Abiotic factors include snow, air, and sunlight. Students' models should include various ways the factors interact. For example, a model might represent how sunlight warms the snow and causes it to melt, providing water for the elk.

Explore Online

Differentiate Instruction

Extra Support After students watch the video, ask questions that guide them through the process of understanding why the Venus flytrap can be classified as a living thing.

Ask: *Which two characteristics of living things do you see in the Venus flytrap in the video? Explain.* **Sample answer:** The Venus flytrap requires an energy source because it eats the insect. It responds to its environment by closing in response to the insect walking on it.

EVIDENCE NOTEBOOK

1. Students may describe a bee and a flower as their biological systems. The flower's system for obtaining water and nutrients is independent from the bee. The bee's system for flying is independent from the flower. The systems are interconnected when the bee extracts nectar from the flower and carries pollen from the flower to other flowers.
2. The robot at the beginning of the lesson does not meet the criteria of being made up of one or more cells, growing, and reproducing. It does meet the criteria of requiring an energy source and responding to changes in its environment. A robot does have some emergent properties. For example, a robot might have the ability to walk.

FORMATIVE ASSESSMENT

One-Minute Essay Have students write a short essay describing how Earth is made of smaller systems that are interconnected.

Sample Answer: Students might focus on interactions between living and nonliving systems, or they might focus on interactions among the geosphere, the biosphere, the atmosphere, and the hydrosphere.

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

1 **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.

2 **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.

CONTINUE YOUR EXPLORATION Engineering

CONTINUE YOUR EXPLORATION

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.

Collaboration

You may choose to assign this activity or direct students to the Online Interactive Student Edition, where they can choose from all of the available paths. These activities can be assigned individually, to pairs, or to small groups.

Modeling a System

Students identify a system and then create a model of the system and revise it based on a consideration of trade-offs. *(no outside research required)*

ETS1-2 Design a solution to a complex real-world problem.

ETS1-3 Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs.

SL.11-12.5 Make strategic use of digital media in presentations.

Differentiate Instruction

Extension Arrange for students to display and explain their model of a school-related problem and the proposed solution to school administrators. Have students work to implement the solution to the problem they have identified.

Explore Online

Viruses: Are They Alive?

Students research and develop a claim based on evidence for whether viruses should be considered living things. Then they create a multimedia presentation that synthesizes the information they found.

Life Under a Microscope

Students ask questions and make observations about the characteristics of organisms found in a drop of pond water. Then they explain the connection of components in the pond ecosystem and the larger biome.

EVALUATE Lesson Self-Check

Can You Explain It?

DCI LS1.A Structure and Function

Systems have certain properties that can be used to identify them as living or nonliving. Living systems are made of one or more cells, they have different levels of organization, they grow and change over time, and they reproduce.

EVIDENCE NOTEBOOK

1 A robot is a system because it is a set of interacting components that work together. A robot does not meet all the characteristics of living things including being made up of one or more cells, growing, and reproducing. It does meet some of the characteristics. For example, a robot requires an energy source to enable it to move or function. A robot also can respond to changes in its environment. For example, if it observes a change in the location of chess pieces, it will respond in a certain way. A robot does have some emergent properties. For example, a robot might have the ability to walk.

Collaboration

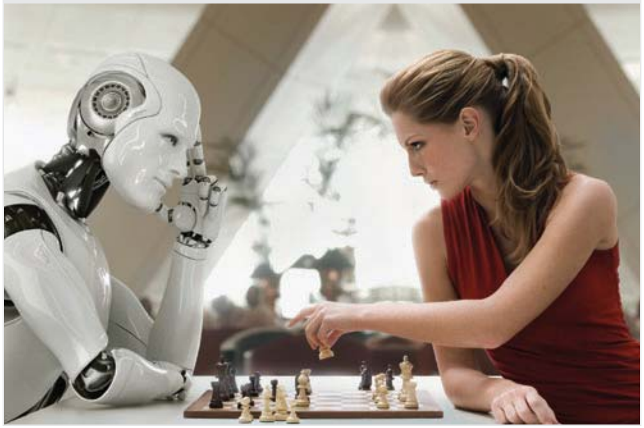
Cultivating New Questions As students complete this lesson, encourage them to identify additional questions they have about systems and system models. They may wish to record the questions in their Evidence Notebook for reference as they study Lesson 2.

EVALUATE

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."

1 **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?

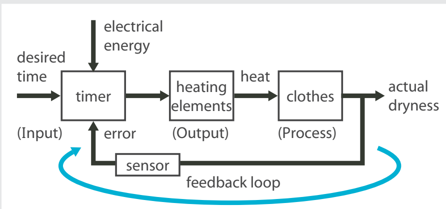
For each of the above questions, include specific examples and evidence to support your claims.

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.

Checkpoints

Answers

1. b
2. c
3. The system is a closed system because while energy moves in and out, matter does not move in or out.
4. In the feedback loop, the sensor monitors the dryness of the clothes and compares it to the desired dryness. It signals the heating element and timer to make adjustments.
5. According to the diagram, the time required for drying would depend on how wet the laundry was, not on the size of the load. The feedback loop will signal the end of drying when the clothes reach the desired level of dryness.
6. a
7. Check student models. Models could show such interactions as a plant (part of the biosphere) taking in carbon dioxide (atmosphere) and water (hydrosphere) and then releasing oxygen into the atmosphere.
8. A common misconception is that movement is a characteristic of living things. While all living things do move in some way (for instance, plants move toward the sunlight), many nonliving things also move.
9. Living things use inputs and outputs in a feedback loop to maintain homeostasis. For example, when the body senses cold (input), the brain sends messages to the muscles to tighten and contract (output). This helps generate heat for the body to maintain a consistent internal temperature (homeostasis). When the external temperature warms up, the brain no longer sends the signal to the muscles.

Make Your Own Study Guide

Have students create a study guide that helps them organize and visualize the important information from this lesson. Their study guide should focus on the main ideas from the lesson and tie multiple ideas together. Students can create an outline, a concept map, a graphic organizer, or other representation.

LESSON 2

Organisms: Cells to Body Systems

Building to Performance Expectation

The learning experiences in this lesson prepare students for mastery of:

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

Trace Tool to the NGSS

Go online to view the complete coverage of standards across lessons, units, and grade levels.

SEP Science & Engineering Practices

Developing and Using Models
Develop and use a model based on evidence to illustrate the relationships between systems or between components of a system.

DCI Disciplinary Core Ideas

LS1.A Structure and Function
Multicellular organisms have a hierarchical structural organization, in which any one system is made up of numerous parts and is itself a component of the next level. (HS-LS1-2)

CCC Crosscutting Concepts

Systems and System Models
Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows—within and between systems at different scales.

CONNECTIONS TO MATH

MP.2 Reason abstractly and quantitatively.

CONNECTIONS TO ENGLISH LANGUAGE ARTS

SL.11-12.5 Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest.

RST.11-12.9 Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.

Supporting All Students, All Standards

Integrating the Three Dimensions of Learning

In this lesson, students will develop and use models **(SEP Developing and Using Models)** to illustrate how multicellular organisms have a hierarchical structural organization **(DCI.HS-LS1.A).** In addition, students use system models **(CCC Systems and System Models)** to illustrate the relationships between components of a system, such as cells, tissues, organs, and organ systems. Students also use models to describe the way these components interact with each other.

Preassessment

Have students complete the unit pretest online or see the Assessment Guide.

Building on Prior Knowledge

Have students list what they know about the levels of organization of a multicellular organism and of plant and animal cells. After they have made a comprehensive list, ask them to share their list with a partner and discuss any differences. Then create a classroom list that can be added to over the course of this lesson.

You may want to review the following concepts:

- A system is a set of interacting components that work together.
- Systems have components, boundaries, inputs, and outputs.
- Complex systems have many levels of organization.
- There are several different types of models, such as physical, conceptual, mathematical, and simulation. Each type of model has a unique function.
- Life on Earth can be organized into hierarchical levels of organization such as biosphere, ecosystem, population, and individual organism.

Professional Development Go online to view **Professional Development videos** with strategies to integrate CCCs and SEPs, including the ones used in this lesson.

Content Background

As a living system, the body of a multicellular organism is arranged into hierarchical levels of structural organization. Cells are arranged into tissues, which are organized into organs. Multiple organs work together to form an organ system. Although each organ system performs its specific functions, it does not work alone. Organ systems interact to perform tasks that benefit the organism as a whole. Having levels of structural organization means that no one structure must perform all the functions that keep the organism alive.

Organelles, each of which performs a unique function, make up cells. Cells in multicellular organisms are specialized to do a certain job. Chloroplasts harness energy in sunlight and convert the energy to chemical energy that is stored in sugar molecules. Mitochondria break down sugars to release energy that cells use to fuel their metabolic functions. Many students think that plant cells do not have mitochondria because they manufacture their own food in chloroplasts. It is important to clarify that a mitochondrion is the organelle that releases energy from the chemical bonds of sugar molecules. Like animal cells, plant cells require energy and contain mitochondria, which supply energy to a cell.

Differentiating Instruction

Lesson Vocabulary

- organ system
- organ
- tissue
- cell
- cell differentiation
- cell membrane
- nucleus
- mitochondrion
- chloroplast

Reinforcing Vocabulary The vocabulary terms in this lesson may be familiar to students, but it is important that students rank the terms in order according to the structural hierarchy. They should recognize that a tissue is made of only one kind of cell, that an organ contains several types of tissues, and that an organ system usually consists of several interacting organs.

ELL Support

Modeling Have students use a process chart to organize information about interacting systems in organisms. Students draw a box and write the first step of a process or cycle in it. Students then draw a second box with an arrow between, and they write the next step or event. Students continue adding boxes until each step of the process or cycle is shown.

ENGAGE: Lesson Phenomenon

Build on Prior Lessons

In Lesson 1, students learned about the properties of systems and explored living and nonliving system models. Lesson 2 builds on these concepts as students explore living systems in greater detail.

Lesson Objective

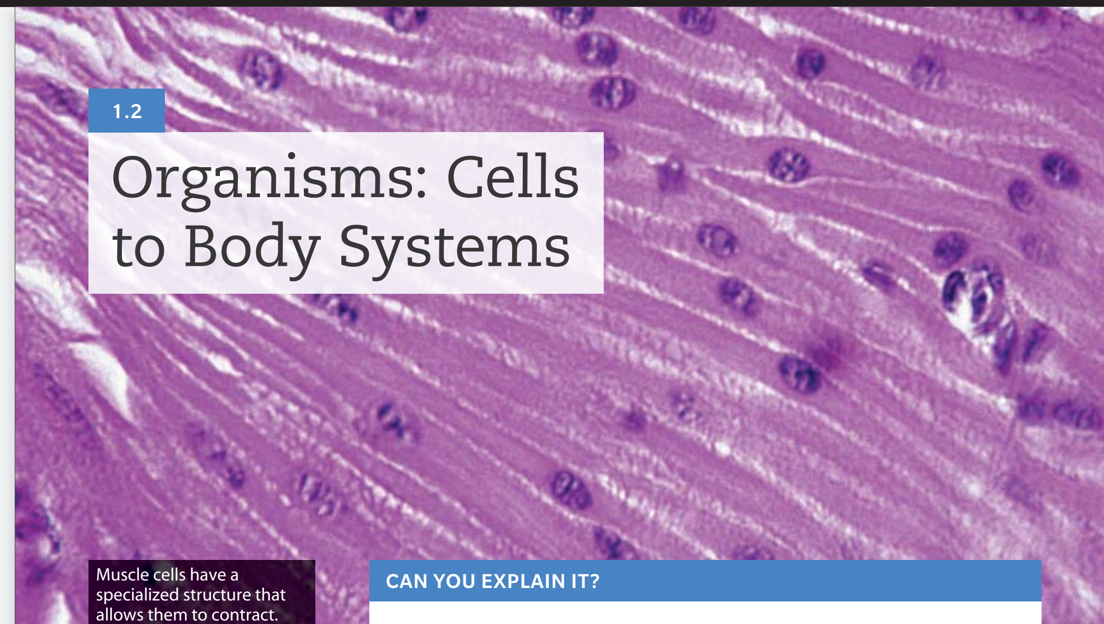
Use a model to explain how systems within an organism interact at different levels to carry out functions necessary for life.

Can You Explain It?

Students are asked to develop models to illustrate how interacting body systems function in response to external signals and interact with each other to regulate overall body function. Students will collect evidence and use it to create models related to these interactions. Students can revise their models throughout the lesson, and use their final model to form an explanation for how this phenomenon occurs.

EVIDENCE NOTEBOOK

1. As students read the lesson, have them model and describe interactions between systems. For example, they should learn that the circulatory and respiratory systems interact during the process of gas exchange.
2. Ask students what organs they think might be interacting when they feel "butterflies" in their stomach. Students may suggest that organs such as the brain, heart, or stomach interact when this sensation occurs. The brain may sense something in the outside environment, and then it sends a signal to the stomach. The stomach may respond in reaction to this signal from the brain.



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.

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

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

Image Credits: (t) ©Biophoto Associates/Science Source; (b) ©MUJAHID SAFODIEN/AFP PHOTO/Getty Images

EXPLORATION 1 Interacting Systems in Organisms

EXPLORATION 1

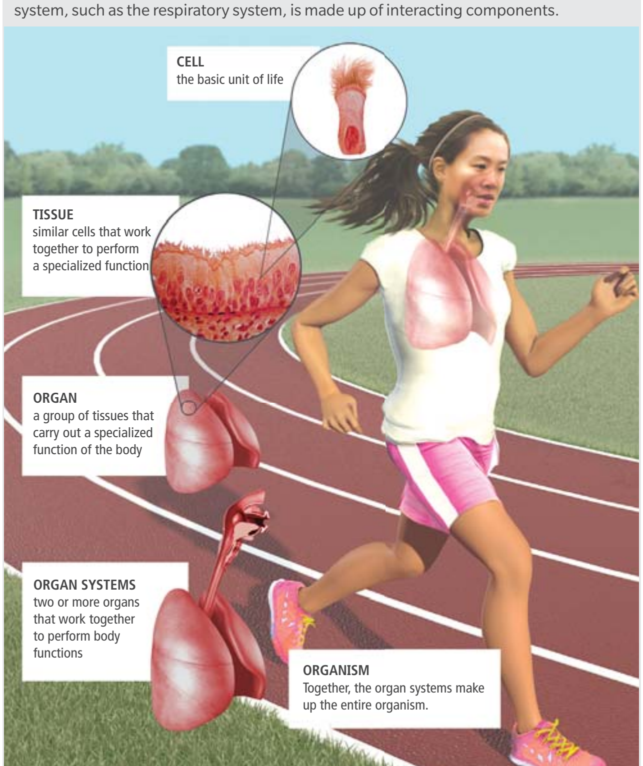
Interacting Systems in Organisms

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 multicellular 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.

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

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



3 **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?

3D Learning Objective

Students learn of the **hierarchical, structural organization of body systems** and **develop and use models** to illustrate the ways that body systems interact to provide important functions. Students draw **system models,** like flow charts, to illustrate interactions within and among systems at different scales.

Exploring Visuals

The Respiratory System The illustration on the student page shows the different scales of the respiratory system. The system is composed of organs (lungs), which in turn are made up of tissues (epithelial tissue), which are composed of cells (epithelial lung cells). Be sure that students understand that the body of a multicellular organism is a system. Systems often contain smaller systems; that is, systems exist on all scales. Students will learn that an organism is made up of organ systems, which are made of organs, which are made of tissues, which are made of cells.

Collaboration

Discussion Discuss with students their experience of activities that require a high degree of attention and coordination, for example skateboarding or ballet. Discuss that the body is a system made up of many other systems, such as the cells, tissues, and organs that maintain coordination.

EVIDENCE NOTEBOOK

3 Cells in the epithelial tissue of the lungs work together to sweep foreign substances and pathogens out of the lungs. The nose and sinuses moisten, filter, and warm the air before it enters the lungs. A sinus infection might lead to the production of extra mucous in the nose and sinuses, which could affect the ability of these organs to carry out their normal functions. If air entering the lungs is not properly filtered, the lungs could become infected.

Differentiate Instruction

Extra Support Some students may have trouble understanding the meaning of hierarchical levels. Explain that there are different levels of organization in everyday life. Use a town or city as an example. The entire town might be analogous to an organism, different neighborhoods might be similar to organ systems, streets may be similar to organs, individual houses may be similar to tissues, and rooms within houses may be similar to cells.

Claims, Evidence, and Reasoning

System Components Have students examine the table and note that two organs are components of more than one system. Make a list of these organs, and ask students to suggest a reason why each is part of two organ systems.

EVIDENCE NOTEBOOK

1 Oxygen and carbon dioxide gas may not be exchanged properly. The person may begin to breathe faster in an attempt to take in and increase the amount of oxygen distributed to cells of the body. Nutrients may not be absorbed and distributed correctly. If the circulatory system does not absorb nutrients from the digestive system, the digestive system may either increase the rate of digestion or shut down due to a backup of nutrients in the small intestine. Homeostasis would then be disrupted by these system imbalances.

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

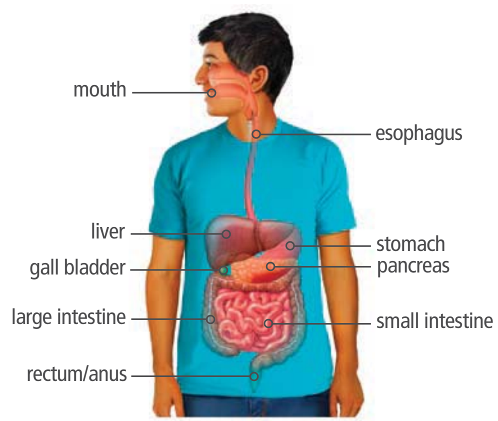
System	Organs and Other Components	Primary Functions
Circulatory	heart, blood vessels, blood, lymph nodes, lymphatic vessels	transports oxygen, nutrients, hormones, and wastes; helps regulate body temperature; collects fluid lost from blood vessels and returns it to the circulatory system
Digestive	mouth, 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

1 **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.

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

Differentiate Instruction

Extra Support Model for students what a flow chart looks like. Allow students to include as much detail in their model as they are comfortable with. Some students may wish to make a simple flow chart with text and arrows.

Extension If there is time, students may want to add drawings, color, and interactive elements to their model. Encourage students to be creative and add unique design elements to enhance the content in their model.

Explore Online

Hands-On Lab
Connecting Form to Function

SEP Structure and Function

Students examine a slice of the roots, stems, and leaves of a plant and explain how their structures relate to their functions. Student lab worksheet and teacher support available online.

CCC Systems and System Models

Help students begin making a model by reading through the text and listing the organs in this system and their basic functions. Once students have recorded this information, have them use arrows and additional text or media to create a simple flow chart showing how each organ contributes to the task of digesting food. **Sample answer:** Student flow charts should include the mouth, esophagus, stomach, small intestine, and large intestine in linear order. The pancreas, liver, and gall bladder should appear in the flow chart as a side pathway that leads into the small intestine. Flow charts should include a brief description of the function of each organ.

EVIDENCE NOTEBOOK

2 The digestive system brings nutrients to the immune system to help it fight pathogens. The digestive system can play a role in breaking down bacteria that enters through the digestive system before they can infect the rest of the body.

SEP Developing and Using Models

The diagram in Figure 5 is a model that illustrates the relationships between the components of a system. Each type of tissue interacts with other tissues to help the organ carry out its function in the body. This model shows the hierarchy of organization in the human body. The stomach is part of a larger system and contains smaller systems such as tissues and cells.

Claims, Evidence, and Reasoning

Structure and Function Group students into groups of four. Have each student in a group select a type of tissue and make a claim for how the structure of that type of tissue makes it suitable for the job it does in the stomach. Students should use evidence from Figure 5 to support their claim, and they should explain their reasoning. For example, the cells that make up the epithelial tissue make an ideal protective lining for the stomach. These cells are tightly packed, so they can prevent unwanted substances from moving through this tissue and into the rest of the body.

Ask: *How does the structure of each type of tissue help it carry out its specific function in the stomach? In other words, how does the shape and arrangement of the cells in this tissue help it do its job?* Tissue, and the cells that make up the tissue, are structured to perform a particular function, such as being elastic for greater flexibility or having more surface area for greater absorption.

EVIDENCE NOTEBOOK

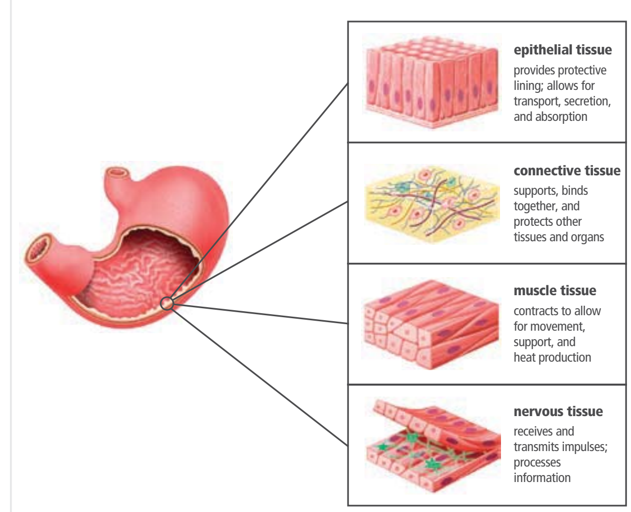
1. A tendon is made of connective tissue. One of the functions of connective tissue is to bind together and support organs, and a tendon binds together muscle and bone.
2. The nervous system sends signals to the muscles of the stomach when it's time to contract. This interaction allows food to become mixed with stomach acid and other chemicals that digest the food. If these two systems did not work together, digestion could not occur and body cells would not have energy to perform their functions.

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.

1 **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?

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



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.

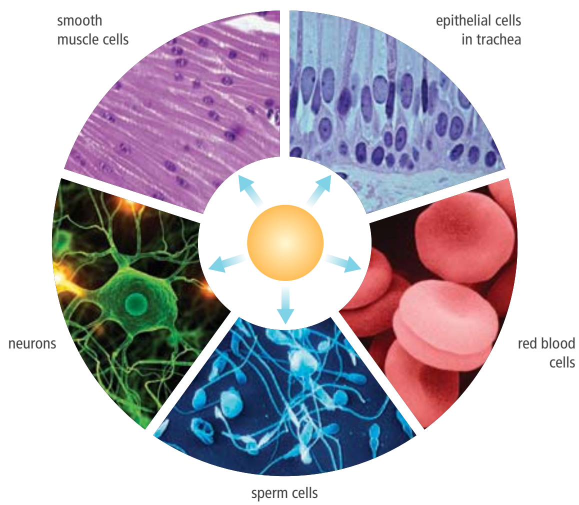
2 **Analyze** How does nervous tissue interact with muscular tissue in the stomach to break down food? Why is it important for the nervous and digestive systems to work together?

20 Unit 1 Living Systems

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.

Collaboration

Discuss Have students name as many different kinds of cells as they can. Ask how all these cells can be different if they all arose from the same cell and, thus, have the same genetic material. After a class discussion, explain that cells in different parts of the developing body begin to differentiate early in development. Chemicals produced in these locations cause some genes to be switched on and other genes to be switched off, resulting in cells that have different structures and functions.

Math Connection

Calculate Because each neuron has many dendrites and axon endings, a single neuron may connect with as many as 1000 other neurons, although some types of neurons connect with far fewer. Ask students to determine how many neurons could be stimulated if each of these 1000 neurons formed connections with another 1000 neurons (one million). Students should see how quickly and widely nerve impulses can travel within the body.

MP.2 Reason abstractly and quantitatively.

Engineering

Electricity and the Heart Explain to students that scientists are currently studying ways to make nanobots that could move through the blood stream. Have students propose ways that the structure of a nanobot might be similar to or different from that of a red blood cell. Ask students to explain what some of the criteria and constraints might be for this type of technology.

Language Arts Connection

RST.11-12.9 Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.

Human red blood cells are shaped like thin discs with bowl-like depressions in the centers on both sides. The cells are small and flexible so they can squeeze through narrow blood vessels. These cells could be compared to a small raft or inner tube that can move through a small tube such as a water slide.

CCC Systems and System Models

Model A typical student flow chart might show the following information. Sensory neurons in a person's eyes and ears send signals, or impulses, to the brain and spinal cord that an object has been dropped. Interneurons in the brain and spinal cord receive the information, process it, and send a response to muscles in the arm and hand via motor neurons. These muscles contract and the object is picked up.

Exploring Visuals

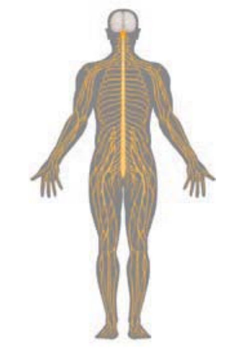
The Nervous System Have students refer to the parts of a neuron in Figure 8 as they read about neuron structure in the text. Ask students to explain how each part of the neuron relates to its function within the nervous system.

Ask: *How do the dendrites help the neuron carry out its function in the nervous system?* **Answer:** Dendrites receive signals from other cells. *How do the axon terminals help the neuron carry out its function in the nervous system?* **Answer:** Axon terminals transmit signals to other cells in the body.

EVIDENCE NOTEBOOK

1 Signals would not be able to travel as efficiently through the axon if the myelin sheath were damaged or destroyed. Thus, nerve transmission would be slowed or it could stop completely. This is similar to a wire that is not properly insulated—the electrical impulse is not contained, and the wire could "shock" a person who touches it.

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



Neurons

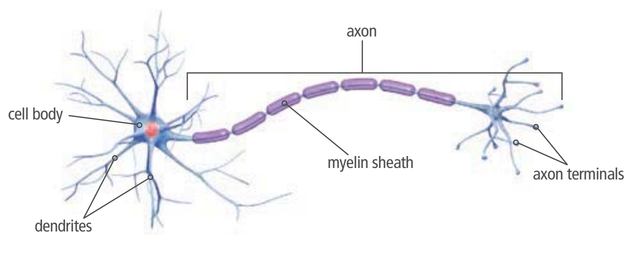
The nervous system is a network of nerves and sensory organs that work together to process information and respond to the environment. The basic unit of the nervous system is the neuron. Neurons are specialized cells that are able to send electrical and chemical signals to help the organism sense information,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

1 **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?

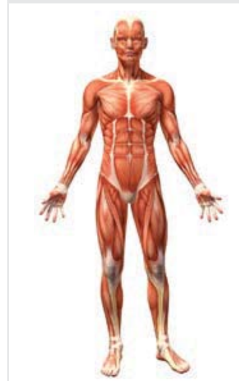
The nervous system interacts with all the other systems in the body. For example, when you eat, your brain signals your digestive system to start making chemicals and churning your food. Neurons also stimulate muscle tissue in the digestive system to contract, which helps the digestive system move and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

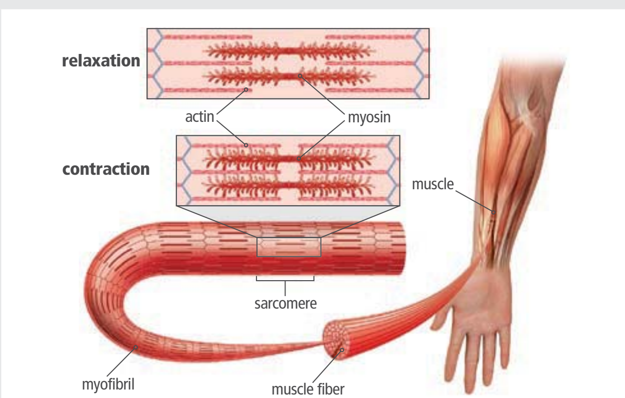
FIGURE 9: Skeletal Muscles



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 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



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

3 **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?

Collaboration

Activity Play a game in class by describing an activity and having students write *voluntary* or *involuntary* on a small whiteboard. Examples of voluntary activities include running, scratching an itch, and using a cell phone. Involuntary activities include beating of the heart, digestion of food, and sneezing.

Exploring Visuals

Muscle Contraction Present the animation. Then break students into pairs or small groups to gather evidence about the mechanism of muscle contraction as illustrated in Figure 10.

EVIDENCE NOTEBOOK

2 A muscle cell has thin fibers that can slide over each other.

3 Models will vary but should include elements of the nervous and digestive systems and generally explain how sense organs detect stressors in the environment, sending signals to the brain and causing muscles in the stomach to contract.

FORMATIVE ASSESSMENT

Have students compare their models of the nervous and digestive systems and make any revisions to their own model as needed. Then have students use their model to write or verbally explain this phenomenon.

Sample model: stressor in environment—>sense organs detect stressor—>sensory neurons transmit signal—>interneurons process information—>motor neurons signal muscle cells—>muscle cells contract—>person feels "butterflies."

Sample explanation: Receptors in sense organs, such as the eyes and ears, might send impulses to the spinal cord and brain transmitting information about a stressful condition in the environment. The impulses pass through interneurons and then to motor neurons that go to the stomach. In the stomach, the impulses cause stomach muscles to contract, leading to a feeling sometimes referred to as "butterflies" in the stomach.

EXPLORATION 2 The Cell System

3D Learning Objective

Students learn that **cells are made of numerous parts that interact to provide specific functions.** Students **develop and use models** to illustrate these interactions. Students use **system models** to illustrate interactions within and among systems at different scales.

Collaboration

Discussion When beginning the lesson, remind students of the characteristics of systems (boundaries, components, inputs and outputs of energy and matter). Then, pair students up and have each pair generate a list of jobs they think might be necessary for maintaining the cell system. Ask each pair to share one job from their list and explain why this job is important. As each pair shares, make a whole-class chart showing the functions that students described.

CCC Systems and System Models

Gather Evidence Have students make a table in their Evidence Notebook to record the name of each organelle, its role in the cell system, and a simple visual or analogy representing that organelle. Describe some common analogies for functions in the cell to help students get started. For example, the nucleus is often compared to the control room or the main office of a building.

EVIDENCE NOTEBOOK

1. Student tables may vary. Confirm they are on the right track when organizing their data.
2. The cell system is separated from its surroundings by a cell membrane. This boundary controls the movement of materials into and out of the cell.
3. Cell A is a prokaryotic cell because it does not have a nucleus or membrane-bound organelles. Cell B is a eukaryotic cell because it does have these structures.

EXPLORATION 2

The Cell System

1 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.

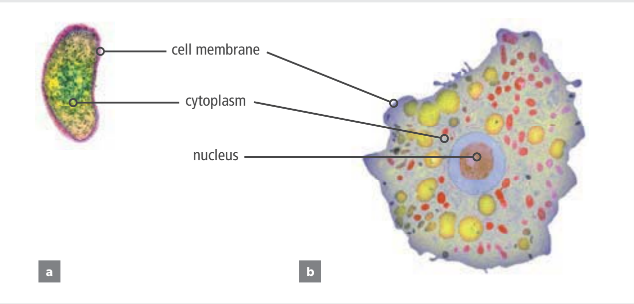
The most basic level of organization in living things is the cell. Organisms may be made up of just one cell, or they may be multicellular. Cells in multicellular organisms are specialized to perform different functions. Your body is made of trillions of cells of many different shapes, sizes, and functions, 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.

2 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

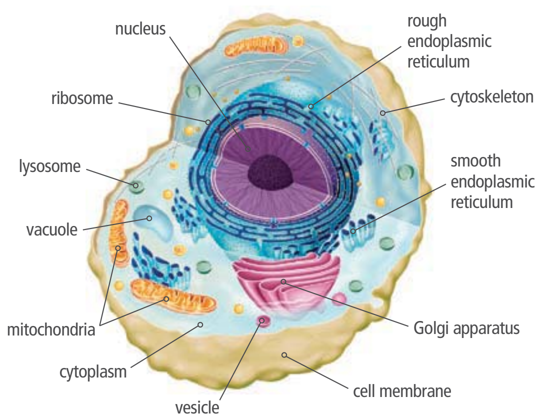
Scientists classify cells into two broad categories based on their internal structures: prokaryotic cells and eukaryotic cells. Prokaryotic cells do not have a nucleus or other membrane-bound organelles. Instead, the cell's DNA is suspended in the cytoplasm. Most prokaryotes are microscopic, single-celled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

3 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.



4 **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.

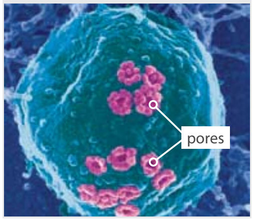
Cytoplasm is itself an important contributor to cell structure. In eukaryotes, it fills the space between the nucleus and the cell membrane. The fluid portion, excluding the organelles, consists mostly of water. Water helps maintain the structure of the cell and provides a medium in which chemical reactions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



Engineering Connection

Compartmentalization Many systems, both living and nonliving, are divided into compartments. Factories are often divided into areas by walls or screens, with different processes taking place in different areas. Similarly, a computer is a system composed of many parts such as the keyboard, mouse, monitor, and memory, all of which have distinct tasks and processes. In living cells, compartments are created by membrane-bound organelles. The advantage of compartmentalization in systems is that incompatible processes can occur in different environments at the same time, increasing the efficiency of the system. In contrast, all functions in prokaryotes take place in the cytoplasm. Incompatible processes must occur separately in time and space.

CCC Structure and Function

Extension Have students research the structure of the nuclear membrane. Students should learn that nuclear pores are protein-lined channels embedded in the nuclear envelope. These openings control the passage of materials into and out of the nucleus. Students should explain how this structure relates to the function of the nucleus. For example, the first stage of protein synthesis requires that certain molecules access the cell's DNA. Nuclear pores allow for the controlled transport of these materials.

EVIDENCE NOTEBOOK

4 The endoplasmic reticulum, mitochondrion, and Golgi apparatus all consist of a stack or network of folded membranes. In the mitochondrion, the organelle is surrounded by an outer membrane and the stacked membranes are internal. In the endoplasmic reticulum and the Golgi apparatus, the organelle itself consists of a network of membranes.

SEP Developing and Using Models

Arrange students into small groups. Have each group design a skit, cartoon, or comic strip to illustrate the functions of at least three different organelles.

Collaboration

Think, Pair, Share Ask the whole class to name some companies that ship products to customers. Then have students write down an analogy for the function of the Golgi apparatus and share their analogy with a partner. Students should recognize that the Golgi's function of packaging and releasing proteins is analogous to the packing and shipping of products that occurs in a warehouse distribution center.

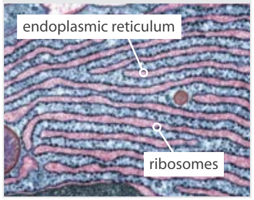
Exploring Visuals

Internal Membranes Point out to students that many organelles, such as the mitochondrion and Golgi apparatus shown on this page, contain a large amount of internal membrane. Explain that enzymes that catalyze chemical reactions that take place in the organelle are often attached to membranes. A large amount of membrane material increases the surface area on which these membranes are found and allows room for more enzymes.

EVIDENCE NOTEBOOK

1. These proteins are located in the cell membrane, so they must be made on ribosomes bound to the rough ER. Ribosomes in the cytoplasm make proteins that are typically used for chemical reactions in the cytoplasm.
2. Mitochondria are the powerhouses of the cell; they supply energy to the cell. A muscle cell needs far more energy than a skin cell because it must contract, a process that uses energy.

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



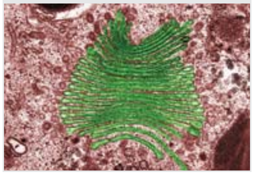
Endoplasmic Reticulum and Ribosomes

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.

1 **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.

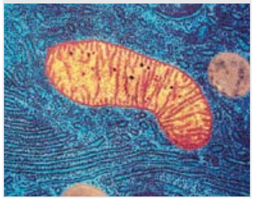


Golgi Apparatus

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.

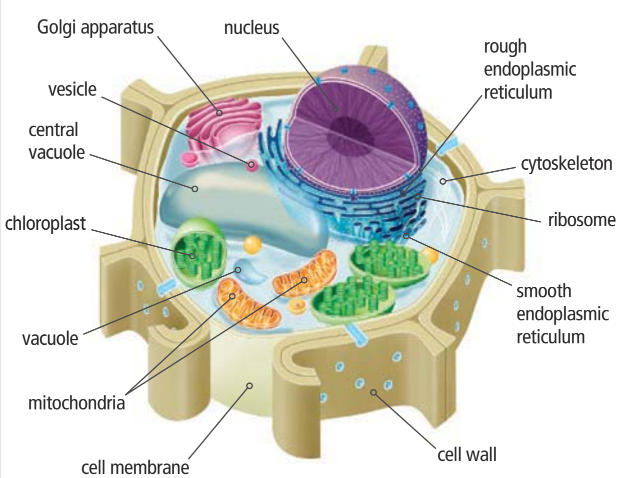
2 **Predict** Which would you predict would have more mitochondria—a muscle cell or a skin cell? Explain your answer.

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.



Explore Online

Hands-On Lab

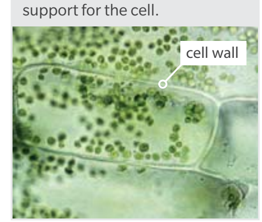
Comparing Cells Use a microscope to investigate the similarities and differences between plant and animal cells.

3 **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?

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.

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



4 **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?

Misconception Alert

Discuss Some students think that animal cells contain mitochondria and that plant cells contain chloroplasts but not mitochondria. Be sure students understand that plant cells contain mitochondria as well as chloroplasts. Many students think that because plants perform photosynthesis to make their own food, they do not need mitochondria. It is important, however, for students to understand that plants use photosynthesis to make food that is broken down in mitochondria to release chemical energy that fuels all of the cell's processes. Animal cells do not need chloroplasts because they do not make their own food; they obtain food from their environment.

Explore Online

Hands-On Lab
Comparing Cells

SEP Structure and Function

Students use a microscope to investigate the similarities and differences between plant and animal cells. Student lab worksheet and teacher support available online.

EVIDENCE NOTEBOOK

3. **Sample answer:** According to this model, the organelles found in plant cells but not in animal cells are the cell wall, chloroplasts, and the central vacuole. The cell wall is most likely involved in protecting the cell and making it stronger. The central vacuole appears to store liquid. The chloroplast is green, so it contains pigment that may give plants their color.
4. **Sample answer:** Channels in the cell wall allow water and other molecules to pass more easily from cell to cell. This helps cells obtain the water and other materials necessary for maintaining homeostasis.

Collaboration

Activity Arrange students into small groups, and give each group photomicrographs of plant root cells, stem cells, and leaf cells. Have each group examine the micrographs and note the relative number of chloroplasts in each kind of cell. Leaf cells will have the most chloroplasts, and root cells will have the least. Have student groups postulate a reason for this difference. They should recognize that chloroplasts are the site of photosynthesis, which requires light. Root cells are found underground, where no light is available. Leaf cells receive the most sunlight. Stem cells receive sunlight but not as much as leaf cells.

EVIDENCE NOTEBOOK

1. The vacuole presses against the inside of the cell membrane and makes the cell rigid. This pressure supports the leaves and holds them erect. When water is scarce, the vacuole loses water, reducing the pressure on the membrane. The cell becomes less rigid, and the leaves shrivel.
2. **Sample answer:** The membrane may have passages that allow only some things in while keeping others out.
3. Answers will vary but should provide an example of at least two organelles that help a cell carry out a particular task.

FORMATIVE ASSESSMENT

Have students write a claim based on evidence for how organization within the cell helps cells function within larger systems. Suggest students use specific examples in their explanation, such as cells they learned about in earlier sections, including neurons, muscle cells, and epithelial cells.

Sample answer: Organelles help the cell carry out specialized tasks within an organism. For example, cells that excrete materials, such as epithelial cells in the stomach, depend on the rough ER and Golgi apparatus to make, package, and transport materials to be excreted out of the cell.

FIGURE 19: Chloroplasts carry out photosynthesis.

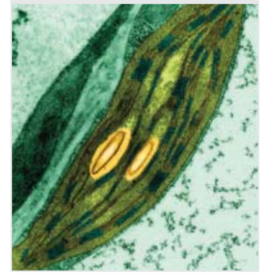
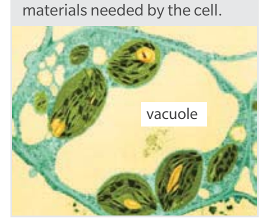


FIGURE 20: The vacuole stores materials needed by the cell.



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.

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

2 **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?

Explaining the Cell System Boundary

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.

3 **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.

CONTINUE YOUR EXPLORATION Engineering

CONTINUE YOUR EXPLORATION

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.

Image Credits: ©Dennis Walsh/UpperCut Images/Getty Images

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

Modeling Interacting Body Systems

CCC Systems and System Models

Model Have groups of individuals decide on a task that interests them. Then have students list three to four organ systems that might interact to help the body complete the task they chose. Have students use Internet resources to find information about the body systems they listed. If students work in small groups, each group member could research one body system from the list. Once the research is complete, have each group sketch their final model on a whiteboard and brainstorm materials they will need to create the model.

Language Arts Connection

SL.11-12.5 Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest.

Gallery Walk Have students present their models in the form of a gallery walk. Half of the student groups should present their models while the other groups listen and score the presentation on a list of criteria. The groups then switch roles.

Explore Online

Plant Tissues and Cells

Students examine photomicrographs to identify various types of plant cells and tissues. They compare their structure and function with those of animal cells and learn how they interact to perform functions that are unique to plants. Students end their study by making a model of interacting systems within a plant.

Comparing Prokaryotes and Eukaryotes

Students conduct research to prepare an informational guide describing the differences and similarities between eukaryotic and prokaryotic cells.

EVALUATE Lesson Self-Check

Can You Explain It?

Collaboration

Research In the Engage section of this lesson, student groups may have considered that only the nervous system and digestive system interact to produce the feeling of "butterflies" in the stomach. Now have student groups research the fight-or-flight response in humans. Students should learn that this response to anxiety begins when the nervous system detects external stress, and it causes a reduction of blood flow to the stomach as blood is shifted to body parts that are more vital to survival. The heart rate and blood pressure increase, sending more blood to muscles. Thus, the nervous system, digestive system, muscular system, and circulatory system all interact. Have student groups choose another fight-or-flight response and determine what body systems are involved and how they respond to the stimulus.

EVIDENCE NOTEBOOK

1 Students should recognize that the nervous system and digestive system interact. They may know that the muscular and circulatory systems are also involved. Students' evidence should be based on information they have gathered throughout the lesson, and their reasoning should follow this evidence in a logical manner. **Sample answer:** (1) The nervous system, digestive system, and muscular system interact when you feel "butterflies" in your stomach. (2) The stomach is made up of four types of tissue, and contraction is caused by muscular tissue. Neurons send and receive signals, so they must send the signal that causes the stomach to contract. Sensory neurons detect stimuli in the environment, interneurons process the information, and motor neurons cause muscle cells to contract. (3) A revised model might include important organelles, such as mitochondria, in the neurons and muscle cells. It might also show signals moving from the brain to the stomach and vice versa, as the text in this section explains can occur.

EVALUATE

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.

1 **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.

EVALUATE

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.

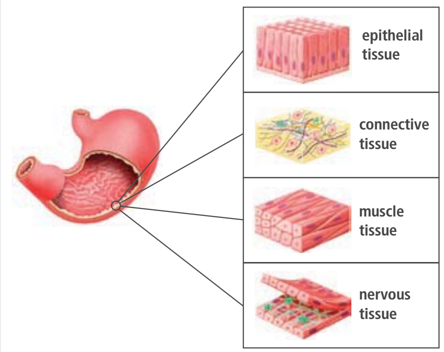
4. Draw a diagram to show the relationship between cells, organs, tissues, organ systems, and organisms. Include media and text in your diagram.

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.

Checkpoints

Answers

1. c
2. d, e
3. An organ is like an instrument or tool because it carries out a specific function. In addition, multiple instruments can be played together to produce one piece of music. This could be compared to the way organs work together to carry out specific tasks in the body.
4. Diagrams should show cells as the smallest system, followed by tissues, organs, organ systems, and organisms. Media could include drawings of cells packed together in a tissue, multiple tissues in an organ, and a system of organs interacting in an organ system.
5. A plant cell has a cell wall, which gives the cell rigidity and helps the plant stay upright. Cell walls can also adhere to each other, which maintains the overall structure of the plant. The central vacuole exerts pressure on the cell walls, providing additional support for the plant.
6. Chloroplasts - capture energy from the sun and produce sugars; Central vacuole - stores water and provides support for the plant; Cell wall - protects and supports cells and the plant system
7. **Sample answer:** The eyes and ears of the nervous system would transmit information that would signal the muscles of the hands and arms to contract. Muscle cells require oxygen and nutrients, which are transported to cells by the circulatory system. The digestive system breaks down food into nutrients, and the respiratory system exchanges gases with the blood.
8. Nervous tissue transmits electrochemical signals to and from other tissues in the stomach. Muscle tissue contracts to help the stomach churn food. Epithelial tissue excretes chemicals that break down food. Connective tissue provides support for the stomach.

Make Your Own Study Guide

Have students create a study guide that helps them organize and visualize the important information from this lesson. Their study guide should focus around the main ideas from the lesson and tie together multiple ideas. Students can create an outline, concept map, graphic organizer, or other representation.

LESSON 3

Mechanisms of Homeostasis

Building to the Performance Expectation

The learning experiences in this lesson prepare students for mastery of:

HS-LS1-3 Plan and conduct an investigation to provide evidence that feedback mechanisms maintain homeostasis.

Trace Tool to the NGSS

Go online to view the complete coverage of standards across lessons, units, and grade levels.

SEP Science & Engineering Practices

Planning and Carrying Out Investigations
Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly.

DCI Disciplinary Core Ideas

LS1.A Structure and Function
Feedback mechanisms maintain a living system's internal conditions within certain limits and mediate behaviors, allowing it to remain alive and functional even as external conditions change within some range. Feedback mechanisms can encourage (through positive feedback) or discourage (negative feedback) what is going on inside the living system. (HS-LS1-3)

CCC Crosscutting Concepts

Stability and Change
Feedback (negative or positive) can stabilize or destabilize a system.

CONNECTIONS TO MATH

MP.2 Reason abstractly and quantitatively.

MP.4 Model with mathematics.

CONNECTIONS TO ENGLISH LANGUAGE ARTS

WHST.9-12.7 Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.

WHST.11-12.8 Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the strengths and limitations of each source in terms of the specific task, purpose, and audience; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and overreliance on any one source and following a standard format for citation.

Supporting All Students, All Standards

Integrating the Three Dimensions of Learning

In this lesson, students will learn about various positive and negative feedback mechanisms that living organisms employ to maintain homeostasis **(DCI LS1.A).** They will explore and model disruptions to homeostasis **(CCC Stability and Change)** and understand how the human body responds. Students will design and conduct an investigation measuring the effects of exercise on the body **(SEP Planning and Carrying Out Investigations).**

Preassessment

Have students complete the unit pretest online or see the Assessment Guide.

Building on Prior Knowledge

In this lesson, students apply what they have learned about systems and the structure and function of living organisms to understand the integrated nature of systems necessary for maintaining homeostasis. Ask students what they already know about how different organisms maintain homeostasis. Create a classroom list that can be added to as students work through the lesson.

You may want to review the following concepts:

- Characteristics of life include being made of cells, the ability to obtain and use energy, and the ability to grow, develop, reproduce, and respond to the environment.
- Organ systems interact closely and the failure of one system can lead to the failure of other organ systems.
- Illness can be a temporary or long-term disruption to the functioning of one or more body systems.
- Molecules and other materials cross the membrane in several ways. Some methods require energy to be expended; others, such as diffusion and osmosis, do not.

Professional Development Go online to view **Professional Development videos** with strategies to integrate CCCs and SEPs, including the ones used in this lesson.

Content Background

Homeostasis is the process by which a living organism maintains a stable internal environment. It is often listed as a characteristic of life itself. Our brains often respond to changes without our even being aware of the regulatory mechanisms in place. Changes we can perceive include rapid breathing, sweating, or reddening of skin as blood vessels dilate. Maintaining blood pH is one example of homeostasis we are not consciously aware of. Humans can live within a pH range of about 7.0 to 7.8. When it is not carrying oxygen, hemoglobin acts as a buffer within blood by absorbing excess hydrogen ions. Most body systems maintain homeostasis through negative feedback mechanisms, which move imbalanced internal conditions back to the normal state. Blood vessels dilate and heartbeat slows when blood pressure rises, for instance. Positive feedback loops occur less commonly, as they create an even greater change rather than a return to a steady state. The cascading effects of uterine contractions during childbirth are an example of a positive feedback loop.

Differentiating Instruction

Lesson Vocabulary

- homeostasis
- stimulus
- hormone
- feedback loop
- negative feedback loop
- positive feedback loop

Scaffolding Understanding Increase students' comprehension of the lesson by providing them with a graphic organizer that builds as they learn more material, demonstrating how the new knowledge integrates with the previous material. As students become familiar with how the graphic organizer grows over time, provide less assistance in building it. Check the graphic organizers occasionally to gain insight into how students understand the new material.

ELL Support

Reinforcing Vocabulary Have students consider the word root *homeo-* and the meaning of *stasis*. Tell students that *homeo-* is from the Greek word meaning "similar" or "of the same kind." *Stasis* is a state in which things do not change, move, or progress. Ask them what the combination of those terms might mean before giving them the definition of homeostasis.

ENGAGE: Lesson Phenomenon

Build on Prior Lessons

In Lesson 2, students learned about how systems within an organism interact to carry out life functions. Lesson 3 builds on these concepts as students explore feedback loops and maintaining homeostasis.

Lesson Objective

Explain how positive and negative feedback loops help an organism to maintain homeostasis.

Can You Explain It?

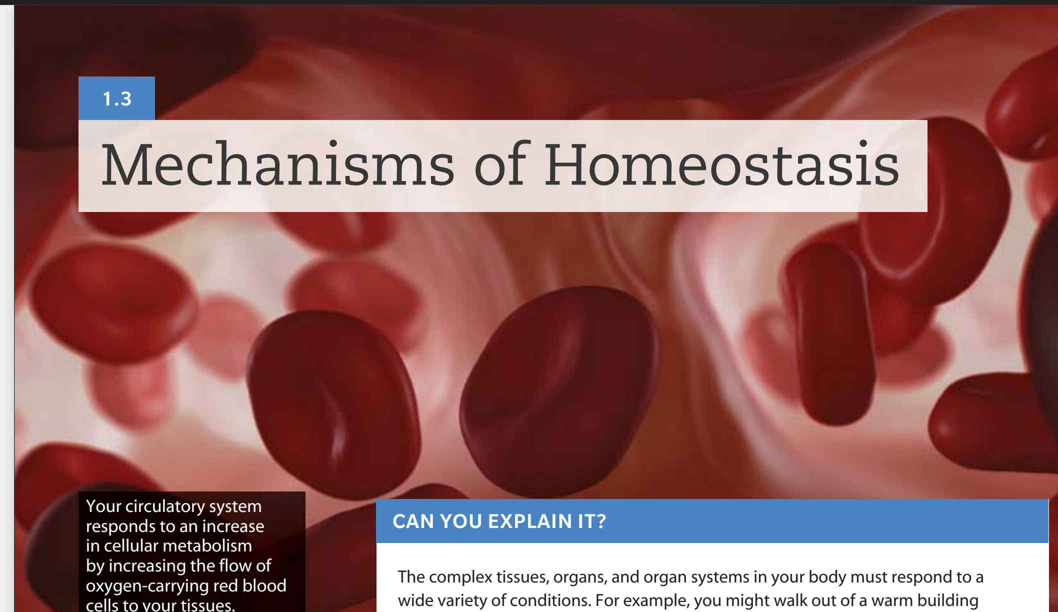
Students are asked to record their initial thoughts about how the human body responds to changing environmental conditions. Students will collect evidence throughout the lesson and revisit the question at the end to use what they have learned to explain how feedback loops help organisms maintain equilibrium.

Physical Science Connection

Equilibrium The return to a steady state is a common theme among many science disciplines. In physics terms, opposite and equal forces create a state of balance. In chemistry, equilibrium occurs when a chemical reaction and its reverse reaction occur at the same rate.

EVIDENCE NOTEBOOK

1. As students gather their evidence about how the body maintains homeostasis, encourage them to identify the feedback loop Involved, negative or positive.
2. Students might recognize that something has happened to make the brain think that the body is not warm enough.



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.

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

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.

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.

2 **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?

Image Credits: (t) ©Science Picture Co./Science Source; (b) ©Hero Images/Alamy

EXPLORATION 1 Control Systems in Organisms

EXPLORATION 1

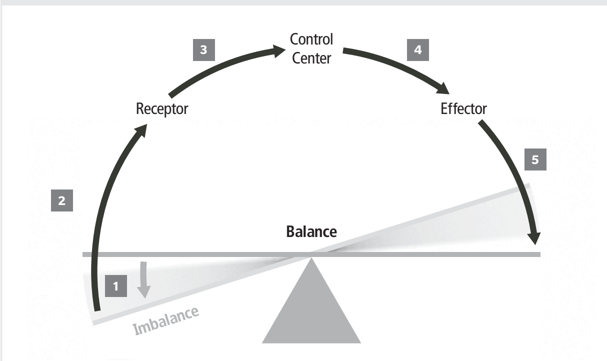
Control Systems in Organisms

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.

3 **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.

3D Learning Objective

Students analyze how **feedback mechanisms maintain a living system's internal conditions** as they use a model to **investigate** homeostasis. Students also show how **feedback can stabilize or destabilize a system.**

Collaboration

Discuss Remind students that changes in the environment go beyond just temperature. For example, what happens to our bodies after an extended time in water?

Sample Answer: Our fingertips and toes begin to wrinkle.

Exploring Visuals

Balance After students study the image of the balance in Figure 2, ask questions and discuss the answers to enhance their understanding.

Ask: *When the balance tips like a seesaw, what will draw it back into a level position? Use the language provided in the diagram.* The receptor recognizes the imbalance and messages the control center, which dispatches a signal to an effector.

Ask: *What is an example of a receptor, control center, and effector that might work together? Use the examples provided in the text.* A receptor might be a specialized skin cell, the control center may be the brain or spinal cord, and an effector may be a muscle.

EVIDENCE NOTEBOOK

3 Examples of changes in the external environment include changes in air temperature, light intensity, humidity, oxygen levels, air pressure, pollution, toxins, and the presence of disease-causing organisms. In the case of changing light conditions, *receptors* in the eye respond to the light *stimulus* and sends signals to the *control center* (i.e., the brain). The brain responds to the *imbalance* by sending a signal to muscles in the eye, the *effectors,* to change the size of the pupil from its *set point* to relieve the *imbalance.*

Language Arts Connection

Summarizing After students read this passage, have a volunteer summarize when the brain is involved in a response and when the spinal cord acts as the control system. For example, doctors test reflexes by tapping the area under the knee cap while the foot dangles above the ground. Would the brain be involved in that response? What are the benefits of not engaging the brain in every response? The brain is not involved in this simple reflex response. Responses are quicker if they do not need to involve the brain.

Hands-On Activity
Modeling Feedback

SEP Scientific Investigations Use a Variety of Methods

Students attempt to balance a book on their heads while walking, both with their eyes opened and closed. They consider what compensations they need to make in their postures so the book doesn't fall. Have students suggest other ways they could model feedback using skeletal muscles.

Analyze

1. Pressure/touch receptors in the skin of the scalp
2. Student answers will vary, but most likely will indicate that students changed their posture and/or their speed when they felt the book move. They are most likely to indicate that it was more difficult to maintain the book's balance when walking with eyes closed because it was necessary to divide attention between the book and determining their own location in space.

EVIDENCE NOTEBOOK

1. When receptors in the surface of the skin sense cold, the stimulus, they send signals to the brain, the control center. The brain responds by sending signals to skeletal muscles, the effectors, which then expand and contract to expend energy and so generate heat, which removes the imbalance.
2. You may need to modify your posture to lean to the left or the right to compensate if you sense the book is moving in the opposite direction.

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

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.

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.

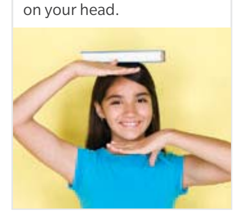
Unlike the nervous system, the endocrine system uses a more indirect—but still rapid—method of communication. Hormones are chemicals secreted into the bloodstream by ductless endocrine glands. The hormones then travel throughout the body, acting only on cells that have receptors for those particular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

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



MATERIALS
- Hardcover book, at least 6" × 8"

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.

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

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.

34 Unit 1 Living Systems

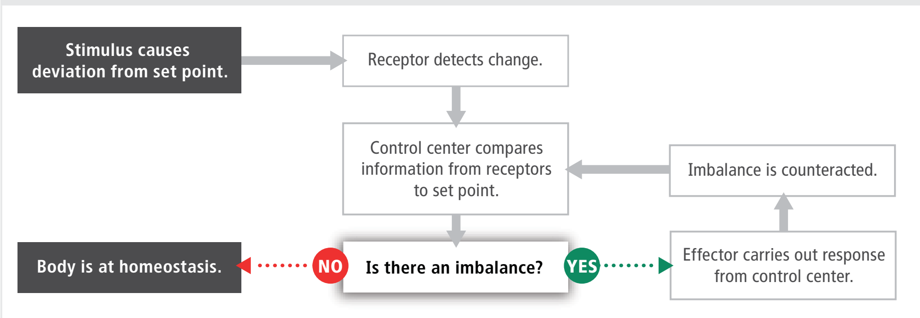
Negative Feedback Loops

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.

3 **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.

DCI LS1.A Structure and Function

Students should understand that feedback mechanisms work to keep internal conditions within certain limits and that response mechanisms may include behaviors.

Exploring Visuals

Flow Diagram Ask students to explain how a person exercising in hot weather would maintain homeostasis. Have students refer to Figure 4 in their explanation.

Collaboration

Discuss Have students work in small groups to discuss how feedback mechanisms might relate to slower movement and a greater likelihood of falling in an elderly adult.

Ask: *What is likely the reason for a slower response to stimuli as a person ages?* slower signal transmission from the receptor to the control center or from the control center to the effector

Differentiate Instruction

Extension Have students use Figure 4 to explain how orthotics might help to prevent falls in the elderly. Orthotics may help convey sensory information to the feet.

EVIDENCE NOTEBOOK

3 When *receptors* in the skin and body core detect an *imbalance* in temperature, they send information to the brain, which is the *control center* for the body. The brain sends a response to the proper *effectors* that will bring body temperature back to *set point*. If the body temperature is too low, the *effectors* are the muscles. If the body temperature is too high, the *effectors* are the sweat glands.

Exploring Visuals

Flow Diagram Ask students to compare Figures 4 and 5. How might the actions represented by the additional box in Figure 5 lead to a quicker response for a positive feedback loop to achieve homeostasis?

Sample answer: It does not require input from the control center every time the imbalance is counteracted.

Collaboration

Think-Pair-Share Have student pairs discuss how positive feedback mechanisms promote labor contractions.

Answer: Since labor is a positive feedback loop, the uterine contractions must stimulate the release of more oxytocin, which stimulates even more contractions directly and through the release of prostaglandins from the placenta.

EVIDENCE NOTEBOOK

1 Water balance is maintained by a negative feedback loop. When water levels in the body are too low, we drink water to restore them to homeostasis. Because the feedback is restoring lost water, it is returning the water level back to set point. If it were a positive feedback loop, it would be moving the water balance further away from the set point.

FORMATIVE ASSESSMENT

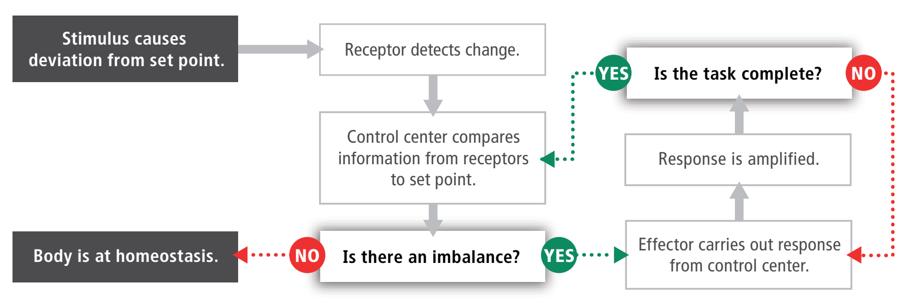
Which Is False? Ask students to look back through the section. Have them write three statements: two true statements and one false. Have students share their statements with the class and see if they can determine which statement is false.

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.

1 **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.

EXPLORATION 2 Homeostasis in the Human Body

EXPLORATION 2

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

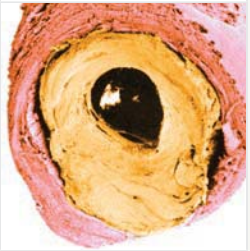
All of your body systems interact to maintain homeostasis, much like a group of dancers interact to perform a highly choreographed ballet. If one dancer misses a cue, it throws the rest of the dancers out of step and time. Consider the importance of a healthy blood pressure to the body. Blood pressure 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.

FIGURE 6: Blocked Artery



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

3D Learning Objective

Students **carry out investigations** to explore how disruptions to **feedback mechanisms** can affect **a living system.** Students analyze data to determine **how feedback can change a system.**

Explore Online

Hands-On Lab

Negative and Positive Feedback

SEP Carrying Out Investigations

Students analyze data and generate graphs to determine whether a process is an example of a negative or positive feedback loop.

Student Lab Worksheet and complete Teacher Support available online.

Chemistry Connection

Glucose Point out that glucose is a simple sugar, or monosaccharide, with the chemical formula $C_6H_{12}O_6$. Besides traveling through the blood stream of many organisms, it is the building block for the starch and cellulose of plants.

Differentiate Instruction

Extension Have students look up ways that extreme athletes fuel up before and during a competition.

EVIDENCE NOTEBOOK

2 **Sample answer**: High or low blood pressure can result in the organs receiving an unacceptable amount of blood. The circulatory system cannot remove wastes as quickly as it should, and clots could form. This can cause the heart to beat more rapidly and become enlarged. If the brain does receive an acceptable supply of oxygen, high- and low-blood-pressure sufferers will feel light headed.

Collaboration

Pairs Divide the class into pairs, and have students look up glycemic index and glycemic load.

Ask: *What is the relationship between glycemic index and glycemic load?* Glycemic index is a measure of how a food affects blood sugar levels. Glycemic load measures how much effect a normal-size serving of the food will have on blood sugar.

Have students choose ingredients for a breakfast, lunch, and dinner that would provide a low glycemic load.

Misconception Alert

Students may be unclear about which terms mentioned in the text are part of the endocrine system. Emphasize to them that insulin and epinephrine are chemical messengers, or hormones, and thus are part of the endocrine system. The pancreas is a gland of the endocrine system, and the liver has secondary endocrine functions, including hormone production and regulation of glycogen storage.

Explore Online

Hands-On Lab
Investigating Homeostasis and Exercise

SEP Carrying Out Investigations

Student lab and worksheet and teacher support available online. This lab is also available on the Elaborate page for this lesson.

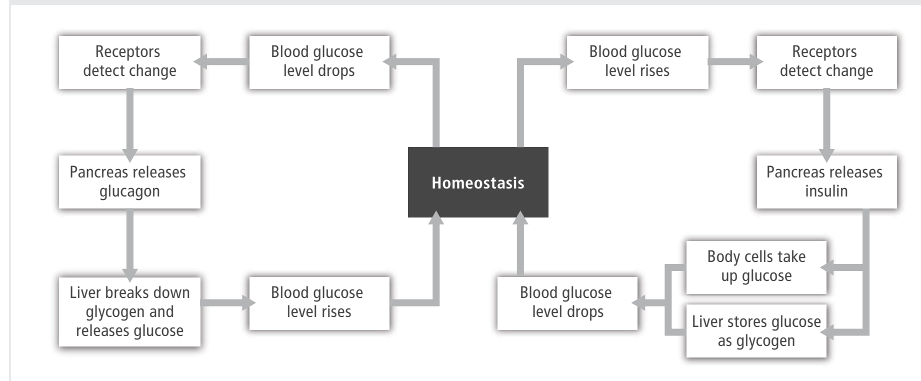
EVIDENCE NOTEBOOK

1 These are negative feedback loops because an increase in blood glucose levels causes the release of a hormone that stimulates a reduction in blood glucose levels.

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.

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

Explore Online

Hands-On Lab

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

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.

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

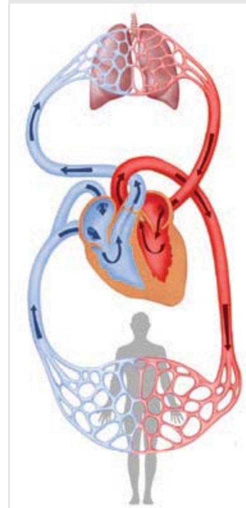
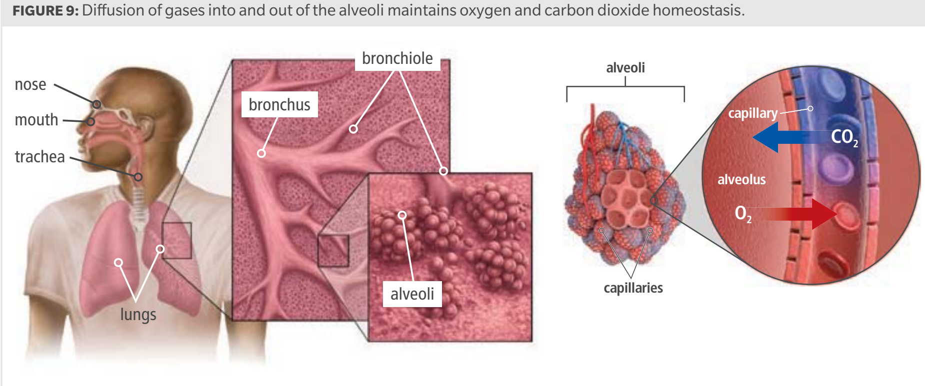


FIGURE 9: Diffusion of gases into and out of the alveoli maintains oxygen and carbon dioxide homeostasis.



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.

2 **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?

Physical Science Connection

Radiators The circulatory system is also involved in homeostasis for warming and cooling of the body. The effect is similar to how a radiator dissipates heat. Blood vessels dilate when the body is too warm, bringing more blood nearer to the skin's surface, causing more heat to be lost. When the body is too cold, blood vessels near the skin's surface constrict (vasoconstriction), conserving body heat.

Exploring Visuals

Gas Exchange Have students watch the animation before they create the flow chart explaining the CO_2 and O_2 homeostasis mechanism.

Ask: *Which organ systems are mainly involved in gas exchange in humans?* the nervous, respiratory, and circulatory systems

Ask: *What is the function of each of these systems in terms of gas exchange?* The nervous system monitors the CO_2 and O_2 concentrations in the blood. The respiratory system moves O_2 into the body and CO_2 out of the body. The circulatory system delivers O_2 directly to cells and removes CO_2 as waste.

Differentiate Instruction

Extra Support Provide context for students by explaining the different types of transport our bodies use. Diffusion is a type of passive transport, requiring no energy from the body as substances move from higher concentrations to lower concentrations. Active transport requires energy, and can work in the opposite direction, moving substances from lower concentrations to higher.

EVIDENCE NOTEBOOK

2 Flow charts should show that O_2 concentration is higher in inhaled air and CO_2 is higher in exhaled air. Charts should also make clear that it is the difference in each gas's concentration in the blood that causes diffusion to occur across the membranes.

DCI LS1.A Structure and Function

Students learn that disruption can occur to the body's ability to maintain internal conditions within certain limits. This lessens the body's ability to remain functional over a short or long timeframe.

Collaboration

Whip Around Have students write the response, positive or negative feedback loop, and one to two reasons why they think this is correct. Call on students to share their answers with the class.

Answers may vary. For example, the production of antibodies is a positive feedback response because their production is amplified in response to the presence of virus particles. Fever is an example of negative feedback, as the body adjusts to the new set point for body temperature.

Evolutionary Biology Connection

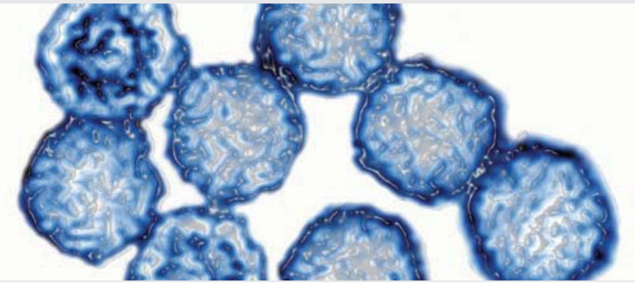
"Goosebumps," also known as "chicken skin" or "goose pimples," are little elevations of the skin caused by contraction of small muscles attached to each hair on our skin. The muscle contraction creates a depression in the skin, causing the surrounding areas to rise up. This response helps animals with a thick fur coat to retain heat so the fur can trap more air close to their bodies. In humans, the response persists as a vestigial response, a remnant trait that has lost function over the course of evolution.

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.

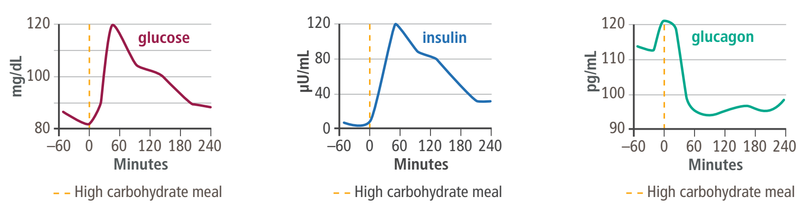
Data Analysis

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.

1 **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.

2 **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.

Data Analysis

MP.4 Model with mathematics

Students will use three graphs, each showing levels of glucose, insulin, and glucagon, to understand direct and inverse relationships.

EVIDENCE NOTEBOOK

1 **1.** Glucose is directly related to insulin, which is inversely related to glucagon. Therefore, glucose is also inversely related to glucagon.

2. In Type I diabetes, the levels of insulin would remain low after a meal. The levels of glucose in the blood would continue to rise after a meal instead of dropping quickly as they would if insulin were released and only begin to drop gradually as glucose is used by cells. Glucagon levels would not rise much, if at all, before a meal, because glucagon is only released when blood glucose drops below the set point.

2 Answers will vary. Students may cite blood pressure as one variable. The brain signals the heart to beat more rapidly or more slowly to maintain an acceptable blood pressure. Clots in arteries or restricted arteries can upset homeostasis and prevent blood pressure from falling into normal levels.

FORMATIVE ASSESSMENT

Oral Questioning Use the following questions to review the Explorations with the class:

Ask: *How do the brain, heart, and blood vessels work together to maintain blood pressure?* If blood pressure is too low, the brain tells the heart to beat faster, and pressure is exerted on blood vessels. If pressure becomes too high, the heart will slow its rate.

Ask: *Why is maintaining glucose levels so important for brain function?* Glucose is used for energy and for making neurotransmitters.

Ask: *What is an example of a short-term disruption to homeostasis? A long-term disruption?* Short term: a cold; Long term: Cushing's syndrome.

EXPLORATION 3 Homeostasis in Other Organisms

3D Learning Objective

Students consider how **feedback mechanisms maintain internal conditions** of organisms other than humans. Students use a model to examine how **feedback mechanisms stabilize** plants affected by drought. Students also **investigate** the effects of exercise on homeostasis.

Collaboration

Discuss Students may not connect that loss of water not only causes stomata to close but also the plant to wilt. If water is provided before too much cellular damage is done, a plant will bounce back to its normal turgid, upright position. Provide students with the following plant adaptations, and have them hypothesize the benefit of the adaptation to the plant.

- large surface area
- waxy cuticle on upper surface of leaf
- few stomata on top surface of leaf
- few stomata on desert plant leaves

Large surface area to maximize photosynthesis; waxy cuticle to prevent water loss from epidermal cells; few stomata on tops of leaves and in desert plants to reduce water loss

EVIDENCE NOTEBOOK

1. Answers will vary. Students might suggest different animals such as reptiles, birds, amphibians, and fish, or even invertebrates. They may also opt to choose a non-animal organism, such as algae or bacteria. Accept all reasonable answers.
2. stimulus—low soil moisture; control center response—release of abscisic acid; effector—guard cells; response—closing of the stomata

EXPLORATION 3

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.

1 **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.

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

Stability and Change

Plant Response to Drought

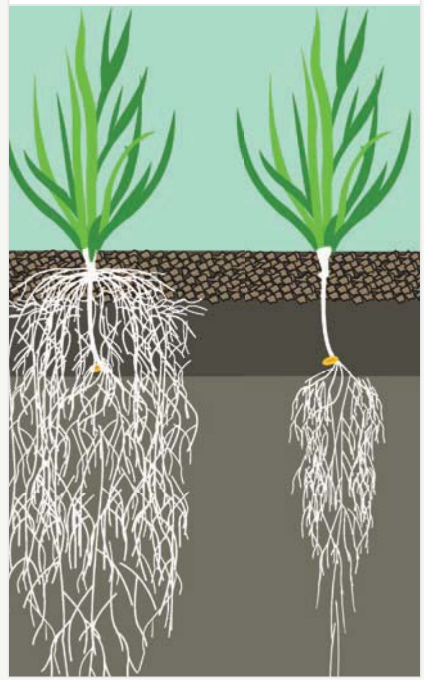
How does a plant cope with long-term or recurring water stress? Again, the homeostatic mechanism begins with the roots. One of the effects of drought is to alter the way roots grow in various plants. For example, when the plant maidenstears (*Silene vulgaris*) experiences moderate drought-stress, its 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.

3 **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.

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

Image Credits: ©marinaqliuxova 30/Fotolia

CCC Stability and Change

Students make a model to simulate how a plant's systems interact to maintain homeostasis during drought conditions.

Language Arts Connection

Research Have students conduct a short research project to learn about the plants discussed: maidenstears, *Silene vulgaris*, and myrtle, *Myrtus communis*. Students should find photos of the plants in bloom, as well as learn about their habits and abundance. Maidenstears is common along roadsides and meadows in North America and is largely considered a weed. In Europe, however, young plants are sometimes used in salads. Myrtle is a small tree planted in warmer areas in the United States, where it produces a showy and fragrant flower that attracts birds.

WHST.9-12.7 Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.

EVIDENCE NOTEBOOK

3 Models will vary, but should demonstrate that during drought conditions, plants try to either extend roots to absorb more water or develop coatings to prevent the water they've already absorbed from diffusing back into the soil. Models should in some way indicate relative water concentrations.

4 Thermoregulation is a type of negative feedback, because it reduces body temperature when it exceeds set point and raises body temperature when it drops below set point. For example, when a human becomes overheated, the brain stimulates a sweating response that helps cool the body by evaporation.

Language Arts Connection

Word Roots *Osmo-* is a Greek root meaning pushing. It is often used to mean absorb, such as osmotrophy, a mode of nutrition by which an organism such as a parasite or fungus absorbs food.

Collaboration

Think-Pair-Share Before students analyze the problem, suggest that they briefly review the basic points of osmosis and concentration gradients, and then apply these to the problem at hand.

Answer: Because the salt water has been diluted by the river water, the fish will have to drink more water and decrease salt excretion through its gills in order to maintain salt balance. Because water intake has increased, water excretion will also need to be increased to maintain osmotic balance.

EVIDENCE NOTEBOOK

1 Answers will vary based on the animals selected and the homeostatic mechanisms explored. Accept all reasonable answers.

FORMATIVE ASSESSMENT

Three-Minute Pause Have students pause to think of the concepts presented in this section and in the lesson. Have them respond to the following prompts.

I became more aware of…

I didn't realize that…

I still don't understand…

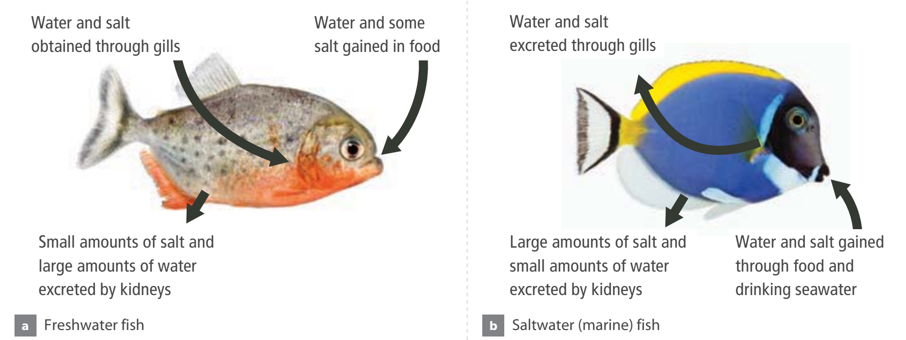
Have volunteers share their responses with the class.

Extension Have students research how osmoregulation occurs in human kidneys.

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.



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.

1 **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.

CONTINUE YOUR EXPLORATION Hands-On Lab

CONTINUE YOUR EXPLORATION

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.

FIGURE 15: Increased activity can affect homeostasis.

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

Student Lab Worksheet and complete Teacher Support with Scoring Rubric are available online.

Hands-On Lab Small Groups 30 minutes

Investigating Homeostasis and Exercise

SEP Planning and Carrying Out Investigations

Students plan and conduct a collaborative investigation, determining the role of each group member and how to best collect data on the effects of exercise on homeostasis. Student lab worksheet and teacher support available online.

Analyze

1. Check student graphs. Graphs should show increases in heart rate, breathing, and perspiration as exercise increases.
2. Students should conclude that prolonged exercise generally tends to increase the variables measured.
3. Students might suggest using more accurate measuring devices, like smartwatches with specialized sensors. They may attribute errors to inaccurate measurements or data collection.
4. Perspiration removes excess heat generated during physical activity. The "sweat" absorbs the body's heat and evaporates.
5. Feedback loops should show that increased exercise results in increased activity in both the circulatory and respiratory systems.

EVIDENCE NOTEBOOK

2 Students will likely predict that the heart will beat faster, breathing rate increase, and perspiration levels rise with exercise and decrease gradually once exercise is stopped.

Explore Online

Disorders of the Endocrine System

Students learn about adrenal insufficiency and thyroid disorders.

Explaining Homeostasis

Students can extend their learning about homeostasis by researching examples of homeostasis in humans and other organisms.

EVALUATE Lesson Self-Check

Can You Explain It?

DCI LS1.A Structure and Function

Students identify how feedback mechanisms cause humans to shiver when they have a fever.

EVIDENCE NOTEBOOK

1
1. By shivering, the body is trying to increase the internal body temperature to meet the new, higher set point caused by the fever.
2. Shivering with fever is a negative feedback response. The increase in body temperature causes an imbalance in body temperature. The body responds to bring the body temperature back to normal set point: the normal body temperature range.
3. Fever, or increased body temperature, is the *stimulus* that disrupts the body's normal temperature *set point*. The body's internal thermostat, or *receptor,* senses the colder internal temperature because the internal temperature is below the new set point. The *control center* (i.e., the brain) responds to the *imbalance* by sending a signal to muscles, the *effectors*, to begin shivering to raise the internal temperature closer to the new set point.

Collaboration

Cultivating New Questions As students complete this lesson, encourage them to identify additional questions they have about maintaining homeostasis in human body systems. They may wish to record the questions in their Evidence Notebook for reference as they study Lesson 4.

EVALUATE

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.

1 **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.

Formal Assessment Go online for student self-checks and other assessments.

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.

Checkpoints

Answers

1. c
2. c
3. b
4. a, c
5. The mother will eventually stop producing milk. Milk is not being removed during breastfeeding, so the stimulus to replenish it will not be present.
6. This is positive feedback, because the loss of blood makes the heart pump harder to increase output, which causes greater blood loss. The heart continues to pump even harder, leading to more blood loss until the patient bleeds out.
7. The lower temperatures and higher humidity reduce the amount of water lost due to evaporation from respiration and sweat.
8. The liver would no longer be able to release stored glucose in response to low blood sugar levels.
9. The brain stem would signal the muscles to contract more rapidly to increase the amount of CO_2 being exhaled.

Make Your Own Study Guide

Have students create a study guide that helps them organize and visualize the important information from this lesson. Their study guide should focus on the main ideas from the lesson and tie together multiple ideas. Students can create an outline, a concept map, a graphic organizer, or other representation.

Differentiate Instruction

Extra Support Create a partially filled study guide to guide students in organizing their ideas. Have students fill in the rest then compare their ideas to a partner's to answer any questions.

On-Level Have students create their own study guide that answers all of the information outlined in the Student Edition. When they are complete, pair students with below-level learners to reinforce the material.

LESSON 4

Bioengineering

Building to the Performance Expectations

The learning experiences in this lesson prepare students for mastery of

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

HS-ETS1-2 Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

HS-ETS1-3 Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.

Trace Tool to the NGSS

Go online to view the complete coverage of standards across lessons, units, and grade levels.

SEP Science & Engineering Practices

Constructing Explanations and Designing Solutions
Design and evaluate a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.

Developing and Using Models
Develop and use a model based on evidence to illustrate the relationships between systems or between components of a system.

DCI Disciplinary Core Ideas

LS1.A Structure and Function
Multicellular organisms have a hierarchical structural organization, in which any one system is made up of numerous parts and is itself a component of the next level. (HS-LS1-2)

ETS1.B Developing Possible Solutions
When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. (HS-ETS1-3)

ETS1.C Optimizing the Design Solution
Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed. (HS-ETS1-2)

CCC Crosscutting Concepts

Systems and System Models
Models can be used to simulate systems and interactions—including energy, matter, and information flows—within and between systems at different scales.

Influence of Science, Engineering, and Technology on Society and the Natural World
New technologies can have deep impacts on society and the environment, including some that were not anticipated. Analysis of costs and benefits is a critical aspect of decisions about technology.

CONNECTIONS TO MATH

MP.2 Reason abstractly and quantitatively.

MP.4 Model with mathematics.

CONNECTIONS TO ENGLISH LANGUAGE ARTS

SL.11-12.5 Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest.

RST.11-12.7 Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem.

RST.11-12.9 Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.

Supporting All Students, All Standards

Integrating the Three Dimensions of Learning

In this lesson, students will analyze technologies that have influenced human health to define benefits and risks **(DCI ETS1.B).** They will predict ways in which technology influences society and society influences technology. Students will define a bioengineering problem and outline criteria and constraints for the solution **(DCI ETS1.B).** They will explain how the engineering design process could be used to evaluate a solution to a human health problem **(SEP Scientific Investigations Use a Variety of Methods, CCC Influence of Science, Engineering, and Technology on Society and the Natural World).** Students also design their own biotechnology solution to a problem **(SEP Constructing Explanations and Designing Solutions)** and create a model to test their solution **(SEP Developing and Using Models, CCC Systems and System Models).**

Preassessment

Have students complete the unit pretest online or see the Assessment Guide.

Building on Prior Knowledge

In this lesson, students apply what they have learned about systems and engineering processes to the development of engineered systems for living things. Call on students to tell what they know about engineering as it relates to living systems, and what considerations need to be included when designing engineered solutions to very human problems.

You may want to review the following concepts:

- A system is a set of interacting components defined by its boundary from the universe. Systems can be studied by analyzing interactions among their components.
- An organism is a type of living system. Cells, tissues, organs, and organ systems interact to carry out specific functions that help maintain homeostasis within a living system.
- A model can be used to study the interactions within a system and between two or more systems. Models can be physical, mathematical, or conceptual.

Professional Development Go online to view **Professional Development videos** with strategies to integrate CCCs and SEPs, including the ones used in this lesson.

Content Background

Bioengineering is an application of engineering to living things. Although there is not a single method for engineering design, the steps often include defining and delimiting the problem, designing a solution, and optimizing design solutions. Each of these steps might be broken down into smaller steps. Defining and delimiting the problem can include identifying the problem, developing criteria, identifying constraints, and conducting research. Designing a solution can include brainstorming solutions, prioritizing criteria, considering tradeoffs, and deciding on a development procedure. Optimizing design solutions can include building a working model and analyzing it based on test results.

Like all aspects of engineering, the design process of bioengineering involves developing or improving technology. Technology is the application of scientific knowledge for practical purposes. This application always involves analyzing benefits, risks, and costs. Designing technology for living systems must always include consideration of how it will affect quality of life. Bioioengineering applies the concepts of engineering to living things whereas biotechnology uses and applies living things and biological processes as part of the technology or product.

Differentiating Instruction

Lesson Vocabulary

- technology
- bioengineering
- biotechnology
- engineering design process

Reinforcing Vocabulary Students have likely heard the word *technology* used in everyday life. Ask volunteers to state what they think it means and to give examples of items that are technology and items that are not technology. Lead them to a definition of technology as the application of scientific knowledge for practical purposes. Explain that in this lesson they will learn about ways technology can be applied to living systems.

ELL Support

Pre-Reading Increase students' comprehension of the lesson by having them read through the headings of each section and looking at the pictures. Engage students by asking them what they think each section is about and what they might learn from it. Discuss how the pictures show scenes that are relevant to students' lives.

ENGAGE: Lesson Phenomenon

Build on Prior Lessons

In Lesson 3, students learned about how organisms, particularly humans, maintain homeostasis. Lesson 4 builds on these concepts as students explore the integration of biotechnology in human body systems to improve human health.

Lesson Objective

Explain how bioengineers design and evaluate solutions to human health problems.

Can You Explain It?

Ask students to record their initial thoughts about features you would need to consider when designing a battery for a pacemaker. Students will collect evidence related to this phenomenon throughout the lesson and revisit the question at the end of the lesson to explain how a nonliving device can be designed to work with a living system.

Physics Connection

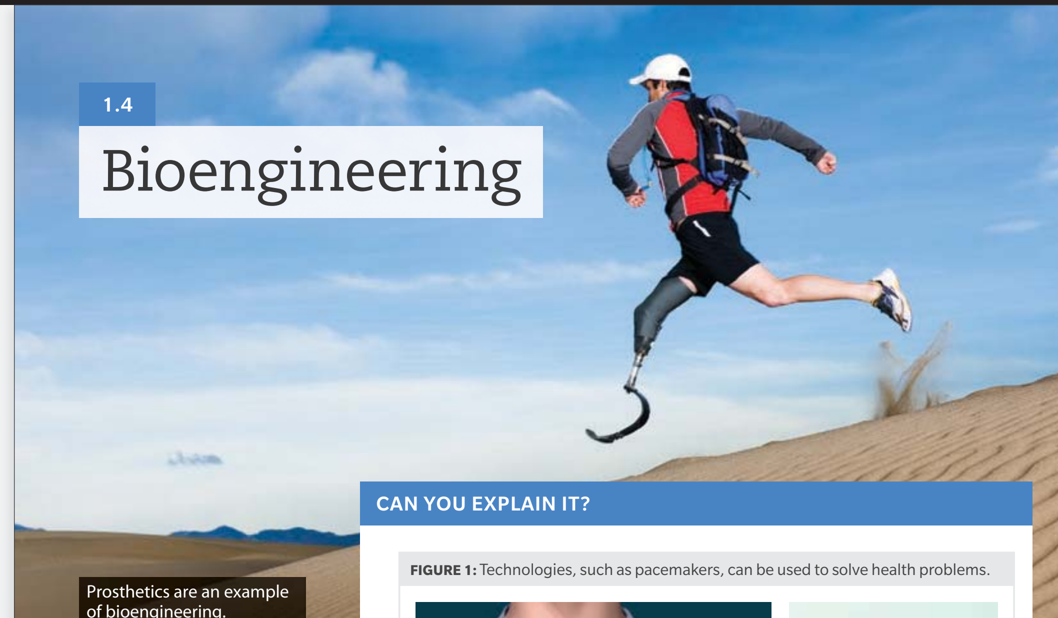
Cardiac Stimulation Electrical impulses generated by a pacemaker travel to the heart through a lead that contains conducting wire. The lead may have one electrode at its tip and one electrode a short distance back from the tip. The tip electrode is the cathode (negatively charged), and the electrode back from the tip is the anode (positively charged). An electric impulse from the battery travels through the cathode, into the heart muscle, and back through the anode.

EVIDENCE NOTEBOOK

1. To design living and nonliving systems to work together most effectively, it's important to know how each system works. The problem should be clearly identified so that the design meets the need. Other considerations are the costs, benefits, and risks involved in implementing the technology.
2. Ask students to think about what features a battery for a pacemaker would need to have. Prompt them as needed to consider such things as it's size, the life of the battery, and the materials with which the battery is made.

1.4

Bioengineering

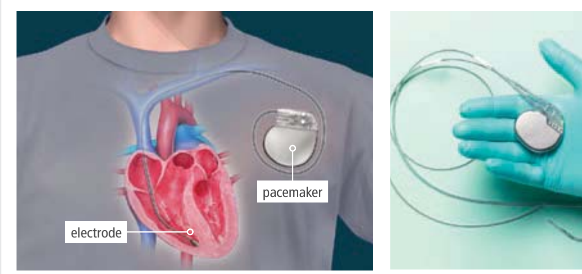


Prosthetics are an example of bioengineering.

1 **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.

2 **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?

EXPLORATION 1 Technology and Living Systems

EXPLORATION 1

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.

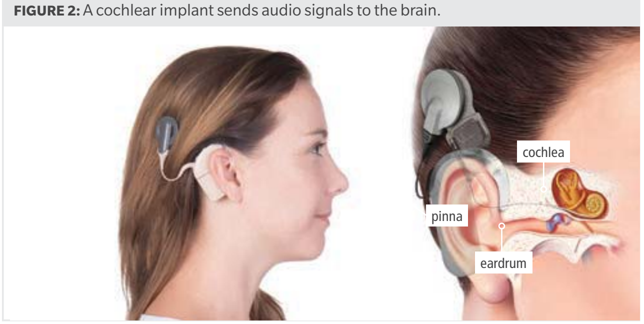


Image Credits: (l) ©iStock/ElizabethHoffmann/Getty Images Plus

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.

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

3D Learning Objective

Students analyze technologies that have influenced human health to **identify a range of constraints and social impacts** to **evaluate potential solutions.** They then **predict ways in which technology influences society and society influences technology.**

Collaboration

Discuss Remind students that "technology" does not always mean a complex machine but may be a very simple device. For example, a light bulb is an important, but relatively simple, technology. Other "simple" technologies students might mention are electric toothbrush, hair dryer and alarm clock.

Exploring Visuals

Cochlear Implant Have students study the image of the cochlear implant in Figure 2. Ask the following questions.

Ask: *What are the steps in hearing a sound experienced by a person who does not have hearing problems?* Sound waves are collected by the pinna and are funneled through the ear canal, causing the eardrum to vibrate. These vibrations are amplified by three tiny bones in the ear and transferred to the fluid-filled cochlea. Tiny hairs in the cochlea send electrical signals to the brain where it is perceived as sound.

Ask: *Why is the cochlear implant's electrode array placed in the cochlea instead of some other part of the ear?* In the cochlea, the electrode array can send impulses directly to the auditory nerve that carries the signals to the brain.

EVIDENCE NOTEBOOK

3 Bones and tiny hairs in the inner ear convert sound into electrical signals that the auditory nerve sends to the brain. The cochlear implant uses a microphone to capture sound and a processor to convert the sound into electrical signals that the auditory nerve can transfer to the brain.

Language Arts Connection

Understanding the Big Picture After students have read this Exploration, ask for volunteers to name a key point in what they have read. Lead the class in discussing how the key points fit together to get the overall meaning of the content. Next ask students to describe how this content fits with what they have read in the previous lessons, focusing on system properties, hierarchy, and models.

CCC Influence of Science, Engineering, and Technology on Society and the Natural World

Read aloud this portion of the text that explains how emergency medical technology has changed society.

Ask: *What are society's expectations for emergency medical care today that people did not have in the past?*
Sample answer: Advances in medicine and medical care have allowed people to live longer. Many injuries and diseases that were once fatal now have treatments.

Ask: *How do technological advances making emergency medical care better today specifically relate to better medical treatments?*
Sample answer: Better automotive designs make ambulances faster and more reliable. In some cities, ambulance drivers are able to regulate traffic lights so they can get a patient to a medical facility more quickly. Ambulances today are equiped with medical devices that can provide needed treatment en route to a medical facility, increasing a patient's chances of survival.

Ask: *How have improvements in emergency medical technology changed our society?*
Sample answer: Improvements in emergency medical technology have allowed many more lives to be saved, because emergency medical technicians and even doctors can provide critical care to patients much more quickly.

EVIDENCE NOTEBOOK

1. Life scientists and engineers work together closely to bioengineer solutions. For example, before a technology can be designed to address a medical problem, the problem must be understood from scientific and engineering views.

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.

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

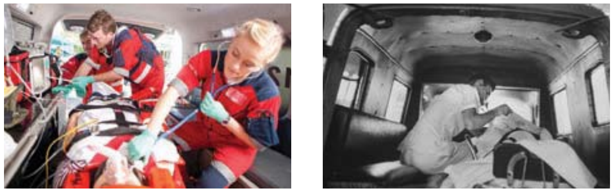
In the case of the cochlear implant, scientists asked questions to learn more about the phenomena of hearing. Scientists might have asked, "How do the ear and brain interact to detect sound?" or "Which structures are affected in patients with hearing loss?" Engineers designed the cochlear implant using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

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.

2 **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.

DCI ETS1.B Developing Possible Solutions

Prepare students for the next Exploration with a discussion about developing solutions, such as vaccines or obtaining safe drinking water. Solutions should address various constraints, such as cost, safety, and reliability. Also, they should consider the impact of each possible solution on society, on culture, and on the environment.

Exploring Visuals

Engineering Designs Have students describe what is happening in Figure 4. An improved design of the water transportation system includes a small barrel inside the larger barrel. As a person pushes the larger barrel, the smaller barrel spins and pulls water from the larger barrel through a filter and into the smaller barrel. In this way, the water is filtered at the same time that it is transported.

Collaboration

Discuss Have students work in small groups to discuss the question and make lists for each type of impact (societal, cultural, and environmental) to consider. Afterward, bring the class back together and have groups share their lists. You may wish to place certain constraints on the water filters that students design.

EVIDENCE NOTEBOOK

2 Answers will vary. Students should define the problem and discuss the solution, including potential benefits, risks, costs, and the impact on society. Students may also identify any tradeoffs when weighing the benefits against risks and costs.

FORMATIVE ASSESSMENT

One-Sentence Summaries Ask students to look back through the Exploration. Have them read each heading and look at the pictures. Then have them write a one-sentence summary describing the main idea for the text under each heading.

EXPLORATION 2 Engineering in Life Science

3D Learning Objective

Students **design a solution** to a bioengineering problem and **outline criteria and a range of constraints for the solution**. Students explain how the engineering design process could be used to **evaluate a solution** to a health problem. They develop and **use a model to simulate a system** and to **illustrate the relationships between components of the system**.

Differentiate Instruction

Extra Support Ensure that students understand how to use the engineering design flow chart. For example:

Ask: *What is the next step if the model meets most, but not all, criteria and constraints?* Make design changes to improve your model.

Ask: *What is the next step if you realize during the process that you don't have a thorough understanding of the problem?* Learn more by conducting additional research on the problem and previous solutions to similar problems.

Enrichment Have students choose a sample engineering project, such as building a new type of bookshelf or building a new style of tennis racquet. Then have them make a T-chart with the name of each step in the engineering design process on the left and a short description of how the step might happen in the design of the project they have chosen.

EXPLORATION 2

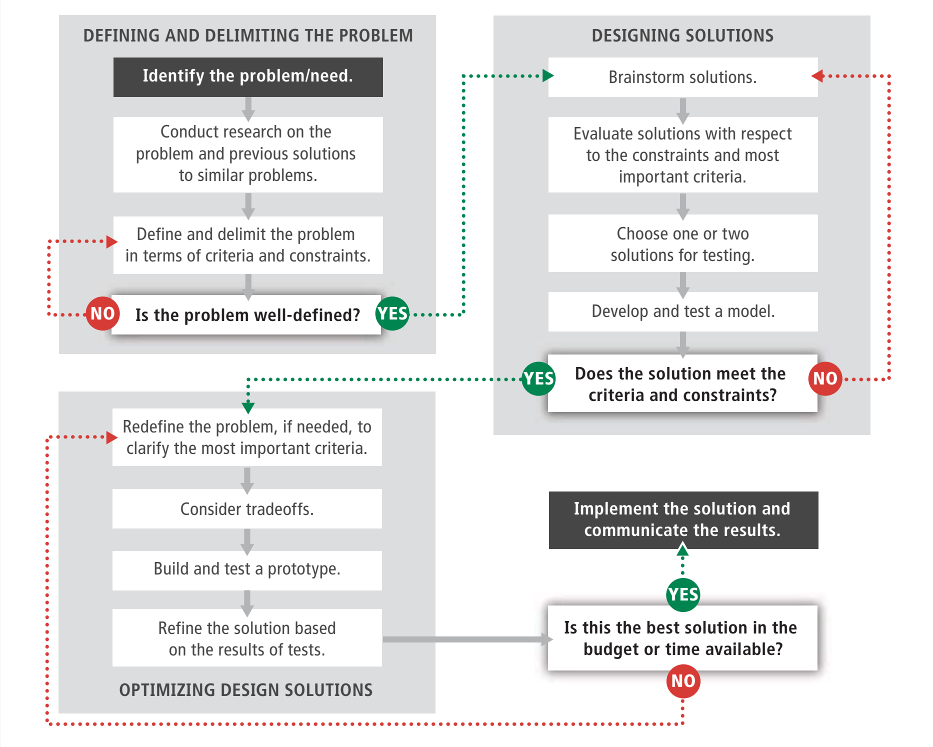
Engineering in Life Science

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.



52 Unit 1 Living Systems

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.

1 **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.

Collaboration

Numbered Heads Together Divide the class into groups, and have them assign a number to each group member. Have them look at the engineering design process flow chart and discuss the advantages of an iterative process. Call numbers from each group to share their thoughts. Students should realize that using feedback from tests and models can continually improve a design solution until it meets all criteria and constraints.

Misconception Alert

Emphasize to students that repeating steps in a design process does not mean looking for mistakes or flaws in the design. Tests or models may show that a design doesn’t work as expected or reveal a better method or design that will work better.

Explore Online

Hands-On Lab
Modeling Joint Movement

SEP **Constructing Explanations and Designing Solutions**

After the students complete the Hands-On Lab, guide them in discussing prioritized criteria and tradeoff considerations in the design process.

Ask: *Why is it important to prioritize criteria during the design process?*
Sample answer: Sometimes the design might have too many criteria to meet. You have to decide which criteria are most important and are essential to producing the most successful design.

EVIDENCE NOTEBOOK

1 Answers will vary. Problem: Need a design for an electric wheelchair. Criteria/Constraints: cost less than $5000, long battery life, able to operate with limited hand movement. Students might say that materials must be chosen to meet the price but be safe for the environment or the user. A tradeoff might be substituting a smaller battery with a shorter life for a larger one that is too heavy or costly.

SEP Constructing Explanations and Designing Solutions

Students consider the steps of prioritizing criteria and considering tradeoffs in the engineering design process. They analyze various solutions to vision correction by comparing tradeoff considerations.

Physics Connection

Refraction and Vision Remind students that the cornea is the clear, outer layer of the eye, and beneath the cornea is the lens. We can see objects because light rays pass through the cornea and the lens onto the retina at the back of the eye. The shape of the cornea is the primary factor that determines how much the light rays entering the eye are refracted, or redirected inward, so that they strike the retina. By reshaping the cornea through the PRK or LASIK procedure, a surgeon can change the amount of refraction so that the eye produces a clearer image.

Differentiate Instruction

Extra Support Have students analyze the tradeoffs listed in the table. One at a time, read a row of the table, and ask students to comment as to how important each feature is to them. Point out to students that the prioritization may vary for different people. For example, the short recovery time for LASIK may be very important to some people but not important to others. As a result, the conclusion about whether to choose eyeglasses, contact lenses, LASIK, or PRK is not the same for every person.

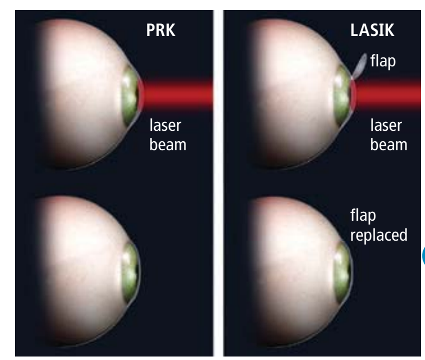
EVIDENCE NOTEBOOK

1 Answers will vary. Doctors might begin by giving patients an idea of the relative costs of each choice, possibly explaining that, while surgery might be more expensive, it lasts longer than a pair of glasses or contacts. Doctors could ask patients how much they wish to spend and what kind of lifestyle they lead, as those with active lifestyles might find glasses or even contacts bothersome.

Engineering

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.

1 **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

Image Credits: (t) ©Brian Chase/Shutterstock; (c) ©JPC-PROD/Shutterstock; (b) ©Phanie/Phanie/Superstock

DCI ETS1.B Developing Possible Solutions

Students take into account a range of constraints by using a decision matrix to assign a number to each criterion in order to identify the design that best meets the criteria. Emphasize to students that although the numbers can in some cases be subjective, they should always consider whether there is an objective way to assign numbers for each criteria.

Engineering

CPAP Designs As students construct their decision matrices, draw attention to the images in Figure 9 showing the three major CPAP designs.

The top image shows a full-face mask:

- It is the only design that covers the mouth, so it would be good for people who breathe out of their mouth during sleep.
- It includes straps along the forehead as well as the jaws.
- It is a wide design that sits on the outer part of the face and doesn't touch the nose.
- The mask needs to sit flat against the face to get a good seal, so it may be more difficult to use when sleeping on your side.
- It is bigger and places more weight on the face than other designs do.

The middle image shows a nasal-pillow mask:

- It is smaller and more lightweight than other designs.
- Its only straps on the face are along the side, so it doesn't obscure a user's view as much as other designs.
- It has a firm fit against the nose, so there is not likely to be air leakage.
- It allows freedom of movement during sleep.

The bottom image shows a nasal-mask design:

- It fits over the nose and forehead and obscures a user's view.
- It includes straps along the forehead as well as the jaws.
- It allows freedom of movement during sleep.

DCI ETS1.C Optimizing the Design Solution

Students consider how the use of a prototype can be used as part of a systematic review of criteria in optimizing a design solution.

SEP Developing and Using Models

Point out that when engineers design a product, they might produce several models during the process to test certain features. A prototype embodies all of the successful features that engineers have identified during the process. It usually is not the same as the end product, but instead it is the best attempt at a working design that will allow engineers to observe how all the parts work together in order to identify any remaining issues with the design.

Collaboration

Whip Around Using ideas from the list below, or any of your own, have students write down thoughts on how advances in each area helped the design of better prosthetics. Have student volunteers read their responses. Have students note if their ideas were similar. When a student has heard all his or her ideas mentioned, he or she can sit down.

- material science
- manufacturing techniques
- knowledge of the body/physiology
- chemistry
- physics

EVIDENCE NOTEBOOK

1 Answers will vary. Even if not an exact model, a prototype can assist engineers in testing some basic aspects of a design. If the prototype fails completely at meeting the needs of the proposed technology, the entire design should be reconsidered.

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.

1 **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.

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.

2 **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?

SEP Scientific Investigations Use a Variety of Methods

Point out to students that one of the purposes of publishing the work of scientists and engineers is so that the results can be widely shared and analyzed. This, in turn, allows new directions to be identified. The ethical reporting of results means ideas from others might lead to modifications that improve the design.

EVIDENCE NOTEBOOK

2 Answers may vary. Students might say that, unlike developing a technology like a cell phone, a biotechnology must be developed with an understanding of the human body in mind. At every step of the design process, engineers must consider how a decision will affect the successful integration of the technology into the human body.

FORMATIVE ASSESSMENT

Oral Questioning Use the following questions to review the Explorations with the class:

Ask: *What is meant in the engineering design process by "delimiting the problem"?* defining constraints on the solution

Ask: *What happens if a proposed engineering design solution does not meet the constraints that you have chosen for the problem?* The solution must be changed in some way.

Ask: *What is a decision matrix, and how is it used?* A decision matrix is a chart that assigns a number that gives each of the criteria a weight based on how important it is. The scores identify the design that best meets the criteria that you have chosen.

Ask: *What is a prototype, and what is its purpose?* A prototype is a model that encompasses all of the features that have proven to be successful during the design process. Its purpose is to show how well all of the parts work together and to identify any remaining issues.

CONTINUE YOUR EXPLORATION Careers in Science

Collaboration

You may choose to assign this activity or direct students online to the Online Interactive Student Edition where they can explore and choose from all three paths. These activities can be assigned individually, to pairs, or to small groups.

Careers in Bioengineering

SEP Constructing Explanations and Designing Solutions

In order to prepare students for the design activity on this page, have them look at the image of the bionic hand, and lead them in discussing what criteria the design team must have identified for the design of the hand. Ask questions such as, *What features should the hand have? In what ways should it be able to move? Did the design team place more emphasis on aesthetics or on functionality?* Encourage students to ask themselves these types of questions when designing their aquatic prosthetic leg.

DCI ETS1.B Developing Possible Solutions

Students use constraints identified in their reading to design a solution for an aquatic prosthetic leg. Suggest that students discuss the importance of each constraint before coming to a group consensus about its value in the decision matrix. The criteria that students choose will determine the types of materials that they use for their models. Emphasize to students that they should get your approval for the design before constructing the model. Make sure the model can be built in a reasonable time period with minimal cost.

CCC Systems and System Models

Students will build and test a prototype model of an aquatic prosthetic leg. During testing, they will simulate how the parts interact to form a system.

CONTINUE YOUR EXPLORATION

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.

58 Unit 1 Living Systems

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.

Image Credits: ©Corbis

3D BIOPRINTING | NANOTECHNOLOGY | Go online to choose one of these other paths.

Language Arts Connection

SL.11-12.5 Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest.

Compare/Contrast Students should gather relevant information about the various fields of engineering from multiple authoritative print and digital sources. As they develop and write their articles, students should avoid plagiarism and overreliance on any one source. Point out that they must cite their sources within the article, but they should use the citation style employed by a standard newspaper rather than the style used for science reports.

Differentiate Instruction

Extra Support Guide students in ways to test their aquatic prosthetic leg. Point out that the method of testing depends on the criteria they choose. Functions that they might test include its ability to move different parts with ease and its ability to twist slightly without damaging the model. Suggest they consider how a swimmer moves in order to design and test their model.

Extension Have students make a waterproof version of their aquatic prosthetic leg that uses more robust materials. Then have them test their prototype by moving it in water.

Explore Online

3D Bioprinting

Students learn about 3D bioprinting and investigate the effects that it has on biotechnology.

Nanotechnology

Students learn that nanotechnology is the study and application of individual atoms and molecules to create engineered solutions.

EVALUATE Lesson Self-Check

Can You Explain It?

Collaboration

Discussion You may wish to revisit this image as a group activity to assess students' understanding of the material. Use the questions in the Student Edition to lead the discussion.

DCI ETS1.B Developing Possible Solutions

Students identify a range of constraints, such as cost, safety, reliability, and aesthetics, in the design of a pacemaker battery.

EVIDENCE NOTEBOOK

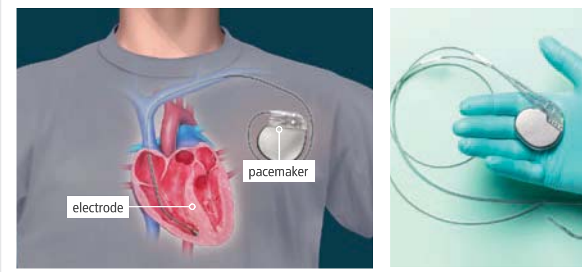
1 Engineers developing batteries for pacemakers need to consider how long the battery is intended to last and whether or not the materials used are safe. They may also consider the ease of replacing the battery. The cost of battery replacement is also a consideration for the patient.

EVALUATE

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.

1 **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.

Formal Assessment Go online for student self-checks and other assessments.

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.

Checkpoints

Answers

1. You would take note of what needs were not met. Was it too costly or could it not perform one of the requirements? After a complete evaluation, you would repeat the design process to address those issues specifically.
2. b
3. a, c, f
4. a, e
5. **Sample answer:** Governments might require that all car exhausts not exceed a certain level of harmful pollutants. This would encourage automakers to improve engine design. However, governments might place so many regulations on a technology that it would become difficult for small, independent inventors to develop a new idea.
6. Check student charts.

Make Your Own Study Guide

Have students create a study guide that helps them organize and visualize the important information from this lesson. Their study guide should focus on the main ideas from the lesson and tie multiple ideas together. Students can create an outline, a concept map, a graphic organizer, or other representation.

Differentiate Instruction

Extra Support Create a partially filled study guide to guide students in organizing their ideas. Have students fill in the rest of the guide and then compare their ideas to a partner's to answer any questions they might have.

On-Level Have students create their own study guide that answers all of the information outlined in the Student Edition. When they are complete, pair students with Below-Level learners to reinforce the material.

Extension Challenge students to make connections between the different models they created and their applications in solving real-world problems.

Teacher Notes

THING EXPLAINER BY RANDALL MUNROE

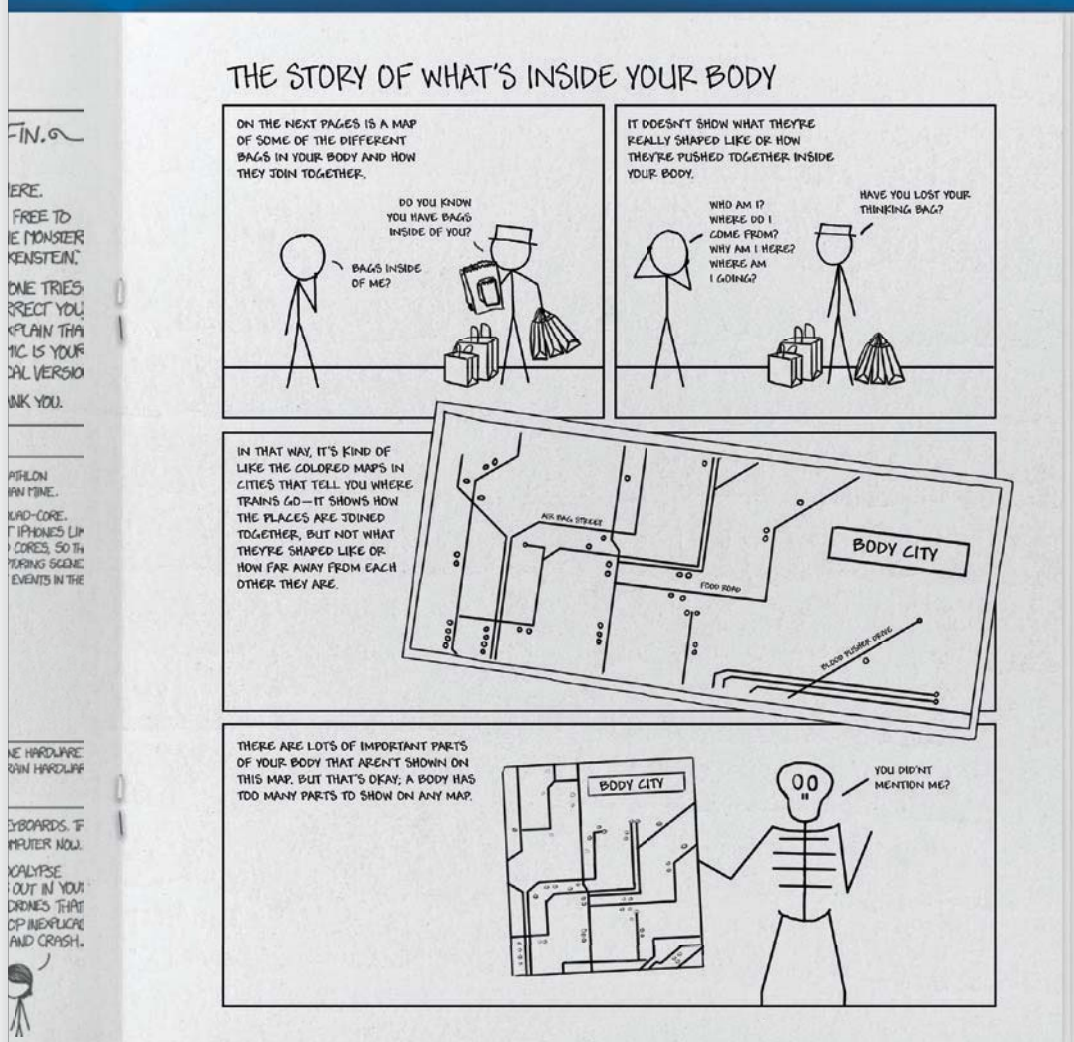
BAGS OF STUFF INSIDE YOU

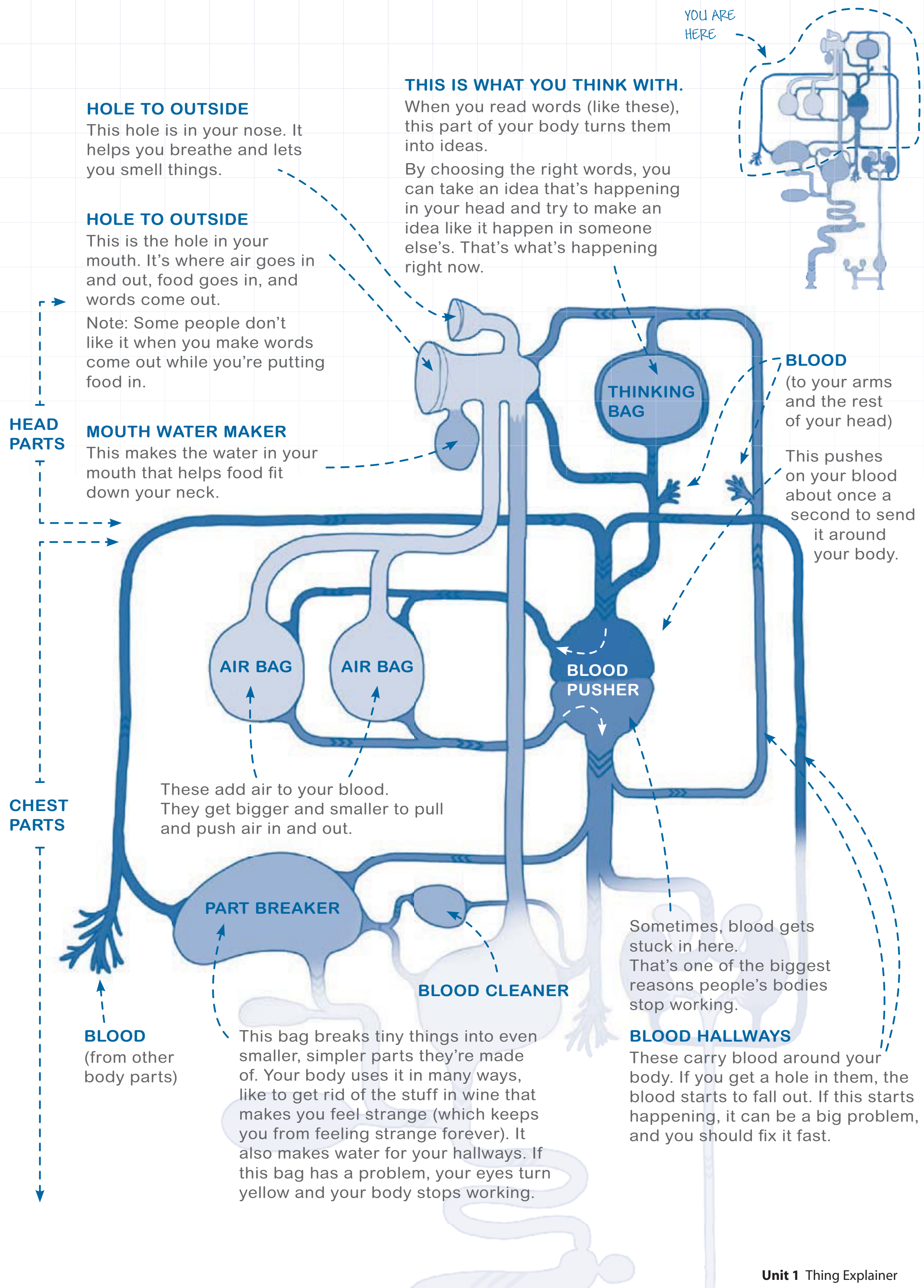
Parts of your body and how they work together

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.

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

RANDALL MUNROE
XKCD.COM

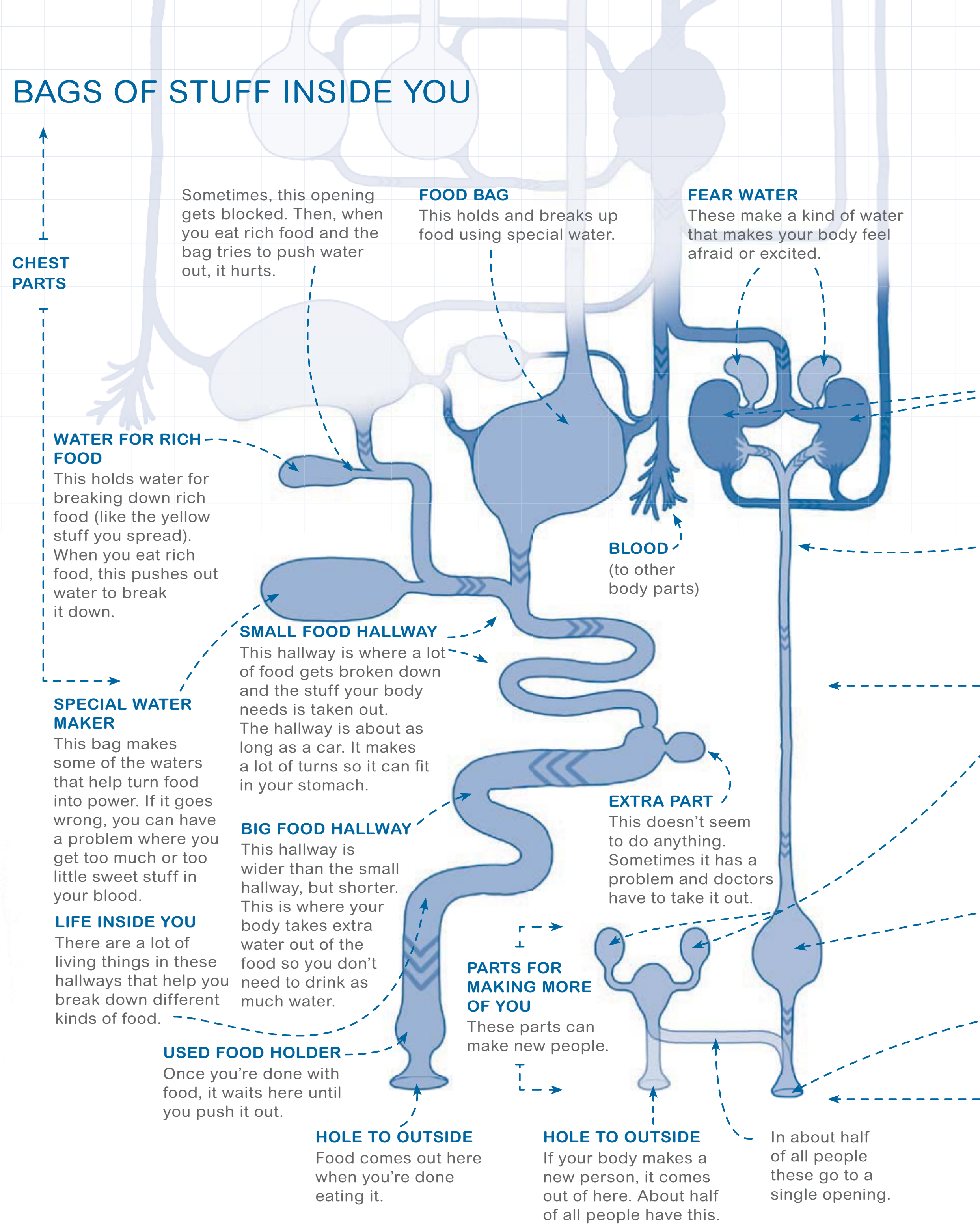


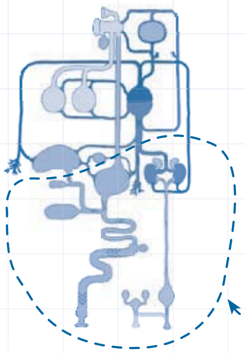


Teacher Notes

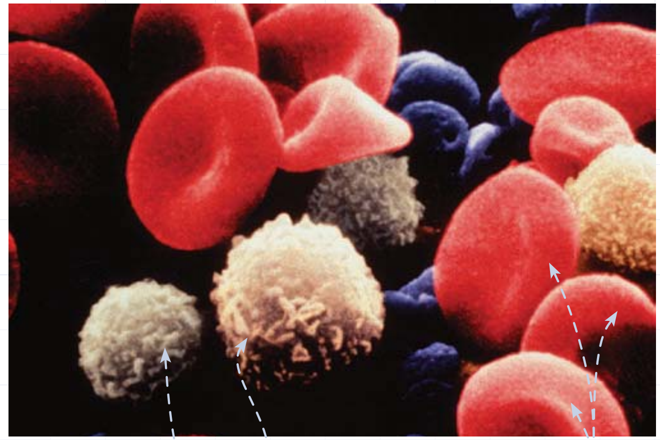
Teacher Notes

BAGS OF STUFF INSIDE YOU





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.)

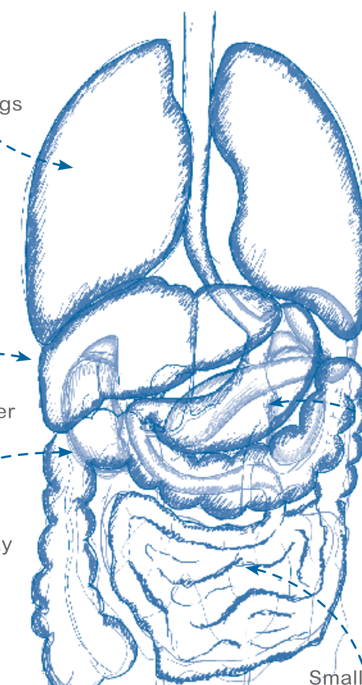
BODY PLAN HOLDERS
These parts hold lots of plans for new people. Each plan is made from pieces of the plans used to make you.
These parts also control how your voice, hair, and body grow.

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.



Teacher Notes

UNIT 1 Connections

Support for Unit Connections

Technology Connection

Diagrams should include components of a computer (e.g., processor, memory, hard drive, microphone, cooling fan, etc.), how the components interact for the computer to fully operate, how the computer links to larger systems (e.g., networks), and the route information and energy flows through the computer systems. Labels for the diagram could be divided into two sets: one set describing the major computer components in the system (e.g., the processor, memory) and one set describing the analogous human components in the system (e.g., the brain). Potential questions may focus on how people are different from computers, because the diagram is emphasizing similarities.

Music Connection

Blog entries should include a claim stating the position taken, scientific evidence to support the claim, and an explanation of how the evidence supports the argument being made.

Earth Science Connection

Criteria and constraints might include: ability to operate in zero gravity, appropriate size (must fit in a space vessel), weight, safety, etc. The list should be prioritized by importance, and students should be able to explain why the list was prioritized in the manner they chose.

UNIT CONNECTIONS

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.

Image Credits: (t) ©Muriel de Seze/DigitalVision/Getty Images; (c) ©Corbis/Steve Hix/Getty Images; (b) ©Courtesy of NASA

UNIT 1 Practice and Review

UNIT PRACTICE AND REVIEW

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.

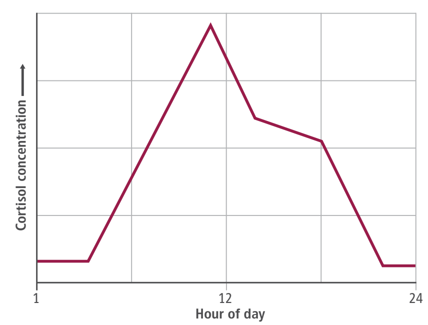
2. Select a relationship that is similar to the following relationship: neuron : send electrical signal
   a. cardiac cell : muscle cell
   b. muscle cell : contraction
   c. circulatory system : blood cell
   d. homeostasis : endocrine system

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

Synthesize the Unit

Suggest students begin by writing the titles of the lessons and the Explorations in each unit as well as any associated vocabulary. Encourage students to draw relationships among concepts introduced in different lessons.

Driving Questions

Students may wish to write a brief explanation of how their understanding of each question has changed since the start of the unit.

Practice and Review

SUMMATIVE ASSESSMENT

Answers

1. c
2. b
3. a, d
4. a

3D Item Analysis	1	2	3	4
SEP Developing and Using Models		•		
DCI LS1.A Structure and Function	•		•	•
CCC Stability and Change				•

5. d

6. b

7. The model should show a flow from reabsorbing less water from kidney tubules, to a decrease in water concentration in the blood, to an increase in the amount of ADH released by the pituitary gland, back to reabsorbing less water from kidney tubules.

8. Based on the feedback diagram provided, removing the option of having more water reabsorbed by the kidneys would make the pathway from reabsorbing more water to releasing less ADH inaccessible. Without any outside effects on this system, the outcome would be atypically low concentration of water in the blood and abnormally high concentration of ADH.

9. c

10. a

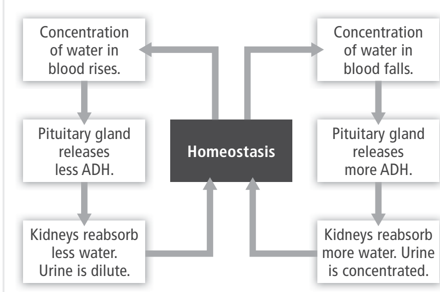
3D Item Analysis	5	6	7	8	9	10
SEP Developing and Using Models	•		•			
SEP Constructing Explanations and Designing Solutions						•
SEP Planning and Carrying Out Investigations						•
DCI LS1.A Structure and Function		•	•	•		
DCI ETS1.B Developing Possible Solutions					•	
CCC Systems and System Models	•		•	•		
CCC Stability and Change				•		

UNIT PRACTICE AND REVIEW

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.

68 Unit 1 Living Systems

UNIT 1 Performance Task

UNIT PERFORMANCE TASK

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

Small Groups 90 minutes

Analyzing a Disease Outbreak

SEP Constructing Explanations and Designing Solutions

Students gather evidence to support their explanation of how a small town can avoid further outbreaks of a disease. They will also construct and use a model as part of their proposed solution that describes how the disease is transmitted and the human immune response.

Answers

1. Statements should define the problem as identifying the cause of the high fevers and how to prevent further cases.
2. Students should identify murine or endemic typhus as the most likely disease.
3. Models should show the infection cycle of the disease; link the symptoms shown during infection to an immune-system response; and demonstrate how homeostasis is related to the immune response.
4. Answers should address controlling the flea population.
5. Presentations should include the defined problem and questions, a model of disease transmission and immune response in humans, recommendations supported by evidence for how to solve the problem, and data that support the solution.

Performance Task Scoring Rubric

Task	Criteria
	problem statement is clearly defined and identifies supporting questions to be answered
	model clearly and accurately represents how the disease is transmitted and the human immune response to infection
	relevant images and data are included to support the solution
	recommendation clearly explains the solution and uses evidence effectively to support the proposed solution