BIOLOGY

The Unity and Diverse of Life

15TH EDITION

STARR TAGGART EVERS STARR

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***Biology: The Unity and Diversity of Life*, Fifteenth Edition**

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A male satin bowerbird decorates his "bower" by painting its component twigs with berry juice. Building and decorating the bower is an essential aspect of his courtship behavior. Female satin bowerbirds preferentially mate with males who have the best built and decorated bowers.

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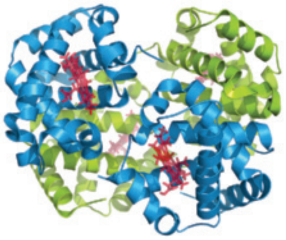
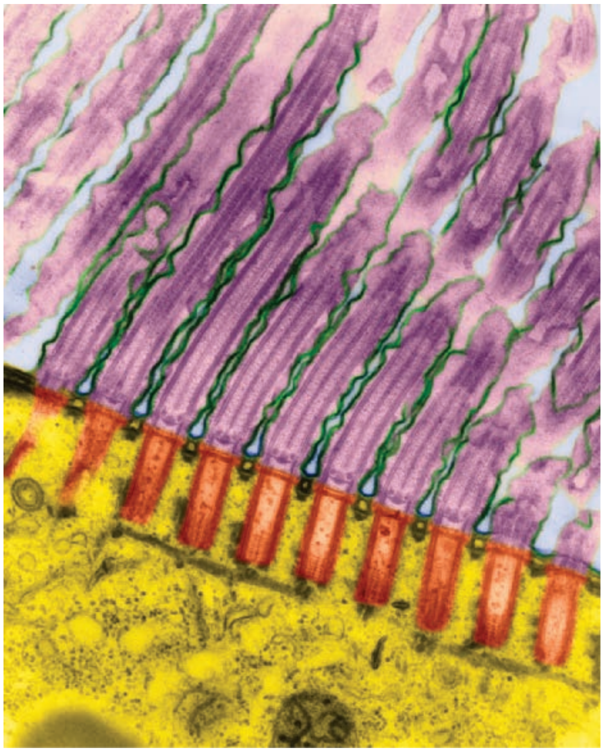
INTRODUCTION

UNIT I PRINCIPLES OF CELLULAR LIFE





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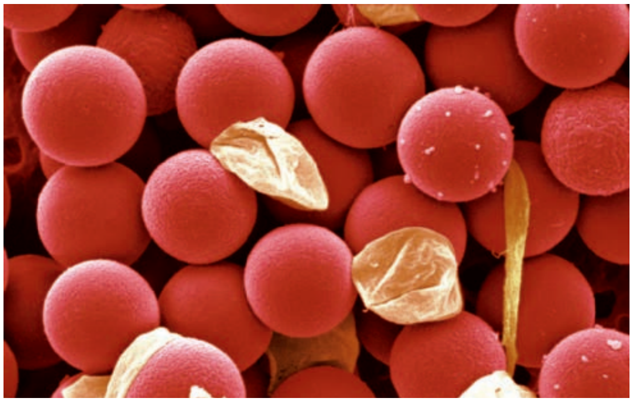

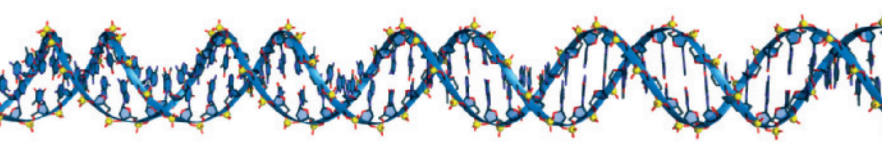

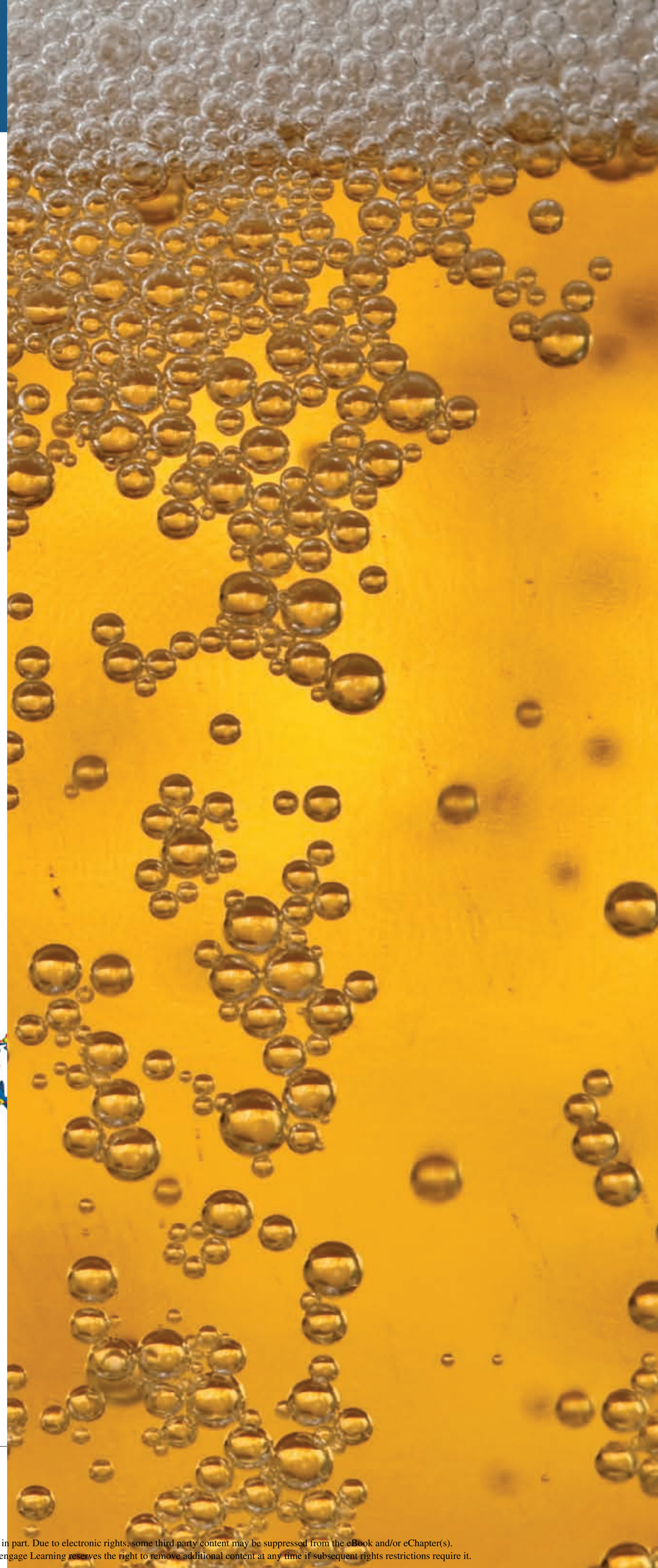

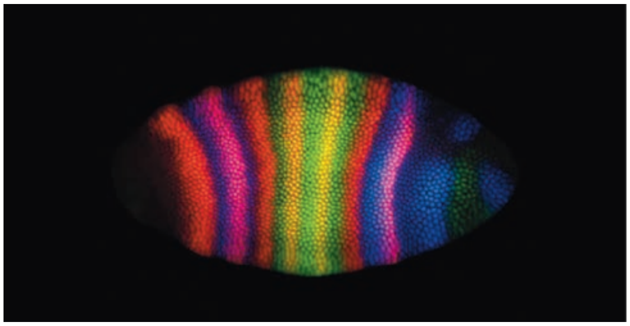

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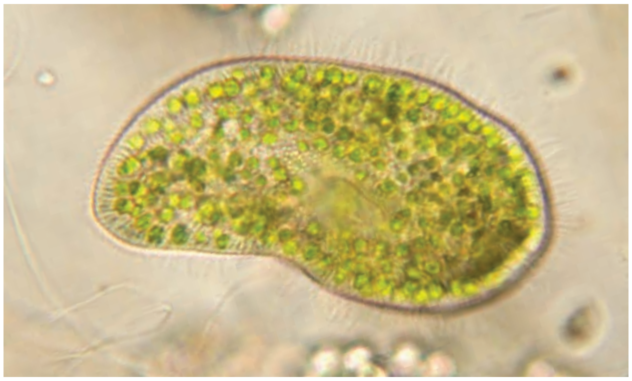
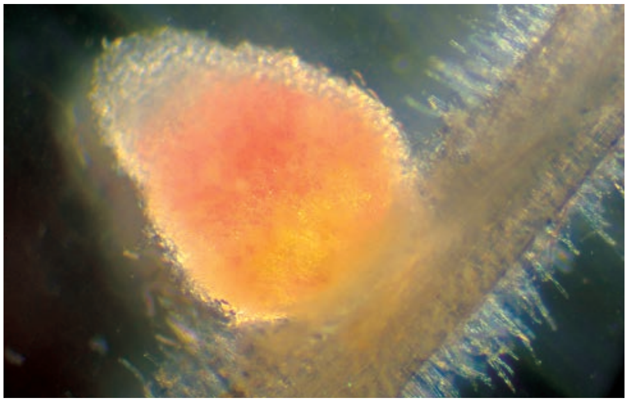
UNIT III PRINCIPLES OF EVOLUTION





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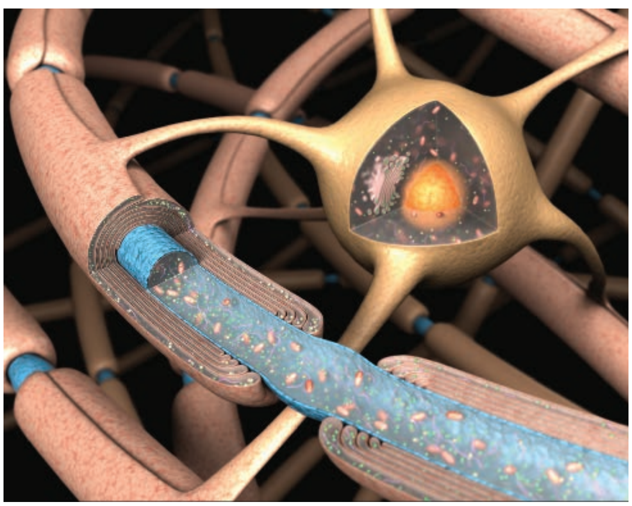

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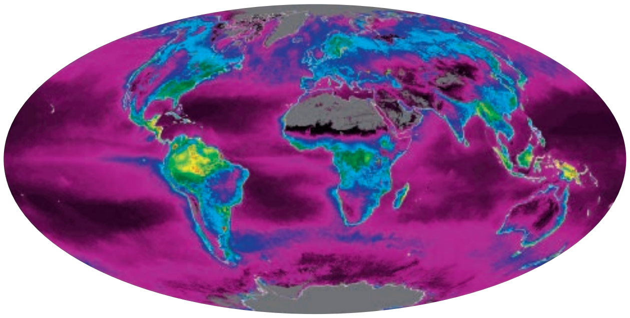
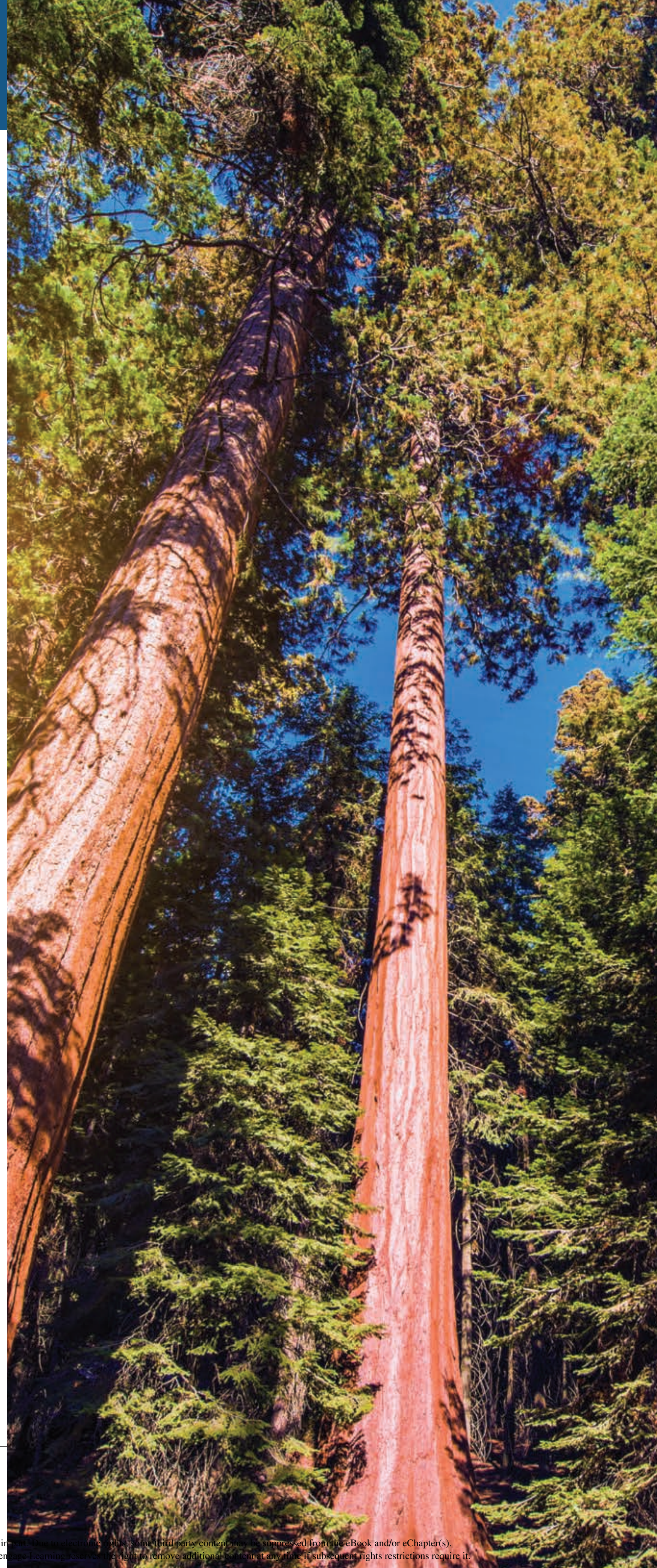


Appendices



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, policymakers, 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 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 the rapidly changing 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. This edition also includes tools to explore core biological concepts from a variety of perspectives (molecular, cellular, organismal, ecological, and so on).

Features of This Edition

Setting the Stage

Each chapter opens with a dramatic photo. 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 Core Concepts: evolution; information flow; systems; pathways of transformation; structure/function; or the process of science.

Section-Based Learning Objectives

The content of every chapter is organized as a series of sections. Learning Objectives associated with each section are phrased as activities that the student should be able to carry out after reading the text.

On-Page Glossary

An On-Page Glossary includes boldface key terms introduced in each section. This section-by-section glossary offers pronunciations, definitions in alternate wording, and it can be used as a quick study aid. 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 continue to alter the environment and threaten both human health and Earth's biodiversity. Each chapter begins and ends with a section that explains a current topic in light of the chapter content.

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-Quiz and Critical Thinking Questions provide additional self-assessment material. Another active-learning feature, the in-text Data Analysis Activity, sharpens analytical skills by asking the student to interpret data presented in graphic or tabular form. The data is presented with relevant chapter content, and is from a published scientific study in most cases.

Some Updates in This Revision

1 Invitation to Biology Expanded section "The Nature of Science" includes new, detailed coverage of pseudoscience and how it differs from science.

2 Life's Chemical Basis New table compares elemental composition of the human body with Earth's crust, seawater, and the universe. Updated art more clearly demonstrates vacancies. New art illustrates and compares bond polarity.

3 Molecules of Life Revised text further emphasizes levels of protein structure as related to protein function. New art illustrates patterns of secondary structure; new content reflects current research elucidating misfolded prion structure and pathogenesis of amyloid diseases.

4 Cell Structure New, major art depicts interactions among components of the endomembrane system. New art reveals ultrastructural details of cell junctions per recent discoveries. New photos illustrate a beneficial biofilm, cuticle, and basement membrane. Expanded section on the nature of life now includes theory of living systems.

5 Ground Rules of Metabolism New photos and art use firefly luciferase to illustrate energy flow in metabolism. Updated art clarifies selective permeability of cell membranes and tonicity, and directional orientation of membrane proteins during exocytosis. Expanded coverage of ATP as a coenzyme.

6 Where It Starts—Photosynthesis Chapter has been reorganized for a better introductory sequence. New art illustrates a special pair, light-harvesting complex, and cyclic photophosphorylation. Expanded discussion of the cyclic pathway emphasizes the interplay between both versions of light reactions, and the evolutionary significance of dual pathways. Expanded discussion of photorespiration incorporates new research on its adaptive value.

7 Releasing Chemical Energy Art updated throughout. New introductory table and art in each section detail inputs and outputs linking steps in aerobic respiration. Revised diagram better illustrates dual PGAL breakdown in glycolysis. New Data Analysis Activity concerns reprogramming of mitochondria in brown fat by dietary fat overload.

8 DNA Structure and Function Nucleotide structure art revised to better illustrate composition and two-dimensional accuracy. Updated art including model of a pyrimidine dimer clarifies how replication errors become mutations.

9 From DNA to Protein New art illustrates the overall structure of a gene and its relationship to RNA translated from it. New table compares DNA and RNA. Revised art better illustrates post-transcriptional modification; major translation figure updated to clarify elongation and polysomes. Expanded section on mutations includes material on a beneficial hemoglobin mutation (E6K, HbC) that offers resistance to malaria without the health consequences of HbS; and how a mutation in a regulatory site (an intron) can affect gene expression (resulting in hairlessness in cats).

10 Control of Gene Expression Updated art better illustrates points of control in eukaryotic gene expression. New flow chart shows gene expression cascade in *Drosophila* development; new art illustrates random nature of X chromosome inactivation. Added coverage of circadian cycles of gene expression; expanded discussion reflects current understanding of epigenetic mechanisms.

11 How Cells Reproduce New ultra-high resolution confocal live-cell images better illustrate mitosis and the spindle. Cell cycle illustration now correlated with illustration of ploidy changes in mitosis. Revised text and art showing cytokinesis include ultrastructural details/processes per current research and paradigms. Expanded material on telomeres now includes telomere-associated triggering and consequences of senescence.

12 Meiosis and Sexual Reproduction New figure illustrates how fertilization restores the chromosome number. Newly discovered mechanism of gene acquisition by individual rotifers added to revisited section.

13 Observing Patterns in Inherited Traits Marfan syndrome discussion updated to reflect change in life expectancy due to increased awareness, accompanied by new photo of former Baylor University basketball star Isaiah Austin.

14 Chromosomes and Human Inheritance Molecular pathogenesis of Huntington's and DMD updated to reflect current research. Table of genetic abnormalities now broken by section. Updated art better depicts chromosome structural changes.

15 Studying and Manipulating Genomes Art depicting recombinant DNA production and reverse transcription revised for clarity. Art and text revised to include structure and utility of eukaryotic expression vectors. New figure illustrates exponential amplification of DNA by PCR. New table lists human genome statistics. Gene therapy section revised to include mechanism, application, and social implications of CRISPR-Cas9 gene editing.

16 Evidence of Evolution Cetacean evolutionary sequence updated to reflect currently accepted narrative. Current research informed revisions of plate tectonics art. Paleogeography art revised to show Mercatur projections.

17 Processes of Evolution Updated material on antibiotic resistance and overuse of antibiotics in livestock. Illustration of HbS allele frequency vs. incidence of malaria updated to reflect recent data in Gabon. New photo of bumblebee on white sage flower added to mechanical isolation figure. Discussion of sympatric speciation in wheat revised to reflect current research.

18 Organizing Information About Species Phylogeny section and parsimony analysis figure revised for clarity. Convergent and divergent evolution terminology introduced. New photo of stem reptile fossil added to divergent evolution figure. New close-up of saguaro cactus spines juxtaposed with Euphorbia spines for better illustration of convergent evolution.

19 Life's Origin and Early Evolution Expanded coverage of the Precambrian, including timeline. Updated information about the possibility of an RNA world, the earliest proposed fossil life, and the archaeal and bacterial ancestors of eukaryotes. New Data Analysis Activity about the effect of some antibiotics on mitochondria.

20 Viruses, Bacteria, and Archaea New opening essay about the human microbiota. Improved art comparing viral structures. Updated information about Ebola, AIDS, and Zika virus. Updated figure showing binary fission. New figure illustrating mechanisms of horizontal gene transfer in prokaryotes. New section about bacteria as pathogens. New Data Analysis Activity about antibiotics inspired by the study of bacteriophages.

21 The Protists Chapter reorganized to reflect our current understanding of the major eukaryotic supergroups. New overview of protist cell structure.

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

23 Fungi Added photos of athlete's foot and ringworm. Updated information about white nose syndrome. Increased coverage of the use of fungi in food production, research, biotechnology, and as sources of medicine.

24 Animals I: Major Invertebrate Groups Added information about sponge regeneration. New figure showing schistosomes. Coverage of placozoans, rotifers, and tardigrades deleted.

25 Animals II: The Chordates New information about bone loss in the evolution of cartilaginous fishes.

26 Human Evolution Updated information about fossil hominids, including discussion of Denisovans and *Homo naledi*.

27 Plant Tissues New art includes illustration of stem structure and location of the vascular cylinder in a root.

28 Plant Nutrition and Transport Added information about use of phytoremediation at Fukushima. New micrographs and associated art detail the flow of water through xylem cells. Updated translocation art coordinates with new art illustrating sieve tube structure.

29 Life Cycles of Flowering Plants Detail added to plant life cycle art for accuracy. New photo illustrates root suckers.

30 Communication Strategies in Plants Current research informed updates to mechanisms of hormonal action. Table summarizing plant hormones has been broken by section. Added material includes the role of ABA in stress-related stomata closure; nastic movements and accompanying new photos; and explanation of *Phylloxera* resistance in American grapevines based on enhanced hypersensitive response involving resveratrol.

31 Animal Tissues and Organ Systems New summary table describing tissue types. Improved graphic illustrating relative volumes of the fluid components of a human body. New information about brown fat versus white fat and white matter and gray matter. Updated information about research on and clinical use of induced pluripotent stem cells (IPSCs) and about transdifferentiation as an alternative source of replacement cells.

32 Neural Control Updated information about brain damage among professional football players. New opening overview of intracellular signaling mechanisms. Revised/reorganized coverage of the peripheral nervous system. New subsection covers tissues and fluid of the CNS; information about neuroglia moved here.

33 Sensory Perception Updated illustration/discussion of retina anatomy to include light-channeling neuroglia.

34 Endocrine Control Added information about sites of human steroid hormone production (gonads/adrenals). Consolidated information about hormones in a single table. Moved discussion of pineal gland to follow discussion of pituitary/hypothalamus. Deleted coverage of the thymus. New Data Analysis Activity covers the disruptive effect of BPA on insulin secretion.

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

36 Circulation Updated photo depicting measurement of blood pressure. Expanded coverage of venule function. New art depicting atherosclerosis. Added discussion of heart attack symptoms and of causes and symptoms of stroke. New Data Analysis Activity on how hypertension affects the risk of stroke and heart attack.

37 Immunity New application section that details vaccination and benefits of herd immunity features a narrative about an unvaccinated child with permanent health consequences of contracting measles. New photos illustrate microbial sectors of a dental plaque biofilm, agglutination, and anaphylaxis. Revised art better illustrates specificity of antigen binding sites in antibodies. New content includes role of keratinocytes as immune cells in contact allergies.

38 Respiration Improved photo of insect tracheal system. Increased emphasis on evolutionary trends in vertebrate lung structure. Added information about the risks of vaping. New Data Analysis Activity addresses effects of tobacco and marijuana smoke on the lungs.

39 Digestion and Human Nutrition New opening essay about the role of human digestive enzymes and genetic variations in these enzymes. Added coverage of sponge digestion with new graphic. New figure compares length of digestive tract regions in a mammalian carnivore and herbivore. New graphics depict peristalsis and segmentation. Coverage of beneficial gut microflora moved to the section about the large intestine.

40 Maintaining the Internal Environment Material reorganized with separate sections describing formation and types of wastes and types of excretory organs. Variations on kidney structure in fish and desert rat kidneys now covered in a separate section after discussion of human kidney structure. Added information about human body hair as a temperature-related adaptation. Deleted coverage of human variation in sodium reabsorption.

41 Animal Reproduction Updated information about STDs, including new discussion of *Mycoplasma genitalium* infection.

42 Animal Development Morphogens now discussed in the context of embryonic induction. Added information about the teratogenic effects of the Zika virus.

43 Animal Behavior New information about epigenetic effects in a variety of contexts. Improved honeybee dance language figure. New information about tent caterpillars, a pre-social species. Added information about reciprocal altruism.

44 Population Ecology New information about research indicating that human hunting altered the life-history traits of wooly mammoths. Updated human population statistics.

45 Community Ecology Added coverage and photos of sundews and spiders that complete for insect prey. Updated photo of Surtsey.

46 Ecosystems Updated information about the increasing level of atmospheric carbon dioxide and the evidence that human activities are responsible for this increase.

47 The Biosphere Updated information about the movement of radioactive compounds released at Fukushima. Figure depicting seasonal overturn in a lake revised. Increased coverage of the importance of dissolved oxygen in aquatic habitats. New coverage of ocean acidification as a threat to reefs.

48 Human Effects on the Biosphere New opening section about the proposal to recognize human effects by naming a new geological epoch—the Anthropocene. New Data Analysis Activity about bioaccumulation of radioactive materials in tuna. Revised, updated coverage of biodiversity hotspots. New closing section about how citizen science can help document the distribution and decline of biodiversity.

Student and Instructor Resources

MindTap

MindTap is an outcome-driven application that propels students from memorization to mastery. MindTap is the only platform that gives you complete ownership of your course—to provide engaging content, to challenge every individual, and to build students' confidence.

MindTap brings ultimate convenience for students and instructors by allowing you to access everything in one place. In addition, the MindTap Mobile App gives students complete flexibility to read, listen, and study anytime, anywhere on their phones—and learn on their terms.

MindTap for *Biology: The Unity and Diversity of Life 15e*

The MindTap Learning Path includes these engaging learning opportunities in every chapter, and more!

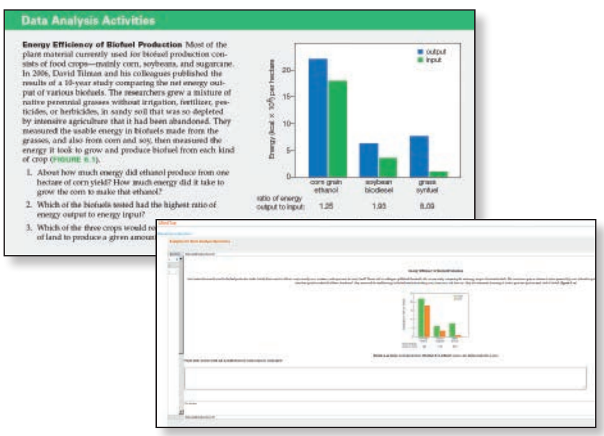
Make It Relevant

Based on the chapter core applications, the popular *How Would You Vote?* feature provides scenarios for further research and critical thinking on topics that show the relevance of biology to student lives. After reading the chapter, students can revisit their original vote in a follow-up activity called *How Would You Vote Now?*

Assign and Grade Content that Matters

The following activities are included and can be set to auto-graded using a simple button-click.

- **Data Analysis Activities** are fully assignable in MindTap! Ensure your students are sharpening their analytical skills by assigning these engaging activities. The data is related to the chapter material, and is taken from a published scientific study in most cases. Other assignable and gradable activities in every chapter include:
- **Conceptual Learning Assignments**
- **Critical Thinking Questions**
- **Chapter Test**



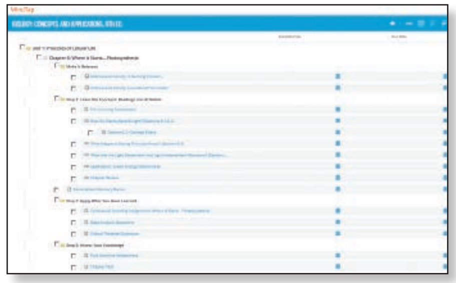
Data Analysis activities in every chapter…assigned in MindTap.

Just for Students: Study and Practice

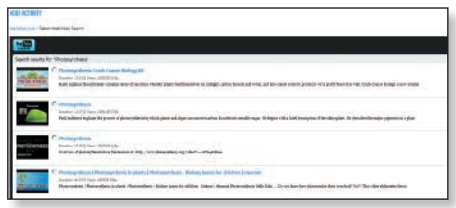
The new MindTap features two sets of activities to ensure students are not only doing the reading but are also engaging and learning the topics.

- **Student Study Card** For each section in every chapter, students read a brief summary, complete answers to learning objective "quick-checks" and get immediate feedback on their responses. Direct links to media related to the section content are included for many sections.
- **Study Guide** For student practice only; this set of detailed questions provides students further practice on the topics in each section.

MindTap is fully customizable to meet your course goals. Easily assign students the content you want them to learn, in the order you want them to learn it.



Make it your own. Insert your own materials—slides, videos, and lecture notes—wherever you want your students to see them.



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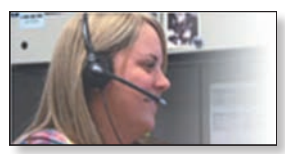
"The technical support provided by Cengage staff in using MindTap was superb. The Digital Support Team was proactive in training and prompt in answering follow-up questions." —K. Sata Sathasivan, The University of Texas at Austin



Instructor Companion Site

Everything you need for your course in one place! This collection of book-specific lecture and class tools is available online via www.cengagebrain.com/login. Access and download PowerPoint presentations, images, instructor's manuals, videos, test banks, and more.

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 as committed as we are to creating and disseminating an exceptional science education product.

Biology is not dogma; paradigm shifts are a common outcome of the fantastic amount of research in the field. Ideas about what material should be taught and how best to present that material to students changes even from one year to the next. It is only with the ongoing input of our many academic reviewers and advisors (see the list of Class Testers and Reviewers for this edition, right) that we can 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.

Thanks to Hal Humphrey, Production Manager; Jake Warde, Content Developer; Tom Ziolkowski, Marketing Manager; and Marina Starkey, Product Assistant. Thank you also to Cheryl DuBois and Christine Myaskovsky for help with photo research.

Lisa Starr and Christine Evers, August 2017

Cengage acknowledges and appreciates Lisa Starr's contribution of more than 300 pieces of art to this edition.

Molecular Structure Reference Data

Structural models in this book were rendered using the following data from RCSB PDB (www.rcsb.org, Berman, H.M., Westbrook, J., Feng, Z., Gilliland, G., Bhat, T.N., Weissig, H., Shindyalov, I.N., Bourne, P.E. (2000) The Protein Data Bank. *Nucleic Acids Research*, 28: 235-242) and The Protein Model DataBase (Castrignanò, T., De Meo, P.D., Cozzetto, D., Talamo, I.G., Tramontano, A. The PMDB Protein Model Database. (2006) *Nucleic Acids Res.* 34 Database issue: D306-9). **Fig 3.6 & Fig 3.16(3,4,5) & Fig 4.3 & Fig 5.18 left & Fig 9.14 & Fig 38.15** PDB ID: 1BBB. Silva, M.M., Rogers, P.H., Arnone, A. A third quaternary structure of human hemoglobin A at 1.7-Å resolution. (1992) *J.Biol.Chem.* 267: 17248-17256. **Fig 3. 17 middle** PDB ID: 1PGX. Achari, A., Hale, S.P., Howard, A.J., Clore, G.M., Gronenborn, A.M., Hardman, K.D., Whitlow, M. 1.67 Å X-ray structure of the B2 immunoglobulin-binding domain of streptococcal protein G and comparison to the NMR structure of the B1 domain. (1992) *Biochemistry* 31: 10449-10457. **Fig 3.18** PMDB ID: PM0074956. Wu, Z., Wagner, M.A., Zheng, L., Parks, J.S., Shy, J.M., Smith, J.D., Gogonea, V., Hazen, S.L. The refined structure of nascent HDL reveals a key functional domain for particle maturation and dysfunction. (2007) *Nat. Struct. Mol. Biol.* 14(9): 861-8. **Fig 3.19A left** PDB ID: 1QM2. Zahn, R., Liu, A., Luhrs, T., Riek, R., Von Schroetter, C., Garcia, F.L., Billeter, M., Calzolai, L., Wider, G., Wuthrich, K. NMR solution structure of the human prion protein. (2000) Proc. *Natl. Acad. Sci.* USA 97: 145. **Fig 3.19A middle, right** PDB ID: 2RNM. Wasmer, C., Lange, A., Van Melckebeke, H., Siemer, A.B., Riek, R., Meier, B.H., Amyloid fibrils of the HET-s(218-289) prion form a beta solenoid with a triangular hydrophobic core. (2008) *Science* 319: 1523-1526. **Page 47** PDB ID: 2W5J. Vollmar, M., Shlieper, D., Winn M., Buechner, C., Groth, G. Structure of the C14 rotor ring of the proton translocating chloroplast ATP synthase. (2009) *J.Biol.Chem.* 284: 18228. **Fig 5.10B** PDB ID: 1HKB. Aleshin, A.E., Zeng, C., Bourenkov, G.P., Bartunik, H.D., Fromm, H.J., Honzatko, R.B. The mechanism of regulation of hexokinase: new insights from the crystal structure of recombinant human brain hexokinase complexed with glucose and glucose-6-phosphate. (1998) *Structure* 6: 39-50. **Fig 5.10A** PDB ID: 1HKC. Aleshin, A.E., Zeng, C., Bartunik, H.D., Fromm, H.J., Honzatko, R.B. Regulation of hexokinase I: crystal structure of recombinant human brain hexokinase complexed with glucose and phosphate. (1998) *J.Mol.Biol.* 282: 345-357. **Fig 6.10** PDB ID: 2BHW. Standfuss, J., Terwisscha Van Scheltinga, A.C., Lamborghini, M., Kuehlbrandt, W. Mechanisms of Photoprotection and Nonphotochemical Quenching in Pea Light-Harvesting Complex at 2.5Å Resolution. (2005) *Embo J.* 24: 919. **Page 141** PDB ID: 1TTD. McAteer, K., Jing, Y., Kao, J., Taylor, J.S., Kennedy, M.A. Solution-state structure of a DNA dodecamer duplex containing a Cis-syn thymine cyclobutane dimer, the major UV photoproduct of DNA. (1998) *J.Mol.Biol.* 282: 1013-1032. **Fig 9.2 right** PDB ID: 2AAI. Rutenber, E., Katzin, B.J., Ernst, S., Collins, E.J., Mlsna, D., Ready, M.P., Robertus, J.D. Crystallographic refinement of ricin to 2.5Å. (1991) *Proteins* 10: 240-250. **Fig 9.10** PDB ID: 3O30. Ben-Shem, A., Jenner, L., Yusupova, G., Yusupov, M. Crystal structure of the eukaryotic ribosome. (2010) *Science* 330: 1203-1209. **Fig 9.11 top left** PDB ID: 1EVV. Jovine, L., Djordjevic, S., Rhodes, D. The crystal structure of yeast phenylalanine tRNA at 2.0 Å resolution: cleavage by Mg(2+) in 15-year old crystals. (2000) *J.Mol.Biol.* 301: 401-414. **Fig 9.2 right** PDB ID: 2AAI. Rutenber, E., Katzin, B.J., Ernst, S., Collins, E.J., Mlsna, D., Ready, M.P., Robertus, J.D. Crystallographic refinement of ricin to 2.5Å. (1991) *Proteins* 10: 240-250. **Fig 10.10** PDB ID: 1IG4. Ohki, I., Shimotake, N., Fujita, N., Jee, J., Ikegami, T., Nakao, M., Shirakawa, M. Solution structure of the methyl-CpG binding domain of human MBD1 in complex with methylated DNA. (2001) *Cell* (Cambridge, Mass.) 105: 487-497. **Fig 37.9** PDB ID: 1IGT. Harris, L.J., Larson, S.B., Hasel, K.W., McPherson, A. Refined structure of an intact IgG2a monoclonal antibody. (1997) *Biochemistry* 36: 1581-1597. **Fig 37.16 left** PDB ID: 1MI5. Kjer-Nielsen, L., Clements, C.S., Purcell, A.W., Brooks, A.G., Whisstock, J.C., Burrows, S.R., McCluskey, J., Rossjohn, J. A structural basis for the selection of dominant alphabeta T Cell receptors in antiviral immunity. (2003) *IMMUNITY* 18: 53-64.

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BIOLOGY

The Unity and Diversity of Life

15TH EDITION

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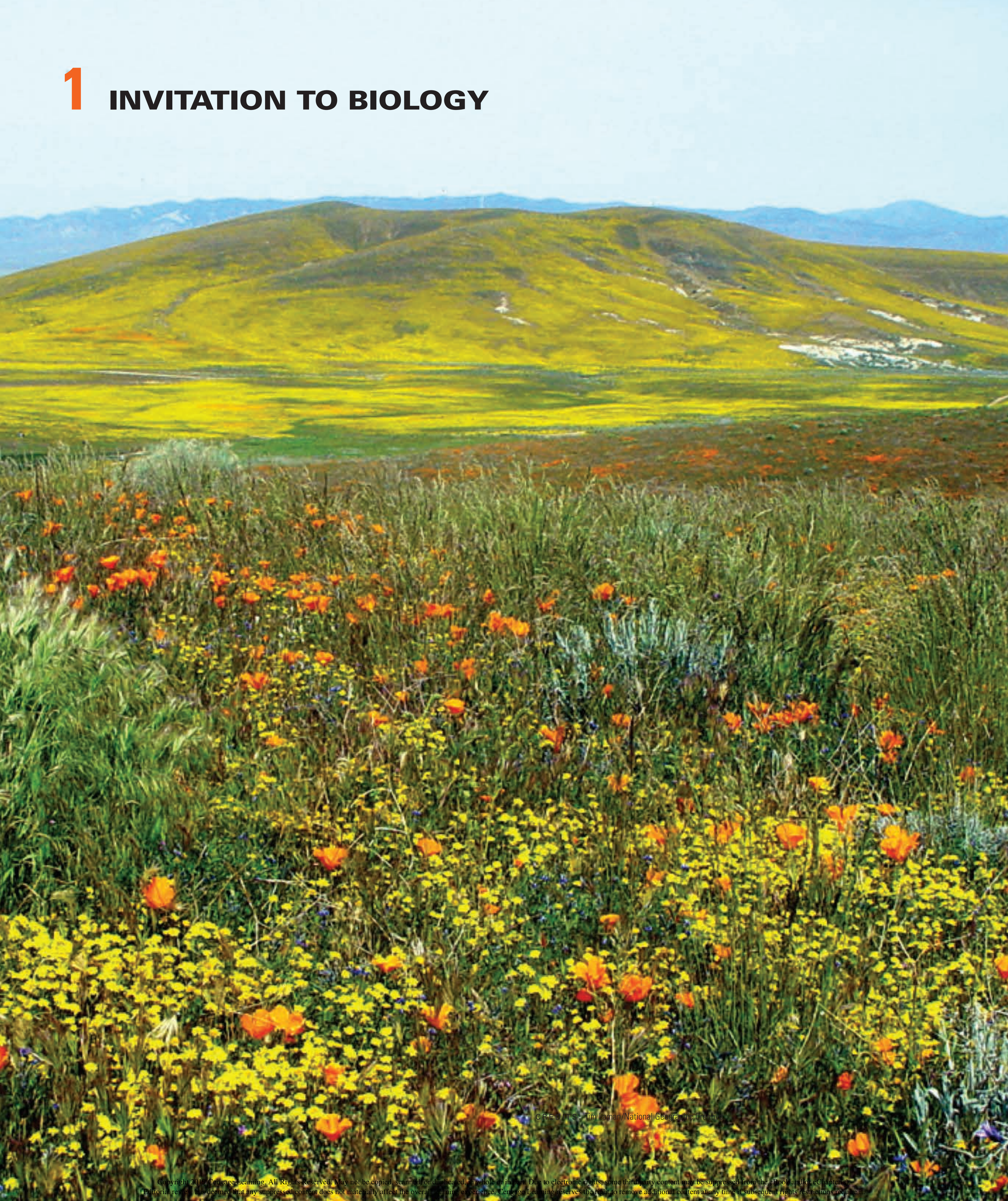
1 INVITATION TO BIOLOGY



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CORE CONCEPTS

Systems

Complex properties arise from interactions among components of a biological system.

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. The movement of matter and energy through ecosystems influences interactions among organisms and their environment.

Evolution

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.

Process of Science

The field of biology consists of and 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 scientific research. Carefully designed experiments that yield objective data help researchers unravel cause-and-effect relationships in complex biological systems.

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.

1.1 Application: Secret Life of Earth

In this era of cell phone GPS, could there possibly be any places left on Earth that humans have not yet explored? Actually, there are plenty. Consider a 2-million-acre cloud forest in the Foja Mountains of New Guinea that was not penetrated by humans until 2005. Since then, about forty new **species**—unique types of organisms—have been discovered there, including a rhododendron plant with flowers the size of dinner plates, a rat the size of a cat, and a frog the size of a pea. Also discovered among the forest's inhabitants were hundreds of species on the brink of extinction in other parts of the world, and some that supposedly had been extinct for decades. A few new or rare species were discovered accidentally, as animals that had never learned to be afraid of humans wandered casually through campsites (**FIGURE 1.1**).

How do we know what species a particular organism belongs to? What is a species, anyway, and why should discovering a new one matter to anyone other than a biologist? You will find the answers to such questions in this book. They are part of the scientific study of life, **biology**, which is one of many ways we humans try to make sense of the world around us. Ironically, the more we learn about the natural world, the more we realize we have yet to learn. But don't take our word for it. Find out what biologists know, and what they do not, and you will have a solid foundation upon which to base your own opinions about how humans fit into this world. By reading this book, you are choosing to learn about the human connection—your connection—with all life on Earth.

FIGURE 1.1 The Pinocchio frog. Biologist Paul Oliver discovered this tiny tree frog perched on a sack of rice during the first survey of a cloud forest in New Guinea. It was named after the Disney character because the male frog's long nose inflates and points upward during times of excitement.

biology The scientific study of life.
species (SPEE-sheez) A unique type of organism.

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1.2 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.

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 complex properties that differentiate living from nonliving things. These properties often emerge from the interactions or arrangements of basic components (**FIGURE 1.2**).

Consider a complex behavior called swarming that is characteristic of honeybees. When bees 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. A characteristic of a system (a swarm's collective intelligence, for example) that does not appear in any of the system's components (individual bees) is called an **emergent property**.

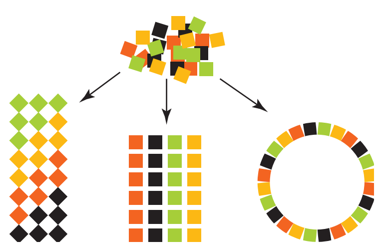


FIGURE 1.2 The same materials, assembled in different ways, form objects with different properties. The property of "roundness" emerges when these squares are assembled in a certain way.

atom The smallest unit of a substance; composes matter.
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 components.
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, a set of interacting organs that carry out a particular body function.
population A group of interbreeding individuals of the same species living in a defined area.
tissue In multicelled organisms, specialized cells organized in a pattern that allows them to perform a collective function.

Life's Organization

Biologists view life in increasingly inclusive levels of organization (**FIGURE 1.3**). This organization begins with the **atom** ❶, the smallest unit of a substance. Atoms and the fundamental particles that compose them are the building blocks of all matter. 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 organized in a particular pattern. The arrangement allows the cells to collectively perform a special function such as protection from injury (dermal tissue) or movement (muscle tissue).

An **organ** is a structure composed of tissues that collectively carry out a particular task or set of tasks ❺. 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).

A **population** is a group of interbreeding individuals of the same species living in a given area. For example, all of the 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 the California poppy population, as well as populations of other plants, animals, microorganisms, and so on ❾. Communities may be large or small, depending on the area defined.

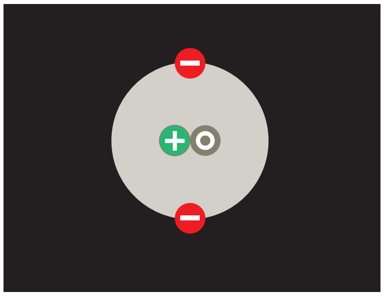
The next level of organization is the **ecosystem**, which is a community interacting with its physical and chemical environment ❿. Earth's largest ecosystem is the **biosphere**, and it encompasses all regions of the planet's crust, waters, and atmosphere in which organisms live ⓫.

TAKE-HOME MESSAGE 1.2

✔ Biologists study life by thinking about it at successive levels of organization. Emergent properties occur at each level.

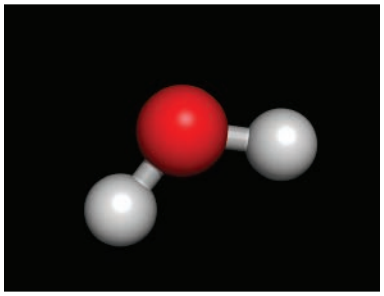
✔ All matter consists of atoms. Atoms join as molecules, and molecules make up cells. The cell is the smallest unit of life.

✔ Organisms, populations, communities, ecosystems, and the biosphere are successively higher levels of life's organization.



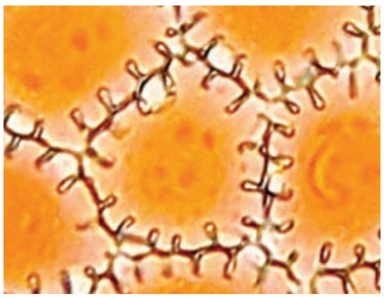
1 Atom

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



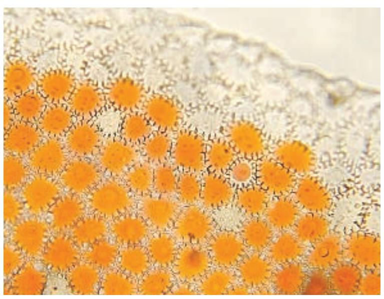
2 Molecule

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

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

5 Organ

A 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

An individual that consists of more than one cell. Cells of this California poppy plant make up its shoot system and root system.

8 Population

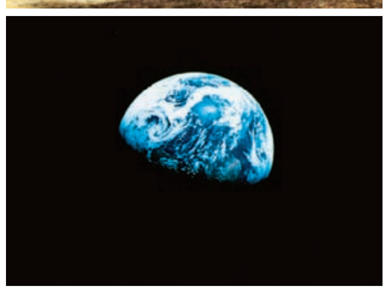
A group of single-celled or multicelled individuals of a species in a given area. This population of California poppy plants is in California's Antelope Valley Poppy Reserve.

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 1.3 Levels of life's organization.
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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1.3 How Living Things Are Alike

LEARNING OBJECTIVES

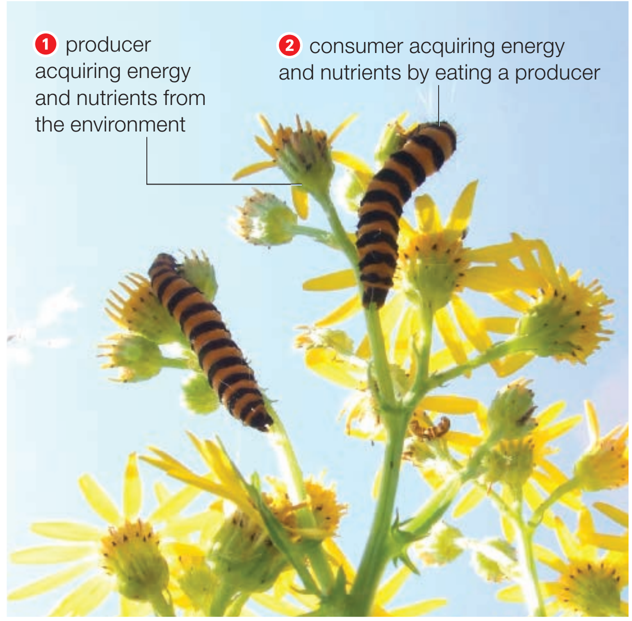
- Distinguish producers from consumers.
- Explain why homeostasis is important for sustaining life.
- Explain how DNA is the basis of similarities and differences among organisms.

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**).

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 to change.
DNA is hereditary material	Genetic information in the form of DNA is passed to offspring.



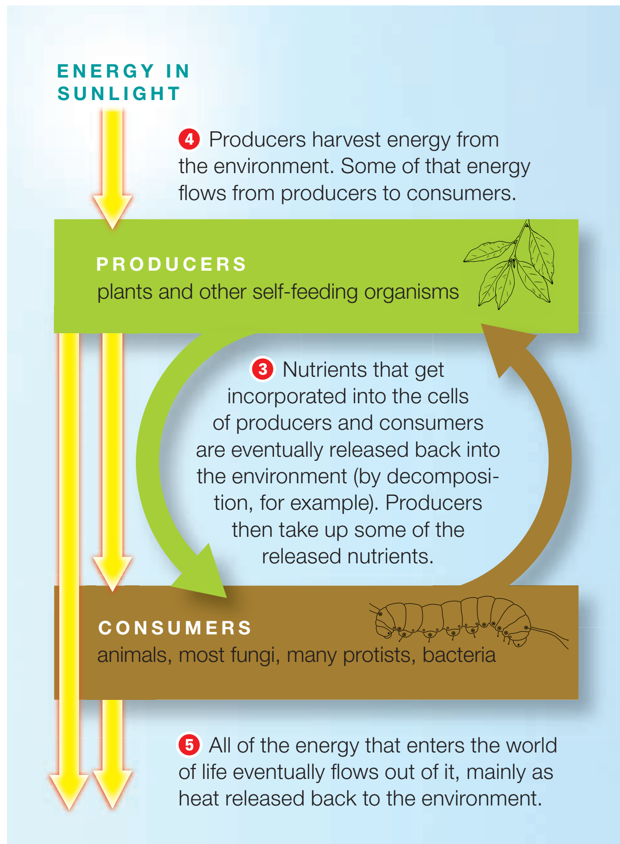


FIGURE 1.4 The one-way flow of energy and cycling of materials through the world of life.

Organisms Require Energy and Nutrients

Not all living things eat, but all require energy and nutrients on an ongoing basis. A **nutrient** is a substance that an organism needs for growth and survival but cannot make for itself.

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 1.4**). A **producer** makes its own food using energy and simple raw materials it obtains from nonbiological sources ❶. 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 ❷. 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 ❸.

Unlike nutrients, energy is not cycled. It flows through the world of life in one direction: from the environment ❹, through organisms, and then back to the environment ❺. 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

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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 responds 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 1.5**). 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.

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.

FIGURE 1.5 Living things sense and respond to their environment. Sweating is a physiological 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.

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.

TAKE-HOME MESSAGE 1.3

- ✔ A one-way flow of energy and a cycling of materials maintain life's complex organization.
- ✔ Organisms sense and respond to conditions inside and outside themselves. They make adjustments that keep conditions in their internal environment within a range that favors cell survival, a process called homeostasis.
- ✔ All organisms use information in the DNA they inherited from their parent or parents to develop, grow, and reproduce. DNA is the basis of similarities and differences among organisms.

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

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

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

growth 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) A 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 An 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.

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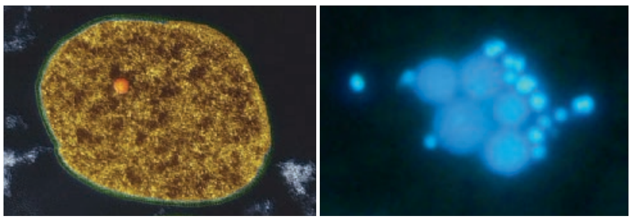
A Bacteria are the most numerous organisms on Earth. Clockwise from upper left, a bacterium with a row of iron crystals that serves as a tiny compass; a common bacterial resident of cat and dog stomachs; photosynthetic bacteria; bacteria found in dental plaque.



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 1.6 A few representative prokaryotes.

1.4 How Living Things Differ

LEARNING OBJECTIVES

- List two characteristics of prokaryotes.
- Name the four main groups of eukaryotes.

You will see in later chapters how 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 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 sac-like structure that contains a cell's DNA. **Bacteria** (singular, bacterium) and **archaea** (singular, archaeon) are the organisms whose DNA is *not* contained within a nucleus (**FIGURE 1.6**). All bacteria and archaea are single-celled, which means each individual consists of one cell. 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. Eukaryotic cells are typically larger and more complex than prokaryotes.

There are four main groups of eukaryotes: protists, fungi, plants, and animals (**FIGURE 1.7**).

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 A multicelled consumer that develops through a series of stages and moves about during part or all of its life.
archaea (are-KEY-uh) Singular, archaeon. Group of single-celled organisms that lack a nucleus but are more closely related to eukaryotes than to bacteria.
bacteria Singular, bacterium. The most diverse and well-known group of single-celled organisms that lack a nucleus.
eukaryote (you-CARE-ee-oat) An organism whose cells characteristically have a nucleus.
fungus Plural, fungi. A single-celled or multicelled eukaryotic consumer that breaks down material outside itself, then absorbs nutrients released from the breakdown.
genus (JEE-nuss) Plural, genera. A group of species that share a unique set of traits.
plant A multicelled eukaryotic producer; typically photosynthetic.
prokaryote (pro-CARE-ee-oat) A single-celled organism without a nucleus.
protist Common term for a eukaryote that is not a plant, animal, or fungus.
specific epithet Second part of a species name.
taxonomy (tax-ON-oh-me) The practice of naming and classifying species.
trait An inherited characteristic of an organism or species.

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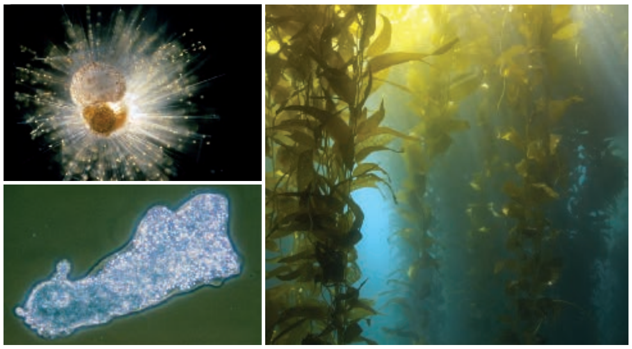

Protists are a group of extremely diverse eukaryotes that range from microscopic free-living cells (left) to giant multicelled seaweeds (right).

Fungi are eukaryotic consumers that secrete substances to break down food outside their body. Some are single-celled (left); 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.

FIGURE 1.7 A few representative eukaryotes.

TAKE-HOME MESSAGE 1.4

✔ Details of appearance and other characteristics vary greatly among living things.

✔ Bacteria and archaea are organisms whose DNA is not contained in a nucleus. All are single-celled.

✔ Protists, fungi, plants, and animals are eukaryotes: organisms whose DNA is contained in a nucleus. Most are multicelled.

1.5 Organizing Information About Species

LEARNING OBJECTIVES

- Explain how organisms are named in the Linnaean system.
- Describe the way species are classified in taxa.
- List the taxa from species to domain.
- Describe the "biological species concept" and explain its limitations.

A Rose by Any Other Name . . .

Each time we discover a new species, we name it, a practice called **taxonomy**. Taxonomy began thousands of years ago, but naming species in a consistent way did not become a priority until the eighteenth century. At the time, European explorers who were just discovering the scope of life's diversity started having more and more trouble communicating with one another because species often had multiple names. For example, the dog rose (a plant native to Europe, Africa, and Asia) was alternately known as briar rose, witch's briar, herb patience, sweet briar, wild briar, dog briar, dog berry, briar hip, eglantine gall, hep tree, hip fruit, hip rose, hip tree, hop fruit, and hogseed—and those are only the English names! Species often had multiple scientific names too, in Latin that was descriptive but often cumbersome. The scientific name of the dog rose was *Rosa sylvestris inodora seu canina* (odorless woodland dog rose), and also *Rosa sylvestris alba cum rubore, folio glabro* (pinkish white woodland rose with smooth leaves).

An eighteenth-century naturalist, Carolus Linnaeus, standardized a naming system that we still use. By the Linnaean system, each species is given a unique two-part scientific name. The first part of a scientific name is the **genus** (plural, genera), which is defined as a group of species that share a unique set of features. The second part of the name is the **specific epithet**. Together, the genus name and the specific epithet designate one species. Thus, the dog rose now has one official name, *Rosa canina*, that is recognized worldwide.

Genus and species names are always italicized. For example, *Panthera* is a genus of big cats. Lions belong to the species *Panthera leo*. Tigers belong to a different species in the same genus (*Panthera tigris*), and so do leopards (*P. pardus*). Note how the genus name may be abbreviated after it has been spelled out.

Distinguishing Species

The individuals of a species share a unique set of inherited characteristics, or **traits**. For example, giraffes normally have very long necks, brown spots on white

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