Biology

Concepts & Applications 10e

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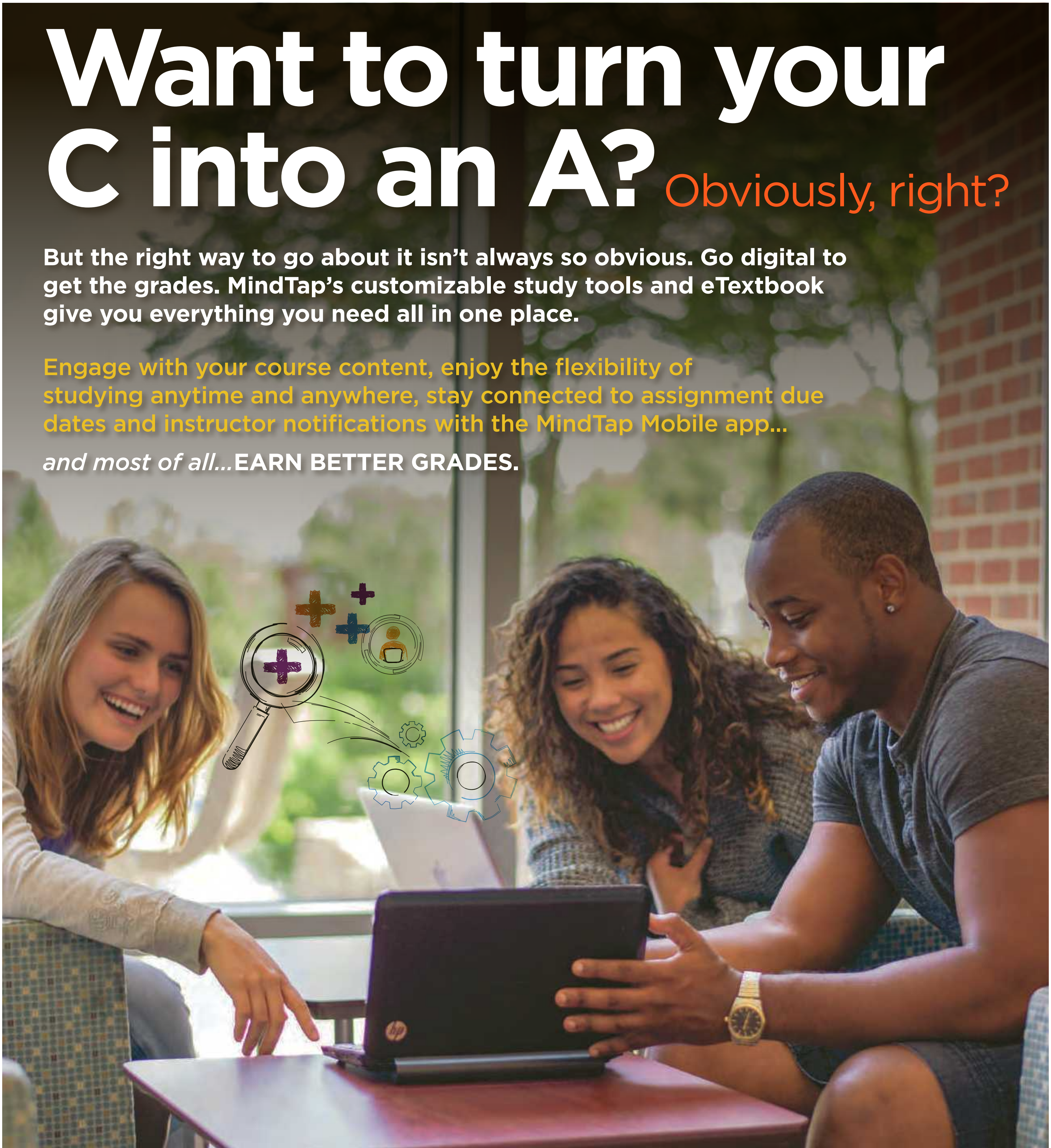

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About the Cover Photo

Portuguese Man-of-War

Anyone unfamiliar with the biology of the venomous Portuguese man-of-war would likely mistake it for a jellyfish. Not only is it not a jellyfish, it's not even an "it," but a "they." The Portuguese man-of-war is a siphonophore, an animal made up of a colony of organisms working together.

The man-of-war comprises four separate polyps. It gets its name from the uppermost polyp, a gas-filled bladder, or pneumatophore, which sits above the water and somewhat resembles an old warship at full sail. A man-of-war is also known as a bluebottle for the purple-blue color of its pneumatophores.

The tentacles are the man-of-war's second organism. These long, thin tendrils can extend 165 feet (50 meters) in length below the surface, although 30 feet (10 meters) is more the average. They are covered in venom-filled nematocysts used to paralyze and kill fish and other small creatures. For humans, a man-of-war sting is excruciatingly painful, but rarely deadly. But beware—even a dead man-of-war washed up on shore can deliver a sting.

Muscles in the tentacles draw prey up to a polyp containing the gastrozooids or digestive organisms. A fourth polyp contains the reproductive organisms.

A man-of-war is found, sometimes in groups of 1,000 or more, floating in warm waters throughout the world's oceans. They have no independent means of propulsion and either drift on the currents or catch the wind with their pneumatophores. To avoid threats on the surface, they can deflate their air bags and briefly submerge.

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Enric Sala/National Geographic Creative

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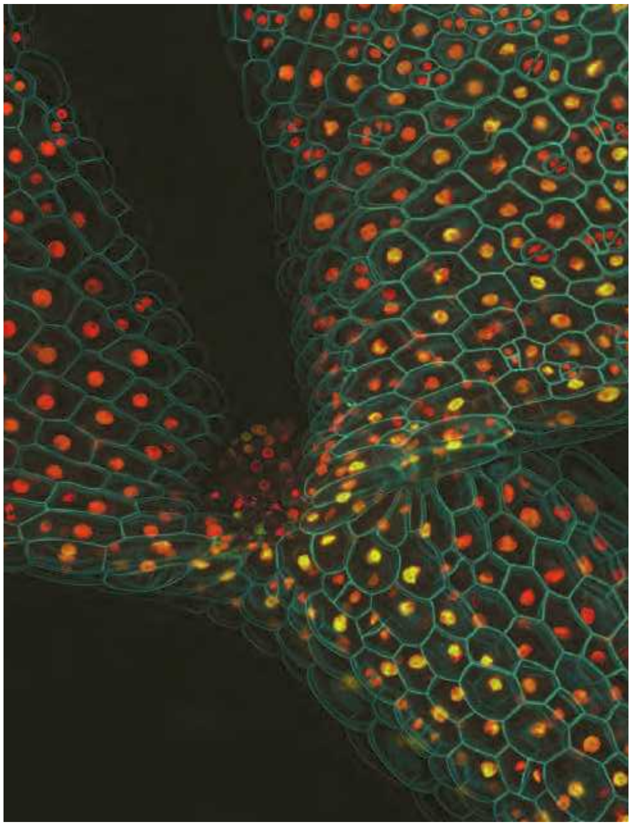

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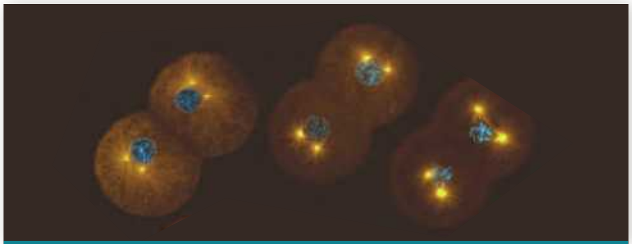

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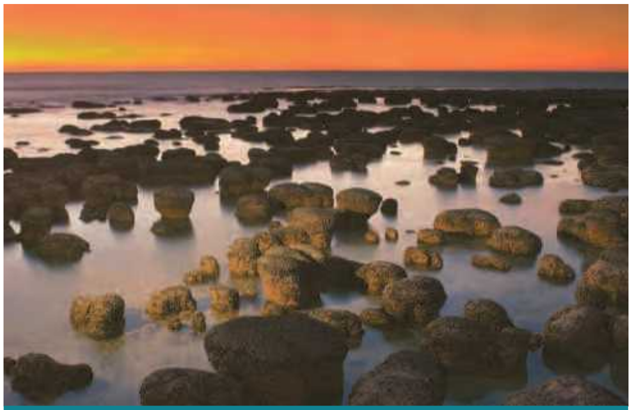

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Preface

A revolution in the way information is shared has fundamentally changed the nature of biological inquiry. Interdisciplinary collaborations facilitated by instant, global access to data and ideas have fostered entirely new areas of research, both theoretical and practical. New discoveries and new technologies emerging from these collaborations are altering the way biologists think about their work—and the field in general.

Realizing that a traditional life science education would not adequately prepare students for the changing field, the American Association for the Advancement of Science and the National Science Foundation initiated a series of national conversations among leading life scientists, policy makers, educators, and students. The result was a document, *Vision and Change in Undergraduate Biology Education*, that calls for a fundamental change in the way life sciences are taught to all undergraduate students. A broad consensus recommends that science education become much more active, because personal experience with the process and limits of science better prepares students to evaluate scientific content and differentiate it from other information. A more concept-oriented approach that uses fundamental biological principles as a context for information (rather than the reverse) better prepares students to understand rapid changes in the field. Our future citizens and leaders will need this understanding to confront urgent societal problems such as climate change, threats to biodiversity, and the global spread of disease.

This book has been revised in alignment with "Vision and Change" recommendations. As always, recent discoveries are integrated in an accessible and appealing introduction to the study of life. In addition, this edition includes tools to explore basic biological concepts from a variety of perspectives (molecular, cellular, organismal, ecological, and so on).

Our quest to educate and engage is shared by the National Geographic Society, with whom we have partnered for this book. You will see the fruits of the partnership in spectacular photographs, informative illustrations, and text features that highlight the wide variety of work supported by the society.

FEATURES OF THIS EDITION

Setting the Stage

Each chapter opens with a dramatic two-page photo spread. A brief *Links to Earlier Concepts* paragraph reminds students of relevant information in previous chapters. A summary of chapter content is organized and presented in terms of three *Core Concepts*, each involving one of the following: evolution; information flow, exchange, and storage; structure and function; pathways and transformation of energy and matter; or systems.

Concept Spreads

The content of every chapter is organized as a series of concepts, each explored in a section that is two pages or less. *Learning Objectives* associated with each concept are phrased as activities that the student should be able to carry out after reading the text.

Engage

Our *Engage* feature associates chapter content with relevant research, while highlighting the diversity of the modern scientific community. Each illustrates one of six core competencies: the ability to apply the process of science (Process of Science), use quantitative reasoning (Quantitative Reasoning), use modeling and simulation (Complex Systems), tap into the interdisciplinary nature of science (Interdisciplinary Science), communicate and collaborate with other disciplines (Collaborative Science), or understand the relationship between science and society (Science & Society). Individuals whose work is spotlighted include well-established and newly minted scientists, as well as a few nonscientists; most are National Geographic Explorers or Grantees.

On-Page Glossary

An *On-Page Glossary* includes boldface key terms introduced in each section. This running glossary, which can be used as a convenient study aid, offers non-phonemic pronunciations and definitions in alternate wording. All glossary terms also appear in boldface in the Chapter Summary.

Emphasis on Relevance

We continue to focus on real world applications, including social issues arising from new research and developments—particularly the many ways in which human activities are continuing to alter the environment and threaten both human health and Earth's biodiversity. Each chapter ends with an *Application* section that explains a current topic in light of the chapter content, and also illustrates one of the core competencies listed above.

Self-Assessment Tools

Many figure captions include a *Figure It Out* question designed to engage students in an active learning process; an upside-down answer allows a quick check of understanding. At the end of each chapter, *Self-Assessment* and *Critical Thinking* questions provide additional self-assessment material. Another active-learning feature, the chapter-end *Data Analysis* class activity, sharpens analytical skills by asking students to interpret data presented in graphic or tabular form. The data is related to the chapter material, and is taken from a published scientific study in most cases.

Chapter-Specific Changes

This new edition contains 208 new photographs and 330 new or updated illustrations. In addition, the text of every chapter has been updated and revised for clarity. A complete section-by-section guide to new content and figures is available upon request, but the highlights are summarized here.

1 The Science of Biology Expanded material on the process of science includes the concept that research is typically nonlinear and unpredictable; text and table contrasting science with pseudoscience; and text detailing the way theories can be modified upon discovery of new data.

2 Life's Chemical Basis New table compares elemental composition of human body with Earth's crust, seawater, and the universe; effects of acid rain are now exemplified with dissolving shells of marine animals.

3 Molecules of Life New chapter opener illustrates formation of glycoaldehyde in interstellar gas; revised text and new art emphasizing protein structure–function relationship includes expanded discussion of amyloid fibrils and plaques.

4 Cell Structure Added nonmotile cilia and their newly discovered roles in cell signaling. New art shows ultrastructural details of cell junctions per recent discoveries. Expanded section on the nature of life now includes theory of living systems.

5 Ground Rules of Metabolism Coenzymes are now illustrated with ascorbic acid/scurvy example.

6 Where It Starts—Photosynthesis Chapter has been reorganized for a better introductory sequence. Expanded discussion of the cyclic pathway emphasizes the interplay between both versions of light reactions; expanded discussion of photorespiration incorporates new research on its adaptive value. New Application discusses biofuels in context of anthropogenic CO_2 and global warming.

7 Releasing Chemical Energy New art and tables emphasize the movement of energy and matter in aerobic respiration. Expanded Application includes mechanisms of mitochondrial malfunction, narrative of affected child, and three-person IVF. New Data Analysis concerns reprogramming of mitochondria in brown fat by dietary fat overload.

8 DNA Structure and Function New micrographs and revised art reinforce DNA structure and clarify mutations.

9 From DNA to Protein Expanded section on mutations includes material on a beneficial hemoglobin mutation (E6K, HbC) that offers resistance to malaria without the health consequences of HbS (E6V); and new art detailing the intron mutation that causes hairlessness in sphynx cats.

10 Control of Gene Expression Now includes RNA interference and microRNAs, and additional evidence for heritability of epigenetic modifications. Application section has expanded information about *BRCA* genes as tumor suppressors.

11 How Cells Reproduce New ultra-high resolution confocal live-cell images of mitosis by Dr. George von Dassow. Text and new art showing cytokinesis include ultrastructural details/processes per current research and paradigms. Expanded material on telomeres now includes telomere-associated triggering and consequences of cell senescence.

12 Meiosis and Sexual Reproduction New 3D structured illumination micrographs of meiosis in corn show synaptonemal complex detail in ultra-high resolution. Newly discovered mechanism of gene acquisition by individual rotifers added to Application essay.

13 Patterns in Inherited Traits Marfan syndrome discussion updated to reflect change in life expectancy due to increased awareness, accompanied by new photo of Baylor's Isaiah Austin. New material details environmentally induced hemoglobin production in *Daphnia*; new photo shows green-to-red phenotype that accompanies the switch.

14 Human Inheritance Molecular pathogenesis of CF, Huntington's, and DMD updated to reflect current research.

15 Biotechnology Heavily revised material includes mechanism, application, and social implications of CRISPR-Cas9 gene editing system.

16 Evidence of Evolution Cetacean evolutionary sequence updated to reflect current accepted narrative.

17 Processes of Evolution New photo of velvet walking worm shooting streams of glue from its head illustrates parapatric speciation. Expanded Application includes current statistics and research on generation and spread of antibiotic-resistant bacteria associated with factory farms, and example of cross-resistance to veterinary and human antibiotics.

18 Life's Origin and Early Evolution Improved descriptions of the Hadean, Archean, and Phanerozoic eons. Added information about Miller–Urey's experiments that simulated conditions around volcanoes. Updated discussion of protocells. Deleted coverage of Jeon's study of endosymbionts in amoebas. New subsection summarizes events of the Precambrian.

Chapter-Specific Changes (continued)

19 Viruses, Bacteria, and Archaea Improved art comparing viral structures. Updated information about Ebola, AIDS, West Nile virus. Added information about the Zika virus. New figure shows viral reassortment. Added figure illustrating the three common bacterial shapes. New table lists common bacterial diseases. New subsection discusses metagenomics, relationships among prokaryotes, and the relationship between prokaryotes and eukaryotes.

20 The Protists New table lists the various protist groups and their traits. Chapter now organized around the major eukaryotic supergroups. New overview of protist cell structure. New information about African trypanosomiasis and expanded coverage of malaria.

21 Plant Evolution Revised life cycle graphics throughout the chapter; improved figure illustrating generalized process of seed production.

22 Fungi Added text and table comparing traits of fungi, plants, and animals. New photos of athlete's foot and ringworm. Updated information about white nose syndrome. New information about medical use of psilocybin.

23 Animals I: Major Invertebrate Groups More on the similarities between choanoflagellates and animals. Coverage of placozoans deleted. New figure illustrates bivalve (clam) anatomy, and sea star anatomy figure has been updated. Expanded coverage of roundworms as a model organism. New information about overharvesting of krill and about copepods as reservoirs for cholera-causing bacteria.

24 Animals II: The Chordates Updated lancelet art. New subsection and figure devoted to declining amphibian diversity. New figure of avian skeleton. Updated discussion of fossil hominins and evidence of interbreeding among humans, Neandertals, and Denisovans.

25 Plant Tissues Many new photos. Expanded Application material includes carbon release by decomposition, relative stability of dead plant matter, and CO_2 and climate change.

26 Plant Nutrition and Transport Many new photos and updated art pieces. Mechanism of regulation of water flow through bordered pits updated per current research.

27 Reproduction and Development of Flowering Plants Revisions include addition/illustration of nastic movements, and explanation of *Phylloxera* resistance in American grapevines based on enhanced hypersensitive response involving resveratrol. New Application involves benefits of plant secondary metabolites using as an example the discovery of epicatechin in cocoa via the low incidence of hypertension among the Kuna tribe, with emphasis on similar signaling pathways in plants and humans.

28 Animal Tissues and Organ Systems New summary table describing tissue types. Improved graphic illustrates relative volumes of the fluid components of a human body. Added information about brown fat versus white fat and white matter and gray matter. New graphic illustrates properties of stem cells. Updated information about research on and clinical use of induced pluripotent stem cells (IPSCs).

29 Neural Control New overview of intracellular signaling. Revised/reorganized coverage of the peripheral nervous system. New photo of a paralyzed veteran using a robotic exoskeleton. New subsection covers tissues and fluid of the CNS. Updated Application with the latest findings about brain damage among professional football players.

30 Sensory Perception Simplified figure for human olfaction. Added frontal view to illustration of visual accommodation. New graphic depicts the anatomy of the retina and includes light-channeling neuroglia. Application now covers both cochlear and retinal implants.

31 Endocrine Control Added information about sites of human steroid hormone production (gonads/adrenals). Added information about hormone type (amino acid or steroid) to Table 31.1. Updated figure depicting feedback control of thyroid hormone.

32 Structural Support and Movement Improved figures depicting locomotion of fly and earthworm. Revised figure showing the structure of skeletal muscle.

33 Circulation Updated photo depicting measurement of blood pressure. Expanded coverage of venule function. New art depicts atherosclerosis. Added discussion of heart attack symptoms and of causes and symptoms of stroke. New Data Analysis exercise on hypertension and risk of stroke.

34 Immunity Text updates reflect current research on role of keratinocytes as immune cells. New Application essay that details vaccination and benefits of herd immunity features a narrative by a mother whose unvaccinated child has permanent health consequences of contracting measles.

35 Respiration Improved photo of insect tracheal system. Increased emphasis on evolutionary trends in discussion of vertebrate lungs. Updated information about risks for SIDS. Added information about risks of vaping.

36 Digestion and Human Nutrition Expanded discussion of sponge digestion with new graphic. New graphic shows diet-related variation in bird beaks. Improved photo of interior of small intestine. New graphics depict peristalsis and segmentation. Updated coverage of human nutrition and factors affecting weight.

37 Maintaining the Internal Environment Improved description of variations in types of nitrogenous wastes. New photo of donor/recipient in living donor kidney transplant. New information about how diseases affect composition of urine. Added information about human body hair as a temperature-related adaptation.

38 Reproduction and Development Improved description of apoptosis. Reorganized discussion of human reproduction; female now precedes male. New information about genetics of bird beak and human facial development, post-fertilization epigenetic reset, mechanism of Ru-486, developmental effects of Zika virus, and banking of sperm and eggs. New Data Analysis exercise about regional variations in male infertility.

39 Animal Behavior New information about oxytocin and human autism and about epigenetic effects in a variety of contexts. Improved honeybee dance language figure. New photo/information about tent caterpillars, a pre-social species. Application now covers effects of shipping noise on whale communication.

40 Population Ecology Introduction now explains applications of population ecology. Updated human population statistics. Improved graphic of intermediate disturbance model.

41 Community Ecology New figure shows sundew plants and spiders as competitors for insect prey. New discussion of study that showed character displacement in Galápagos finches.

42 Ecosystems Updated information about current level of atmospheric carbon dioxide; expanded discussion of sources of fossil fuels.

43 The Biosphere Improved description of how Earth's shape influences wind direction. More details about plant adaptations to coastal life. New coverage of ocean acidification and other threats to reefs.

44 Human Effects on the Biosphere Added information about habitat fragmentation, the Great Pacific Garbage Patch, ill effects of ammonium and mercury deposition, nitrous oxide's effect on the ozone layer, and the leakage of methane from pipelines.

Acknowledgments

Writing, revising, and illustrating a biology textbook is a major undertaking for two full-time authors, but our efforts constitute only a small part of what is required to produce and distribute this one. We are truly fortunate to be part of a huge team of very talented people who are just as committed to creating and disseminating this exceptional science education product.

Biology is not dogma; the fantastic amount of research in the field makes paradigm shifts common. Only with the ongoing input of our many academic reviewers and advisors (see following page) can we continue to tailor this book to the needs of instructors and students while integrating new information and models. We continue to learn from and be inspired by these dedicated educators.

This book benefits from a collaborative association with the National Geographic Society in Washington D.C. The Society has graciously allowed us to enhance our presentation with its extensive resources, including beautiful maps and images, Society explorer and grantee materials, and online videos.

At Cengage, Hal Humphrey managed all of the inhouse production operations. April Cognato's efforts, vision, and leadership brought this book forward with Vision and Change; Jake Warde provided insightful suggestions, kind support, and encouragement. Kellie Petruzzelli coordinated nearly all of the development of study, testing, and online active learning resources. Grace Davidson orchestrated a continuous flow of files, photos, and illustrations while managing schedules, budgets, and whatever else happened to be on fire. (Grace, thank you as always for your patience and dedication.) Cheryl DuBois at Lumina Datamatics, and Christine M. Myaskovsky and Betsy Hathaway at Cengage Learning, were responsible for photo research. Valuable suggestions from copyeditor Anita Wagner Hueftle and proofreader Diane Miller again kept our text clear and concise.

—Lisa Starr, Chris Evers, and Cecie Starr 2016

Tom McHugh/Science Source.

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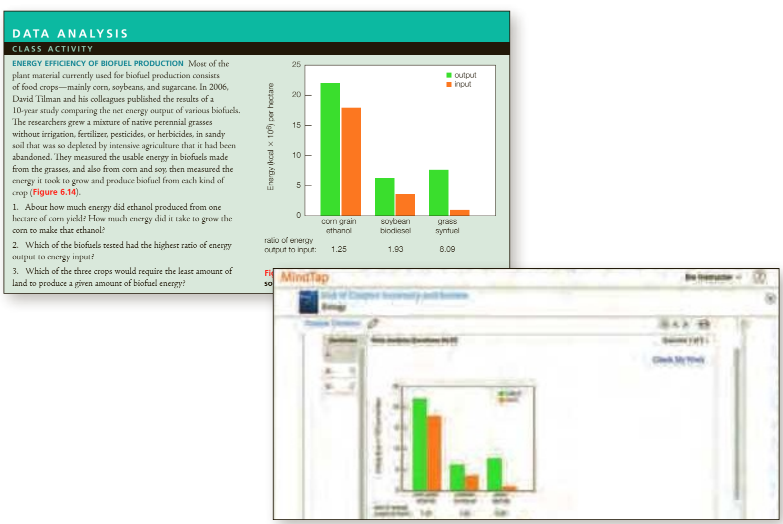
DATA ANALYSIS
CLASS ACTIVITY

ENERGY EFFICIENCY OF BIOFUEL PRODUCTION Most of the plant material currently used for biofuel production consists of food crops—mainly corn, soybeans, and sugarcane. In 2006, David Tilman and his colleagues published the results of a 10-year study comparing the net energy output of various biofuels. The researchers grew a mixture of native perennial grasses without irrigation, fertilizer, pesticides, or herbicides, in sandy soil that was so depleted by intensive agriculture that it had been abandoned. They measured the usable energy in biofuels made from the grasses, and also from corn and soy, then measured the energy it took to grow and produce biofuel from each kind of crop (Figure 6.14).

1. About how much energy did ethanol produced from one hectare of corn yield? How much energy did it take to grow the corn to make that ethanol?
2. Which of the biofuels tested had the highest ratio of energy output to energy input?
3. Which of the three crops would require the least amount of land to produce a given amount of biofuel energy?

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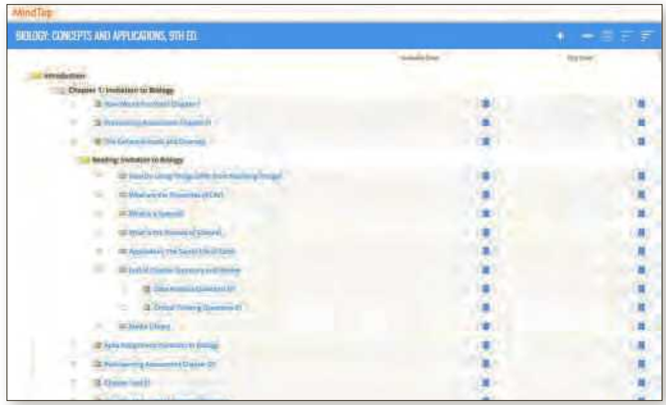

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Biology

Concepts & Applications 10e

1 The Science of Biology

Links to Earlier Concepts

Whether or not you have studied biology, you already have an intuitive understanding of life on Earth because you are part of it. Every one of your experiences with the natural world—from the warmth of the sun on your skin to the love of your pet—contributes to that understanding.

Core Concepts

Interactions among the components of a biological system give rise to complex properties.

We can understand life by studying it at increasingly inclusive levels, starting with atoms that compose matter, and extending to the biosphere. Each level is a biological system composed of interacting parts. Interactions among the components of a system give rise to complex properties not found in any of the components. Interactions among organisms and their environment result in the movement of matter and energy.

Evolution underlies the unity and diversity of life.

Shared core processes and features that are widely distributed among organisms provide evidence that all living things are linked by lines of descent from common ancestors. All biological systems are sustained by the exchange of matter and energy; all store, retrieve, transmit, and respond to information essential for life.

The field of biology relies upon experimentation and the collection and analysis of scientific evidence.

Science addresses only testable ideas about observable events and processes. Observation, experimentation, quantitative analysis, and critical thinking are key aspects of research in biology. Carefully designed experiments that yield objective data help researchers unravel cause-and-effect relationships in complex biological systems.

Near a tent serving as a makeshift laboratory, herpetologist Paul Oliver records the call of a frog on an expedition to New Guinea's Foja Mountains cloud forest.

Photograph by Tim Laman/National Geographic Creative.

1.1 Life Is More Than the Sum of Its Parts

LEARNING OBJECTIVES

Describe the successive levels of life's organization.

Explain the idea of emergent properties and give an example.

EMERGENT PROPERTIES

Biologists study life. What, exactly, is "life"? We may never actually come up with a concise definition, because living things are too diverse, and they consist of the same basic components as nonliving things. When we try to define life, we end up with a long list of properties that differentiate living from nonliving things. These properties often emerge from the interactions of basic components. To understand how that works, take a look at the groups of squares in **Figure 1.1**. The property of "roundness" emerges when the component squares are organized one way, but not other ways. Another example is a complex behavior called swarming. When honeybees swarm, they fly en masse to establish a hive in a new location. Each bee is autonomous, but the new hive's location is decided collectively based on an integration of signals from hivemates. The swarm's collective intelligence is the emergent property in this example.

A characteristic of a system (a colony of bees swarming, for example) that does not appear in any of the system's components (individual bees) is called an **emergent property**. The idea that structures or systems with emergent properties can be assembled from the same components is a recurring theme in our world—and also in biology.

LIFE'S ORGANIZATION

Biologists view life as having nested levels of organization; interactions among the components of each level give rise to emergent properties (**Figure 1.2**). This organization begins with atoms. **Atoms** are the smallest units of a substance; they and the fundamental particles that compose them are the building blocks of all matter ❶. Atoms bond together to form **molecules** ❷. There are no atoms unique to living things, but there are unique molecules. A **cell** ❸, which is the smallest unit of life, consists of many of these "molecules of life."

Some cells live and reproduce independently. Others do so as part of a multicelled organism. An **organism** is an individual that consists of one or more cells ❼. In most multicelled organisms, cells are organized as tissues ❹. A **tissue** consists of specific types of cells in an arrangement that allows the cells to collectively perform some function—protection from injury (dermal tissue) or movement (muscle tissue), for example. An **organ** is a structure composed of tissues that collectively carry out a particular task or set of tasks ❺. For example, a flower is an organ of reproduction in plants; a heart, an organ that pumps blood in animals. An **organ system** is a set of interacting organs and tissues that fulfill one or more body functions ❻. Examples of organ systems include the aboveground parts of a plant (the shoot system), and the heart and blood vessels of an animal (the circulatory system).

Unique types of organisms—California poppies, for example—are called **species**. A **population** is a group of interbreeding individuals of the same species living in a given area. For example, all California poppies growing in California's Antelope Valley Poppy Reserve form a population ❽. A **community** consists of all populations of all species in a given area. The Antelope Valley Reserve community includes California poppies and all other plants, as well as animals, microorganisms, and so on ❾. Communities may be large or small, depending on the area defined. The next level of organization is the **ecosystem**, which is a community interacting with its physical and chemical environment ❿. Earth's largest ecosystem is the **biosphere**, and it encompasses all regions of the planet's crust, waters, and atmosphere in which organisms live ⓫.

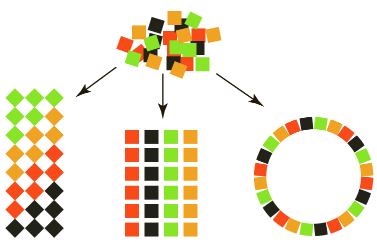
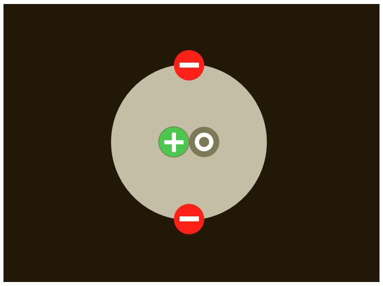
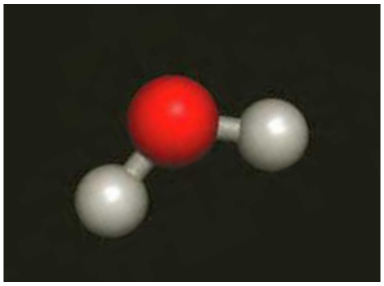


Figure 1.1 The same materials, assembled in different ways, form objects with different properties. The property of "roundness" emerges when the squares are assembled one way, but not the others.

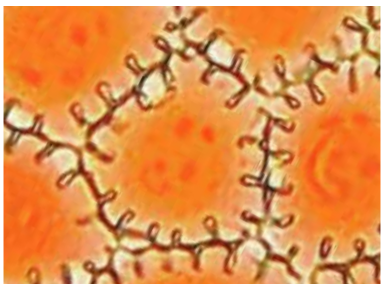
atom Smallest unit of a substance; consists of subatomic particles.
biosphere (BY-oh-sfeer) All regions of Earth where organisms live.
cell Smallest unit of life.
community All populations of all species in a defined area.
ecosystem A community interacting with its environment.
emergent property (ee-MERGE-ent) A characteristic of a system that does not appear in any of the system's component parts.
molecule (MAUL-ick-yule) Two or more atoms bonded together.
organ In multicelled organisms, a structure that consists of tissues engaged in a collective task.
organism (ORG-uh-niz-um) An individual that consists of one or more cells.
organ system In multicelled organisms, set of interacting organs that carry out a particular body function.
population Group of interbreeding individuals of the same species living in a defined area.
species (SPEE-sheez) Unique type of organism.
tissue In multicelled organisms, specialized cells organized in a pattern that allows them to perform a collective function.



1 atom
Atoms and the particles that compose them make up all matter.



2 molecule
Atoms join other atoms in molecules. This is a model of a water molecule. The molecules special to life are much larger and more complex than water.



3 cell
The cell is the smallest unit of life. Some, like these plant cells, live and reproduce as part of a multicelled organism; others do so on their own.

4 tissue
Organized array of cells that interact in a collective task. This is dermal tissue on the outer surface of a flower petal.

5 organ
Structural unit of interacting tissues. Flowers are the reproductive organs of some plants.

6 organ system
A set of interacting organs. The shoot system of this poppy plant includes its aboveground parts: leaves, flowers, and stems.

7 multicelled organism
Individual that consists of more than one cell. Cells of this California poppy plant make up its shoot system and root system.

8 population
Group of single-celled or multicelled individuals of a species in a given area. This population of California poppy plants is in California's Antelope Valley Poppy Reserve.

9 community
All populations of all species in a specified area. These plants are part of the community in the Antelope Valley Poppy Reserve.

10 ecosystem
A community interacting with its physical environment through the transfer of energy and materials. Sunlight and water sustain the community in the Antelope Valley.

11 biosphere
The sum of all ecosystems: every region of Earth's waters, crust, and atmosphere in which organisms live.

Figure 1.2 Levels of life's organization. New emergent properties appear at each successive level.

FIGURE IT OUT
At which level does the emergent property of "life" appear?
Answer: The cell

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1.2 Life's Unity

LEARNING OBJECTIVES

- Distinguish producers from consumers.
- Define homeostasis and explain why it is important for sustaining life.
- List some functions that are guided by an organism's DNA.
- Explain how DNA is the basis of similarities and differences among organisms.

All living things share a particular set of key features. You already know one of these features: Because the cell is the smallest unit of life, all organisms consist of at least one cell. For now, we introduce three more: All living things require ongoing inputs of energy and raw materials; all sense and respond to change; and all use DNA as the carrier of genetic information (Table 1.1).

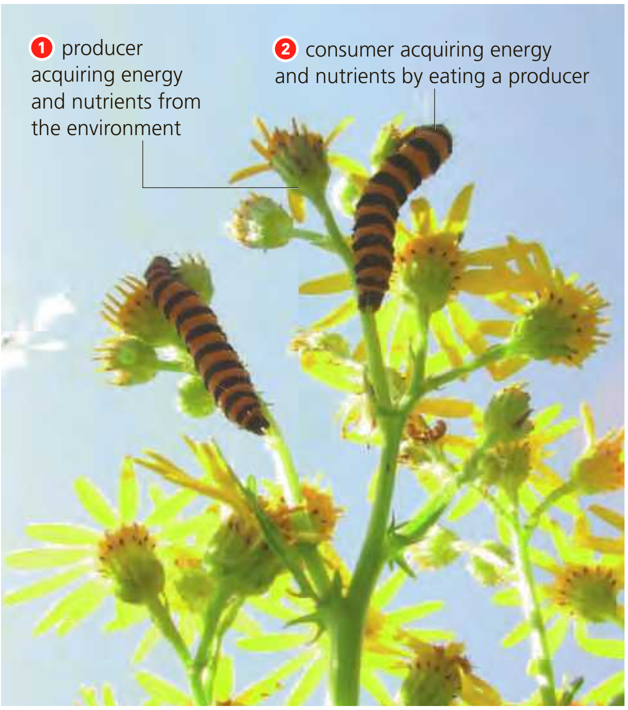
ENERGY AND NUTRIENTS

Not all living things eat, but all require nutrients on an ongoing basis. A **nutrient** is a substance that an organism acquires from the environment in order to support growth and survival. Both nutrients and energy are essential to maintain the organization of life, so organisms spend a lot of time acquiring them. However, the source of energy and the type of nutrients required differ among organisms. These differences allow us to classify all living things into two categories: producers and consumers (Figure 1.3). A **producer** makes its own food using energy and simple raw materials it obtains from nonbiological sources (1). Plants are producers. By a process called **photosynthesis**, plants can use the energy of sunlight to make sugars from carbon dioxide (a gas in air) and water. Consumers, by contrast, cannot make their own food. A **consumer** obtains energy and nutrients by feeding on other organisms (2). Animals are consumers. So are decomposers, which feed on the wastes or remains of other organisms. Leftovers from consumers' meals end up in the environment, where they serve as nutrients for producers. Said another way, nutrients cycle between producers and consumers (3).

TABLE 1.1

Some Key Features of Life

Cellular basis	All living things consist of one or more cells.
Requirement for energy and nutrients	Life is sustained by ongoing inputs of energy and nutrients.
Homeostasis	Living things sense and respond appropriately to change.
DNA is hereditary material	Genetic information in the form of DNA is passed to offspring.



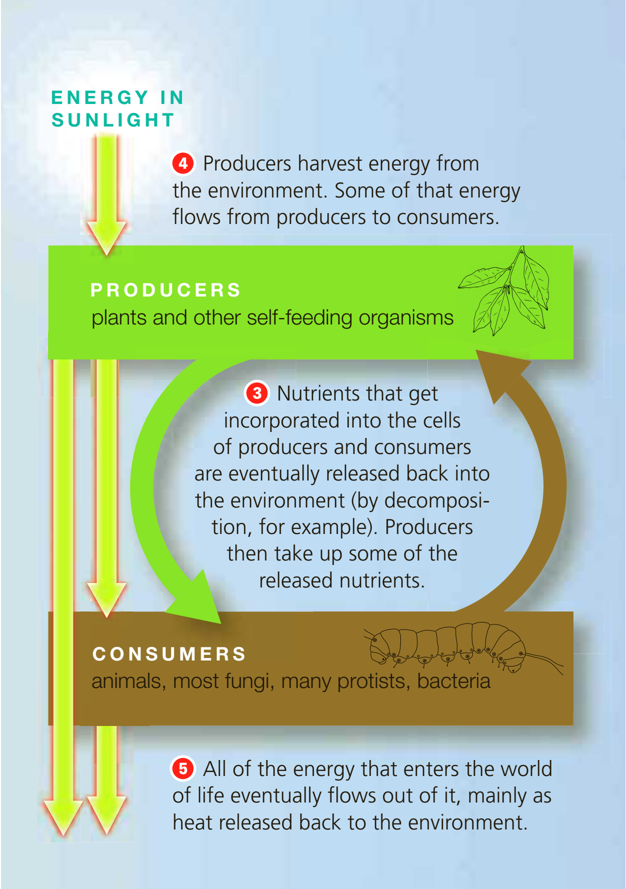


Figure 1.3 The one-way flow of energy and cycling of materials through the world of life.

Unlike nutrients, energy is not cycled. It flows in one direction: from the environment 4, through organisms, and back to the environment 5. This flow maintains the organization of every living cell and body, and it also influences how individuals interact with one another and their environment. The energy flow is one-way, because with each transfer, some energy escapes as heat, and cells cannot use heat as an energy source. Thus, energy that enters the world of life eventually leaves it (we return to this topic in Chapter 5).

HOMEOSTASIS

An organism cannot survive for very long unless it can respond appropriately to specific stimuli inside and outside of itself. For example, humans and some other animals normally perspire (sweat) when the body's internal temperature rises above a certain set point (Figure 1.4). The moisture cools the skin, which in turn helps cool the body.

All of the internal fluids that bathe the cells in your body are collectively called your internal environment. Temperature and many other conditions in that environment must be kept within certain ranges, or your cells will die (and so will you). By sensing and adjusting to change, all organisms keep conditions in their internal environment within ranges that favor cell survival. **Homeostasis** is the name for this process, and it is one of the defining features of life.

Figure 1.4 Living things sense and respond to their environment. Sweating is a response to an internal body temperature that exceeds the normal set point. The response cools the skin, which in turn helps return the internal temperature to the set point.

DNA IS HEREDITARY MATERIAL

With little variation, the same types of molecules perform the same basic functions in every organism. For example, information in an organism's **DNA** (deoxyribonucleic acid) guides ongoing cellular activities that sustain the individual through its lifetime. Such functions include **development**: the process by which the first cell of a new individual gives rise to a multicelled adult; **growth**: increases in cell number, size, and volume; and **reproduction**: processes by which organisms produce offspring. **Inheritance**, the transmission of DNA to offspring, occurs during reproduction. All organisms inherit their DNA from one or more parents.

Individuals of every natural population are alike in most aspects of body form and behavior because their DNA is very similar: Humans look and act like humans and not like poppy plants because they inherited human DNA, which differs from poppy plant DNA in the information it carries. Individuals of almost every natural population also vary—just a bit—from one another: One human has blue eyes, the next has brown eyes, and so on. Such variation arises from small differences in the details of DNA molecules, and herein lies the source of life's diversity. As you will see in later chapters, differences among individuals of a species are the raw material of evolutionary processes.

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consumer (kun-SUE-murr) Organism that gets energy and nutrients by feeding on tissues, wastes, or remains of other organisms.

development (dih-VELL-up-ment) Process by which the first cell of a multicelled organism gives rise to a multicelled adult.

DNA Deoxyribonucleic (dee-ox-ee-ribe-oh-nuke-LAY-ick) acid; molecule that carries hereditary information; guides development and other activities.

growth In multicelled species, an increase in the number, size, and volume of cells.

homeostasis (home-ee-oh-STAY-sis) Process in which organisms keep their internal conditions within tolerable ranges by sensing and responding appropriately to change.

inheritance (in-HAIR-ih-tunce) Transmission of DNA to offspring.

nutrient (NEW-tree-unt) Substance that an organism acquires from the environment to support growth and survival.

photosynthesis (foe-toe-SIN-thuh-sis) Process by which producers use light energy to make sugars from carbon dioxide and water.

producer Organism that makes its own food using energy and nonbiological raw materials from the environment.

reproduction (ree-pruh-DUCK-shun) Processes by which organisms produce offspring.

CREDIT: (4) iStockphoto.com/gvillani.

1.3 Life's Diversity

LEARNING OBJECTIVES

List two characteristics of prokaryotes.

Name the four main groups of eukaryotes.

Differences in the details of DNA molecules are the basis of a tremendous range of differences among types of organisms. Various classification schemes help us organize what we understand about the scope of this variation, which is an important aspect of Earth's biodiversity. For example, organisms can be grouped on the basis of whether they have a nucleus, which is a saclike structure containing a cell's DNA. **Bacteria** (singular, bacterium) and **archaea** (singular, archaeon) are organisms whose DNA is *not* contained within a nucleus. All bacteria and archaea are single-celled, which means each organism consists of one cell (**Figure 1.5A,B**). Collectively, these organisms are the most diverse representatives of life. Different kinds are producers or consumers in nearly all regions of Earth. Some inhabit such extreme environments as frozen desert rocks, boiling sulfurous lakes, and nuclear reactor waste. The first cells on Earth may have faced similarly hostile conditions.

Traditionally, organisms without a nucleus have been classified as **prokaryotes**, but the designation is now used only informally. This is because bacteria and archaea are less related to one another than we once thought, despite their similar appearance. Archaea turned out to be more closely related to **eukaryotes**, which are organisms whose DNA is contained within a nucleus. Some eukaryotes live as individual cells; others are multicelled (**Figure 1.5C**). Eukaryotic cells are typically larger and more complex than bacteria or archaea.

There are four main groups of eukaryotes: protists, fungi, plants, and animals. **Protist** is the common term for a collection of eukaryote groups that are not plants, animals, or fungi. Collectively, they vary dramatically, from single-celled consumers to giant, multicelled producers.

Fungi (singular, fungus) are eukaryotic consumers that secrete substances to break down food externally, then absorb nutrients released by this process. Many fungi are decomposers. Most fungi, including those that form mushrooms, are multicellular. Fungi that live as single cells are called yeasts.

Plants are multicelled eukaryotes, and the vast majority of them are photosynthetic producers that live on land. Besides feeding themselves, plants also serve as food for most other land-based organisms.

Animals are multicelled consumers that ingest other organisms or components of them. Unlike fungi, animals break down food inside their body. They also develop through a series of stages that lead to the adult form. All animals actively move about during at least part of their lives.

animal Multicelled consumer that breaks down food inside its body, develops through a series of stages, and moves about during part or all of its life.

archaea (are-KEY-uh) Group of single-celled organisms that lack a nucleus but are more closely related to eukaryotes than to bacteria.

bacteria The most diverse and well-known group of single-celled organisms that lack a nucleus.

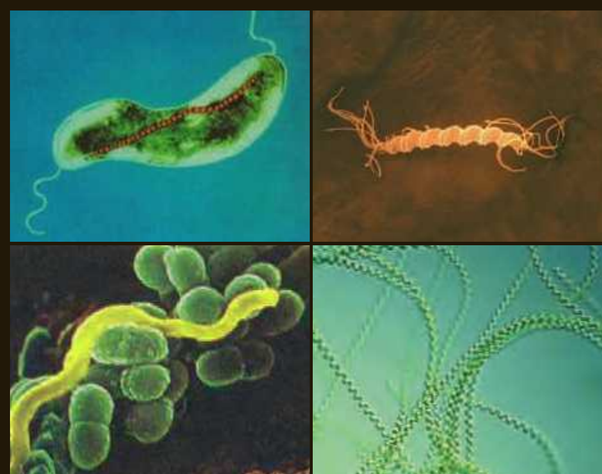
eukaryote (you-CARE-ee-oat) Organism whose cells characteristically have a nucleus.

fungus Single-celled or multicelled eukaryotic consumer that breaks down material outside itself, then absorbs nutrients released from the breakdown.

plant A multicelled, typically photosynthetic producer.

prokaryote (pro-CARE-ee-oat) Single-celled organism without a nucleus.

protist Common term for a eukaryote that is not a plant, animal, or fungus.



A Bacteria are the most numerous organisms on Earth. Clockwise from upper left, a bacterium with a row of iron crystals that serves as a tiny compass; a common resident of cat and dog stomachs; photosynthetic bacteria; types found in dental plaque.

B Archaea resemble bacteria, but are more closely related to eukaryotes. Left, an archaeon that grows in sulfur hot springs. Right, two types of archaea from a seafloor hydrothermal vent.

Figure 1.5 A few representatives of life's diversity.

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Protists are a group of extremely diverse eukaryotes that range from microscopic free-living cells (left) to giant multicelled seaweeds (right).

Fungi are eukaryotic consumers that secrete substances to break down food outside their body. Some are single-celled (left), but most are multicelled (right).

Plants are multicelled eukaryotes, most of which are photosynthetic. Nearly all have roots, stems, and leaves.

Animals are multicelled eukaryotes that ingest other organisms or their parts, and they actively move about during part or all of their life cycle.

C **Eukaryotes** are single-celled or multicelled organisms whose DNA is contained within a nucleus. Eukaryotes include protists, plants, fungi, and animals.

ENGAGE: PROCESS OF SCIENCE

Figure 1.6 On a survey in New Guinea, Kristofer Helgen finds a critically endangered long-beaked echidna. The only known living populations of this animal occur in New Guinea, and all are in rapid decline.

Kristofer Helgen

National Geographic Explorer Kristofer Helgen discovers new animals. Deep in a New Guinea rain forest (**Figure 1.6**). High on an Andean mountainside. Resting in a museum's specimen drawer. "Conventional wisdom would have it that we know all the mammals of the world," he notes. "In fact, we know so little. Unique species, profoundly different from anything ever discovered, are out there waiting to be found." His own efforts prove this. Helgen himself has discovered approximately 100 new species of mammals previously unknown to science. "Since I was three years old, I've been transfixed by animals," he recalls. "Even then, my excitement revolved around figuring out how many different kinds there were."

Helgen's search plunges him into the wild on almost every continent. Yet about three times as many new finds are made within the walls of museums. "An expert can go into any large natural history museum and identify kinds of animals no one knew existed," he explains. When only a few specimens of a species exist, and reside in museums scattered across the globe, sheer logistics often prevent researchers from pinpointing a new find. Helgen recently discovered a specimen of a long-beaked echidna in a London museum. It had been collected from Australia in 1901, misidentified, and left forgotten in the bottom of a drawer. Long-beaked echidnas were thought to be extinct in Australia for at least 5,000 years. Helgen's discovery that one was alive in 1901 means a population might still exist there, waiting to be discovered.

CREDITS: (5C) Protists: top left, Courtesy of Allen W.H. Bé and David A. Caron; bottom left, MI Walker/Science Source; right, © worldswildlifewonders/Shutterstock.com; Plants: left, © Jag_cz/Shutterstock.com; right, Martin Ruegner/Radius Images/Getty Images; Fungi: left, London Scientific Films / Exactostock-1598/SuperStock; right, Kichigin/Shutterstock.com; Animals: left, AAAS; middle, Thomas Eisner, Cornell University; right, iStockphoto.com/keeweeboy; (6) Tim Laman/National Geographic Creative.