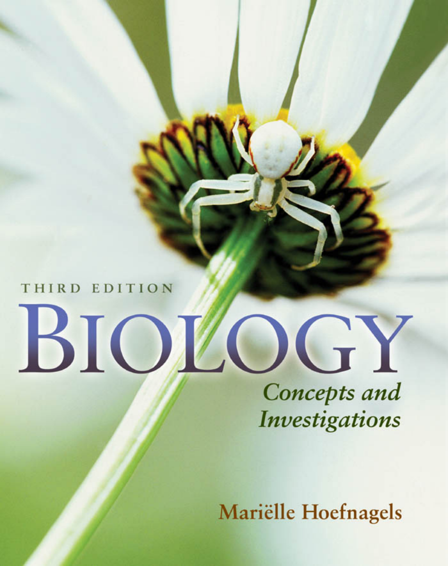

THIRD EDITION

BIOLOGY

Concepts and Investigations

Mariëlle Hoefnagels

BIOLOGY

Concepts and Investigations

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THIRD EDITION

BIOLOGY

Concepts and Investigations

Mariëlle Hoefnagels

THE UNIVERSITY OF OKLAHOMA

Mc Graw Hill Education

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Brief Contents

About the Author

Mariëlle Hoefnagels is an associate professor in the Department of Biology and the Department of Microbiology and Plant Biology at the University of Oklahoma, where she teaches courses in introductory biology, mycology, and science writing. She has received the University of Oklahoma General Education Teaching Award and the Longmire Prize (the Teaching Scholars Award from the College of Arts and Sciences). She has also been awarded honorary memberships in several student honor societies.

Dr. Hoefnagels received her B.S. in environmental science from the University of California at Riverside, her M.S. in soil science from North Carolina State University, and her Ph.D. in plant pathology from Oregon State University. Her dissertation work focused on the use of bacterial biological control agents to reduce the spread of fungal pathogens on seeds. In addition to authoring *Biology: Concepts and Investigations* and *Biology: The Essentials*, her recent publications have focused on creating investigative teaching laboratories and methods for teaching experimental design in beginning and advanced biology classes. She frequently gives presentations on study skills and related topics to student groups.

Preface

Vision and Change in Undergraduate Biology Education: A Call to Action encourages instructors to improve student engagement and learning in introductory biology courses. The central idea of the *Vision and Change* report is that we need to turn away from teaching methods that reward students who memorize and regurgitate superficial knowledge. Instead, we need to emphasize deeper learning that requires students to understand and apply course content. This idea is precisely what I have tried to achieve since I started teaching at the University of Oklahoma in 1997, and it has been a guiding principle in the creation of my books and digital material as well.

As you examine this new edition and its supplements, I hope you will see an emphasis on connections and the "big picture." In addition to new features like chapter summary figures, integrated media icons, SmartBook™, and tutorial animations, we've updated and improved many features present in the last edition, including chapter opening essays, Investigating Life sections, boxed readings, and multiple choice and open-ended questions. Every chapter also has a study tip, so students learn to master the skills they need to be successful in biology and every other class.

I agree with the *Vision and Change* report's call for instructors to embrace active learning techniques, but I also believe that one set of tools and techniques does not work in every classroom. For that reason, my team and I are proud to create a package that gives you the flexibility to teach introductory biology in a way that works best for you. Pages viii–xiii illustrate the features and resources for this edition that can help you meet your teaching goals.

I hope that you and your students enjoy this text and that it helps cultivate an understanding of, and deep appreciation for, biology.

Mariëlle Hoefnagels
The University of Oklahoma

Author's Guide *To Using this Textbook*

This guide lists the main features of each chapter and describes some of the ways that I use them in my own classes.

The Learning Outline introduces the chapter's main headings and helps students keep the big picture in mind.

Each heading is a complete sentence that summarizes the most important idea of the section.

The gradual change in leaf colors as a chapter unfolds indicates where the student is in the chapter's big picture.

Students can also flip to the end of the chapter before starting to read; the chapter summary and Pull It Together concept map can serve as a review or provide a preview of what's to come.

Learn How to Learn study tips help students develop their study skills.

Each chapter has one Learn How to Learn study tip, and you can find a complete list in the inside back cover of the book.

I present a *Study Minute* in class each week, with examples of how to use these study tips.

Prenatal Diagnosis Highlights Ethical Dilemmas

BARBARA IS PREGNANT. Like many women, she periodically has her fetus examined by ultrasound. Barbara delights in seeing her unborn child, but her latest scan has revealed a possible abnormality. Her physician cannot be sure of the diagnosis without ordering a test of the fetus's chromosomes.

How is it possible to see chromosomes hidden inside the cells of a fetus, which is itself tucked into the mother's uterus? A technician begins by extracting a small amount of the fluid or tissue surrounding the developing fetus. Fetal cells in the fluid can then be used to prepare a photograph of the fetus's chromosomes.

The image may reveal several types of abnormalities, including extra chromosomes, missing chromosomes, or the movement of genetic material from one chromosome to another. If the physician detects a chromosomal abnormality, Barbara may consult a counselor who can advise her on how best to prepare for the birth of her baby. In the case of a severe abnormality, Barbara may decide to seek an abortion, ending the pregnancy. But this choice raises many difficult issues.

Prenatal diagnosis illustrates one of many intersections between morality and science. Few people would argue against Barbara's use of prenatal diagnosis to learn more about a possible illness. But should parents have the right to expose a fetus to the small risks of prenatal screening simply to determine its sex? Should parents be allowed to abort a fetus of the "wrong" sex? What if an expectant mother lives in a country where having a second female child can bring economic ruin?

Furthermore, what constitutes a "severe" abnormality? Clearly, many chromosomal defects are not survivable, and the child will die shortly after birth (if not before). On the other hand, the symptoms of many conditions range from mild to severe, and a karyotype cannot always predict the severity. And what if a mother or family lacks the resources to care for a child with special needs? These are difficult questions without scientific answers.

Science can, however, help us understand the origin of chromosomal abnormalities. Many of them trace to errors that occur during a specialized form of cell division called meiosis. In humans and many other organisms, meiosis plays a starring role in the production of sperm and egg cells, which lie at the heart of sexual reproduction. This chapter explains the chromosomal choreography of meiosis.

LEARNING OUTLINE

- 9.1 Why Sex?
- 9.2 Diploid Cells Contain Two Homologous Sets of Chromosomes
- 9.3 Meiosis Is Essential in Sexual Reproduction
  - A. Gametes Are Haploid Sex Cells
  - B. Specialized Germ Cells Undergo Meiosis
  - C. Meiosis Halves the Chromosome Number and Scrambles Alleles
- 9.4 In Meiosis, DNA Replicates Once, but the Nucleus Divides Twice
  - A. In Meiosis I, Homologous Chromosomes Pair Up and Separate
  - B. Meiosis II Yields Four Haploid Cells
- 9.5 Meiosis Generates Enormous Variability
  - A. Crossing Over Shuffles Alleles
  - B. Chromosome Pairs Align Randomly During Metaphase I
  - C. Fertilization Multiplies the Diversity
- 9.6 Mitosis and Meiosis Have Different Functions: A Summary
- 9.7 Errors Sometimes Occur in Meiosis
  - A. Polyploidy Means Extra Chromosome Sets
  - B. Nondisjunction Results in Extra or Missing Chromosomes
  - C. Smaller-Scale Chromosome Abnormalities Also Occur
- 9.8 Haploid Nuclei Are Packaged into Gametes
  - A. In Humans, Gametes Form in Testes and Ovaries
  - B. In Plants, Gametophytes Produce Gametes
- 9.9 Investigating Life: Hermaphrodites and Parasites Meet the Red Queen

LEARN HOW TO LEARN
Write It Out—Really!

Get out a pen and a piece of scratch paper, and answer the open-ended Write It Out questions at the end of each chapter. This tip applies even if the exams in your class are multiple choice. Putting pen to paper (as opposed to just saying the answer in your head) forces you to organize your thoughts and helps you discover the difference between what you know and what you only THINK you know.

167

New media icons direct students to resources that can help them understand difficult topics.

Animation 

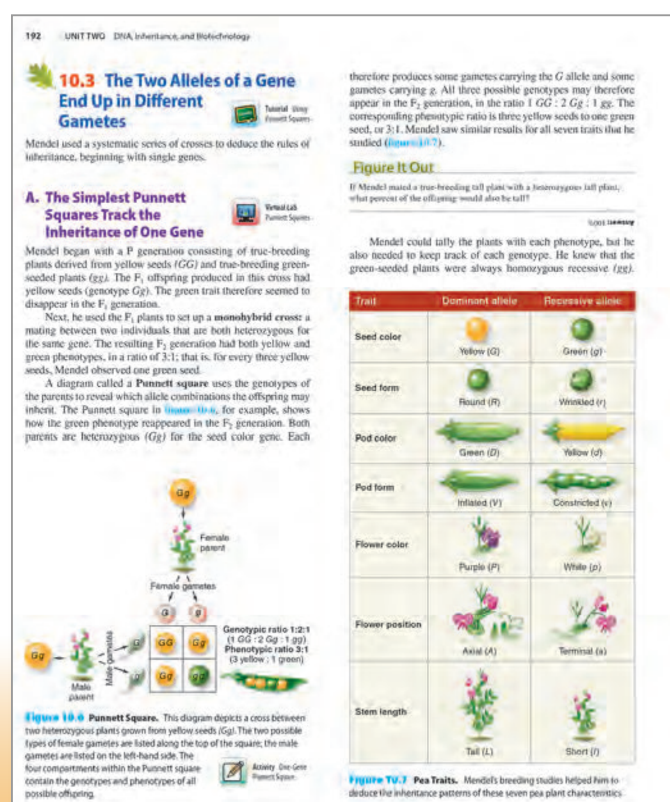
Video 

3-D Animation 

Virtual Lab 

Tutorial 

Activity 



192 UNIT TWO DNA, Inheritance, and Biotechnology

10.3 The Two Alleles of a Gene End Up in Different Gametes

Tutorial Using Punnett Squares

Mendel used a systematic series of crosses to deduce the rules of inheritance, beginning with single genes.

A. The Simplest Punnett Squares Track the Inheritance of One Gene

Virtual Lab Punnett Squares

Mendel began with a P generation consisting of true-breeding plants derived from yellow seeds (*GG*) and true-breeding green-seeded plants (*gg*). The F_1 offspring produced in this cross had yellow seeds (genotype *Gg*). The green trait therefore seemed to disappear in the F_1 generation.

Next, he used the F_1 plants to set up a **monohybrid cross:** a mating between two individuals that are both heterozygous for the same gene. The resulting F_2 generation had both yellow and green phenotypes, in a ratio of 3:1; that is, for every three yellow seeds, Mendel observed one green seed.

A diagram called a **Punnett square** uses the genotypes of the parents to reveal which allele combinations the offspring may inherit. The Punnett square in figure 10.6, for example, shows how the green phenotype reappeared in the F_2 generation. Both parents are heterozygous (*Gg*) for the seed color gene. Each therefore produces some gametes carrying the *G* allele and some gametes carrying *g*. All three possible genotypes may therefore appear in the F_2 generation, in the ratio 1 *GG* : 2 *Gg* : 1 *gg*. The corresponding phenotypic ratio is three yellow seeds to one green seed, or 3:1. Mendel saw similar results for all seven traits that he studied (figure 10.7).

Figure 10.6 Punnett Square. This diagram depicts a cross between two heterozygous plants grown from yellow seeds (*Gg*). The two possible types of female gametes are listed along the top of the square; the male gametes are listed on the left-hand side. The four compartments within the Punnett square contain the genotypes and phenotypes of all possible offspring.

Activity One-Gene Punnett Square

Figure It Out

If Mendel mated a true-breeding tall plant with a heterozygous tall plant, what percent of the offspring would also be tall?

Mendel could tally the plants with each phenotype, but he also needed to keep track of each genotype. He knew that the green-seeded plants were always homozygous recessive (*gg*).

Trait	Dominant allele	Recessive allele
Seed color	Yellow (G)	Green (g)
Seed form	Round (R)	Wrinkled (r)
Pod color	Green (D)	Yellow (d)
Pod form	Inflated (V)	Constricted (v)
Flower color	Purple (P)	White (p)
Flower position	Axial (A)	Terminal (a)
Stem length	Tall (L)	Short (l)

Figure 10.7 Pea Traits. Mendel's breeding studies helped him to deduce the inheritance patterns of these seven pea plant characteristics.

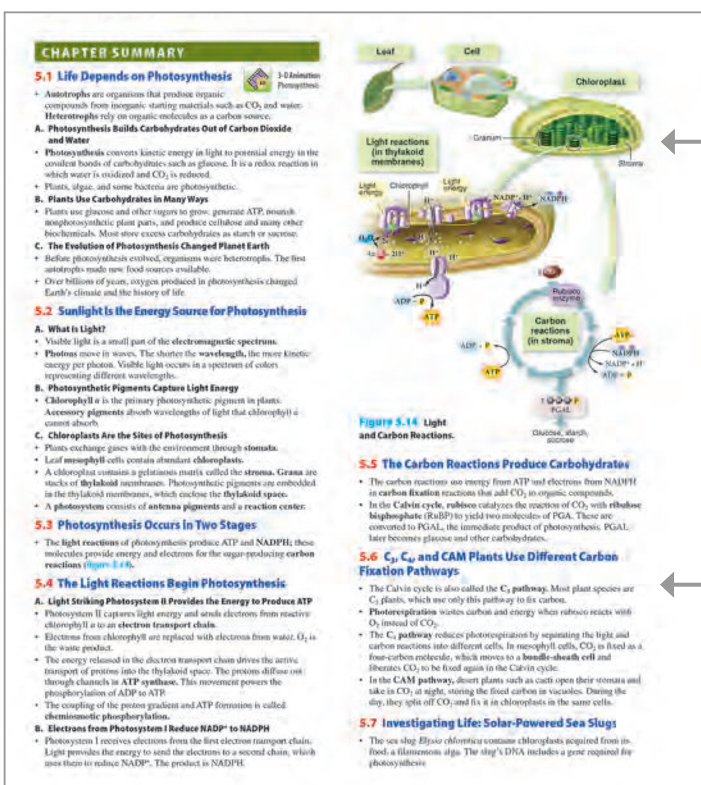
Investigating Life describes a real experiment focusing on an evolutionary topic related to each chapter's content.

Each case concludes with critical thinking questions that can be used as an in-class group activity. The studies touch on concepts found in other units; you can encourage students to draw a concept map illustrating the relationships between ideas. You might also use the case as a basis for discussion of the nature of science.

This edition offers Connect interactive and test bank questions focused on the Investigating Life cases. Questions assess students' understanding of the science behind the Investigating Life case and their ability to integrate those concepts with information from other units.

New summary figures emphasize the relationships among topics in the chapter.

These figures consist of "big-picture" combinations of art from the chapter.



The Chapter Summary highlights key points and terminology from the chapter.

Write It Out and Mastering Concepts questions are useful for student review or as short in-class writing assignments.

I compile them into a list of *Guided Reading Questions* that help students focus on material I cover in class. I also use them as discussion questions in Action Centers, where students can come for additional help with course material.


5.3 Photosynthesis Occurs in Two Stages

5.3 MASTERING CONCEPTS

1. What happens in each of the two main stages of photosynthesis?
2. Explain the role of each of the products of the light reactions and the carbon reactions.

BurningQuestion

Why do leaves change colors in the fall?

Burning Questions cover topics that students wonder about.

I ask my students to write down a Burning Question on the first day of class. I answer all of them during the semester, whenever a relevant topic comes up in class.

Figure It Out questions reinforce chapter concepts and typically have numeric answers (supporting student math skills).

Students can work on these in small groups, in class, or in Action Center. Most could easily be used as clicker questions as well.

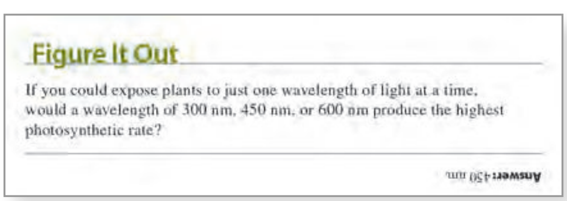


Figure It Out

If you could expose plants to just one wavelength of light at a time, would a wavelength of 300 nm, 450 nm, or 600 nm produce the highest photosynthetic rate?

Answer: 450 nm.

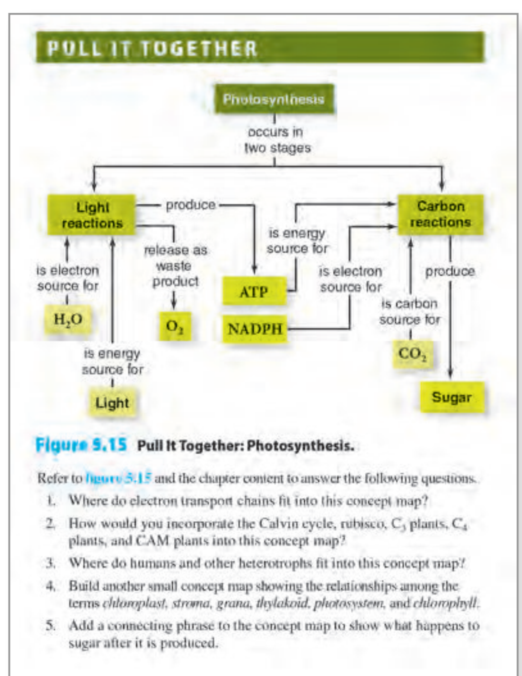

PULL IT TOGETHER

Figure 5.15 Pull It Together: Photosynthesis.

Refer to figure 5.15 and the chapter content to answer the following questions.

1. Where do electron transport chains fit into this concept map?
2. How would you incorporate the Calvin cycle, rubisco, C_3 plants, C_4 plants, and CAM plants into this concept map?
3. Where do humans and other heterotrophs fit into this concept map?
4. Build another small concept map showing the relationships among the terms *chloroplast, stroma, grana, thylakoid, photosystem,* and *chlorophyll*.
5. Add a connecting phrase to the concept map to show what happens to sugar after it is produced.

Pull It Together concept maps help students see the big picture.

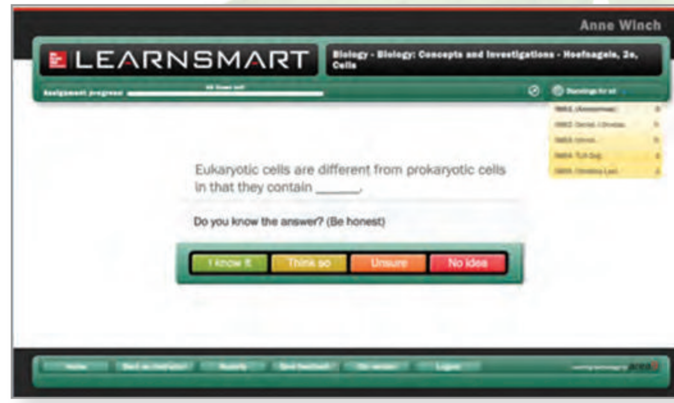
After spending class time discussing the key points in constructing concept maps, I have my students draw concept maps of their own.

Author's Guide *To Using Digital Tools*

McGraw-Hill LearnSmart® is a popular tool that helps students learn material ahead of class and practice with it afterward.

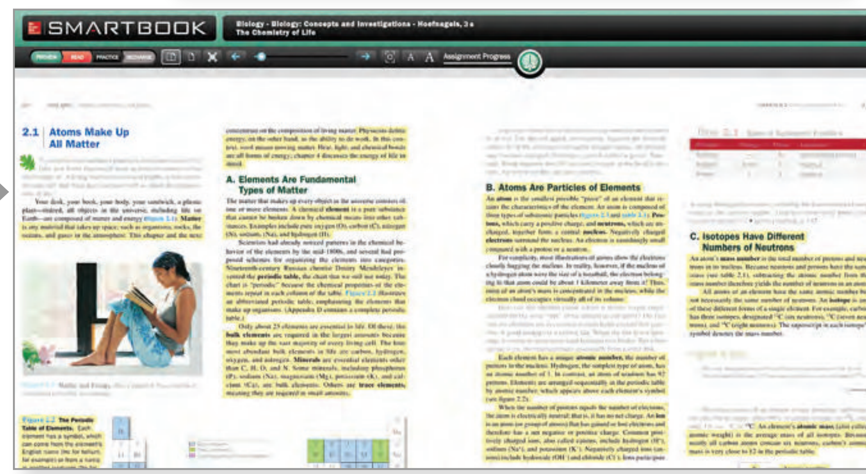
I assign LearnSmart before each week's lectures and let my students practice with it all they want throughout the semester. You can assign any sections you want and adjust the amount of detail depending on how much time you expect students to spend on the assignment.

Reports show which topics students struggled with, so your in-class time can be spent more productively.



New SmartBook™ measures what students know and then highlights the content they most need to study.

SmartBook predicts when students are likely to forget specific information and revisits that content to promote long-term memory.



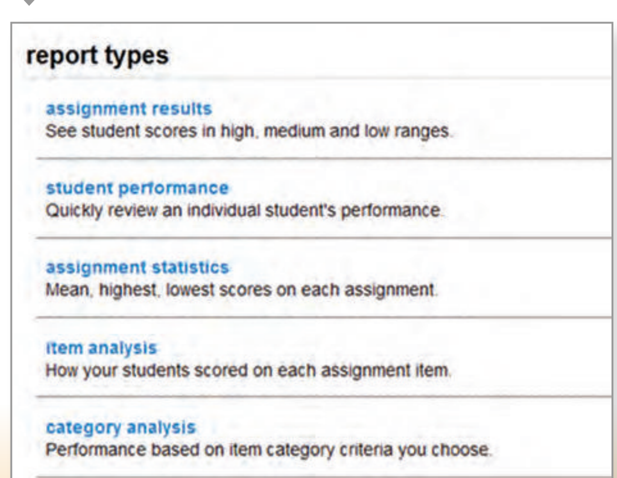
McGraw-Hill Connect® question banks contain integrative activities that can be sorted by Bloom's Level, Topic, Section, or Learning Outcome.

I assign Connect homework assignments using interactive questions before each exam.

This edition features new question banks that integrate content from each chapter in the unit and between units.

Connect reports reveal which topics need additional review prior to the exam.

Reports can help assess overall class performance or data for a specific student, using several different criteria.



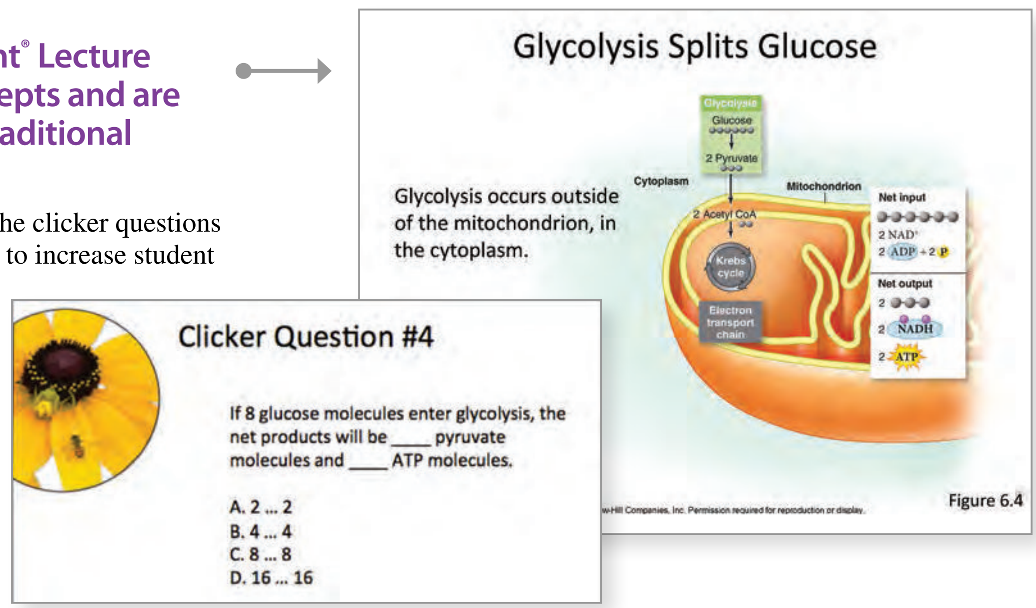
You can use McGraw-Hill Tegrity® to record your lectures and make them available to students in Connect as a first step to learning your content or as review.

Whether your course is traditional, fully online, or a hybrid, your students can access your content when it works for them.

Students can search your lecture by key term and go right to that point in your lecture to review.

New customizable PowerPoint® Lecture Outlines are focused on concepts and are useful for online, hybrid, or traditional courses.

I use clickers in my course, and I find the clicker questions in the PowerPoints® to be a handy way to increase student engagement and assess where I need to spend more time.



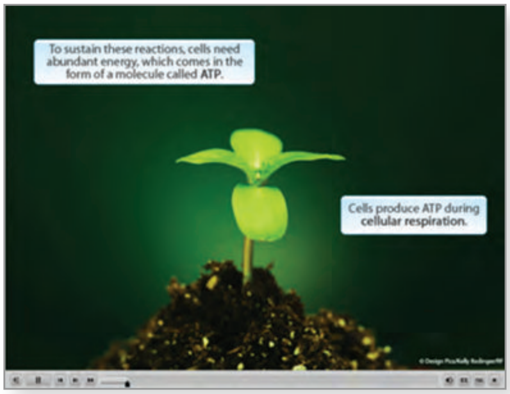
Use McGraw-Hill Create™ to develop course material that matches what you do in the classroom.

Create lets you select the chapters you want to use, arrange them to follow your syllabus, combine material from other sources, and upload your own notes.

You can choose the delivery method that best suits you and the students you teach.

http://create.mcgraw-hill.com

Animated tutorials guide students through complicated topics, using illustrations and examples from the book.



I created these to walk students through the most difficult material, step by step. You can assign the tutorials with accompanying critical thinking questions from the interactive question banks, or use the embedded PowerPoint® files in your presentations.

Your students can review the tutorials through the eBook or by using the media tab in Connect. Topics include

Organization of Life
Scientific Method and Interpreting a Graph
Chemical Bonding
Dehydration Synthesis and Hydrolysis
Anatomy of a Cell Membrane
ATP
Enzymes
Reaction Energetics
Osmosis
Cell Structure
Overview of Photosynthesis
Light Reactions
The Calvin Cycle
Overview of Respiration
Mitochondrial Electron Transport Chain
Fermentation
Protein Structure
Protein Synthesis
Overview of DNA Replication
Stages of Mitosis
Stages of Meiosis
Comparison of Mitosis and Meiosis
Crossing Over
Nondisjunction
Homologous Chromosomes
Constructing and Interpreting a Punnett Square
DNA Profiling
Mechanisms of Evolution
Genetic Variation: The Basis of Natural Selection
Understanding the Hardy–Weinberg Equation
Evidence for Evolution
Evidence for Human Evolution
Radiometric Dating
Reading an Evolutionary Tree
Origin of Life
Endosymbiont Theory
Viral Replication
Lytic and Lysogenic Cycles
Replication of HIV
Prokaryote Diversity
Protist Diversity
Plant Diversity
Moss Reproductive Cycle
Fern Reproductive Cycle
Conifer Reproductive Cycle
Sexual Reproduction in Angiosperms
Basidiomycete Reproductive Cycle
Diversity of Fungi
Animal Diversity
Overview of Plant Tissues
Phloem Sap Transport
Water Movement Through the Xylem
Alternation of Generations
Fruit Development
Overview of Animal Tissues
Organ System Interactions
Example of Negative Feedback
Action Potential
The Synapse
Overview of the Senses
Sense of Vision
Sense of Hearing
Cell Responses to Hormones
Role of ATP in Muscle Contraction
The Heartbeat
Respiratory Surfaces
Digestion and Food Molecules
Nephron Function
Adaptive Immunity
Allergies
Oogenesis
Human Male and Female Reproductive Systems
Ovarian and Menstrual Cycles
Proximate and Ultimate Behaviors
Population Growth Models
Biomagnification
Water Cycle
Nitrogen Cycle
Phosphorus Cycle
Carbon Cycle
Earth's Climate and Biomes
CO_2 and Earth's Average Temperature
Threats to Biodiversity

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It takes an army of people to make a textbook, and while I don't work with everyone directly, I greatly appreciate the contributions of each person who makes it possible.

Matt Taylor has worked alongside me at every stage, from first draft to finished product; in addition, he has seamlessly integrated the book's approach into our digital assets. His careful work and insights are invaluable.

I appreciate the help of my colleagues at the University of Oklahoma, including Doug Gaffin, Ben Holt, Sharon Kessler, Heather Ketchum, Edie Marsh-Matthews, Heather McCarthy, Ingo Schlupp, and Mark Walvoord. Helpful colleagues from other institutions include Kimberly Demnicki, Pete Ducey, Paul Graham, Leslie Jones, and Tony Stancampiano.

I am grateful to several OU students. Caleb Cosper and Emily North have scrutinized art and narrative with good humor and a gentle touch. Rachel Hunter analyzed page layouts early on, and conversations with students in my classes spark many good ideas.

My team at McGraw-Hill is wonderful. Thank you to Michael Hackett for his guidance and friendship. Lynn Breithaupt, a recent addition to the team, has been supportive in many ways. I admire Eric Weber for his devotion to creating quality products that really help students learn. Anne Winch has an amazing ability to juggle many tasks, all while remaining both responsive and funny. Chris Loewenberg contributes energy and great ideas to the marketing side. Sheila Frank keeps the production team moving forward with enviable skill, and I appreciate designer Michelle Whitaker's support and eye for detail. Emily Tietz and John Leland provide outstanding service in photo selections. Christine Foushi is my software lifeline. Jane Peden has made life easier in countless ways. Finally, I appreciate my friends Michael Lange (now retired) and Patrick Reidy, without whom I would not be writing textbooks at all.

Electronic Publishing Services, Inc., produced the art and composed the beautiful page layouts. I appreciate their artistic talent and creative ideas for integrating the narrative with the illustrations and remain in awe of their ability to turn my rough sketches into new art.

My family and friends continue to encourage me. Thank you to my parents and sister for their pride and support. I also thank my friends Nicole Campbell, Kelly Damphousse, Ben and Angie Holt, Karen and Bruce Renfroe, Ingo and Andrea Schlupp, Clarke and Robin Stroud, Matt Taylor and Elise Knowlton, and Mark Walvoord. Sidecar the cat occasionally stops in at the office as well. Finally, my husband Doug Gaffin is always there for me, helping in countless large and small ways. I could not do this work without him.

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Angelo State University
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University of Mary Washington
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Robert R. Wise
University of Wisconsin–Oshkosh
Kimberly Zahn
Thomas Nelson Community College
Martin Zahn
Thomas Nelson Community College
Ted Zerucha
Appalachian State University

Changes by Chapter

UNIT 1 Science. Chemistry, and Cells

- **Chapter 1 (The Scientific Study of Life):** Broadened the focus of the chapter-opening essay to better illustrate the scope of biology; added illustration for homeostasis; clarified explanation of how to write a scientific name; improved descriptions of terms related to the process of science, such as how predictions follow from hypotheses and the distinction between facts and theories.
- **Chapter 2 (The Chemistry of Life):** Wrote new chapter-opening essay on chemical defenses; added new illustrations of isotopes, electronegativity trends, adhesion and cohesion, functional groups, diverse protein shapes and functions, and denaturation; added more everyday examples; responded to student requests to simplify several paragraphs and rearrange section subheadings; added new Investigating Life on aphids that change color.
- **Chapter 3 (Cells):** Added table to explain cell theory and figures to depict cell similarities, improved cell membrane figure to show selective permeability, added sterols to plant cell membranes, added new illustration showing free and membrane-bound ribosomes, created new Investigating Life piece on bacteria that detect magnetic fields.
- **Chapter 4 (The Energy of Life):** Added new figure showing how the cell uses ATP, included an analogy of oxidation–reduction in narrative and art; improved figures to connect activation energy with enzyme action, brought examples of enzyme inhibitors closer to the passage on negative feedback, added table that compares and contrasts different forms of membrane transport.
- **Chapter 5 (Photosynthesis):** Modified some headings to improve clarity of main ideas, added new Figure It Out, added a table to clarify that photosynthesis occurs in bacteria and eukaryotes, improved illustration and description of photosystem structure and pigments, improved explanation in the box on why leaves change color in the fall, added illustration in Apply It Now box showing where herbicides block photosynthesis, improved the illustration of C_3 and C_4 leaves.
- **Chapter 6 (How Cells Release Energy):** Clarified that all cells need ATP and that aerobic cellular respiration is extremely common in eukaryotes, bacteria, and archaea; named and labeled the "transition step" throughout the chapter's figures; improved explanation of and added a summary figure depicting substrate-level phosphorylation; added a Figure It Out question on fat metabolism; debunked the myth that lactic acid causes delayed muscle soreness; reworked figure summarizing the main energy pathways; explained evolutionary significance of chloroplasts' and mitochondria's double membranes.

UNIT 2 DNA, Inheritance, and Biotechnology

- **Chapter 7 (DNA Structure and Gene Function):** Reworked the chapter opening essay to acknowledge that the Human Genome Project is "old news," yet its implications reach far into the future; streamlined section 7.2; added a figure illustrating the relationships among cells, chromosomes, DNA, and genes; introduced epigenetics; reworked the section on mutations to improve clarity; moved biotechnology content to a new chapter (chapter 11).
- **Chapter 8 (DNA Replication, Binary Fission, and Mitosis):** Wrote new chapter opening essay on gigantism and dwarfism, added binary fission; clarified number of chromosomes in figures throughout chapter, improved explanation of the participants in DNA replication, added a new figure showing origins of replication, clarified the distinction between "chromatin" and "chromosome" in the figure showing DNA packing, added figure on ethnicity and breast cancer mutations, added photo of syndactyly to the apoptosis figure, moved biotechnology content to a new chapter (chapter 11).
- **Chapter 9 (Sexual Reproduction and Meiosis):** Clarified number of chromosomes in figures throughout chapter, reworked nondisjunction figure to improve separation between meiosis and fertilization, added Figure It Out to reinforce the "reduction" function of meiosis, wrote new Investigating Life piece on how sexual reproduction is adaptive in an environment containing evolving parasites.
- **Chapter 10 (Patterns of Inheritance):** Changed upper- and lower-case letters to be more easily distinguishable from one another throughout art, improved context of many figures to enhance clarity, added two new Figure It Out questions in the section on linked genes and chromosome mapping, reworked figures illustrating pleiotropy and epistasis, added a new Burning Question box on obesity and epigenetics, developed new figure on X chromosome inactivation and Rett syndrome, replaced all genetics problems in end of chapter materials, modified "How to Solve a Genetics Problem" to add a labeled section for the product rule.
- **Chapter 11 (DNA Technology):** This new chapter contains parts of chapters 7 and 8 from the second edition, with new content added on DNA probes, preimplantation genetic diagnosis, genetic testing for disease, gene therapy, and ethical issues surrounding the medical use of DNA technology; revised content on DNA profiling, stem cells, and cloning; added boxed readings on gene doping and genetic engineering.

UNIT 3 The Evolution of Life

- **Chapter 12 (The Forces of Evolutionary Change):** Added introductory section introducing the concepts of population, gene pool, and allele frequencies; refuted the misconception of evolution as being "need-based"; explained the distinction between artificial selection and human-influenced natural selection; reworked Hardy–Weinberg section for simplicity and clarity; updated Investigating Life piece on fish harvesting experiment.
- **Chapter 13 (Evidence of Evolution):** Revised geologic time scale figure to add information and improve accuracy; added examples of convergent evolution in plants; added art showing how homeotic genes control limb development in chicks and pythons; rearranged section on molecular evidence to place all DNA evidence together; revised other art for clarity; moved Investigating Life on *Tiktaalik* and *Najash* fossils to this chapter, to better illustrate how scientists study evolutionary transitions.

- **Chapter 14 (Speciation and Extinction):** Reworked multiple figures for clarity, added figure illustrating similarities between species that share a taxonomic level, added Burning Question on watching speciation and evolution in action, expanded Apply It Now box to include data on vertebrate and plant extinctions, updated data in Investigating Life section.
- **Chapter 15 (The Origin and History of Life):** Moved figure summarizing origin of life earlier in the chapter, so it serves as an advance organizer; added figures on the accumulation of O_2 in the atmosphere and on secondary endosymbiosis; reworked figure on membrane infolding; added Burning Question explaining why mitochondria and chloroplasts cannot live independently; created new Investigating Life on human genetic diversity within and between continents.

UNIT 4 The Diversity of Life

- **Chapter 16 (Viruses):** Added a figure comparing a virus, a bacterial cell, and a eukaryotic cell; improved viral replication and HIV figures for accuracy and clarity; revised Apply It Now box on anti-HIV drugs to incorporate new research on coreceptors, gene therapy, and stem cells; expanded Burning Question to explain that HPV is associated with mouth and throat cancers in men.
- **Chapter 17 (Bacteria and Archaea):** Added figure comparing archaea and bacteria, added figure comparing gram-negative and gram-positive cells, added figure illustrating examples of anaerobic and aerobic habitats, reworked horizontal gene transfer figure for clarity and to make it more explanatory, expanded Apply It Now box to explain what ordinary people can do to prevent the spread of antibiotic-resistant bacteria, moved figure and description of binary fission to chapter 8 (DNA Replication, Binary Fission, and Mitosis), mentioned the microbes that helped clean up after the Deepwater Horizon blowout in 2010.
- **Chapter 18 (Protists):** Improved illustration showing primary and secondary endosymbiosis, improved explanation of eukaryotic "supergroups" with changes to the narrative and an updated table, added new Investigating Life piece on bioluminescent dinoflagellates.
- **Chapter 19 (Plants):** Rearranged the description of the bryophyte life cycle to correspond better to the step numbers in the figure, reworked step numbers in the gymnosperm and angiosperm life cycles to begin with the most familiar part (the mature tree), added to the list of destinations for corn in the Apply It Now box.
- **Chapter 20 (Fungi):** Added illustration to show the difference between haploid, dikaryotic, and diploid cells; reworked Pull It Together to provide more information about spore and hypha types.
- **Chapter 21 (Animals):** Added chapter opener describing possible causes of the Cambrian explosion; reworked phylogenetic trees to eliminate confusion between the name of each group and its list of characteristics; reworked taxon-specific art to follow a uniform format, including evolutionary trees showing key features and a consistent set of information relevant to each group; reworked the narrative to emphasize how the environment selects for each group's adaptations; combined hagfishes and lampreys into one section; expanded coverage of fishes, including the versatility of the jaw and the evolution of limbs from fins; created new Investigating Life on the evolution of genes contributing to complex body plans in the Cambrian explosion.

UNIT 5 Plant Life

- **Chapter 22 (Plant Form and Function):** Added illustration comparing woody and herbaceous plants; added photos and reworked figures showing modified stems, leaves, and roots; added cross section of monocot leaf for comparison to the eudicot leaf; rearranged chapter to improve the transition from primary to secondary growth; added inset for intercalary meristem to figure illustrating meristems; added rays to illustrations of secondary growth; added whole tree for context to wood anatomy figure.
- **Chapter 23 (Plant Nutrition and Transport):** Clarified explanation and illustration of changes in guard cells as stomata open and close; rearranged section on xylem transport, creating a new section explaining water movement into roots; improved illustration of aphids feeding on phloem; reworked illustration in Investigating Life section to improve connection between treatments and results.
- **Chapter 24 (Reproduction and Development of Flowering Plants):** Added illustrations of asexual reproduction and grafting; clarified figure depicting angiosperm life cycle; improved explanations of seed dormancy, fruit functions, and seed dispersal; clarified why cotyledons are called "seed leaves"; clarified the role of abscisic acid; reworked illustration of phytochrome to make its action less abstract; distinguished among annual, biennial, and perennial plants.

UNIT 6 Animal Life

- **Chapter 25 (Animal Tissues and Organ Systems):** Updated statistics for organ transplantation, improved illustration of anatomical terms, added interstitial fluid and clarified role of urinary system in illustration of organ system interactions, clarified explanations of negative and positive feedback, reworked Investigating Life to clarify the vitamin D/folic acid tradeoff.
- **Chapter 26 (The Nervous System):** Created new chapter opener on concussions, improved illustration of interacting neuron types, added illustration of simplified action potential, improved explanation and illustration of reflex arc, expanded Burning Question box to include honey bee venom, clarified illustration of sympathetic and parasympathetic divisions of the nervous system, clarified distinction between structural and functional regions of the cerebrum, added illustration of blood-brain barrier.
- **Chapter 27 (The Senses):** Clarified the roles of the senses beyond maintaining homeostasis, improved connection between each sense and relevant brain regions, clarified illustration of sensory receptors in skin, clarified location of photoreceptor cells in octopus eye, clarified and simplified illustration of the path of light in the retina, simplified terminology in describing path from eyes to primary visual cortex, reworked and clarified Apply It Now box on correcting vision, added illustration of "unrolled" cochlea to show how the ear perceives sounds of different frequencies, clarified function of the vestibular apparatus, created new Investigating Life on pain perception in naked mole rats.

- **Chapter 28 (The Endocrine System):** Created new chapter-opening essay on stress hormones, clarified the distinction between types of water-soluble hormones, added information on how cells can alter their sensitivity to particular hormones, clarified description of hormone-induced signaling cascade, improved illustration of hormones of the hypothalamus and pituitary, clarified role of prolactin, simplified figure of adrenal hormones, clarified the explanation of the use of epinephrine injections in severe allergic reactions, improved illustration of pancreas, updated data on obesity and diabetes, added information about gastric bypass surgery and type 2 diabetes, added Investigating Life on antidiuretic hormone and pair-bonding.
- **Chapter 29 (The Skeletal and Muscular Systems):** Created new chapter opener on prosthetic limbs, improved illustrations of hydrostatic skeleton and scoliosis, clarified description of bone marrow, simplified description and illustration of bone anatomy, improved explanation of role of compact bone, clarified role of estrogen in osteoporosis, improved illustration of interaction between motor neurons and muscle cells, added figure illustrating fast- and slow-twitch muscles, added Burning Question on why heat soothes sore muscles.
- **Chapter 30 (The Circulatory System):** Added Burning Question on bruises; simplified illustration of heart anatomy; improved illustrations and descriptions of open circulatory system, valves in veins, electrical changes during the heartbeat, capillary beds, how skeletal muscles drive blood flow in veins, blood pressure measurement, and lymphatic system; simplified illustration comparing blood pressure, blood velocity, and vessel cross-sectional area.
- **Chapter 31 (The Respiratory System):** Clarified the relationship between the concentration gradient and the rate of gas exchange; improved illustration of diversity in respiratory systems; improved connection between circulatory system and respiratory system evolution in vertebrates; clarified illustrations of breathing in frogs, birds, and humans; improved illustration comparing composition of inhaled and exhaled air; clarified illustration of hemoglobin.
- **Chapter 32 (Digestion and Nutrition):** Created new chapter-opening essay on gut microbes, added figure summarizing the stages of acquiring and using food, improved figure showing where food molecules are digested, added content on the treatment of eating disorders, created Investigating Life on phenotypic plasticity of gut length in tadpoles.
- **Chapter 33 (Regulation of Temperature and Body Fluids):** Improved figure comparing ectotherms and endotherms; clarified figure illustrating nitrogenous wastes; improved figures of urinary system anatomy and nephron function; added information about diabetes, high blood pressure, and kidney damage to Apply It Now box.
- **Chapter 34 (The Immune System):** Improved illustrations of immune system anatomy, white blood cells, and clonal selection; added figures comparing innate and acquired immunity and summarizing innate immune defenses; simplified presentation of MHC proteins; clarified how humoral and cell-mediated immunity are activated; added box on tick-transmitted meat allergies.
- **Chapter 35 (Animal Reproduction and Development):** Clarified passage on oogenesis, added figures for hormonal interactions in males and females, reworked table on contraception to show how each method works, added Burning Question box on the fertility awareness method of birth control, added information about the HPV vaccine for females and males, added cervical cancer to the table of STDs, simplified figure on fertilization, improved table summarizing development, added customized timescales to all figures illustrating development, clarified figure on extraembryonic membranes and the placenta, added Investigating Life on sexual cannibalism in spiders.

UNIT 7 The Ecology of Life

- **Chapter 36 (Animal Behavior):** Reworked introductory section around a specific example (dung beetles), clarified numerous illustrations, reworked description of how animals find specific locations, added photos of bird courtship rituals.
- **Chapter 37 (Populations):** Added illustration to reinforce the distinctions among organism, population, community, and ecosystem; improved illustrations of exponential growth, logistic growth, density-dependent and density-independent limits, opportunistic vs. equilibrium species, and the demographic transition; reworked the Figure It Out questions on exponential and logistic population growth; clarified the discussion of survivorship curves; updated information on the human population; added Investigating Life on the effect of acidic cave habitats on life history evolution in Atlantic mollies.
- **Chapter 38 (Communities and Ecosystems):** Reworked narrative and illustrations for competitive exclusion, coevolution, community diversity, biomagnification, and eutrophication; reworked Burning Question box to emphasize human missions to Mars; improved distinction between scavengers and decomposers; moved keystone species after section on food webs; improved appearance of trophic pyramids; brightened colors for water/nutrient cycles and added step numbers.
- **Chapter 39 (Biomes):** Revised chapter-opening essay to emphasize the importance of the discovery of deep-sea hydrothermal vents; clarified definition of "biome," added Burning Question about research into past climates, added image showing bands of temperature from the equator to the poles; improved rain shadow illustration, labeled biome "mini-maps" to eliminate ambiguity, reworked figure showing the distribution of global water resources, created new Investigating Life on species shifts from biome to biome.
- **Chapter 40 (Preserving Biodiversity):** Revised chapter-opening essay to focus on additional threats to the Everglades ecosystem, revised sections on habitat destruction and water pollution, promoted global climate change to its own major heading, updated data on CO_2 accumulation and global average temperature, added figure showing global warming-induced melting of Arctic ice, updated numbers of threatened and invasive species in the United States, added Investigating Life on the relationship between elevated temperatures and genetic diversity in chipmunks at Yosemite National Park.

Contents

BIOLOGY

Concepts and Investigations

CHAPTER

1 The Scientific Study of Life

Stingray Squadron. Golden cownose rays cruise coastal waters near Santa Cruz Island, one of the Galápagos Islands off the coast of Ecuador.

UNIT 1

Life Is Everywhere

WELCOME TO BIOLOGY, THE SCIENTIFIC STUDY OF LIFE. Living organisms surround us. You are alive, and so are your friends, your pets, and the plants in your home and yard. Bacteria thrive on and in your body. Any food you ate today was (until recently, anyway) alive. And the news is full of biology-related discoveries about fossils, new cancer treatments, genetics, global climate change, and the environment.

Stories such as these enjoy frequent media coverage because this is an exciting time to study biology. Not only is the field changing rapidly, but its new discoveries and applications might change your life. DNA technology has brought us genetically engineered bacteria that can manufacture life-saving drugs—and genetically engineered plants that produce their own pesticides. This same technology may one day enable physicians to routinely cure hemophilia, cystic fibrosis, and other genetic diseases by replacing faulty DNA with a functional "patch."

Biology also includes the study of nonhuman life. We exist only because of our interactions with other species, which provide food, oxygen, clean water, clothing, shelter, and other necessities. Even species that do not directly "serve" us are essential to the ecosystems that sustain all life. Human activities, however, are pushing many ecosystems dangerously out of balance.

Consider the stingrays pictured on the facing page. These oddly shaped fish consume shellfish in shallow coastal waters. In waters near Ecuador's Galápagos Islands, overfishing and habitat destruction are causing stingray populations to decline. But the opposite problem affects the east coast of the United States. There, other stingray species are exploding as sharks—their natural predators—disappear. Schools of hungry rays devastate oyster beds and crab fisheries, with far-reaching consequences not only to coastal ecosystems but also to the economy.

The list of biology-related topics goes on and on: global climate change, stem cell therapies, infectious disease, improved crop plants, synthetic life, infertility treatment, endangered species, DNA fingerprinting, biofuels, pollution, the history of life, and more. This book will bring you a taste of what we know about life and help you make sense of the science-related news you see every day. Chapter 1 begins your journey by introducing the scope of biology and explaining how science teaches us what we know about life.

LEARNING OUTLINE

LEARN HOW TO LEARN
Real Learning Takes Time

You got good at basketball, running, dancing, art, music, or video games by putting in lots of practice. Likewise, you will need to commit time to your biology course if you hope to do well. To get started, look for the "Learn How to Learn" tip in each chapter of this textbook. Each hint is designed to help you use your study time productively.

1.1 What Is Life?

Biology is the scientific study of life. The second half of this chapter explores the meaning of the term *scientific,* but first we will consider the question, "What is life?" We all have an intuitive sense of what life is. If we see a rabbit on a rock, we know that the rabbit is alive and the rock is not. But it is difficult to state just what makes the rabbit alive. Likewise, in the instant after an individual dies, we may wonder what invisible essence has transformed the living into the dead.

One way to define life is to list its basic components. The **cell** is the basic unit of life; every **organism,** or living individual, consists of one or more cells. Every cell has an outer membrane that separates it from its surroundings. This membrane encloses the water and other chemicals that carry out the cell's functions. One of those biochemicals, deoxyribonucleic acid (DNA), is the informational molecule of life (figure 1.1). Cells use genetic instructions—as encoded in DNA—to produce proteins, which enable cells to carry out specialized functions in tissues, organs, and organ systems.

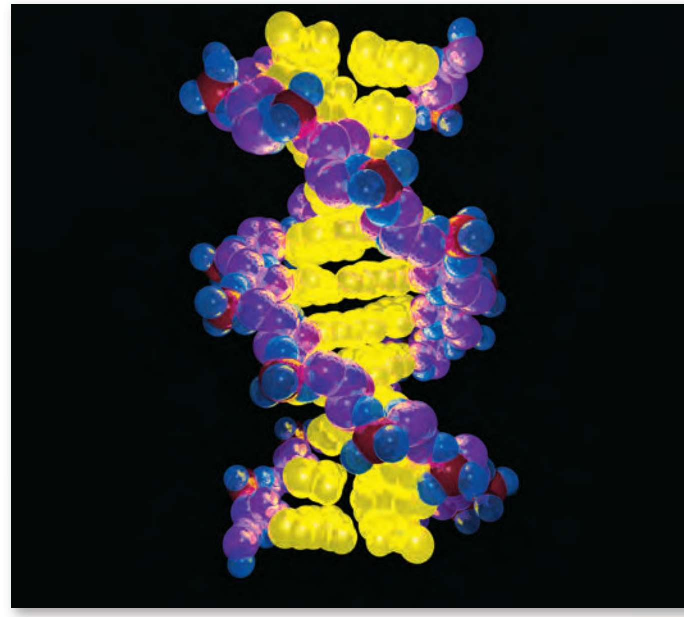


Figure 1.1 Informational Molecule of Life. All cells contain DNA, a series of "recipes" for proteins that each cell can make.

A list of life's biochemicals, however, provides an unsatisfying definition of life. After all, placing DNA, water, proteins, and a membrane in a test tube does not create artificial life. And a crushed insect still contains all of the biochemicals that it had immediately before it died.

In the absence of a concise definition, scientists have settled on five qualities that, in combination, constitute life (table 1.1). An organism is a collection of structures that function together and exhibit all of these qualities. Note, however, that each of the traits listed in table 1.1 may also occur in nonliving objects. A rock crystal is highly organized, but it is not alive. A fork placed in a pot of boiling water absorbs heat energy and passes it to the hand that grabs it, but this does not make the fork alive. A fire can "reproduce" and grow very rapidly, but it lacks most of the other characteristics of life. It is the *combination* of these five characteristics that makes life unique.

A. Life Is Organized

Tutorial Organization of Life

Just as the city where you live belongs to a county, state, and nation, living matter also consists of parts organized in a hierarchical pattern (figure 1.2). At the smallest scale, all living structures are composed of particles called **atoms,** which bond together to form **molecules.** These molecules are often grouped into **organelles,** which are compartments that carry out specialized functions in cells (note that not all cells contain organelles). Many organisms consist of single cells. In multicellular organisms (such as the tree illustrated in figure 1.2), however, the cells are organized into specialized **tissues** that make up **organs.** Multiple organs are linked into an individual's **organ systems.**

We have now reached the level of the organism, which may consist of just one cell or of many cells organized into tissues, organs, and organ systems. Organization in the living world extends beyond the level of the individual organism as well. A **population** includes members of the same species occupying the same place at the same time. A **community** includes the populations of different species in a region, and an **ecosystem** includes both the living and nonliving components of an area. Finally, the **biosphere** refers to all parts of the planet that can support life.

Biological organization is apparent in all life. Humans, eels, and evergreens, although outwardly very different, are all organized into specialized cells, tissues, organs, and organ systems.

TABLE 1.1 Characteristics of Life: A Summary

Characteristic	Example
Organization	Atoms make up molecules, which make up cells, which make up tissues, and so on.
Energy use	A kitten uses the energy from its mother's milk to fuel its own growth.
Maintenance of internal constancy	Your kidneys regulate your body's water balance by adjusting the concentration of your urine.
Reproduction, growth, and development	An acorn germinates, develops into an oak seedling, and, at maturity, reproduces sexually to produce its own acorns.
Evolution	Increasing numbers of bacteria survive treatment with antibiotic drugs.

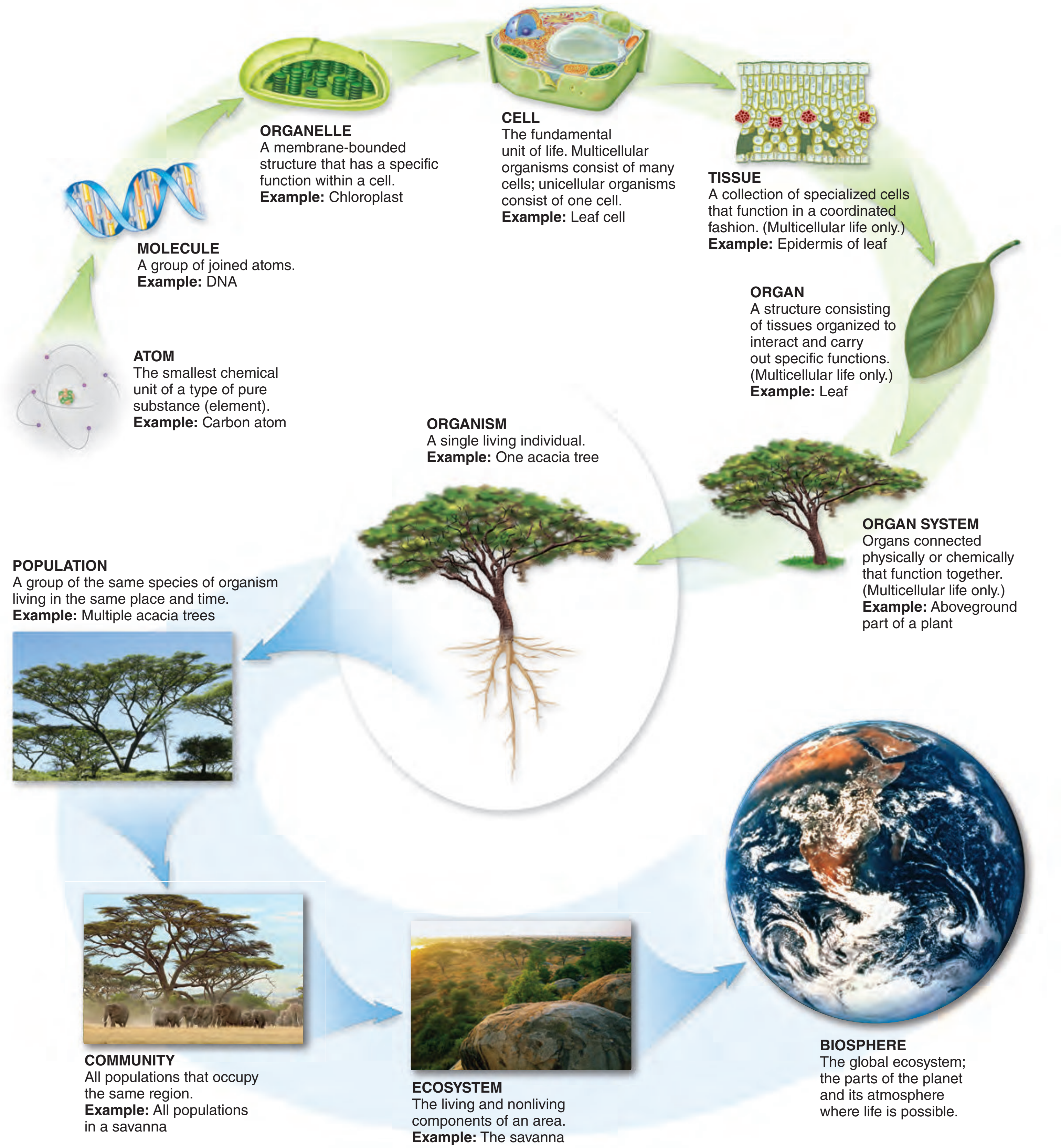


Figure 1.2 Life's Organizational Hierarchy. This diagram applies life's organizational hierarchy to a multicellular organism (an acacia tree). At the smallest level, atoms are arranged into molecules, which form organelles in the plant's cells. Multiple cells are organized into tissues, which make up organs and, in turn, organ systems. A population consists of individuals of the same species, and communities are multiple populations sharing the same space. Communities interact with the nonliving environment to form ecosystems, and the biosphere consists of all places on Earth where life occurs.

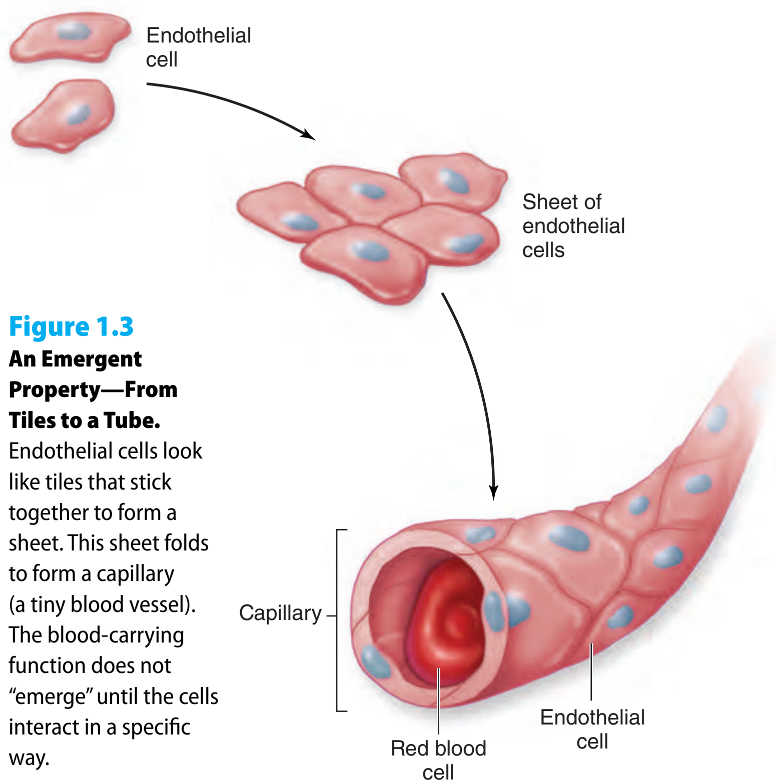


Figure 1.3 An Emergent Property—From Tiles to a Tube. Endothelial cells look like tiles that stick together to form a sheet. This sheet folds to form a capillary (a tiny blood vessel). The blood-carrying function does not "emerge" until the cells interact in a specific way.

Single-celled bacteria, although less complex than animals or plants, still contain DNA, proteins, and other molecules that interact in highly organized ways.

An organism, however, is more than a collection of successively smaller parts. When those components interact, they create new, complex functions called **emergent properties** (figure 1.3). These characteristics arise from physical and chemical interactions among a system's components, much as flour, sugar, butter, and chocolate can become brownies—something not evident from the parts themselves. For an emergent property, the whole is greater than the sum of the parts.

Emergent properties explain why structural organization is closely tied to function. Disrupt a structure, and its function ceases. Shaking a fertilized hen's egg, for instance, disturbs critical interactions and stops the embryo from developing. Likewise, if a function is interrupted, the corresponding structure eventually breaks down, much as unused muscles begin to waste away. Biological function and form are interdependent.

B. Life Requires Energy

Inside each living cell, countless chemical reactions sustain life. These reactions, collectively called metabolism, allow organisms to acquire and use energy and nutrients to build new structures, repair old ones, and reproduce.

Biologists divide organisms into broad categories, based on their source of energy and raw materials (figure 1.4). **Producers,** also called autotrophs, make their own food by extracting energy and nutrients from nonliving sources. The most familiar producers are the plants and microbes that capture light energy from the sun, but some bacteria can derive chemical energy from rocks. **Consumers,** in contrast, obtain energy and nutrients by eating other organisms, living or dead; consumers are also called heterotrophs. You are a consumer, relying on energy and atoms from food to stay alive. **Decomposers** are heterotrophs that obtain energy and nutrients from wastes or dead organisms. These organisms, which include fungi and some bacteria, recycle nutrients to the nonliving environment.

Within an ecosystem, organisms are linked into elaborate food webs, beginning with producers and continuing through several levels of consumers (including decomposers). Although atoms are continuously recycled, energy is not; instead, energy is lost as heat at every step (see figure 1.4). Because no organism can use heat as an energy source, it represents a permanent loss from the cycle of life. All ecosystems therefore depend on a continuous stream of energy from an outside source, usually the sun.

C. Life Maintains Internal Constancy

An important characteristic of life is the ability to sense and react to stimuli. The conditions inside cells must remain within a constant range, even if the surrounding environment changes. For

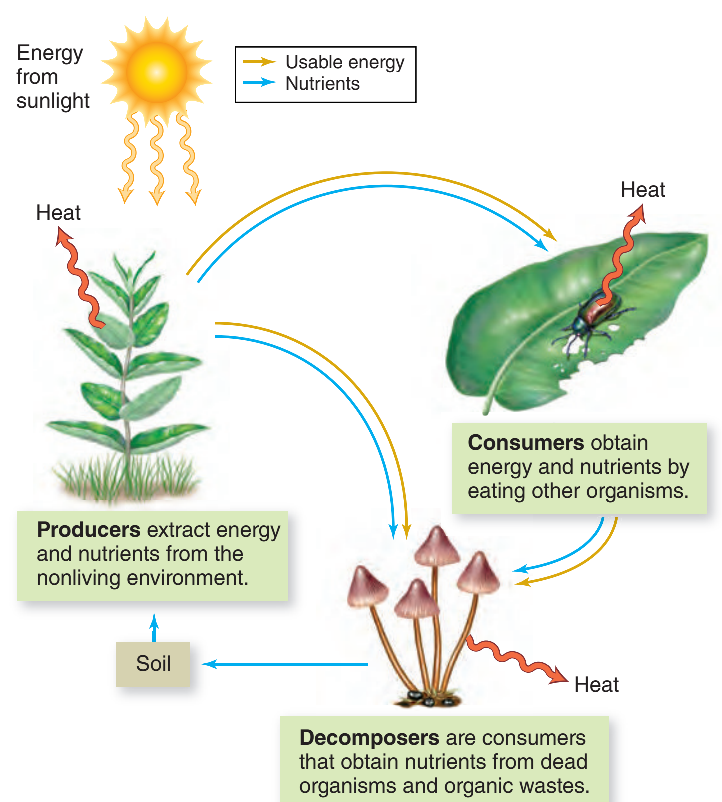


Figure 1.4 Life Is Connected. All organisms extract energy and nutrients from the nonliving environment or from other organisms. Decomposers recycle nutrients back to the nonliving environment. At every stage along the way, heat is lost to the system.

a. b.

Figure 1.5 Temperature Homeostasis. (a) Shivering and (b) sweating are responses that maintain body temperature within an optimal range.

example, a living cell must maintain a certain temperature—not too high and not too low. The cell must also take in nutrients, excrete wastes, and regulate its many chemical reactions to prevent a shortage or surplus of essential substances. **Homeostasis** is the process by which a cell or organism maintains this state of internal constancy, or equilibrium.

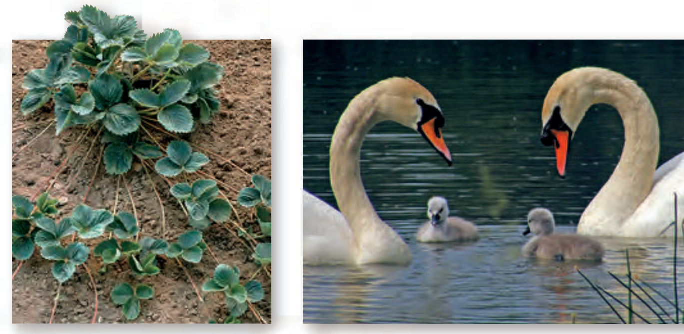
Your body, for example, has several mechanisms that maintain your internal temperature at about 37°C (figure 1.5). When you go outside on a cold day, you may begin to shiver; heat from these muscle movements warms the body. In severe cold, your lips and fingertips may turn blue as your circulatory system diverts blood away from your body's surface. Conversely, on a hot day, sweat evaporating from your skin helps cool your body.

D. Life Reproduces Itself, Grows, and Develops

Organisms reproduce, making other individuals that are similar to themselves (figure 1.6). Reproduction transmits DNA from generation to generation; this genetic information defines the inherited characteristics of the offspring.

Reproduction occurs in two basic ways: asexually and sexually. In **asexual reproduction,** genetic information comes from only one parent, and all offspring are virtually identical. One-celled organisms such as bacteria reproduce asexually by doubling and then dividing the contents of the cell. Many multicellular organisms also reproduce asexually. For example, a strawberry plant's "runners" sprout roots and leaves, forming new plantlets identical to the parent (figure 1.6a). The green, white, or black powder on moldy bread or cheese is made of the countless asexual spores of fungi. Some animals, including sponges, reproduce asexually when a fragment of the parent animal detaches and develops into a new individual.

In **sexual reproduction,** genetic material from two parent individuals unites to form an offspring, which has a new combination of inherited traits. By mixing genes at each generation, sexual reproduction results in tremendous diversity in a



a. b.

Figure 1.6 Asexual and Sexual Reproduction. (a) Identical plantlets develop along the runners of a wild strawberry plant. (b) Two swans protect their offspring, the products of sexual reproduction.

population. Genetic diversity, in turn, enhances the chance that some individuals will survive even if conditions change. Sexual reproduction is therefore a very successful strategy, especially in an environment where conditions change frequently; it is extremely common among plants and animals (figure 1.6b).

If each offspring is to reproduce, it must grow and develop to adulthood. Each young swan in figure 1.6b, for example, started as a single fertilized egg cell. That cell divided over and over, developing into an embryo. Continued cell division and specialization yielded the newly hatched swans, which will eventually mature into adults that can also reproduce—just like their parents.

Video Natural Selection

E. Life Evolves

One of the most intriguing questions in biology is how organisms become so well-suited to their environments. A beaver's enormous front teeth, which never stop growing, are ideal for gnawing wood. Tubular flowers have exactly the right shapes for the beaks of their hummingbird pollinators. Some organisms have color patterns that enable them to fade into the background (figure 1.7).

Figure 1.7 Hiding in Plain Sight. This pygmy seahorse is barely visible in its coral habitat, thanks to its unique body shape, skin color, and texture.

These examples, and countless others, illustrate adaptations. An **adaptation** is an inherited characteristic or behavior that enables an organism to survive and reproduce successfully in its environment.

Where do these adaptive traits come from? The answer lies in natural selection. The simplest way to think of natural selection is to consider two facts. First, resources such as food and habitat are limited, so populations produce many more offspring than will survive to reproduce. A single mature oak tree may release thousands of acorns in one season, but only a few are likely to germinate, develop, and reproduce. The rest die. Second, no organism is exactly the same as any other. Genetic mutations—changes in an organism's DNA sequence—generate variability in all organisms, even those that reproduce asexually.

Tutorial Variation and Natural Selection

Of all the offspring in a population, which will survive long enough to reproduce? The answer is those with the best adaptations to the current environment; poorly adapted organisms are most likely to die before reproducing. **Natural selection,** then, is a process in which individuals with certain inherited characteristics contribute more offspring to the next generation than do individuals lacking those characteristics (figure 1.8). That is, individuals with the best gene combinations survive and reproduce, while those with less suitable characteristics fail to do so. Over many generations, individuals with adaptive traits make up most or all of the population.

But the environment is constantly changing. Continents shift, sea levels rise and fall, climates warm and cool. What happens to a population when the selective forces that drive natural selection change? Only some organisms survive: those with the "best" traits in the *new* environment. Features that may once have been rare become more common as the reproductive success of individuals with those traits improves. Notice, however, that this outcome depends on variability within the population. If no individual can reproduce in the new environment, the species may go extinct.

Natural selection is one mechanism of **evolution,** which is a change in the genetic makeup of a population over multiple generations. Although evolution can also occur in other ways, natural selection is the mechanism that selects for adaptations. Charles Darwin became famous in the 1860s after the publication of his book *On the Origin of Species by Means of Natural Selection,* which introduced the theory of evolution by natural selection; another naturalist, Alfred Russel Wallace, independently developed the same idea at around the same time.

Evolution is the single most powerful idea in biology. As unit 3 describes in detail, evolution has been operating since life began, and it explains the current diversity of life. In fact, the similarities among existing organisms strongly suggest that all species descend from a common ancestor. Evolution has molded the life that has populated the planet since the first cells formed almost 4 billion years ago, and it continues to act today.

1.1 MASTERING CONCEPTS

1. Does any nonliving object possess all of the characteristics of life? Explain your answer.
2. List the levels of life's organizational hierarchy from smallest to largest, starting with atoms and ending with the biosphere.
3. If evolution requires genetic variation, can populations of asexually reproducing organisms evolve? Explain.

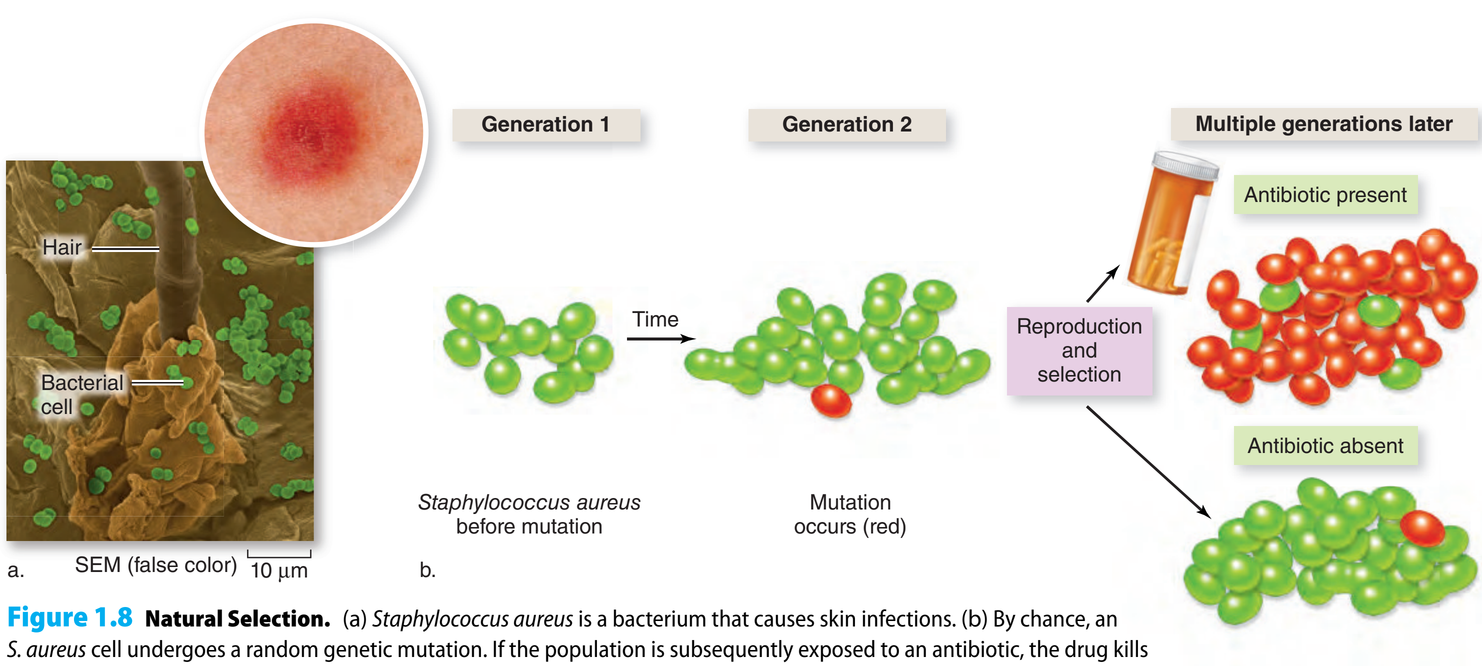


Figure 1.8 Natural Selection. (a) *Staphylococcus aureus* is a bacterium that causes skin infections. (b) By chance, an *S. aureus* cell undergoes a random genetic mutation. If the population is subsequently exposed to an antibiotic, the drug kills most of the unmutated cells. The mutated cell, however, is unaffected and can reproduce. After many generations of exposure to the antibiotic, the mutation is common.

1.2 The Tree of Life Includes Three Main Branches

Biologists have been studying life for centuries, documenting the existence of everything from bacteria to blue whales. An enduring problem has been how to organize the ever-growing list of known organisms into meaningful categories. **Taxonomy** is the biological science of naming and classifying organisms.

The basic unit of classification is the **species,** which designates a distinctive "type" of organism. Closely related species are grouped into the same **genus.** Together, the genus and a specific descriptor denote the unique, two-word scientific name of each species. A human, for example, is *Homo sapiens.* (Note that scientific names are always italicized and that the genus is capitalized, but the specific descriptor is not). Scientific names help taxonomists and other biologists communicate with one another.

Taxonomists also strive to classify organisms according to what we know about evolutionary relationships; that is, how recently one type of organism shared an ancestor with another type of organism. The more recently they diverged from a shared ancestor, the more closely related the two types of organisms are. Researchers infer these relationships by comparing anatomical, behavioral, cellular, genetic, and biochemical characteristics.

Section 14.6 describes the taxonomic hierarchy in more detail. For now, it is enough to know that genetic evidence suggests that all species fall into one of three **domains**, the broadest (most inclusive) taxonomic category. Figure 1.9 depicts the three domains: Bacteria, Archaea, and Eukarya. Species in domains Bacteria and Archaea are superficially similar to one another; all are prokaryotes, meaning that their DNA is free in the cell and not confined to an organelle called a nucleus. Major differences in DNA sequences separate these two domains from each other. Domain Eukarya, on the other hand, contains all species of eukaryotes, which are unicellular or multicellular organisms whose cells contain a nucleus.

The species in each domain are further subdivided into **kingdoms;** figure 1.9 shows the kingdoms within domain Eukarya. Three of these kingdoms—Animalia, Fungi, and Plantae—are familiar to most people. Within each one, organisms share the same general strategy for acquiring energy. For example, plants are autotrophs. Fungi and animals are consumers, although they differ in the details of how they obtain food. But the fourth group of eukaryotes, the Protista, contains a huge collection of unrelated species. Protista is a convenient but artificial "none of the above" category for the many species of eukaryotes that are not plants, fungi, or animals.

1.2 MASTERING CONCEPTS

1. What are the goals of taxonomy?
2. How are domains related to kingdoms?
3. List and describe the four main groups of eukaryotes.

Figure 1.9 Life's Diversity. The three domains of life (Bacteria, Archaea, and Eukarya) arose from a hypothetical common ancestor, shown at the base of the evolutionary tree. Just as a tree trunk produces numerous branches and twigs, the first cells eventually diversified into many unique types of organisms.