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CONCEPTS & CONNECTIONS

EIGHTH EDITION

REECE · TAYLOR · SIMON · DICKEY · HOGAN

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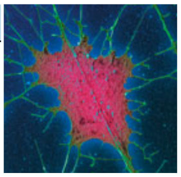

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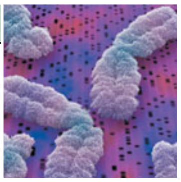

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EIGHTH EDITION

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Jane B. Reece has worked in biology publishing since 1978, when she joined the editorial staff of Benjamin Cummings. Her education includes an A.B. in biology from Harvard University, an M.S. in microbiology from Rutgers University, and a Ph.D. in bacteriology from the University of California, Berkeley. At UC Berkeley, and later as a postdoctoral fellow in genetics at Stanford University, her research focused on genetic recombination in bacteria. Dr. Reece taught biology at Middlesex County College (New Jersey) and Queensborough Community College (New York). During her 12 years as an editor at Benjamin Cummings, she played a major role in a number of successful textbooks. She is coauthor of *Campbell Biology*, Tenth Edition, *Campbell Biology in Focus*, *Campbell Essential Biology*, and *Campbell Essential Biology with Physiology*, Fourth Edition.

Martha R. Taylor has been teaching biology for more than 35 years. She earned her B.A. in biology from Gettysburg College and her M.S. and Ph.D. in science education from Cornell University. At Cornell, she has served as assistant director of the Office of Instructional Support and has taught introductory biology for both majors and nonmajors. Most recently, she was a lecturer in the Learning Strategies Center, teaching supplemental biology courses. Her experience working with students in classrooms, in laboratories, and with tutorials has increased her commitment to helping students create their own knowledge of and appreciation for biology. She has been the author of the *Student Study Guide* for all ten editions of *Campbell Biology*.

Eric J. Simon is a professor in the Department of Biology and Health Science at New England College (Henniker, New Hampshire). He teaches introductory biology to science majors and nonscience majors, as well as upper-level courses in tropical marine biology and careers in science. Dr. Simon received a B.A. in biology and computer science and an M.A. in biology from Wesleyan University, and a Ph.D. in biochemistry from Harvard University. His research focuses on innovative ways to use technology to improve teaching and learning in the science classroom, particularly for nonscience majors. Dr. Simon is the lead author of the introductory nonmajors biology textbooks *Campbell Essential Biology,* Fifth Edition, and *Campbell Essential Biology with Physiology,* Fourth Edition, and the author of the introductory biology textbook *Biology: The Core.*

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Kelly Hogan is a faculty member in the Department of Biology at the University of North Carolina at Chapel Hill, teaching introductory biology and introductory genetics to science majors. Dr. Hogan teaches hundreds of students at a time, using active-learning methods that incorporate technology such as cell phones as clickers, online homework, and peer evaluation tools. Dr. Hogan received her B.S. in biology at the College of New Jersey and her Ph.D. in pathology at the University of North Carolina, Chapel Hill. Her research interests relate to how large classes can be more inclusive through evidence-based teaching methods and technology. She provides faculty development to other instructors through peer-coaching, workshops, and mentoring. Dr. Hogan is the author of *Stem Cells and Cloning,* Second Edition, and is lead moderator of the *Instructor Exchange*, a site within MasteringBiology® for instructors to exchange classroom materials and ideas.

Neil A. Campbell (1946–2004) combined the inquiring nature of a research scientist with the soul of a caring teacher. Over his 30 years of teaching introductory biology to both science majors and nonscience majors, many thousands of students had the opportunity to learn from him and be stimulated by his enthusiasm for the study of life. While he is greatly missed by his many friends in the biology community, his coauthors remain inspired by his visionary dedication to education and are committed to searching for ever better ways to engage students in the wonders of biology.

To the Student: How to use this book and MasteringBiology®

Make important connections between biological concepts and your life

NEW! Each chapter opens with a **high-interest question** to spark your interest in the topic. Questions are revisited later in the chapter, in either a Scientific Thinking or Evolution Connection module.

CHAPTER 12

DNA Technology and Genomics

Are genetically modified organisms safe?

Papaya fruit, shown in the photograph below, are sweet and loaded with vitamin C. They are borne on a rapidly growing treelike plant (*Carica papaya*) that grows only in tropical climates. In Hawaii, papaya is both a dietary staple and a valuable export crop.

Although thriving today, Hawaii's papaya industry seemed doomed just a few decades ago. A deadly pathogen called the papaya ringspot virus (PRV) had spread throughout the islands and appeared poised to completely eradicate the papaya plant population. But scientists from the University of Hawaii were able to rescue the industry by creating new, genetically engineered PRV-resistant strains of papaya. Today, the papaya industry is once again vibrant—and the vast majority of Hawaii's papayas are genetically modified organisms (GMOs).

However, not everyone is happy about the circumstances surrounding the recovery of the Hawaiian papaya industry. Although genetically modified papayas are approved for consumption in the United States (as are many other GMO fruits and vegetables), some critics have raised safety concerns—for the people who eat them and for the environment. On three occasions over a three-year

span, thousands of papaya trees
down under the cover of
GMO crops. Although few
should we in fact be concerned
question continues to foster

In addition to GMOs in our
in many other ways: Gene
dustrial products, DNA
ence, new technologies produce
and DNA can even be used to
chapter, we'll discuss each of
specific techniques used, how
legal, and ethical issues that are

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The New York Times

May 12, 2013

Seeking Clues to Heart Disease in DNA of an Unlucky Family

By GINA KOLATA

Early heart disease ran in Rick Del Sontro's family, and every time he went for a run, he was scared his heart would betray him. So he did all he could to improve his odds. He kept himself lean, stayed away from red meat, spurned cigarettes and exercised intensely, even completing an Ironman Triathlon.

MasteringBiology®

ABC News Videos and Current Events articles from The *New York Times* connect what you learn in biology class to fascinating stories in the news.


the big island of Hawaii were hacked
presumably as a protest against
condone such criminal behavior,
but the safety of GMO crops? This
derable debate and disagreement.
et, DNA technologies affect our lives
is used to produce medical and in-
has changed the field of forensic sci-
aluable data for biological research,
estigate historical questions. In this
e applications. We'll also consider the
ey are applied, and some of the social,
aised by the new technologies.

BIG IDEAS

Gene Cloning (12.1–12.5)
A variety of laboratory techniques can be used to copy and combine DNA molecules.

Genetically Modified Organisms (12.6–12.10)
Transgenic cells, plants, and animals are used in agriculture and medicine.

DNA Profiling (12.11–12.16)
Genetic markers can be used to definitively match a DNA sample to an individual.

Genomics (12.17–12.21)
The study of complete DNA sets helps us learn about evolutionary history.

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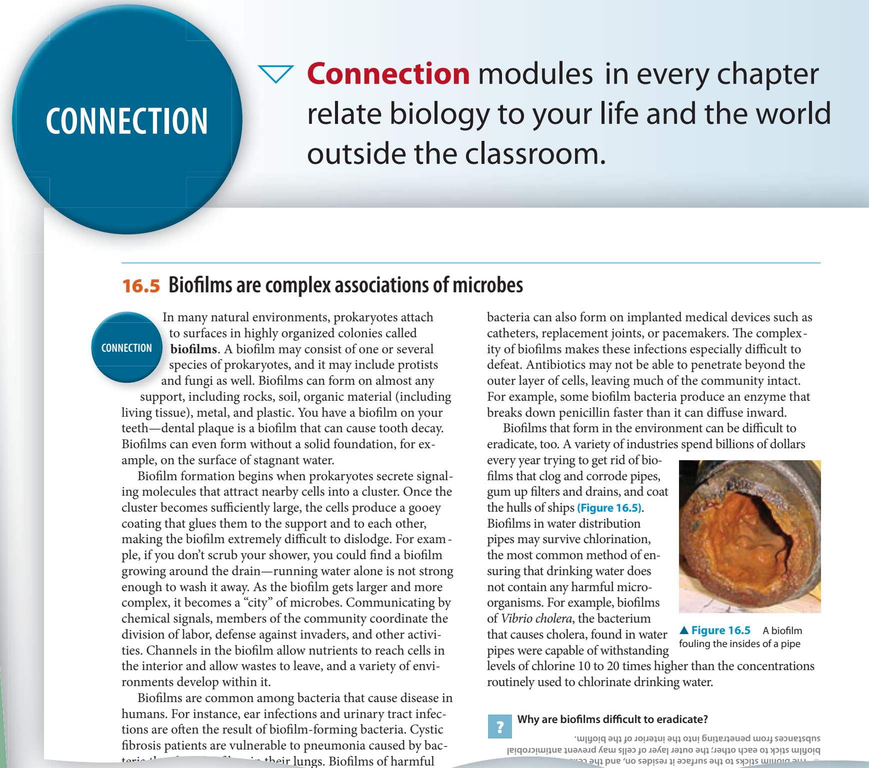
Big Ideas help you connect the overarching concepts that are explored in the chapter.

Connection modules in every chapter relate biology to your life and the world outside the classroom.


CONNECTION

16.5 Biofilms are complex associations of microbes

CONNECTION

In many natural environments, prokaryotes attach to surfaces in highly organized colonies called **biofilms**. A biofilm may consist of one or several species of prokaryotes, and it may include protists and fungi as well. Biofilms can form on almost any support, including rocks, soil, organic material (including living tissue), metal, and plastic. You have a biofilm on your teeth—dental plaque is a biofilm that can cause tooth decay. Biofilms can even form without a solid foundation, for example, on the surface of stagnant water.

Biofilm formation begins when prokaryotes secrete signaling molecules that attract nearby cells into a cluster. Once the cluster becomes sufficiently large, the cells produce a gooey coating that glues them to the support and to each other, making the biofilm extremely difficult to dislodge. For example, if you don't scrub your shower, you could find a biofilm growing around the drain—running water alone is not strong enough to wash it away. As the biofilm gets larger and more complex, it becomes a "city" of microbes. Communicating by chemical signals, members of the community coordinate the division of labor, defense against invaders, and other activities. Channels in the biofilm allow nutrients to reach cells in the interior and allow wastes to leave, and a variety of environments develop within it.

Biofilms are common among bacteria that cause disease in humans. For instance, ear infections and urinary tract infections are often the result of biofilm-forming bacteria. Cystic fibrosis patients are vulnerable to pneumonia caused by bac-
... their lungs. Biofilms of harmful bacteria can also form on implanted medical devices such as catheters, replacement joints, or pacemakers. The complexity of biofilms makes these infections especially difficult to defeat. Antibiotics may not be able to penetrate beyond the outer layer of cells, leaving much of the community intact. For example, some biofilm bacteria produce an enzyme that breaks down penicillin faster than it can diffuse inward.

Biofilms that form in the environment can be difficult to eradicate, too. A variety of industries spend billions of dollars every year trying to get rid of biofilms that clog and corrode pipes, gum up filters and drains, and coat the hulls of ships (Figure 16.5). Biofilms in water distribution pipes may survive chlorination, the most common method of ensuring that drinking water does not contain any harmful microorganisms. For example, biofilms of *Vibrio cholera*, the bacterium that causes cholera, found in water pipes were capable of withstanding levels of chlorine 10 to 20 times higher than the concentrations routinely used to chlorinate drinking water.

▲ **Figure 16.5** A biofilm fouling the insides of a pipe

? Why are biofilms difficult to eradicate?


EVOLUTION CONNECTION

10.19 Emerging viruses threaten human health

EVOLUTION CONNECTION

Emerging viruses are ones that seem to burst on to the scene, becoming apparent to the medical community quite suddenly. There are many familiar examples, such as the 2009 H1N1 influenza virus (discussed in the chapter introduction). Another example is **HIV** (human immunodeficiency virus), the virus that causes **AIDS** (acquired immunodeficiency syndrome). HIV appeared in New York and California in the early 1980s, seemingly out of nowhere. Yet another example is the deadly Ebola virus, recognized initially in 1976 in central Africa; it is one of several emerging viruses that cause hemorrhagic fever, an often fatal syndrome characterized by fever, vomiting, massive bleeding, and circulatory system collapse. A number of other dangerous newly recognized viruses cause encephalitis, inflammation of the brain. One example is the West Nile virus, which appeared in North America in 1999 and has since spread to all 48 contiguous U.S. states. West Nile virus is spread primarily by mosquitoes, which carry the virus in blood sucked from one victim and can transfer it to another victim. West Nile virus cases surged in 2012, especially in Texas. Severe acute respiratory syndrome (SARS) first appeared in China in 2002. Within eight months, about 8,000 ... and 10% died. Researchers quickly ...

Why are viral diseases such a constant threat?

Colorized TEM 180,000×

▼ **Figure 10.19** A Hong Kong health-care worker prepares to cull a chicken to help prevent the spread of the avian flu virus (shown in the inset)

Evolution Connection modules present concrete examples of the evidence for evolution within each chapter, providing you with a coherent theme for the study of life.

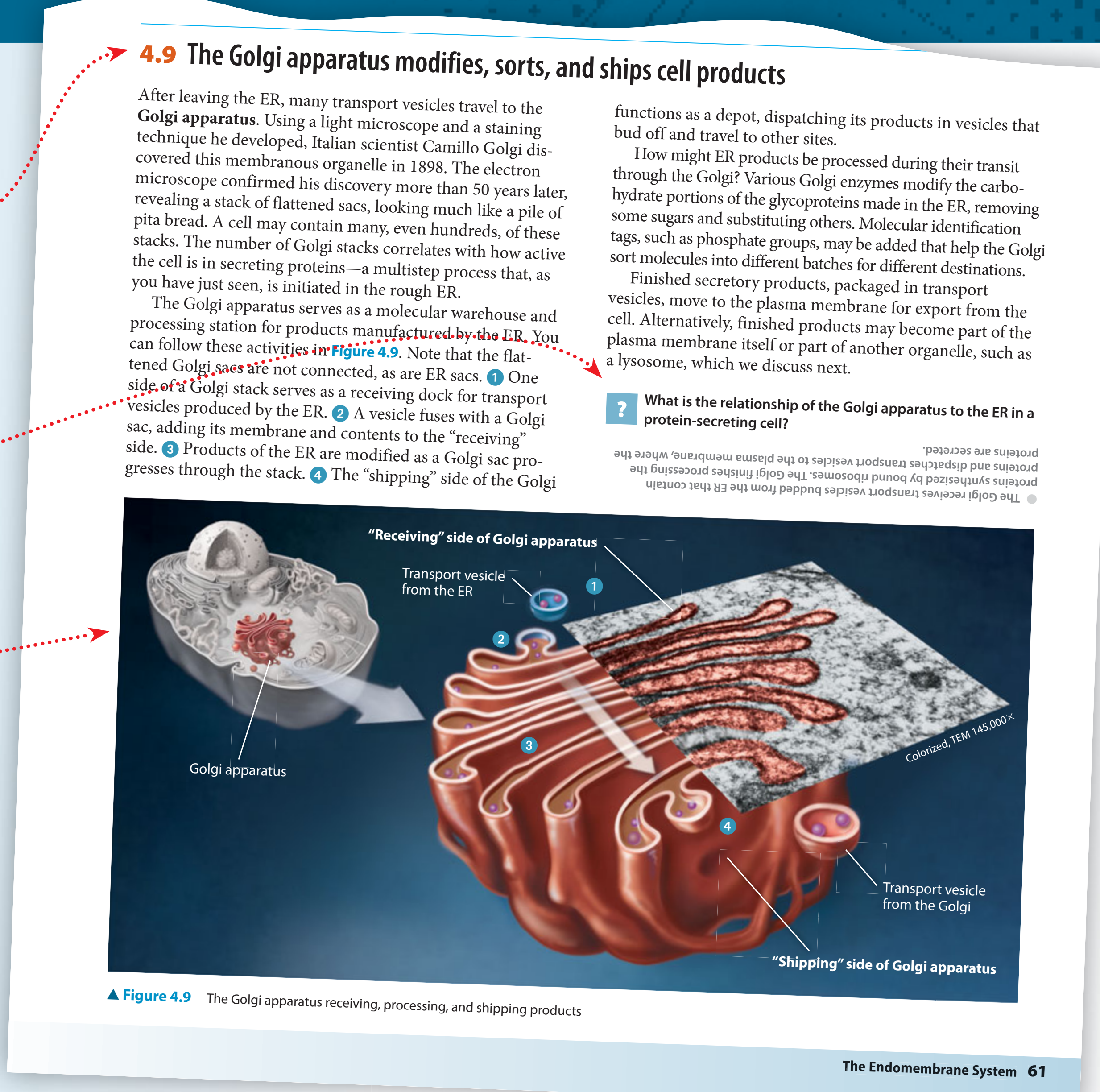
To the Student: How to use this book and MasteringBiology®

Stay focused on the key concepts

Central concepts summarize the key topic of each module, helping you stay focused as you study.

Checkpoint questions at the end of each module help you stay on track.

NEW and revised art provides clear visuals to help you understand key topics. Selected figures include numbered steps that are keyed to explanations in the text.



4.9 The Golgi apparatus modifies, sorts, and ships cell products

After leaving the ER, many transport vesicles travel to the **Golgi apparatus**. Using a light microscope and a staining technique he developed, Italian scientist Camillo Golgi discovered this membranous organelle in 1898. The electron microscope confirmed his discovery more than 50 years later, revealing a stack of flattened sacs, looking much like a pile of pita bread. A cell may contain many, even hundreds, of these stacks. The number of Golgi stacks correlates with how active the cell is in secreting proteins—a multistep process that, as you have just seen, is initiated in the rough ER.

The Golgi apparatus serves as a molecular warehouse and processing station for products manufactured by the ER. You can follow these activities in Figure 4.9. Note that the flattened Golgi sacs are not connected, as are ER sacs. 1 One side of a Golgi stack serves as a receiving dock for transport vesicles produced by the ER. 2 A vesicle fuses with a Golgi sac, adding its membrane and contents to the "receiving" side. 3 Products of the ER are modified as a Golgi sac progresses through the stack. 4 The "shipping" side of the Golgi functions as a depot, dispatching its products in vesicles that bud off and travel to other sites.

How might ER products be processed during their transit through the Golgi? Various Golgi enzymes modify the carbohydrate portions of the glycoproteins made in the ER, removing some sugars and substituting others. Molecular identification tags, such as phosphate groups, may be added that help the Golgi sort molecules into different batches for different destinations.

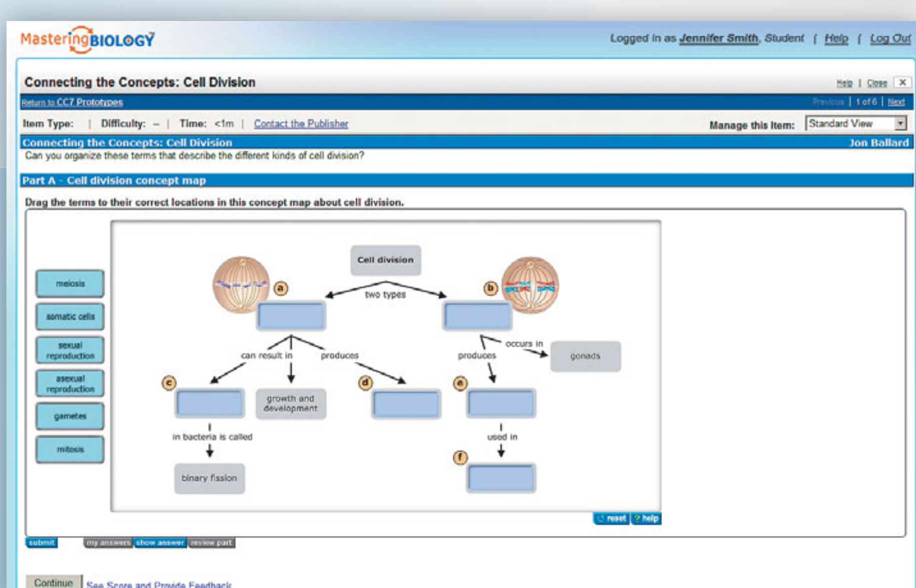
Finished secretory products, packaged in transport vesicles, move to the plasma membrane for export from the cell. Alternatively, finished products may become part of the plasma membrane itself or part of another organelle, such as a lysosome, which we discuss next.

? What is the relationship of the Golgi apparatus to the ER in a protein-secreting cell?

The Golgi receives transport vesicles budded from the ER that contain proteins synthesized by bound ribosomes. The Golgi finishes processing the proteins and dispatches transport vesicles to the plasma membrane, where the proteins are secreted.

▲ Figure 4.9 The Golgi apparatus receiving, processing, and shipping products

The Endomembrane System 61

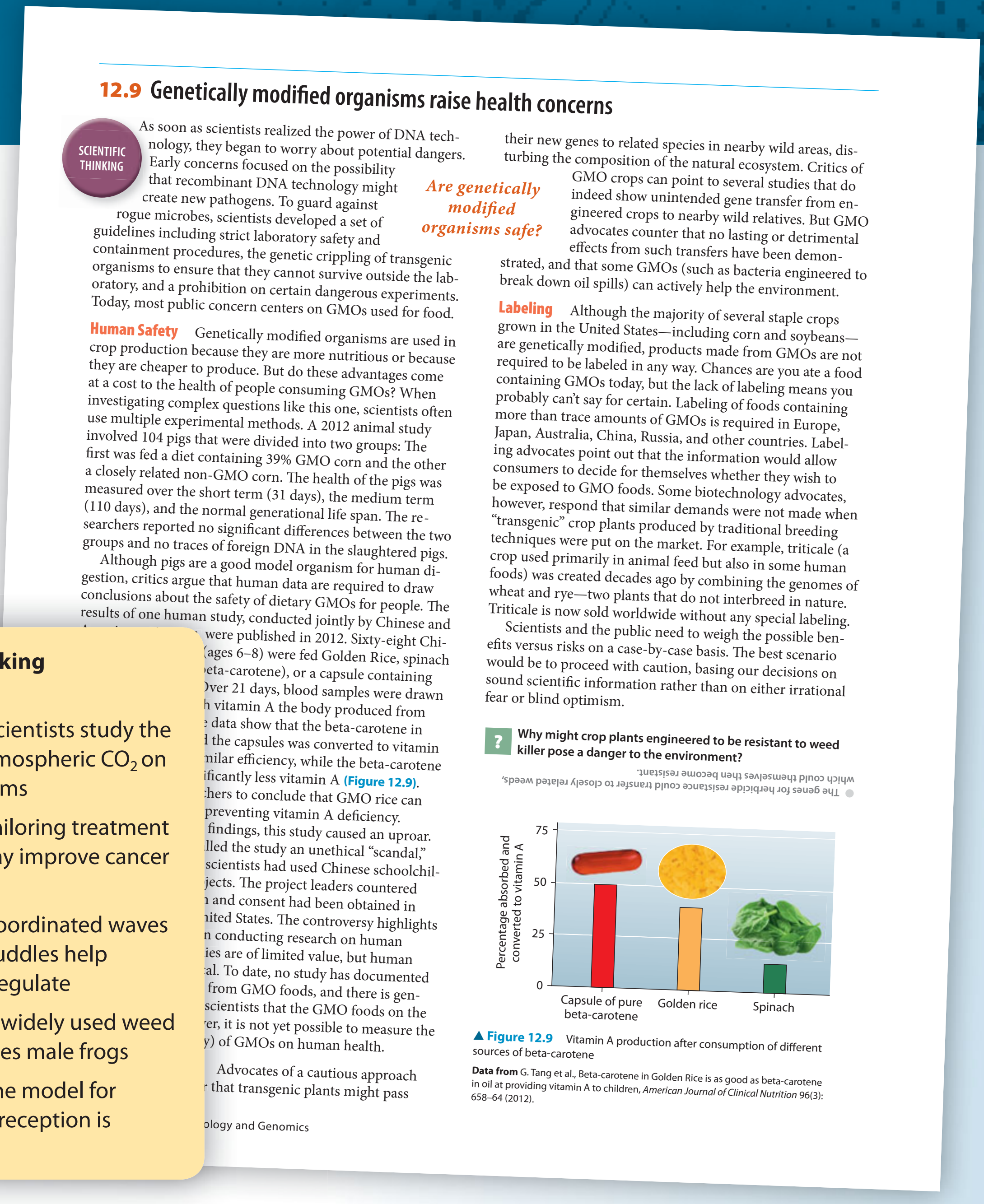


MasteringBiology®

Connecting the Concepts activities link one biological concept to another.

Learn how to to think like a scientist

New Scientific Thinking modules explore how scientists use the processes of science for discovery. Each module concludes with a question that challenges you to think like a scientist.


12.9 Genetically modified organisms raise health concerns

SCIENTIFIC THINKING

As soon as scientists realized the power of DNA technology, they began to worry about potential dangers. Early concerns focused on the possibility that recombinant DNA technology might create new pathogens. To guard against rogue microbes, scientists developed a set of guidelines including strict laboratory safety and containment procedures, the genetic crippling of transgenic organisms to ensure that they cannot survive outside the laboratory, and a prohibition on certain dangerous experiments. Today, most public concern centers on GMOs used for food.

Are genetically modified organisms safe?

Human Safety Genetically modified organisms are used in crop production because they are more nutritious or because they are cheaper to produce. But do these advantages come at a cost to the health of people consuming GMOs? When investigating complex questions like this one, scientists often use multiple experimental methods. A 2012 animal study involved 104 pigs that were divided into two groups: The first was fed a diet containing 39% GMO corn and the other a closely related non-GMO corn. The health of the pigs was measured over the short term (31 days), the medium term (110 days), and the normal generational life span. The researchers reported no significant differences between the two groups and no traces of foreign DNA in the slaughtered pigs.

Although pigs are a good model organism for human digestion, critics argue that human data are required to draw conclusions about the safety of dietary GMOs for people. The results of one human study, conducted jointly by Chinese and ... were published in 2012. Sixty-eight Chi... (ages 6–8) were fed Golden Rice, spinach ... beta-carotene), or a capsule containing ... Over 21 days, blood samples were drawn ... vitamin A the body produced from ... data show that the beta-carotene in ... the capsules was converted to vitamin ... similar efficiency, while the beta-carotene ... significantly less vitamin A (Figure 12.9). ... chers to conclude that GMO rice can ... preventing vitamin A deficiency. ... findings, this study caused an uproar. ... lled the study an unethical "scandal," ... scientists had used Chinese schoolchil... jects. The project leaders countered ... and consent had been obtained in ... nited States. The controversy highlights ... n conducting research on human ... ies are of limited value, but human ... al. To date, no study has documented ... from GMO foods, and there is gen... scientists that the GMO foods on the ... er, it is not yet possible to measure the ... y) of GMOs on human health.

Advocates of a cautious approach ... that transgenic plants might pass their new genes to related species in nearby wild areas, disturbing the composition of the natural ecosystem. Critics of GMO crops can point to several studies that do indeed show unintended gene transfer from engineered crops to nearby wild relatives. But GMO advocates counter that no lasting or detrimental effects from such transfers have been demonstrated, and that some GMOs (such as bacteria engineered to break down oil spills) can actively help the environment.

Labeling Although the majority of several staple crops grown in the United States—including corn and soybeans—are genetically modified, products made from GMOs are not required to be labeled in any way. Chances are you ate a food containing GMOs today, but the lack of labeling means you probably can't say for certain. Labeling of foods containing more than trace amounts of GMOs is required in Europe, Japan, Australia, China, Russia, and other countries. Labeling advocates point out that the information would allow consumers to decide for themselves whether they wish to be exposed to GMO foods. Some biotechnology advocates, however, respond that similar demands were not made when "transgenic" crop plants produced by traditional breeding techniques were put on the market. For example, triticale (a crop used primarily in animal feed but also in some human foods) was created decades ago by combining the genomes of wheat and rye—two plants that do not interbreed in nature. Triticale is now sold worldwide without any special labeling.

Scientists and the public need to weigh the possible benefits versus risks on a case-by-case basis. The best scenario would be to proceed with caution, basing our decisions on sound scientific information rather than on either irrational fear or blind optimism.

? Why might crop plants engineered to be resistant to weed killer pose a danger to the environment?

The genes for herbicide resistance could transfer to closely related weeds, which could then become resistant themselves.

▲ Figure 12.9 Vitamin A production after consumption of different sources of beta-carotene

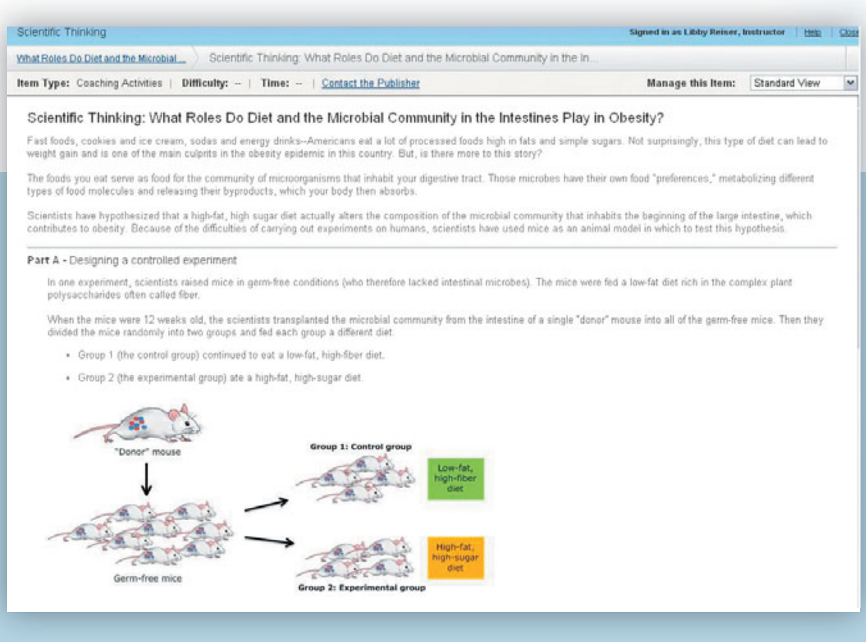
Data from G. Tang et al., Beta-carotene in Golden Rice is as good as beta-carotene in oil at providing vitamin A to children, *American Journal of Clinical Nutrition* 96(3): 658–64 (2012).

...ology and Genomics

SCIENTIFIC THINKING

New Scientific Thinking topics include:

- **Module 2.15** — Scientists study the effects of rising atmospheric CO_2 on coral reef ecosystems
- **Module 8.10** — Tailoring treatment to each patient may improve cancer therapy
- **Module 25.3** — Coordinated waves of movement in huddles help penguins thermoregulate
- **Module 26.3** — A widely used weed killer demasculinizes male frogs
- **Module 29.2** — The model for magnetic sensory reception is incomplete


Scientific Thinking | Signed in as Libby Reiser, Instructor | Help | Close

What Roles Do Diet and the Microbial ... > Scientific Thinking: What Roles Do Diet and the Microbial Community in the In...

Item Type: Coaching Activities | Difficulty: -- | Time: -- | Contact the Publisher | Manage this Item: Standard View

Scientific Thinking: What Roles Do Diet and the Microbial Community in the Intestines Play in Obesity?

Fast foods, cookies and ice cream, sodas and energy drinks—Americans eat a lot of processed foods high in fats and simple sugars. Not surprisingly, this type of diet can lead to weight gain and is one of the main culprits in the obesity epidemic in this country. But, is there more to this story?

The foods you eat serve as food for the community of microorganisms that inhabit your digestive tract. Those microbes have their own food "preferences," metabolizing different types of food molecules and releasing their byproducts, which your body then absorbs.

Scientists have hypothesized that a high-fat, high sugar diet actually alters the composition of the microbial community that inhabits the beginning of the large intestine, which contributes to obesity. Because of the difficulties of carrying out experiments on humans, scientists have used mice as an animal model in which to test this hypothesis.

Part A - Designing a controlled experiment

In one experiment, scientists raised mice in germ-free conditions (who therefore lacked intestinal microbes). The mice were fed a low-fat diet rich in the complex plant polysaccharides often called fiber.

When the mice were 12 weeks old, the scientists transplanted the microbial community from the intestine of a single "donor" mouse into all of the germ-free mice. Then they divided the mice randomly into two groups and fed each group a different diet.

- Group 1 (the control group) continued to eat a low-fat, high-fiber diet.
- Group 2 (the experimental group) ate a high-fat, high-sugar diet.

MasteringBiology®

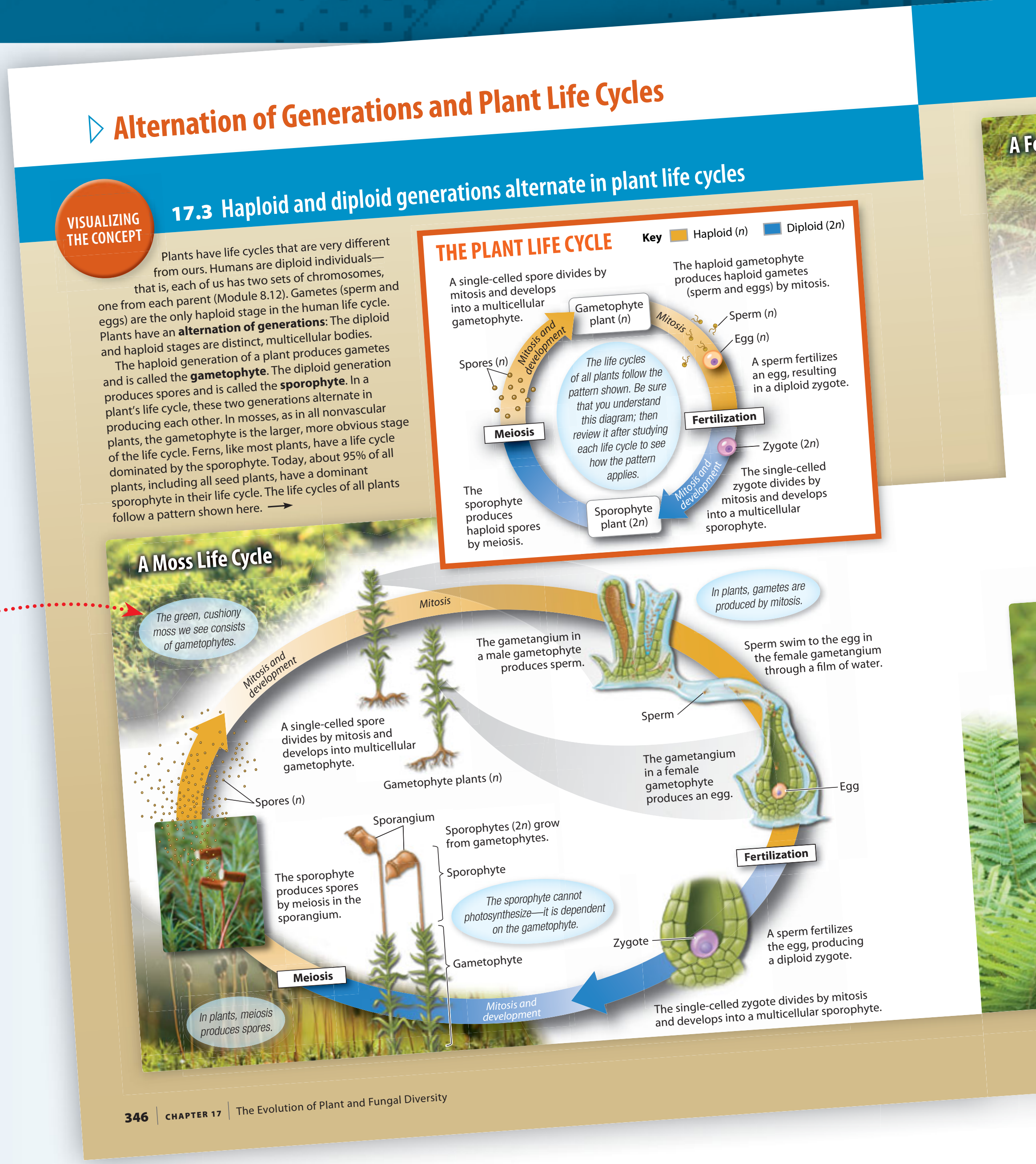
NEW! Scientific Thinking activities teach you how to practice important scientific skills like understanding variables and making predictions. Specific wrong-answer feedback coaches you to the correct response.

To the Student: How to use this book and MasteringBiology®

Maximize your learning and success

- **New Visualizing the Concept** modules walk you through challenging concepts and complex processes.
- The brief narrative works together with the artwork to help you visualize and understand the topic.

Hints embedded within the module emulate the guidance that you might receive during instructor office hours or in a tutoring session. These hints provide additional information to deepen your understanding of the topic.



Alternation of Generations and Plant Life Cycles

VISUALIZING THE CONCEPT

17.3 Haploid and diploid generations alternate in plant life cycles

Plants have life cycles that are very different from ours. Humans are diploid individuals—that is, each of us has two sets of chromosomes, one from each parent (Module 8.12). Gametes (sperm and eggs) are the only haploid stage in the human life cycle. Plants have an **alternation of generations**: The diploid and haploid stages are distinct, multicellular bodies. The haploid generation of a plant produces gametes and is called the **gametophyte**. The diploid generation produces spores and is called the **sporophyte**. In a plant's life cycle, these two generations alternate in producing each other. In mosses, as in all nonvascular plants, the gametophyte is the larger, more obvious stage of the life cycle. Ferns, like most plants, have a life cycle dominated by the sporophyte. Today, about 95% of all plants, including all seed plants, have a dominant sporophyte in their life cycle. The life cycles of all plants follow a pattern shown here.

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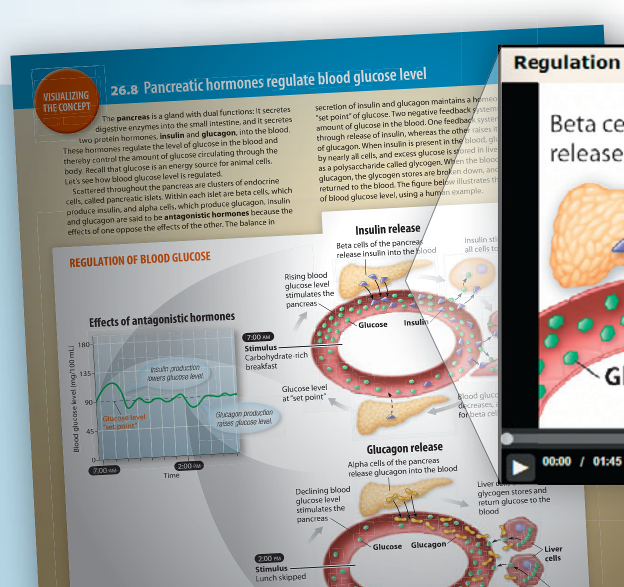
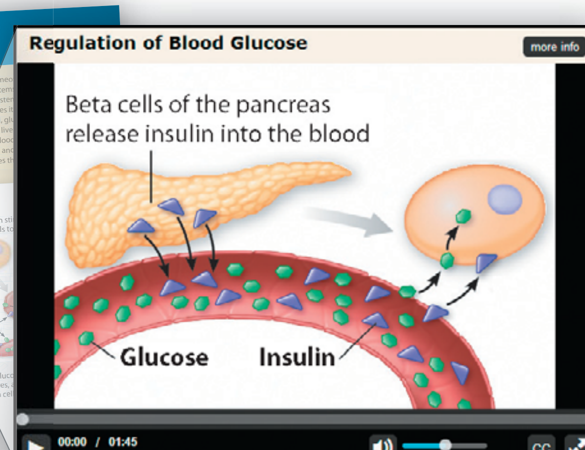
- **NEW! Visualizing the Concept Activities** include interactive videos that were created and narrated by the authors of the text.

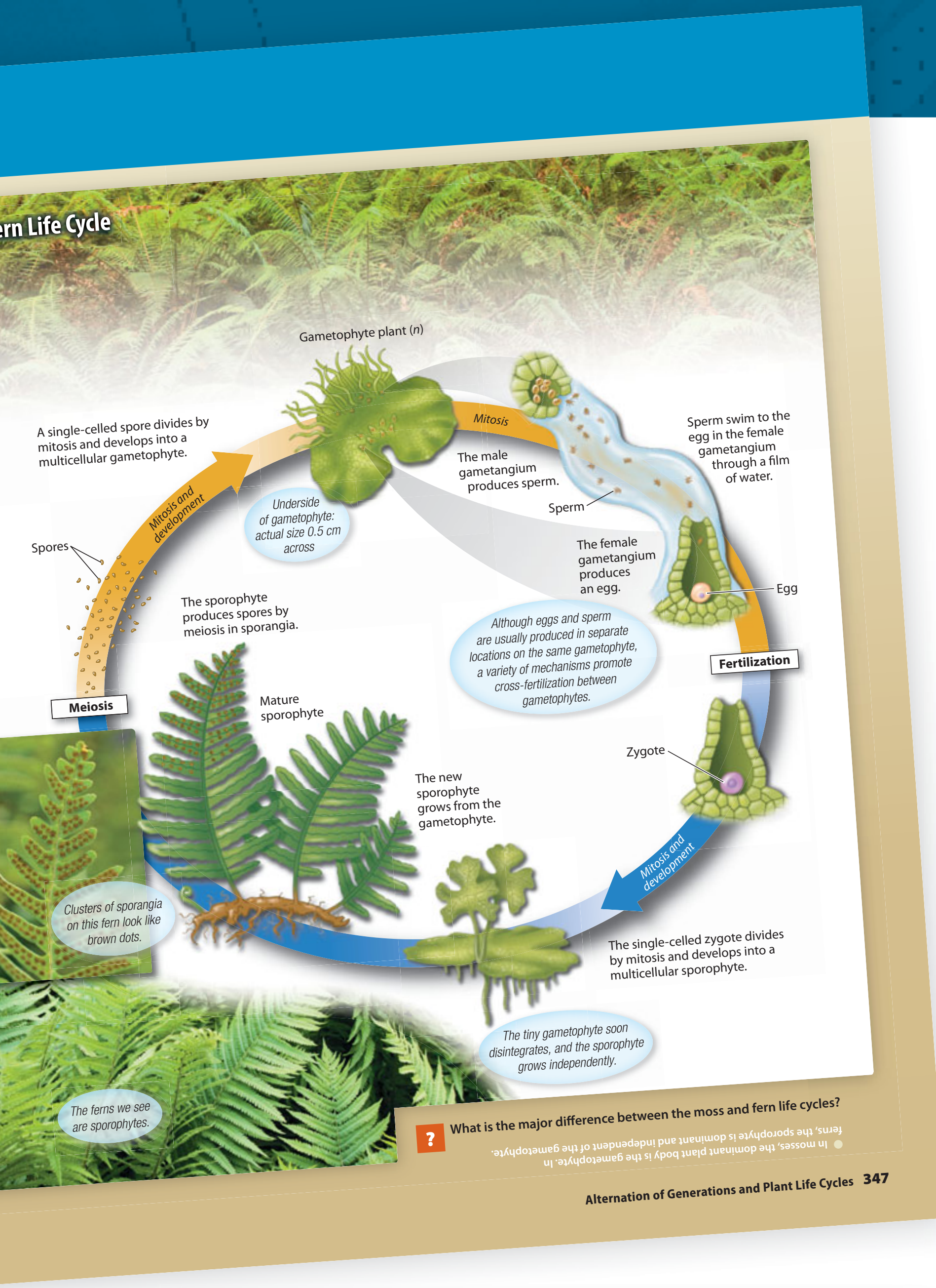


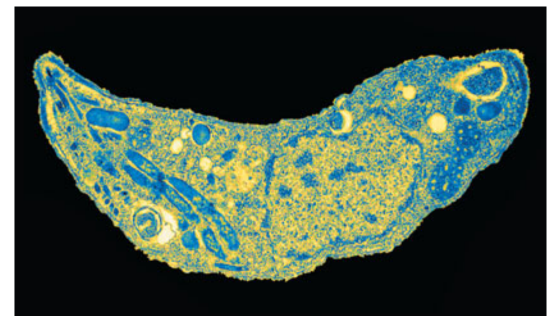
VISUALIZING THE CONCEPT

26.8 Pancreatic hormones regulate blood glucose level

The **pancreas** is a gland with dual functions: It secretes digestive enzymes into the small intestine, and it secretes two protein hormones, **insulin** and **glucagon**, into the blood.



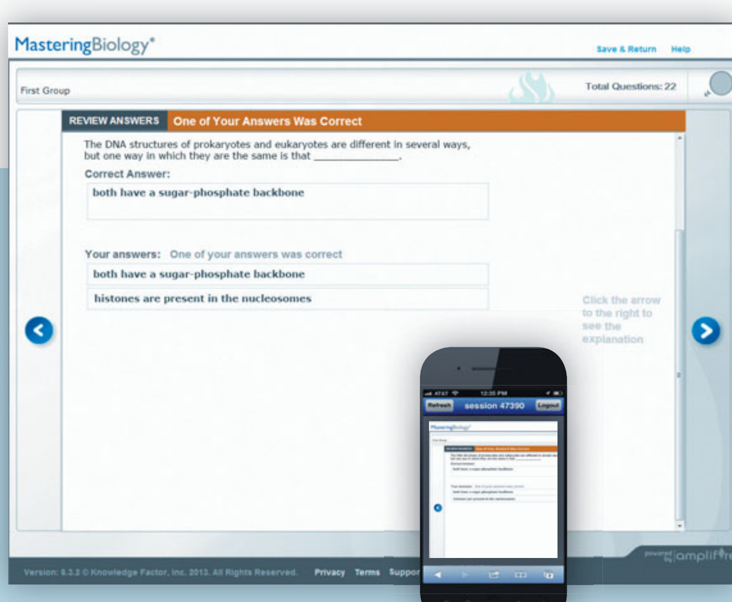




▲ **Figure 4.1C** Transmission electron micrograph of *Toxoplasma* (This parasite of cats can be transmitted to humans, causing the disease toxoplasmosis.)

Try This Describe a major difference between the *Paramecium* in Figure 4.1B and the protist in this figure. (*Hint*: Compare the notations along the right sides of the micrographs.)

New! Try This activities help you actively engage with the figures and develop positive study habits.



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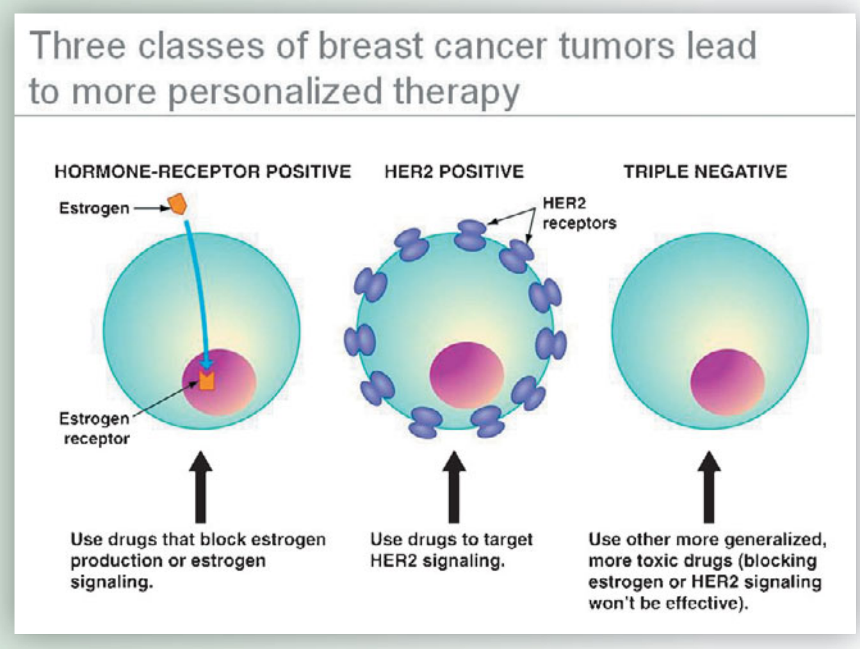

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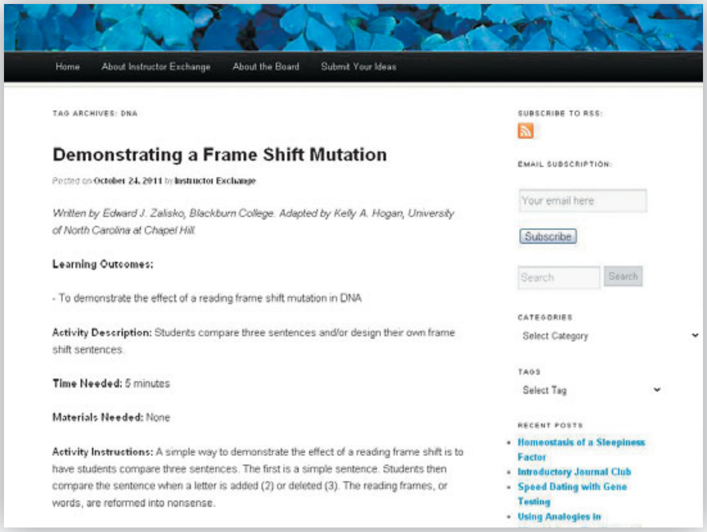
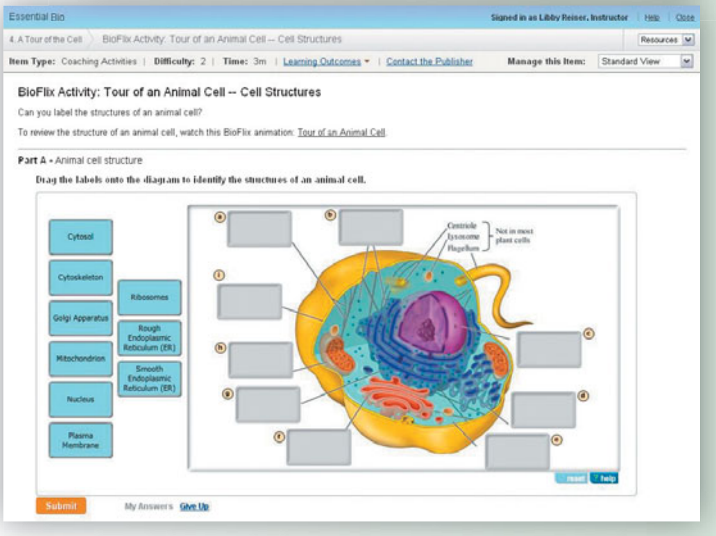


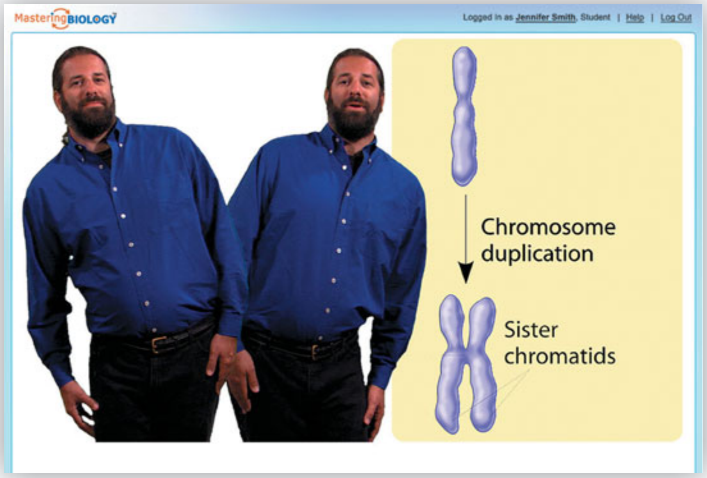
Instructor Exchange, moderated by co-author Kelly Hogan, offers a library of active learning strategies contributed by instructors from across the country.

BioFlix activities offer students 3-D animations to help them visualize and learn challenging topics.



Assign tutorials to help students prepare for class

Video Tutor Sessions and MP3 Tutor Sessions, hosted by co-author Eric Simon, provide on-the-go tutorials focused on key concepts and vocabulary.



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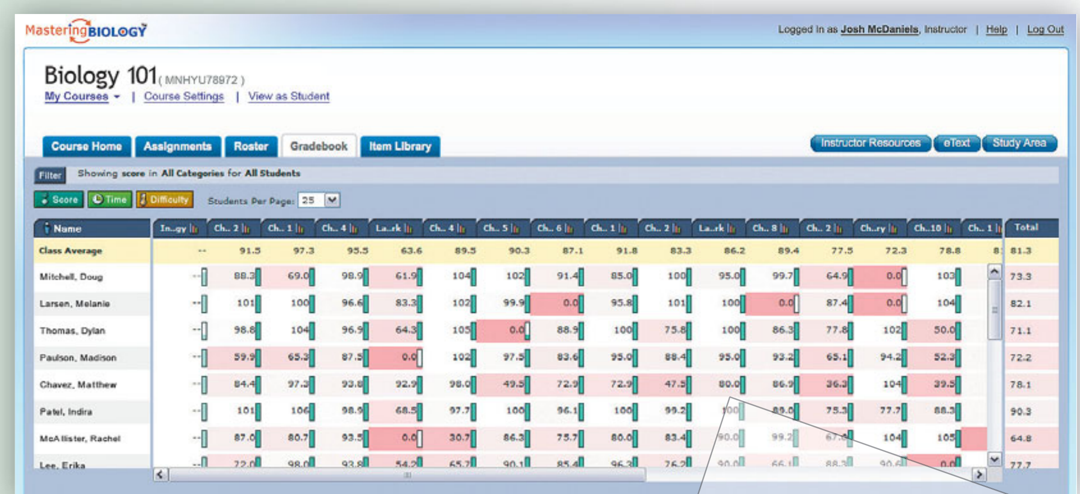

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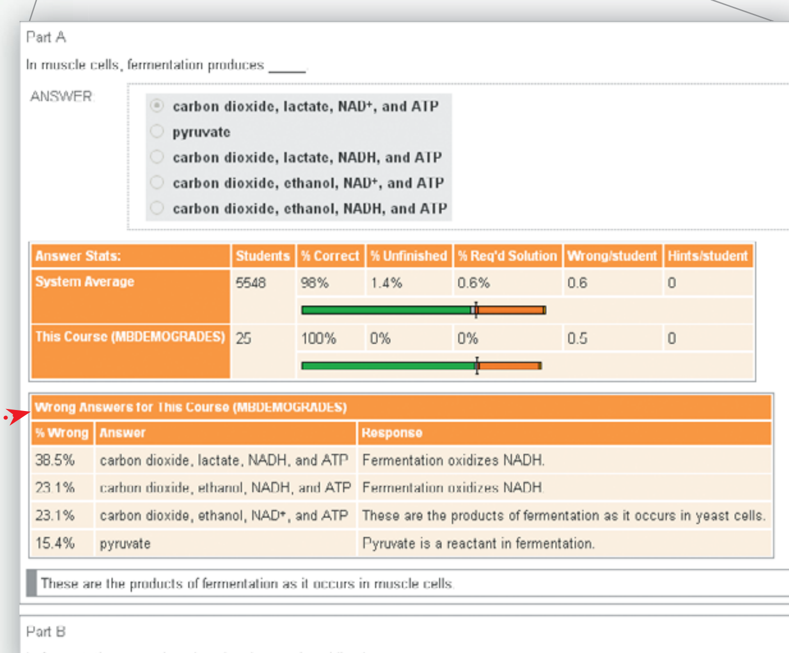
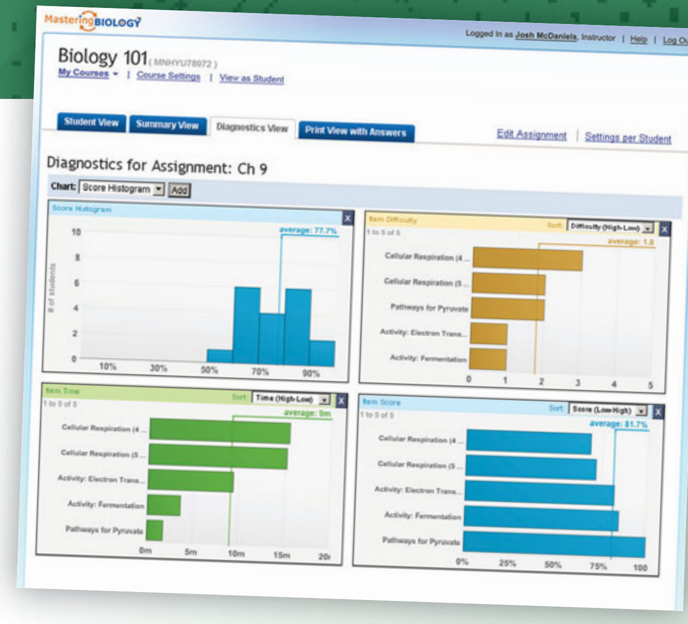


Gain insight into student progress at a glance



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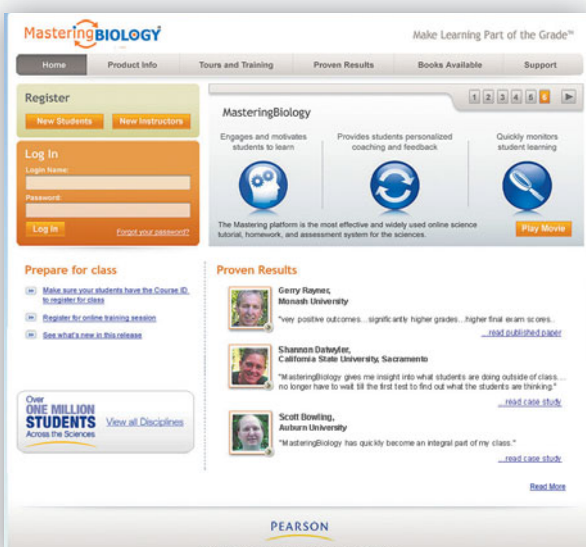

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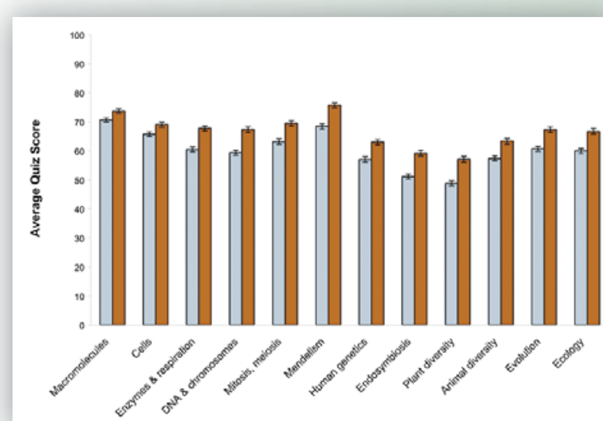

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Preface

Inspired by the thousands of students in our own classes over the years and by enthusiastic feedback from the many instructors who have used our book, we are delighted to present this new, Eighth Edition. We authors have worked together closely to ensure that both the book and the supplementary material online reflect the changing needs of today's courses and students, as well as current progress in biology. Titled *Campbell Biology: Concepts & Connections* to honor Neil Campbell's founding role and his many contributions to biology education, this book continues to have a dual purpose: to engage students from a wide variety of majors in the wonders of the living world and to show them how biology relates to their own existence and the world they inhabit. Most of these students will not become biologists themselves, but their lives will be touched by biology every day. Understanding the concepts of biology and their connections to our lives is more important than ever. Whether we're concerned with our own health or the health of our planet, a familiarity with biology is essential. This basic knowledge and an appreciation for how science works have become elements of good citizenship in an era when informed evaluations of health issues, environmental problems, and applications of new technology are critical.

Concepts and Connections

Concepts Biology is a vast subject that gets bigger every year, but an introductory biology course is still only one or two semesters long. This book was the first introductory biology textbook to use concept modules to help students recognize and focus on the main ideas of each chapter. The heading of each module is a carefully crafted statement of a key concept. For example, "A nerve signal begins as a change in the membrane potential" announces a key concept about the generation of an action potential (Module 28.4). Such a concept heading serves as a focal point, and the module's text and illustrations converge on that concept with explanation and, often, analogies. The module text walks the student through the illustrations, just as an instructor might do in class. And in teaching a sequential process, such as the one diagrammed in Figure 28.4, we number the steps in the text to correspond to numbered steps in the figure. The synergy between a module's narrative and graphic components transforms the concept heading into an idea with meaning to the student. The checkpoint question at the end of each module encourages students to test their understanding as they proceed through a chapter. Finally, in the Chapter Review, all the key concept statements are listed and briefly summarized under the overarching section titles, explicitly reminding students of what they've learned.

Connections Students are more motivated to study biology when they can connect it to their own lives and interests—for example, when they are able to relate science to health issues, economic problems, environmental quality, ethical controversies, and social responsibility. In this edition, blue Connection icons mark the numerous application modules that go beyond the core biological concepts. For example, the new Connection Module 26.12 describes the potential role oxytocin plays in human–dog bonding. In addition, our Evolution Connection modules, identified by green icons, connect the content of each chapter to the grand unifying theme of evolution, without which the study of life has no coherence. Explicit connections are also made between the chapter introduction and either the Evolution Connection module or the new Scientific Thinking module in each chapter; new high-interest questions introduce each chapter, drawing students into the topic and encouraging a curiosity to explore the question further when it appears again later in the chapter.

New to This Edition

New Scientific Thinking Modules In this edition we placed greater emphasis on the process of scientific inquiry through the addition to each chapter of a new type of module called Scientific Thinking, which is called out with a purple icon. These modules cover recent scientific research as well as underscore the spirit of inquiry in historical discoveries. All Scientific Thinking modules strive to demonstrate to students what scientists do. Each of these modules identifies key attributes of scientific inquiry, from the forming and testing of hypotheses to the analysis of data to the evaluation and communication of scientific results among scientists and with society as a whole. For example, the new Module 2.15 describes how scientists use both controlled experiments and observational field studies to document the effects of rising atmospheric CO_2 on coral reef ecosystems. Module 13.3 describes the scientific search for the common ancestor of whales, using different lines of inquiry from early fossil clues, molecular comparisons, and a series of transitional fossils that link whales to cloven-hoofed mammals, animals that live on land. And to prepare students for the renewed focus in the book on how biological concepts emerge from the process of science, we have significantly revised the introduction in Chapter 1, Biology: Exploring Life. These changes will better equip students to think like scientists and emphasize the connections between discovery and the concepts explored throughout the course.

New Visualizing the Concept Modules Also new to this edition are modules that raise our hallmark art–text integration to a new level. These Visualizing the Concept modules take challenging concepts or processes and walk students through them in a highly visual manner, using engaging, attractive art; clear and concise labels; and instructor "hints" called out in light blue bubbles. These short hints emulate the one-on-one coaching an instructor might provide to a students during office hours and help students make key connections within the figure. Examples of this new feature include Module 9.8, which demonstrates to students the process of reading and analyzing a family pedigree; Module 17.3, which introduces the concept of plant life cycles through a combination of photographs and detailed life cycle art displayed across an impressive two-page layout; and Module 26.8, which walks students through the concept of homeostatic controls in blood glucose levels.

New "Try This" Tips One theme of the revision for the Eighth Edition is to help all students learn positive study habits they can take with them throughout their college careers and, in particular, to encourage them to be active in their reading and studying. To foster good study habits, several figures in each chapter feature a new "Try This" study tip. These action-oriented statements or questions direct students to study a figure more closely and explain, interpret, or extend what the figure presents. For example, in Figure 3.13B, students are asked to "Point out the bonds and functional groups that make the R groups of these three amino acids either hydrophobic or hydrophilic." Figure 6.10B is a new figure illustrating the molecular rotary motor ATP synthase, and the accompanying Try This tip asks students to "Identify the power source that runs this motor. Explain where this 'power' comes from." Figure 36.7, on the effect of predation on the life history traits of guppies, offers the following Try This tip: "Use the figure to explain how the hypothesis was tested."

Improvements to End-of-Chapter Section The Testing Your Knowledge questions are now arranged to reflect Bloom's Taxonomy of cognitive domains. Questions and activities are grouped into Level 1: Knowledge/Comprehension, Level 2: Application/Analysis, and Level 3: Synthesis/Evaluation. In addition, a new Scientific Thinking question has been added to each chapter that connects to and extends the topic of the Scientific Thinking module. Throughout the Chapter Review, new questions have been added that will help students better engage with the chapter topic and practice higher-level problem solving.

New Design and Improved Art The fresh new design used throughout the chapters and the extensive reconceptualization of many figures make the book even more appealing and accessible to visual learners. The cellular art in Chapter 4, A Tour of the Cell, for example, has been completely reimagined for more depth perspective and richer color. The new big-picture diagrams of the animal and plant cells are vibrant and better demonstrate the spatial relationships among the cellular structures with an almost three-dimensional style. The illustrations of cellular organelles elsewhere in Chapter 4 include electron micrographs overlaid on diagrams to emphasize the connection between the realistic micrograph depiction and the artwork. Figure 4.9, for example, shows a micrograph of an actual Golgi apparatus paired with an illustration; an accompanying orientation diagram—a hallmark of *Concepts and Connections*—continues to act as a roadmap that reminds students of how an organelle fits within the overall cell structure. Finally, throughout the book we have introduced new molecular art; for example, see Figure 10.11B for a new representation of a molecule of tRNA binding to an enzyme molecule.

The Latest Science Biology is a dynamic field of study, and we take pride in our book's currency and scientific accuracy. For this edition, as in previous editions, we have integrated the results of the latest scientific research throughout the book. We have done this carefully and thoughtfully, recognizing that research advances can lead to new ways of looking at biological topics; such changes in perspective can necessitate organizational changes in our textbook to better reflect the current state of a field. You will find a unit-by-unit account of new content and organizational improvements in the "New Content" section on pp. xvii–xviii following this Preface.

New MasteringBiology® A specially developed version of MasteringBiology, the most widely used online tutorial and assessment program for biology, continues to accompany *Campbell Biology: Concepts & Connections*. In addition to 170 author-created activities that help students learn vocabulary, extend the book's emphasis on visual learning, demonstrate the connections among key concepts (helping students grasp the big ideas), and coach students on how to interpret data, the Eighth Edition features two additional new activity types. New Scientific Thinking activities encourage students to practice the basic science skills explored in the in-text Scientific Thinking feature, allowing students to try out thinking like a scientist and allowing instructors to assess this understanding; new Visualizing the Concept activities take students on an animated and narrated tour of select Visualizing the Concept modules from the text, offering students the chance to review key concepts in a digital learning modality. MasteringBiology® for *Campbell Biology: Concepts & Connections,* Eighth Edition, will help students to see strong connections through their print textbook, and the additional practice available online allows instructors to capture powerful data on student performance, thereby making the most of class time.

This Book's Flexibility

Although a biology textbook's table of contents is by design linear, biology itself is more like a web of related concepts without a single starting point or prescribed path. Courses can navigate this network by starting with molecules, with ecology, or somewhere in between, and courses can omit topics. *Campbell Biology: Concepts & Connections* is uniquely suited to offer flexibility and thus serve a variety of courses. The seven units of the book are largely self-contained, and in a number of the units, chapters can be assigned in a different order without much loss of coherence. The use of numbered modules makes it easy to skip topics or reorder the presentation of material.

■ ■ ■

For many students, introductory biology is the only science course that they will take during their college years. Long after today's students have forgotten most of the specific content of their biology course, they will be left with general impressions and attitudes about science and scientists. We hope that this new edition of *Campbell Biology: Concepts & Connections* helps make those impressions positive and supports instructors' goals for sharing the fun of biology. In our continuing efforts to improve the book and its supporting materials, we benefit tremendously from instructor and student feedback, not only in formal reviews but also via informal communication. Please let us know how we are doing and how we can improve the next edition of the book.

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New Content

Below are some important highlights of new content and organizational improvements in *Campbell Biology: Concepts & Connections*, Eighth Edition.

Chapter 1, Biology: Exploring Life The snowy owl, our cover organism for the Eighth Edition, is featured in the chapter introduction. The discussion of the evolutionary adaptations of these owls to life on the arctic tundra links to a new Scientific Thinking module on testing the hypothesis that camouflage coloration protects some animals from predation. An expanded module on evolution as the core theme of biology now includes a phylogenetic tree of elephants to enhance the discussion of the unity and diversity of life.

Unit I, The Life of the Cell Throughout the Eighth Edition, the themes introduced in new chapter introductions are expanded and further explored in either Scientific Thinking or Evolution Connection modules. For instance, in this unit, Chapter 5, The Working Cell, begins with the question "How can water flow through a membrane?" and an essay that describes the role these water channels play in kidney function; the essay is illustrated with a computer model of aquaporins spanning a membrane. Module 5.7, a Scientific Thinking module, then details the serendipitous discovery of aquaporins and presents data from a study that helped identify their function. Chapter 7, Photosynthesis: Using Light to Make Food, begins with the question "Will global climate change make you itch?" and uses the example of proliferation of poison ivy to introduce this chapter on photosynthesis. Then, Module 7.13, another Scientific Thinking module, explores various ways that scientists test the effects of rising atmospheric CO_2 levels on plant growth and presents results from a study on poison ivy growth. The Scientific Thinking question at the end of the chapter continues this theme, with data from a study on pollen production by ragweed under varying CO_2 concentrations, beginning with the question "Will global climate change make you sneeze as well as itch?" This unit also has three of the new Visualizing the Concept modules: Module 3.14: A protein's functional shape results from four levels of structure; Module 5.1: Membranes are fluid mosaics of lipids and proteins with many functions; and Module 7.9: The light reactions take place within the thylakoid membranes. These modules use both new and highly revised art to guide students through these challenging topics in a visual, highly intuitive manner. Chapter 6, How Cells Harvest Chemical Energy, now includes a new figure and expanded explanation of the amazing molecular motor, ATP synthase. The art program in Chapter 4, A Tour of the Cell, has been completely reimagined and revised. The beautiful new diagrams of animal and plant cells and their component parts are designed to help students appreciate the complexities of cell structure and explore the relationship between structure and function.

Unit II, Cellular Reproduction and Genetics The purpose of this unit is to help students understand the relationship between DNA, chromosomes, and organisms and to help them see that genetics is not purely hypothetical but connects in many important and interesting ways to their lives, human society, and other life on Earth. In preparing this edition, we worked to clarify difficult concepts, enhancing text and illustrations and providing timely new applications of genetic principles. The content is reinforced with updated discussions of relevant topics, such as personalized cancer therapy, the H1N1 and H5N1 influenza viruses, umbilical cord blood banking, and the science and controversy surrounding genetically modified foods. This edition includes discussion of many recent advances in the field. Some new topics concern our basic understanding of genetics and the cell cycle, such as how sister chromatids are physically attached during meiosis, how chemical modifications such as methylation and acetylation affect inheritance, and the roles of activators and enhancers in controlling gene expression. Other topics include recent advances in our understanding of genetics, such as the analysis of recent human evolution of high-altitude-dwelling Sherpas, expanded roles for microRNAs in the control of genetic information, and our improved understanding of the cellular basis of health problems in cloned animals. In some cases, sections within chapters have been reorganized to present a more logical flow of materials. Examples of new organization include the discussion of human karyotypes and the diagnosis of chromosomal abnormalities (Modules 8.18–8.20) and the processes of reproductive and therapeutic cloning (Modules 11.12–11.14). Material throughout the unit has been updated to reflect recent data, such as the latest cancer statistics and results from whole-genome sequencing.

Unit III, Concepts of Evolution This unit presents the basic principles of evolution and natural selection, the overwhelming evidence that supports these theories, and their relevance to all of biology—and to the lives of students. A new chapter introduction in Chapter 13, How Populations Evolve, highlights the role that evolution plays in thwarting human attempts to eradicate disease. The chapter has been reorganized so that the opening module on Darwin's development of the theory of evolution is followed immediately by evidence for evolution, including a Scientific Thinking module on fossils of transitional forms. Another new module (13.4) assembles evidence from homologies, including an example of "pseudogenes." New material in this unit also supports our goal of directly addressing student misconceptions about evolution. For example, a new chapter introduction and Scientific Thinking module in Chapter 14, The Origin of Species, tackle the question "Can we observe speciation occurring?" and a new chapter introduction in Chapter 15, Tracing Evolutionary History, poses the question (answered in Module 15.12) "How do brand-new structures arise by evolution?"

Unit IV, The Evolution of Biological Diversity The diversity unit surveys all life on Earth in less than a hundred pages! Consequently, descriptions and illustrations of the unifying characteristics of each major group of organisms, along with a small sample of its diversity, make up the bulk of the content. Two recurring elements are interwoven with these descriptions: evolutionary history and examples of relevance to our everyday lives and society at large. For the Eighth Edition, we have improved and updated those two elements. For example, Chapter 16, Microbial Life: Prokaryotes and Protists, opens with a new introduction on human microbiota and the question "Are antibiotics making us fat?" The related Scientific Thinking module (16.11) updates the story of Marshall's discovery of the role of *Helicobacter pylori* in ulcers with a new hypothesis about a possible connection between *H. pylori* and obesity. A new chapter introduction and Scientific Thinking module in Chapter 17, The Evolution of Plant and Fungal Diversity, highlight the interdependence of plants and fungi. The alternation of generations and the life cycle in mosses and ferns are presented in an attractive two-page Visualizing the Concept module (17.3), while details of the pine life cycle have been replaced with a new Module 17.5 that emphasizes pollen and seeds as key adaptations for terrestrial life. The animal diversity chapters (18, The Evolution of Invertebrate Diversity; and 19, The Evolution of Vertebrate Diversity) also have new opening essays. A Visualizing the Concept module (18.3) beautifully illustrates features of the animal body plan. A new Module 18.16 calls attention to the value of invertebrate diversity. Chapter 19 includes a Visualizing the Concept module (19.9) on primate diversity and also updates the story of hominin evolution, including the recently described *Australopithecus sediba*.

Unit V, Animals: Form and Function This unit combines a comparative approach with an exploration of human anatomy and physiology. Many chapters begin with an overview of a general problem that animals face and a comparative discussion of how different animals address this problem, all framed within an evolutionary context. For example, the introduction to Chapter 20, Unifying Concepts of Animal Structure and Function, begins with the question "Does evolution lead to the perfect animal form?" Module 20.1 is a new Evolution Connection that discusses the long, looped laryngeal nerve in vertebrates (using the giraffe as an example) to illustrate that a structure in an ancestral organism can become adapted to function in a descendant organism without being "perfected," thereby combating common student misconceptions about evolution. The main portion of every chapter is devoted to detailed presentations of human body systems, frequently illuminated by discussion of the health consequences of disorders in those systems. For example, Chapter 28, Nervous Systems, includes new material describing a genetic risk for developing Alzheimer's disease, the long-term consequences of traumatic brain injury, and how some antidepressants may not be as effective at combating depression as once thought. In many areas, content has been updated to reflect newer issues in biology. The chapter introduction and new Scientific Thinking module in Chapter 26, Hormones and the Endocrine System, discuss the consequences of endocrine disruptors in the environment. The Scientific Thinking module in Chapter 23 describes large clinical trials investigating the hypothesis that heart attacks are caused by the body's inflammatory response. Chapter 27, Reproduction and Embryonic Development, has a new chapter introduction on viral STDs, improved figures presenting embryonic development, as well as a Visualizing the Concept module on human pregnancy. Improvements to this unit also include a significant revision to the presentation of nutrition in Modules 21.14 to 21.21 and a reorganization of text and art in Modules 25.6 and 25.7 to guide students through the anatomy and physiology of the kidneys.

Unit VI, Plants: Form and Function To help students gain an appreciation of the importance of plants, this unit presents the anatomy and physiology of angiosperms with frequent connections to the importance of plants to society. New Connections in this edition include an increased discussion of the importance of agriculture to human civilization (including presentation of genomic data investigating this question) in Chapter 31, issues surrounding organic farming (including presentation of data on the nutritional value of organic versus conventionally grown produce) in Chapter 32, an expanded discussion of phytoestrogens, as well as a new discussion on the production of seedless vegetables in Chapter 33. Throughout the unit, the text has been revised with the goal of making the material more engaging and accessible to students. For example, the difficult topic of transpiration is now presented in an entirely new, visual style within a Visualizing the Concept module (Module 32.3), and streamlined and simplified discussions were written for such topics as the auxin hormones and phytochromes. All of these changes are meant to make the point that human society is inexorably connected to the health of plants.

Unit VII, Ecology In this unit, students learn the fundamental principles of ecology and how these principles apply to environmental problems. Along with a new introduction in each chapter, the Eighth Edition features many new photos and two Visualizing the Concept modules (35.7 and 37.9)—one focuses on whether animal movement is a response to stimuli or requires spatial learning and the other explores the interconnection of food chains and food webs. Scientific Thinking modules sample the variety of approaches to studying ecology, including the classic field study that led to the concept of keystone species (37.11); the "natural experiment" of returning gray wolves to the Yellowstone ecosystem (38.11); and the combination of historical records, long-term experimentation, and modern technology to investigate the snowshoe hare–lynx population cycle (36.6). The pioneering work of Rachel Carson (34.2) and Jane Goodall (35.22) is also described in Scientific Thinking modules. Modules that present data on human population (36.3, 36.9–36.11), declining biodiversity (38.1), and global climate change (38.3, 38.4) have all been updated.

Acknowledgments

This Eighth Edition of *Campbell Biology: Concepts & Connections* is a result of the combined efforts of many talented and hardworking people, and the authors wish to extend heartfelt thanks to all those who contributed to this and previous editions. Our work on this edition was shaped by input from the biologists acknowledged in the reviewer list on pages xx–xxii, who shared with us their experiences teaching introductory biology and provided specific suggestions for improving the book. Feedback from the authors of this edition's supplements and the unsolicited comments and suggestions we received from many biologists and biology students were also extremely helpful. In addition, this book has benefited in countless ways from the stimulating contacts we have had with the coauthors of *Campbell Biology*, Tenth Edition.

We wish to offer special thanks to the students and faculty at our teaching institutions. Marty Taylor thanks her students at Cornell University for their valuable feedback on the book. Eric Simon thanks his colleagues and friends at New England College, especially within the collegium of Natural Sciences and Mathematics, for their continued support and assistance. Jean Dickey thanks her colleagues at Clemson University for their expertise and support. And Kelly Hogan thanks her students for their enthusiasm and thanks her colleagues at the University of North Carolina, Chapel Hill, for their continued support.

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We thank Gary Hespenheide for creating a beautiful and functional interior design and a stunning cover, and we are again indebted to design manager Marilyn Perry for her oversight and design leadership. The new Visualizing the Concept modules benefited from her vision, as well as from the early input of art editor Elisheva Marcus and the continuing contributions of artist Andrew Recher of Precision Graphics. Art editor Kelly Murphy envisioned the beautiful new cell art throughout the book.

The value of *Campbell Biology: Concepts & Connections* as a learning tool is greatly enhanced by the hard work and creativity of the authors of the supplements that accompany this book: Ed Zalisko (*Instructor's Guide* and *PowerPoint® Lecture Presentations*); Jean DeSaix, Tanya Smutka, Kristen Miller, and Justin Shaffer (*Test Bank*); Dana Kurpius (*Active Reading Guide*); Robert Iwan and Amaya Garcia (*Reading Quizzes* and media correlations); and Shannon Datwyler (*Clicker Questions* and *Quiz Shows*). In addition to senior supplements project editor Susan Berge, the editorial and production staff for the supplements program included supplements production project manager Jane Brundage, *PowerPoint® Lecture Presentations* editor Joanna Dinsmore, and project manager Sylvia Rebert of Progressive Publishing Alternatives. And the superlative MasteringBiology® program for this book would not exist without Lauren Fogel, Stacy Treco, Tania Mlawer, Katie Foley, Sarah Jensen, Juliana Tringali, Daniel Ross, Dario Wong, Taylor Merck, Caroline Power, and David Kokorowski and his team. And a special thanks to Sarah Young-Dualan for her thoughtful work on the Visualizing the Concepts interactive videos.

For their important roles in marketing the book, we are very grateful to senior marketing manager Amee Mosley, executive marketing manager Lauren Harp, and vice president of marketing Christy Lesko. We also appreciate the work of the executive marketing manager for MasteringBiology®, Scott Dustan. The members of the Pearson Science sales team have continued to help us connect with biology instructors and their teaching needs, and we thank them.

Finally, we are deeply grateful to our families and friends for their support, encouragement, and patience throughout this project. Our special thanks to Paul, Dan, Maria, Armelle, and Sean (J.B.R.); Josie, Jason, Marnie, Alice, Jack, David, Paul, Ava, and Daniel (M.R.T.); Amanda, Reed, Forest, and dear friends Jamey, Nick, Jim, and Bethany (E.J.S.); Jessie and Katherine (J.L.D.); and Tracey, Vivian, Carolyn, Brian, Jake, and Lexi (K.H.)

Jane Reece, Martha Taylor, Eric Simon, Jean Dickey, and Kelly Hogan

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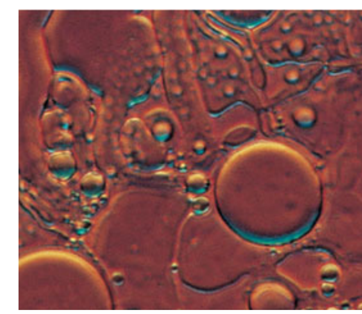

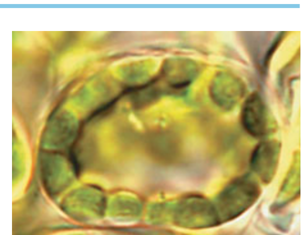

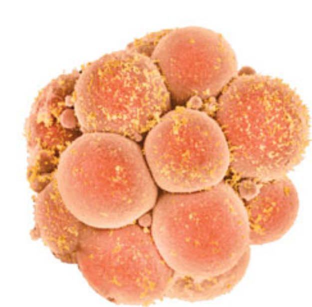

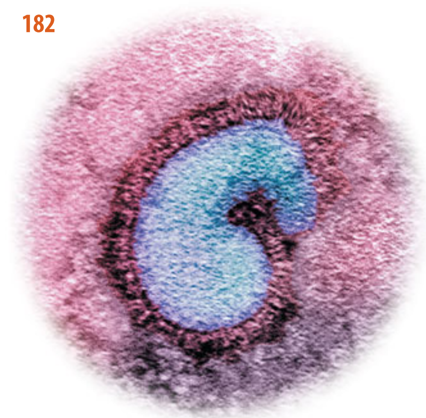

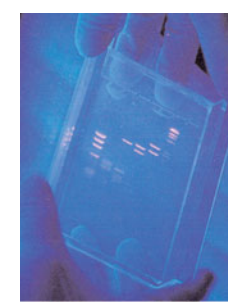

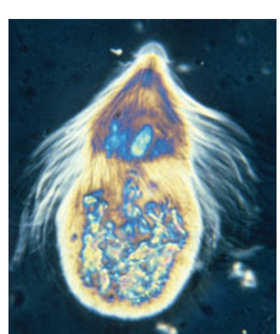

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CHAPTER 1

Biology: *Exploring Life*

Why do so many animals match their surroundings?

Snowy owls (*Bubo scandiacus*), such as the one on the cover of this textbook and pictured below, are strikingly beautiful owls with bright orange eyes and wingspans as wide as five feet. These swift and silent predators exhibit remarkable adaptations for life in their frozen, barren habitat. The layers of fine feathers on their face, body, legs, and even their feet provide insulation in subzero weather. They breed on the Arctic tundra, nesting on open ground. The female broods the eggs and young, while the male provides a steady supply of food. His keen vision and acute hearing help him locate small mammals such as voles and lemmings, which he then snatches in mid-flight with his sharp talons.

The majority of owl species are nocturnal. But during the endless days of arctic summers, snowy owls hunt in daylight. Projecting upper eyelids help shield their eyes from bright sun. As with all owls, the overlapping fields of vision of their forward-facing eyes provide superior depth perception. These large eyes cannot move, so an owl must turn its whole head to follow a moving object. This is not a problem for an owl, as you can see in the photo below, because adaptations of its neck

vertebrae enable it to rotate its head a full 270 degrees. Imagine being able to look over your left shoulder by turning your head to the right!

You may think of owls in general in shades of brown, nesting in tree cavities and blending in with their surroundings. And with snowy owls, you may think of Harry Potter's white-feathered companion. In real life, these owls also blend in with their wintry habitat. Later in this chapter, you will read about an experiment that tests the hypothesis that camouflage coloration protects animals from predators.

The amazing adaptations of snowy owls are the result of evolution, the process that has transformed life from its earliest beginnings to the astounding array of organisms living today. In this chapter, we begin our exploration of biology—the scientific study of life.

BIG IDEAS

Themes in the Study of Biology
(1.1–1.4)

Common themes help to organize the study of life.

Evolution, the Core Theme of Biology
(1.5–1.7)

Evolution accounts for the unity and diversity of life and the evolutionary adaptations of organisms to their environment.

The Process of Science
(1.8–1.9)

In studying nature, scientists make observations, form hypotheses, and test predictions.

Biology and Everyday Life
(1.10–1.11)

Learning about biology helps us understand many issues involving science, technology, and society.

Themes in the Study of Biology

1.1 All forms of life share common properties

Defining **biology** as the scientific study of life raises the obvious question: What is *life*? Even a small child realizes that a bug or a flower is alive, whereas a rock or a car is not. But the phenomenon we call life defies a simple, one-sentence definition. We recognize life mainly by what living things do. **Figure 1.1** highlights seven of the properties and processes that we associate with life.

1. *Order.* This sunflower illustrates the ordered structure that typifies life. Living cells make up this complex organization.
2. *Reproduction.* Organisms reproduce their own kind. Here a baby African elephant walks beneath its mother.
3. *Growth and development.* Inherited information in the form of DNA controls the pattern of growth and development of all organisms, including this hatching crocodile.
4. *Energy processing.* This caterpillar will use the chemical energy stored in the plant it is eating to power its own activities and chemical reactions.
5. *Regulation.* Many types of mechanisms regulate an organism's internal environment, keeping it within limits that sustain life. Pictured here is a lizard "sunbathing"—which helps raise its body temperature on cool mornings.
6. *Response to the environment.* All organisms respond to environmental stimuli. This Venus flytrap closed its trap rapidly in response to the stimulus of a damselfly landing on it.
7. *Evolutionary adaptation.* A snowy owl's sharp talons facilitate prey capture and its feathered feet keep it warm in its cold habitat. Such adaptations evolve over many generations as individuals with traits best suited to their environment have greater reproductive success and pass their traits to offspring.

Figure 1.1 reminds us that the living world is wondrously varied. How do biologists make sense of this diversity and complexity, and how can you? Indeed, biology is a subject of enormous scope that gets bigger all the time. One of the ways to help you organize this information is to connect what you learn to a set of themes that you will encounter throughout your study of life. The next few modules introduce several important themes: novel properties emerging at each level of biological organization, the correlation of structure and function, and the exchange of matter and energy as organisms interact with the environment. We then focus on the core theme of biology—evolution, the theme that makes sense of both the unity and diversity of life.

Let's begin our journey with a tour through the levels of the biological hierarchy.

? **How would you define life?**

Life can be defined by a set of common properties such as those described in this module.

▲ **Figure 1.1** Some important properties of life

1.2 In life's hierarchy of organization, new properties emerge at each level

As **Figure 1.2** illustrates, the study of life extends from the global scale of the biosphere to the microscopic level of molecules. At the upper left we take a distant view of the **biosphere**, all of the environments on Earth that support life. These include most regions of land, bodies of water, and the lower atmosphere. A closer look at one of these environments brings us to the level of an **ecosystem**, which consists of all the organisms living in a particular area, as well as the physical components with which the organisms interact, such as air, soil, water, and sunlight.

The entire array of organisms in an ecosystem is called a **community**. In this community, we find alligators and snakes, herons and egrets, myriad insects, trees and other plants, fungi, and enormous numbers of microorganisms. Each unique form of life is called a species.

A **population** includes all the individuals of a particular species living in an area. Next in the hierarchy is the **organism**, an individual living thing, such as an alligator.

Within a complex organism, life's hierarchy continues to unfold. An **organ system**, such as the circulatory system or nervous system, consists of several organs that cooperate in a specific function. For instance, the organs of the nervous system are the brain, the spinal cord, and the nerves. An alligator's nervous system controls all its actions.

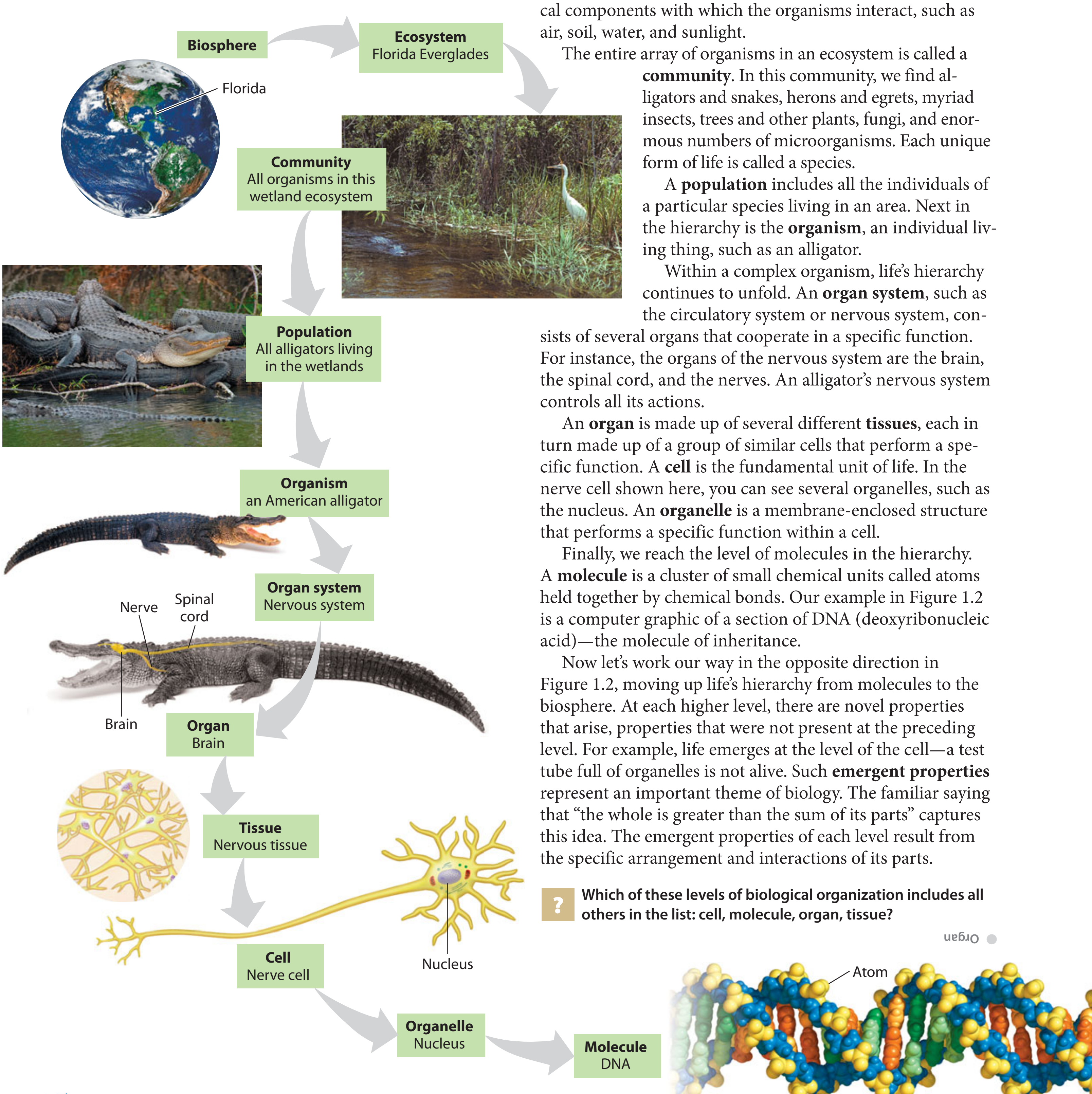
An **organ** is made up of several different **tissues**, each in turn made up of a group of similar cells that perform a specific function. A **cell** is the fundamental unit of life. In the nerve cell shown here, you can see several organelles, such as the nucleus. An **organelle** is a membrane-enclosed structure that performs a specific function within a cell.

Finally, we reach the level of molecules in the hierarchy. A **molecule** is a cluster of small chemical units called atoms held together by chemical bonds. Our example in Figure 1.2 is a computer graphic of a section of DNA (deoxyribonucleic acid)—the molecule of inheritance.

Now let's work our way in the opposite direction in Figure 1.2, moving up life's hierarchy from molecules to the biosphere. At each higher level, there are novel properties that arise, properties that were not present at the preceding level. For example, life emerges at the level of the cell—a test tube full of organelles is not alive. Such **emergent properties** represent an important theme of biology. The familiar saying that "the whole is greater than the sum of its parts" captures this idea. The emergent properties of each level result from the specific arrangement and interactions of its parts.

? Which of these levels of biological organization includes all others in the list: cell, molecule, organ, tissue?

Organ



▲ **Figure 1.2** Life's hierarchy of organization

1.3 Cells are the structural and functional units of life

The cell has a special place in the hierarchy of biological organization. It is the level at which the properties of life emerge—the lowest level of structure that can perform all activities required for life. A cell can regulate its internal environment, take in and use energy, respond to its environment, and build and maintain its complex organization. The ability of cells to give rise to new cells is the basis for all reproduction and also for the growth and repair of multicellular organisms.

All organisms are composed of cells. They occur singly as a great variety of unicellular (single-celled) organisms, such as amoebas and most bacteria. And cells are the subunits that make up multicellular organisms, such as owls and trees. Your body consists of trillions of cells of many different kinds.

All cells share certain characteristics. For example, every cell is enclosed by a membrane that regulates the passage of materials between the cell and its surroundings. And every cell uses DNA as its genetic information. However, we can distinguish between two main forms of cells. **Prokaryotic cells** were the first to evolve and were Earth's sole inhabitants for more than 1.5 billion years. Fossil evidence indicates that **eukaryotic cells** evolved from prokaryotic ancestral cells about 1.8 billion years ago.

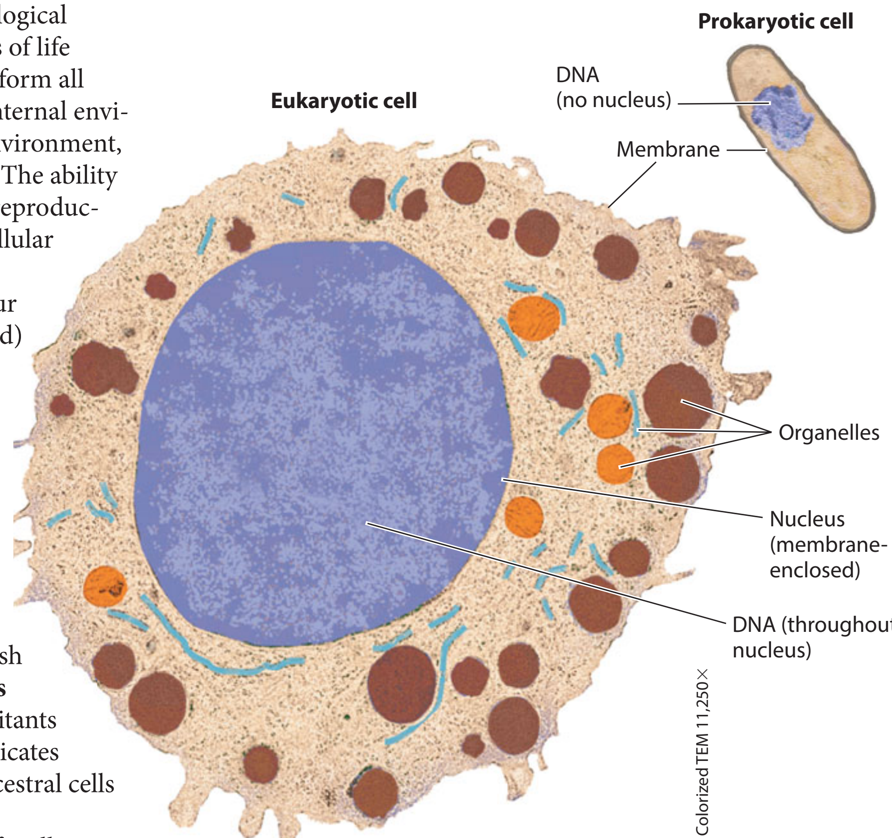
Figure 1.3 shows these two types of cells as artificially colored photographs taken with an electron microscope. A prokaryotic cell is much simpler and usually much smaller than a eukaryotic cell. The cells of the microorganisms we call bacteria are prokaryotic. Plants, animals, fungi, and protists (mostly unicellular organisms) are all composed of eukaryotic cells. As you can see in Figure 1.3, a eukaryotic cell is subdivided by membranes into various functional compartments, or organelles. These include a nucleus, which houses the cell's DNA.

The properties of life emerge from the ordered arrangement and interactions of the structures of a cell. Such a combination of components forms a more complex organization that we can call a *system*. Systems and their emergent properties are not unique to life. Consider a box of bicycle parts. When all of the individual parts are properly assembled, the result is a mechanical system you can use for exercise or transportation.

The emergent properties of life, however, are particularly challenging to study because of the unrivaled complexity of biological systems. Biologists today often use an approach called **systems biology**—the study of a biological system and the modeling of its dynamic behavior by analyzing the interactions among its parts. Biological systems can range from the functioning of the biosphere to the molecular machinery of an organelle.

Cells illustrate another theme of biology: the correlation of structure and function. Experience shows you that form generally fits function. A screwdriver tightens or loosens screws, a hammer pounds nails. Because of their form, these tools can't do each other's jobs. Applied to biology, this theme of form fitting function is a guide to the structure of life at all its organizational levels. For example, the long extension of the nerve cell shown in Figure 1.2 enables it to transmit impulses across long distances in the body. Often, analyzing a biological structure gives us clues about what it does and how it works.

The activities of organisms are all based on cells. For example, your every thought is based on the actions of nerve cells, and your movements depend on muscle cells. Even a global process such as the cycling of carbon is the result of cellular activities, including the photosynthesis of plant cells and the cellular respiration of nearly all cells, a process that uses oxygen to break down sugar for energy and releases carbon dioxide. In the next module, we explore these processes and how they relate to the theme of organisms interacting with their environments.



▲ **Figure 1.3** Contrasting the size and complexity of prokaryotic and eukaryotic cells (shown here approximately 11,250 times their real size)

? **Why are cells considered the basic units of life?**

● They are the lowest level in the hierarchy of biological organization at which the properties of life emerge.

1.4 Organisms interact with their environment, exchanging matter and energy

An organism interacts with its environment, and that environment includes other organisms as well as physical factors. **Figure 1.4** is a simplified diagram of such interactions taking place in a forest in Canada. Plants are the producers that provide the food for a typical ecosystem. A tree, for example, absorbs water (H_2O) and minerals from the soil through its roots, and its leaves take in carbon dioxide (CO_2) from the air. In photosynthesis, a tree's leaves use energy from sunlight to convert CO_2 and H_2O to sugar and oxygen (O_2). The leaves release O_2 to the air, and the roots help form soil by breaking up rocks. Thus, both organism and environment are affected by the interactions between them.

The consumers of a ecosystem eat plants and other animals. The moose in Figure 1.4 eats the grasses and tender shoots and leaves of trees in a forest ecosystem in Canada. To release the energy in food, animals (as well as plants and most other organisms) take in O_2 from the air and release CO_2. An animal's wastes return other chemicals to the environment.

Another vital part of the ecosystem includes the small animals, fungi, and bacteria in the soil that decompose wastes and the remains of dead organisms. These decomposers act as recyclers, changing complex matter into simpler chemicals that plants can absorb and use.

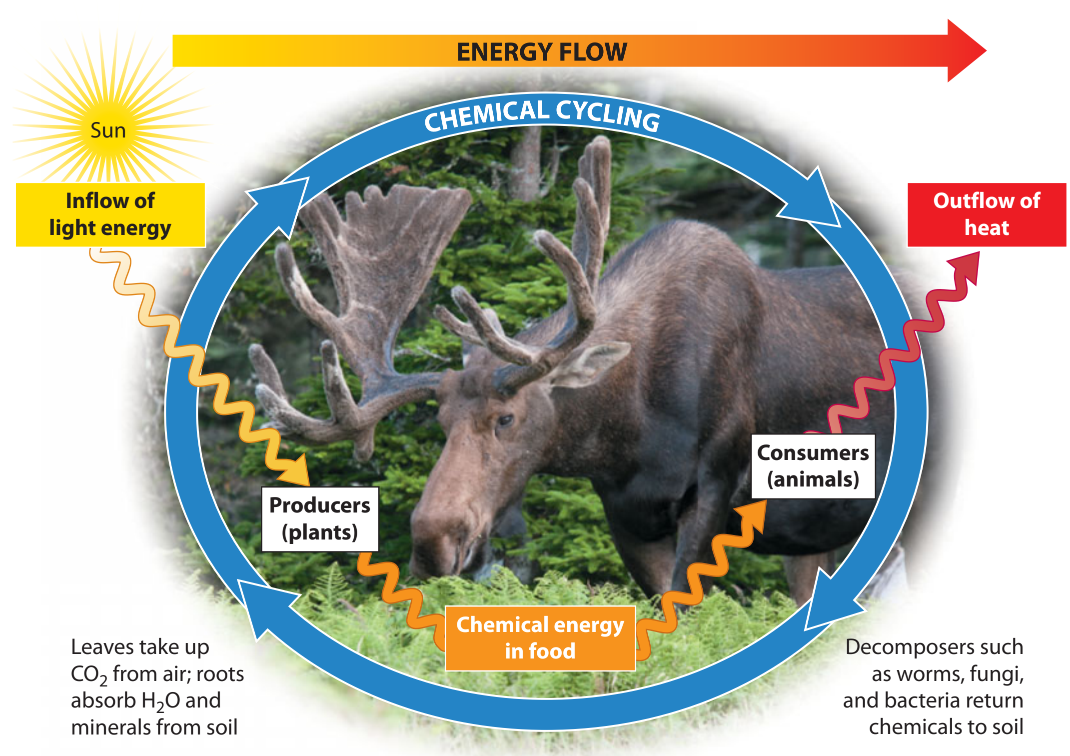
The dynamics of ecosystems include two major processes—the recycling of chemicals and the flow of energy. These processes are illustrated in Figure 1.4. The most basic chemicals necessary for life—carbon dioxide, oxygen, water, and various minerals—cycle within an ecosystem from the air and soil to plants, to animals and decomposers, and back to the air and soil (shown with blue arrows in the figure).

By contrast, an ecosystem gains and loses energy constantly. Energy flows into the ecosystem when plants and other photosynthesizers absorb light energy from the sun (yellow arrow) and convert it to the chemical energy of sugars and other complex molecules. Chemical energy (orange arrow) is then passed through a series of consumers and, eventually, to decomposers, powering each organism in turn. In the process of these energy conversions between and within organisms, some energy is converted to heat, which is then lost from the system (red arrow). In contrast to chemicals, which recycle within an ecosystem, energy flows through an ecosystem, entering as light and exiting as heat.

In this first section, we have touched on several themes of biology, from emergent properties in the biological hierarchy of organization, to cells as the structural and functional units of life, to the exchange of matter and energy as organisms interact with their environment. In the next section, we begin our exploration of evolution, the core theme of biology.

? Explain how the photosynthesis of plants functions in both the cycling of chemicals and the flow of energy in an ecosystem.

Photosynthesis uses light energy to convert carbon dioxide and water to energy-rich food, making it the pathway by which both chemicals and energy become available to most organisms.



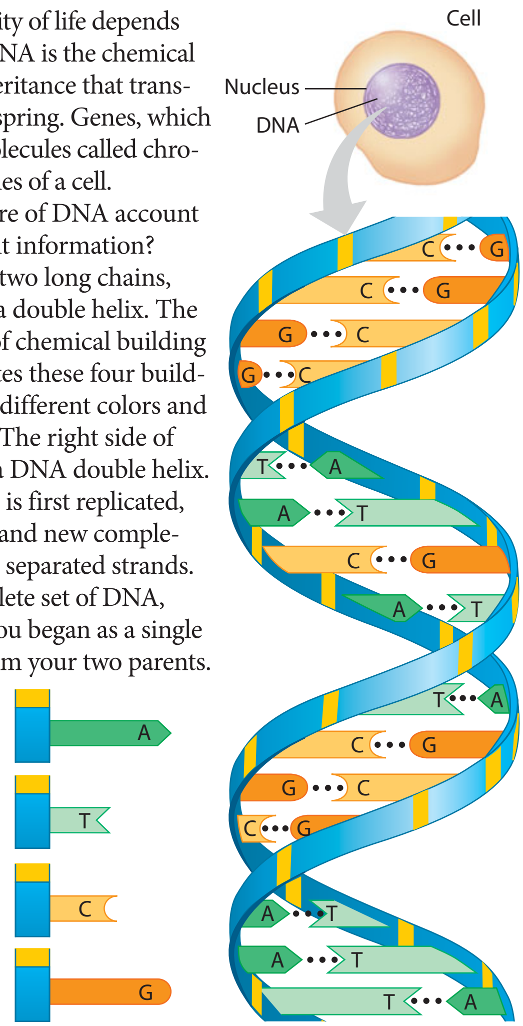
▲ **Figure 1.4** The cycling of chemicals and flow of energy in an ecosystem

Evolution, the Core Theme of Biology

1.5 The unity of life is based on DNA and a common genetic code

All cells have DNA, and the continuity of life depends on this universal genetic material. DNA is the chemical substance of **genes**, the units of inheritance that transmit information from parents to offspring. Genes, which are grouped into very long DNA molecules called chromosomes, also control all the activities of a cell.

How does the molecular structure of DNA account for its ability to encode and transmit information? Each DNA molecule is made up of two long chains, called strands, coiled together into a double helix. The strands are made up of four kinds of chemical building blocks. **Figure 1.5** (left side) illustrates these four building blocks, called nucleotides, with different colors and letter abbreviations of their names. The right side of the figure shows a short section of a DNA double helix.



▲ **Figure 1.5** The four building blocks of DNA (left); part of a DNA double helix (right)

Each time a cell divides, its DNA is first replicated, or copied—the double helix unzips and new complementary strands assemble along the separated strands. Thus, each new cell inherits a complete set of DNA, identical to that of the parent cell. You began as a single cell stocked with DNA inherited from your two parents. The replication of that DNA during each round of cell division transmitted copies of the DNA to what eventually became the trillions of cells of your body.

The way DNA encodes a cell's information is analogous to the way we arrange letters of the alphabet into precise sequences with specific meanings. The word *rat*, for example, conjures up an image of a rodent; *tar* and *art*, which contain the same letters, mean very different things. We can think of the four building blocks as the alphabet of inheritance. Specific sequential arrangements of these four chemical letters encode precise information in genes, which are typically hundreds or thousands of "letters" long.

The DNA of genes provides the blueprints for making proteins, and proteins serve as the tools that actually build and maintain the cell and carry out its activities. A bacterial gene may direct the cell to "Make a yellow pigment." A particular human gene may mean "Make the hormone insulin." All forms of life use essentially the same genetic code to translate the information stored in DNA into proteins. This makes it possible to engineer cells to produce proteins normally found only in some other organism. Thus, bacteria can be used to produce insulin for the treatment of diabetes by inserting a gene for human insulin into bacterial cells.

The diversity of life arises from differences in DNA sequences—in other words, from variations on the common theme of storing genetic information in DNA. Bacteria and humans are different because they have different genes. But both sets of instructions are written in the same language.

The entire "library" of genetic instructions that an organism inherits is called its **genome**. A typical human cell has two similar sets of chromosomes, and each set contains about 3 billion nucleotide pairs. In recent years, scientists have determined the entire sequence of nucleotides in the human genome, as well as the genomes of thousands of other species. More species continue to be added to the list of species whose genomes have been sequenced as the rate at which sequencing can be done has accelerated rapidly in recent years. To deal with the resulting deluge of data, scientists are applying a systems biology approach at the molecular level. In an emerging field known as genomics, researchers now study whole sets of genes in a species and then compare genes across multiple species. The benefits from such an approach range from identifying genes that may be implicated in human cancers to revealing the evolutionary relationships among diverse organisms based on similarities in their genomes. Genomics affirms the unity of life based on the universal genetic material—DNA.

In the next module, we see how biologists attempt to organize the diversity of life.

? **What are the two main functions of DNA?**

● DNA is the genetic material that is passed from parents to offspring, and it codes for proteins that control the activity of cells.

1.6 The diversity of life can be arranged into three domains

We can think of biology's enormous scope as having two dimensions. The "vertical" dimension, which we examined in Module 1.2, is the size scale that stretches from molecules to the biosphere. But biology also has a "horizontal" dimension, spanning across the great diversity of organisms existing now and over the long history of life on Earth.

Diversity is a hallmark of life. Biologists have so far identified and named about 1.8 million species. Estimates of the total number of species range from 10 million to more than 100 million.

There seems to be a human tendency to group things, such as owls or butterflies, although we recognize that each group includes many different species. And then we cluster groups into broader categories, such as birds and insects. Taxonomy, the branch of biology that names and classifies species, arranges species into a hierarchy of broader and broader groups: genus, family, order, class, phylum, and kingdom.

Historically, biologists divided all of life into five kingdoms. But new methods for assessing evolutionary relationships, such as comparisons of DNA sequences, have led to an ongoing reevaluation of the number and boundaries of kingdoms. Although the debate on such divisions continues, there is consensus among biologists that life can be organized into three higher levels called **domains**. **Figure 1.6** shows representatives of domains Bacteria, Archaea, and Eukarya.

▲ **Figure 1.6** The three domains of life

Domains **Bacteria** and **Archaea** both consist of prokaryotes, organisms with prokaryotic cells. Bacteria are the most diverse and widespread prokaryotes. Many of the prokaryotes known as archaea live in Earth's extreme environments, such as salty lakes and boiling hot springs. Each rod-shaped or round structure in the photos of the prokaryotes in Figure 1.6 is a single cell. These photos were made with an electron microscope, and the number along the side indicates the magnification of the image.

All the eukaryotes, organisms with eukaryotic cells, are grouped in domain **Eukarya**. Protists are a diverse collection of mostly single-celled organisms. Pictured in Figure 1.6 is an assortment of protists in a drop of pond water. Biologists are currently assessing how to group the protists to reflect their evolutionary relationships.

The three remaining groups within Eukarya are distinguished partly by their modes of nutrition. Kingdom Plantae consists of plants, which produce their own food by photosynthesis. The plant pictured in Figure 1.6 is a tropical bromeliad, a plant native to the Americas.

Kingdom Fungi, represented by the mushrooms in Figure 1.6, is a diverse group whose members mostly decompose the remains of dead organisms and organic wastes and absorb the nutrients into their cells.

Animals obtain food by eating other organisms. The sloth in Figure 1.6 resides in South American rain forests. There are actually members of two other groups in the sloth photo. The sloth is clinging to a tree (kingdom Plantae), and the greenish tinge in its hair is a luxuriant growth of photosynthetic prokaryotes (domain Bacteria). This photograph exemplifies a theme reflected in our book's title: connections between living things. The sloth depends on trees for food and shelter; the tree uses nutrients from the decomposition of the sloth's feces; the prokaryotes gain access to the sunlight necessary for photosynthesis by living on the sloth; and the sloth is camouflaged from predators by its green coat.

The diversity of life and its interconnectedness are evident almost everywhere. Earlier we looked at life's unity in its shared properties and common genetic code. In the next module, we explore how evolution explains both the unity and the diversity of life.

? **To which of the three domains of life do we belong?**

● Eukarya

1.7 Evolution explains the unity and diversity of life

Evolution can be defined as the process of change that has transformed life on Earth from its earliest beginnings to the diversity of organisms living today. The fossil record documents the fact that life has been evolving on Earth for billions of years, and patterns of ancestry can be traced through this record. For example, the mammoth being excavated in **Figure 1.7A** is clearly related to present-day elephants. We can explain the shared traits of mammoths and elephants with the premise that they descended from a common ancestor in the distant past. Their differences reflect the evolutionary changes that occurred within their separate lineages during the history of their existence on Earth. Thus, evolution accounts for life's dual nature of kinship and diversity.

▲ **Figure 1.7A** Excavation of 26,000-year-old fossilized mammoth bones from a site in South Dakota

This evolutionary view of life came into sharp focus in November 1859, when Charles Darwin **(Figure 1.7B)** published one of the most important and influential books ever written. Entitled *On the Origin of Species by Means of Natural Selection*, Darwin's book was an immediate bestseller and soon made his name synonymous with the concept of evolution.

▲ **Figure 1.7B** Charles Darwin in 1859

As a young man, Darwin made key observations that greatly influenced his thinking. During a five-year, around-the-world voyage, he collected and documented plants and animals in widely varying locations—from the isolated Galápagos Islands off the coast of Ecuador to the heights of the Andes mountains to the jungles of Brazil. He was particularly struck by the adaptations of these varied organisms that fit them to their diverse habitats. After returning to England, Darwin spent more than two decades continuing his observations, performing experiments, corresponding with other scientists, and refining his thinking before he finally published his work.

The first of two main points that Darwin presented in *The Origin of Species* was that species living today arose from a successor of ancestors that differed from them. Darwin called this process "descent with modification." It was an insightful phrase, because it captured both the unity of life (descent from a common ancestor) and the diversity of life (modifications that evolved as species diverged from their ancestors). **Figure 1.7C** illustrates this unity and diversity among birds. These three birds all have a common "bird" body plan of wings, beak, feet, and feathers, but these features are highly specialized for each bird's unique lifestyle.

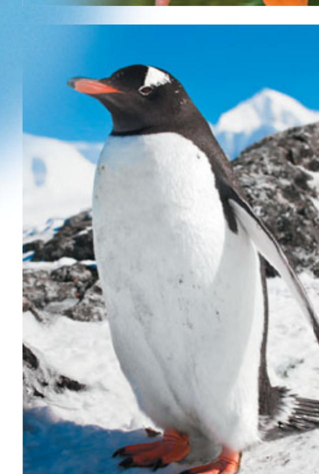
Darwin's second point was to propose a mechanism for evolution, which he called **natural selection**. Darwin started with two observations, from which he drew two inferences.

OBSERVATION #1: *Individual variation.* Individuals in a population vary in their traits, many of which are inherited from parents to offspring.

OBSERVATION #2: *Overproduction of offspring.* All species can produce far more offspring than the environment can support. Competition for resources is thus inevitable, and many of these offspring fail to survive and reproduce.

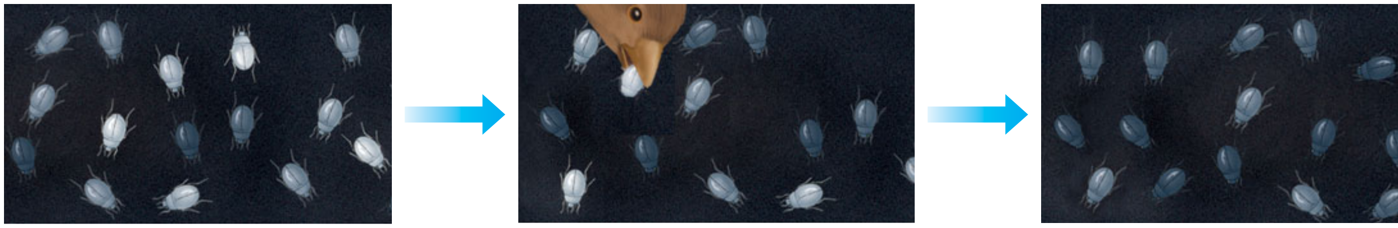
INFERENCE #1: *Unequal reproductive success.* Individuals with heritable traits best suited to the local environment are more likely to survive and reproduce than are less well-suited individuals.

INFERENCE #2: *Accumulation of favorable traits over time.* As a result of this unequal reproductive success over many generations, a higher and higher proportion of individuals in the population will have the advantageous traits.



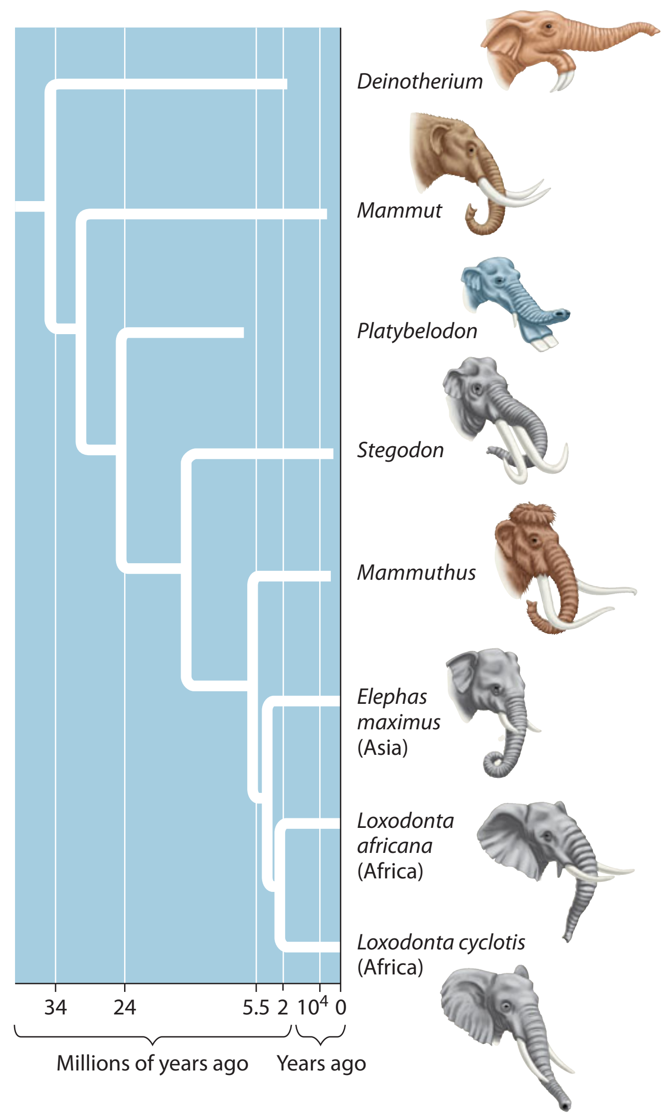
▲ **Figure 1.7C** Unity and diversity among birds

Try This For each bird, describe some adaptations that fit it to its environment and way of life.



▲ **Figure 1.7D** An example of natural selection in action

Try This Describe what might happen if some of these beetles colonized a sand dune habitat.



▲ **Figure 1.7E** An evolutionary tree of elephants

Try This Use this tree to determine when mastadons (in the genus *Mammut*) last shared a common ancestor with African elephants.

Figure 1.7D uses a simple example to show how natural selection works. ❶ An imaginary beetle population has colonized an area where the soil has been blackened by a recent brush fire. Initially, the population varies extensively in the inherited coloration of individuals, from very light gray to charcoal. ❷ A bird eats the beetles it sees most easily, the light-colored ones. This selective predation reduces the number of light-colored beetles and favors the survival and reproductive success of the darker beetles, which pass on the genes for dark coloration to their offspring. ❸ After several generations, the population is quite different from the original one. As a result of natural selection, the frequency of the darker-colored beetles in the population has increased.

Darwin realized that numerous small changes in populations as a result of natural selection could eventually lead to major alterations of species. He proposed that new species could evolve as a result of the gradual accumulation of changes over long periods of time. This could occur, for example, if one population fragmented into subpopulations isolated in different environments. In these separate arenas of natural selection, one species could gradually divide into multiple species as isolated populations adapted over many generations to different sets of environmental factors.

The fossil record provides evidence of such diversification of species from ancestral species. **Figure 1.7E** traces an evolutionary tree of elephants and some of their relatives. (Biologists' diagrams of evolutionary relationships generally take the form of branching trees, usually turned sideways and read from left to right.) You can see that the three living species of elephants are very similar because they shared a recent common ancestor (dating to about 3 million years ago, which is relatively recent in an evolutionary timeframe). Notice that all the other close relatives of elephants are extinct—their branches do not extend to the present. (The mammoth being excavated in Figure 1.7A belonged to the genus *Mammuthus,* whose members became extinct less than 10,000 years ago.) If we were to trace this family tree back to about 60 million years ago, however, you would find a common ancestor that connects elephants to their closest living relatives—the manatees and hyraxes. The fossil record, along with other evidence such as comparisons of DNA, allows scientists to trace the evolutionary history of life back through time.

All of life is connected, and the basis for this kinship is evolution—the core theme that makes sense of everything we know and learn about life. In the next module, we introduce scientific inquiry, the process we use to study the natural world.

? **Explain the cause and effect of unequal reproductive success.**

● Those individuals with heritable traits best suited to the local environment produce the greatest number of offspring. Over many generations, the frequency of those adaptive traits increases in the population.