ESSENTIALS OF Biology

Fifth Edition

Sylvia S. Mader
Michael Windelspecht

Mc Graw Hill Education

ESSENTIALS OF Biology

Fifth Edition

Sylvia S. Mader

Michael Windelspecht

Mc Graw Hill Education

ESSENTIALS OF BIOLOGY, FIFTH EDITION

This book is printed on acid-free paper.

1 2 3 4 5 6 7 8 9 0 LMN 21 20 19 18 17

ISBN 978–1–259–66026-9
MHID 1–259–66026–5

Senior Vice President, Products & Markets: *G. Scott Virkler*
Vice President, General Manager, Products & Markets: *Marty Lange*
Vice President, Content Design & Delivery: *Betsy Whalen*
Managing Director: *Lynn Breithaupt*
Executive Brand Manager: *Michelle Vogler*
Director of Development: *Rose M. Koos*
Product Developer: *Anne Winch*
Director of Digital Content: *Michael Koot, PhD*
Market Development Manager: *Jenna Paleski*
Marketing Manager: *Britney Ross*
Program Manager: *Angie FitzPatrick*
Content Project Manager (Core): *Jayne Klein*
Content Project Manager (Assessment): *Brent dela Cruz*
Senior Buyer: *Sandy Ludovissy*
Designer: *David W. Hash*
Cover Image: © *Antonio Cali66/EyeEm/Getty Images*
Content Licensing Specialists: *Lori Hancock/Lorraine Buczek*
Compositor: *Aptara*
Typeface: *10/13 STIX MathJax Main*
Printer: *LSC Communications*

Library of Congress Cataloging-in-Publication Data

Names: Mader, Sylvia S., author. | Windelspecht, Michael, 1963- , author.
Title: Essentials of biology / Sylvia S. Mader, Michael Windelspecht ; with contributions by Dave Cox, Lincoln Land Community College, Gretel Guest, Durham Technical Community College.
Description: Fifth edition | New York, NY : McGraw-Hill Education, 2016.
Identifiers: LCCN 2016042242| ISBN 9781259660269 (alk. paper) | ISBN 1259660265 (alk. paper)
Subjects: LCSH: Biology--Textbooks.
Classification: LCC QH308.2 .M24 2016 | DDC 570--dc23 LC record available athttps://lccn.loc.gov/2016042242

www.mhhe.com

Brief Contents

About the Authors

© Jacqueline Baer Photography

Dr. Sylvia S. Mader Sylvia Mader has authored several nationally recognized biology texts published by McGraw-Hill. Educated at Bryn Mawr College, Harvard University, Tufts University, and Nova Southeastern University, she holds degrees in both Biology and Education. Over the years she has taught at University of Massachusetts, Lowell; Massachusetts Bay Community College; Suffolk University; and Nathan Mayhew Seminars. Her ability to reach out to science-shy students led to the writing of her first text, *Inquiry into Life,* which is now in its fifteenth edition. Highly acclaimed for her crisp and entertaining writing style, her books have become models for others who write in the field of biology.

Dr. Mader enjoys taking time to visit and explore the various ecosystems of the biosphere. Her several trips to the Florida Everglades and Caribbean coral reefs resulted in talks she has given to various groups around the country. She has visited the tundra in Alaska, the taiga in the Canadian Rockies, the Sonoran Desert in Arizona, and tropical rain forests in South America and Australia. A photo safari to the Serengeti in Kenya resulted in a number of photographs for her texts. She was thrilled to think of walking in Darwin's footsteps when she journeyed to the Galápagos Islands with a group of biology educators. Dr. Mader was also a member of a group of biology educators who traveled to China to meet with their Chinese counterparts and exchange ideas about the teaching of modern-day biology.

© Ricochet Creative Productions LLC

Dr. Michael Windelspecht As an educator, Dr. Windelspecht has taught introductory biology, genetics, and human genetics in the online, traditional, and hybrid environments at community colleges, comprehensive universities, and military institutions. For over a decade he served as the Introductory Biology Coordinator at Appalachian State University, where he directed a program that enrolled over 4,500 students annually.

He received degrees from Michigan State University (BS, zoology–genetics) and the University of South Florida (PhD, evolutionary genetics) and has published papers in areas as diverse as science education, water quality, and the evolution of insecticide resistance. His current interests are in the analysis of data from digital learning platforms for the development of personalized microlearning assets and next generation publication platforms. He is currently a member of the National Association of Science Writers and several science education associations. He has served as the keynote speaker on the development of multimedia resources for online and hybrid science classrooms. In 2015 he won the DevLearn HyperDrive competition for a strategy to integrate student data into the textbook revision process.

As an author and editor, Dr. Windelspecht has over 20 reference textbooks and multiple print and online lab manuals. He has founded several science communication companies, including Ricochet Creative Productions, which actively develops and assesses new technologies for the science classroom. You can learn more about Dr. Windelspecht by visiting his website at www.michaelwindelspecht.com.

Preface

This Fifth Edition of *Essentials of Biology* provides nonscience majors with a fundamental understanding of the science of biology. The overall focus of this edition addresses the learning styles of modern students, and in the process, increases their understanding of the importance of science in their lives.

Students in today's world are being exposed, almost on a daily basis, to exciting new discoveries and insights that, in many cases, were beyond our predictions even a few short years ago. It is our task, as instructors, not only to make these findings available to our students, but to enlighten students as to why these discoveries are important to their lives and society. At the same time, we must provide students with a firm foundation in those core principles on which biology is founded, and in doing so, provide them with the background to keep up with the many discoveries still to come.

In addition to the evolution of the introductory biology curriculum, students and instructors are increasingly requesting digital resources to utilize as learning resources. McGraw-Hill Education has long been an innovator in the development of digital resources, and this text, and its authors, are at the forefront of the integration of these technologies into the science classroom.

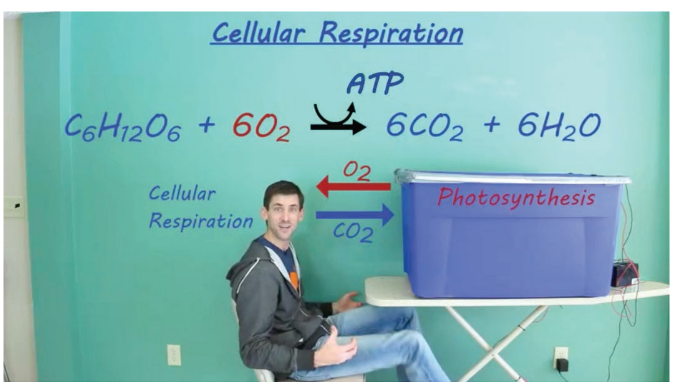
The authors identified several goals that guided the preparation of this new edition:

1. Updating of chapter openers and Connections content to focus on issues and topics important in a nonscience majors classroom
2. Utilization of the data from the LearnSmart adaptive learning platforms to identify content areas within the text that students demonstrated difficulty in mastering
3. Refinement of digital assets to provide a more effective assessment of learning outcomes to enable instructors in the flipped, online, and hybrid teaching environments
4. Development of a new series of videos and websites to introduce relevancy and engage students in the content

Relevancy

The use of real world examples to demonstrate the importance of biology in the lives of students is widely recognized as an effective teaching strategy for the introductory biology classroom. Students want to learn about the topics they are interested in. The development of relevancy-based resources is a major focus for the authors of the Mader series of texts. Some examples of how we have increased the relevancy content of this edition include:

- A series of new chapter openers to introduce relevancy to the chapter. The authors chose topics that would be of interest to a nonscience major, and represent what would typically be found on a major news source.
- The development of new relevancy-based videos, BioNow, that offer relevant, applied classroom resources to allow students to feel that they can actually do and learn biology themselves.



- A website, RicochetScience.com, managed by Dr. Windelspecht, that provides updates on news and stories that are interesting to nonscience majors. The Biology101 project links these resources to the major topics of the text. The site also features videos and tutorial animations to assist the students in recognizing the relevancy of what they are learning in the classroom.

Ricochet Science™

- In addition, the author's website, michaelwindelspecht.com, contains videos and articles on how the *Essentials of Biology* text may be easily adapted for use in a topics-based course, or in the hybrid, online, and flipped classroom environments.

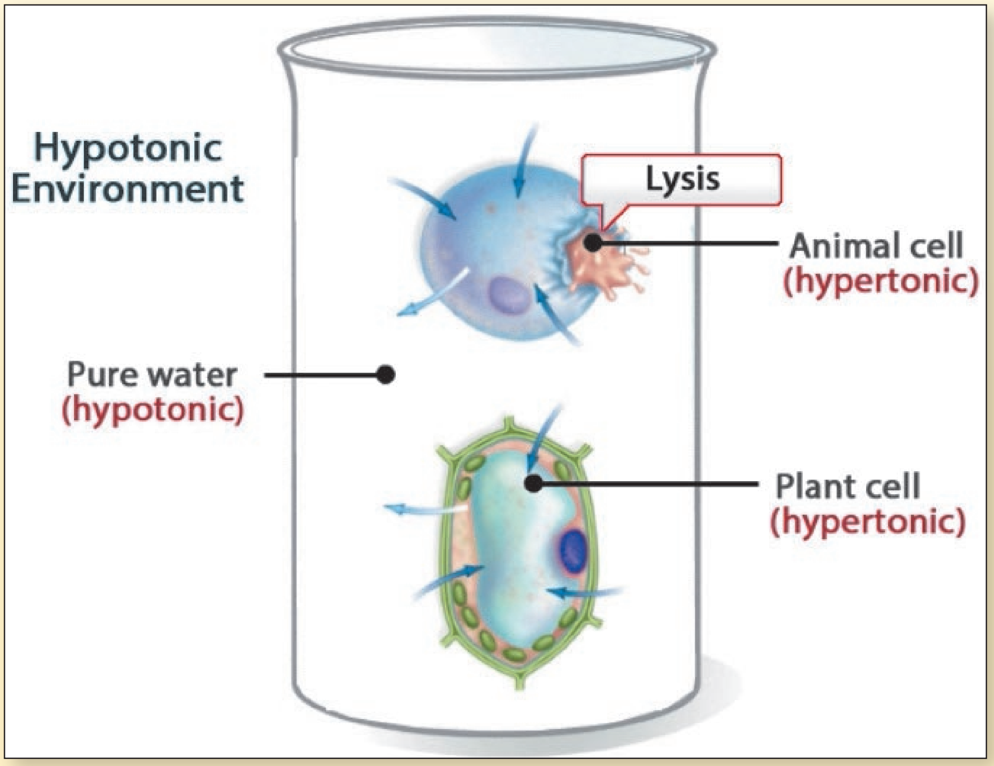
Engaging Students

Today's science classroom relies heavily on the use of digital assets, including animations and videos, to engage students and reinforce difficult concepts. *Essentials of Biology* includes two resources specifically designed for the introductory science class to help you achieve these goals.

BioNow Videos

The BioNow series of videos, narrated and produced by educator Jason Carlson, provide a relevant, applied approach that allows your students to feel they can actually do and learn biology themselves. While tying directly to the content of your course, the videos help students relate their daily lives to the biology you teach and then connect what they learn back to their lives.

Each video provides an engaging and entertaining story about applying the science of biology to a real situation or problem. Attention is taken to use tools and techniques that any regular person could perform, so your students see the science as something they could do and understand.



Tutorial Videos

The author, Michael Windelspecht, has prepared a series of tutorial videos to help students understand some of the more difficult topics in each chapter. Each video explores a specific figure in the text. During the video, important terms and processes are called out, allowing you to focus on the key aspects of the figure.

For students, these act as informal office hours, where they can review the most difficult concepts in the chapter at a pace which helps them learn. Instructors of hybrid and flipped courses will find these useful as online supplements.

Overview of Content Changes to *Essentials of Biology,* Fifth Edition

A number of the chapters in this edition now include references and links to new BioNow relevancy videos that have been designed to show students how the science of biology applies to their everyday lives. All of these are available in the instructor and student resources section within Connect. In addition, within the end of chapter material, the Connecting the Concepts content has been included in the Summarize section to better help the students understand the connections within the chapter.

Chapter 1: Biology: The Science of Life contains an updated chapter opener on species that have been recently discovered. The levels of biological organization now includes a description of species. The content on challenges facing science (Section 1.4) now includes more content on biodiversity loss, emerging diseases, and climate change.

Part I *The Cell*

The chapter opener for **Chapter 2: The Chemical Basis of Life** has been updated to include recent discoveries associated with the search for the precursors of life on Titan and comets. **Chapter 4: Inside the Cell** starts with a discussion of the importance of stem cells. **Chapter 6: Energy for Life** contains a new figure (Fig. 6.5) on the absorption spectrum of the major photosynthetic pigments.

Part II *Genetics*

Chapter 8: Cellular Reproduction starts with a new chapter opener on the *p53* gene and cancer. The material on mitosis in a plant cell (Fig. 8.6) has been expanded to make it more similar to the coverage of the animal cells. The content on the treatments of cancer (Section 8.5) has been expanded to include immunotherapy. The first section of **Chapter 10: Patterns of Inheritance** now explains why earlobes and dimples should not be used as examples of Mendelian traits in humans. The material on non-Mendelian genetics (Section 10.3) includes eye color in humans as an example of genetic interactions. **Chapter 11: DNA Biology** begins with a new chapter opener on the possibilities of synthetic DNA. The chapter has a new figure on semi-conservative replication (Fig. 11.6). **Chapter 12: Biotechnology and Genomics** begins with a new chapter opener on CRISPR and genome editing. The section on biotechnology (Section 12.1) now includes a discussion on genetic sequencing and genome editing (CRISPR, Fig. 12.4). The material on biotechnology products (Section 12.3) includes new examples of both plant and animal products. **Chapter 13: Genetic Counseling** was renamed to indicate a focus on how DNA changes and the processes of genetic testing and gene therapy. The section on genetic testing (Section 13.3) includes content on genetic sequencing for individuals and the reliability of OTC genetic tests.

Part III *Evolution*

Chapter 14: Darwin and Evolution now begins with a chapter opener on the evolution of antibiotic resistance, including both MRSA and *Shigella.* Figure 14.11 has been updated to better demonstrate Wallace's contribution to the study of biogeography. In **Chapter 15: Evolution on a Small Scale,** a new chapter opener now describes how changes in a single gene have allowed humans to live at high elevations. A new figure on the types of selection (Fig. 15.1) has been added. The examples of directional selection now focus on studies of coloration in guppies. **Chapter 16: Evolution on a Large Scale** starts with a new chapter opener on the evolution of the birds. The geological timescale (Table 16.1) has been updated.

Part IV *Diversity of Life*

In **Chapter 17: The Microorganisms: Viruses, Bacteria, and Protists,** a new opener on the Ebola outbreak in Africa has been included. A new connection piece on the world's largest virus has been added. The content on eukaryotic supergroups (Table 17.1) has been updated to reflect recent classification changes and a new figure (Fig. 17.20) added. The entire chapter has been reorganized according to eukaryotic supergroups. **Chapter 18: The Plants and Fungi** contains a new illustration of fungal evolution (Fig. 18.19). **Chapter 19: The Animals** starts with a new opener on canine evolution. New figures illustrate the general characteristics of animals (Fig. 19.1) and the general evolution of animals (Fig. 19.4). For the insects (Section 19.4), a new connection piece explores why mosquitoes are disease vectors. In the section on human evolution (Section 19.5), the diagram of human evolution (Fig. 19.38) has been updated, and a new illustration added (Fig. 19.41) on the migration of *Homo erectus.* Additional content has been added on both Neandertals and Denisovans.

Part VI *Animal Structure and Function*

Chapter 22: Being Organized and Steady contains a new chapter opener on the homeostatic requirements of pop icon Taylor Swift during performances. In **Chapter 23: The Transport Systems,** a new chapter opener on synthetic blood is included. The content on nutrition and the digestive system (previously in Chapter 24) has been combined in **Chapter 25: Digestion and Human Nutrition.** The chapter opener now explores the relationship between gluten and celiac disease. A new section (Section 25.4) is included that outlines how nutritional information is updated and how to interpret nutrition labels on food. **Chapter 26: Defenses Against Disease** begins with a look at the development of a vaccine against the Zika virus. **Chapter 29: Reproduction and Embryonic Development** has a new chapter opener on in-vitro fertilization (IVF) using genetic material from three parents. The introductory content on the differences between sexual and asexual reproduction have been separated into distinct headings. A new reading has been added on how Zika virus contributes to birth defects.

Part VII *Ecology*

Chapter 30: Ecology and Populations contains a new chapter opener on population growth in the asian carp. The levels of biological organization have been updated (Fig. 30.1) to reflect changes introduced in Chapter 1. The human population statistics have been updated throughout to reflect 2015 data. The information on predator-prey dynamics has been updated to include more current research on hare-lynx populations. **Chapter 31: Communities and Ecosystems** contains a new opener on the consequences of global climate change. New figures (Fig. 31.27) illustrate projections of global temperature increases and the influence of climate change in the United States (Fig. 31.28). A new map of terrestrial biomes (Fig. 31.29) has been added. The chapter opener for **Chapter 32: Human Impact on the Biosphere** now examines the Flint water crisis.

connect®

Required=Results


©Getty Images/iStockphoto

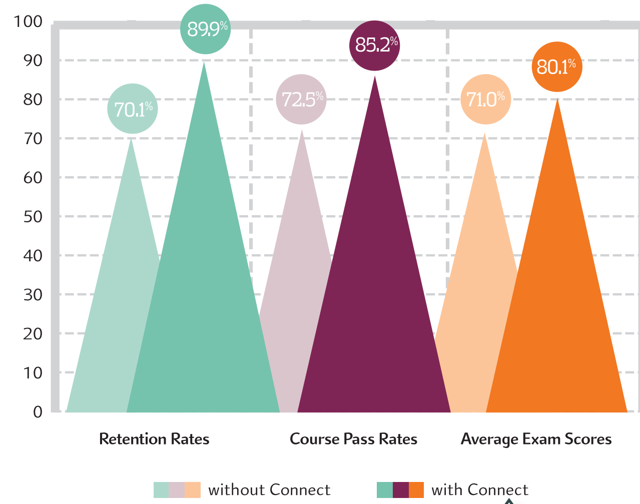
McGraw-Hill Connect®
Learn Without Limits

Connect is a teaching and learning platform that is proven to deliver better results for students and instructors.

Connect empowers students by continually adapting to deliver precisely what they need, when they need it, and how they need it, so your class time is more engaging and effective.

> 73% of instructors who use **Connect** require it; instructor satisfaction **increases** by 28% when **Connect** is required.

Connect's Impact on Retention Rates, Pass Rates, and Average Exam Scores



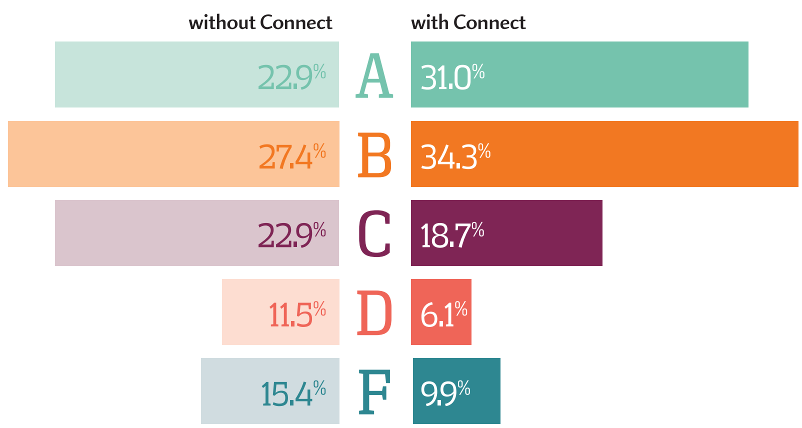
Using **Connect** improves retention rates by **19.8%**, passing rates by **12.7%**, and exam scores by **9.1%.**

Analytics

Connect Insight®

Connect Insight is Connect's new one-of-a-kind visual analytics dashboard that provides at-a-glance information regarding student performance, which is immediately actionable. By presenting assignment, assessment, and topical performance results together with a time metric that is easily visible for aggregate or individual results, Connect Insight gives the user the ability to take a just-in-time approach to teaching and learning, which was never before available. Connect Insight presents data that helps instructors improve class performance in a way that is efficient and effective.

Impact on Final Course Grade Distribution



Adaptive

THE **ADAPTIVE READING EXPERIENCE** DESIGNED TO TRANSFORM THE WAY STUDENTS READ

More students earn **A's** and **B's** when they use McGraw-Hill Education **Adaptive** products.

SmartBook®

Proven to help students improve grades and study more efficiently, SmartBook contains the same content within the print book, but actively tailors that content to the needs of the individual. SmartBook's adaptive technology provides precise, personalized instruction on what the student should do next, guiding the student to master and remember key concepts, targeting gaps in knowledge and offering customized feedback, and driving the student toward comprehension and retention of the subject matter. Available on tablets, SmartBook puts learning at the student's fingertips—anywhere, anytime.

Over **8 billion questions** have been answered, making McGraw-Hill Education products more intelligent, reliable, and precise.

www.mheducation.com

STUDENTS WANT

SMARTBOOK®

95% of students reported **SmartBook** to be a more effective way of reading material.

100% of students want to use the Practice Quiz feature available within **SmartBook** to help them study.

100% of students reported having reliable access to off-campus wifi.

90% of students say they would purchase **SmartBook** over print alone.

95% of students reported that **SmartBook** would impact their study skills in a positive way.

Mc Graw Hill Education

*Findings based on 2015 focus group results administered by McGraw-Hill Education

Acknowledgments

Dr. Sylvia Mader is one of the icons of science education. Her dedication to her students, coupled to her clear, concise writing style, has benefited the education of thousands of students over the past four decades. As an educator, it is an honor to continue her legacy and to bring her message to the next generation of students.

As always, I had the privilege to work with a phenomenal group of people on this edition. I would especially like to thank you, the numerous instructors who have shared emails with me or have invited me into your classrooms, both physically and virtually, to discuss your needs as instructors and the needs of your students. You are all dedicated and talented teachers, and your energy and devotion to quality teaching is what drives a textbook revision.

Many dedicated and talented individuals assisted in the development of *Essentials of Biology,* Fifth Edition. I am very grateful for the help of so many professionals at McGraw-Hill who were involved in bringing this book to fruition. Therefore, I would like to thank the following:

- The product developer, Anne Winch, for her patience and impeccable ability to keep me focused.
- My brand manager, Michelle Vogler, for her guidance and reminding me why what we do is important.
- My marketing manager, Britney Ross, and market development manager, Jenna Paleski, for placing me in contact with great instructors, on campus and virtually, throughout this process.
- The digital team of Eric Weber and Christine Carlson for helping me envision the possibilities in our new digital world.
- My content project manager, Jayne Klein, and program manager, Angie Fitzpatrick, for calmly steering this project throughout the publication process.
- Lori Hancock and Jo Johnson for the photos within this text. Biology is a visual science, and your contributions are evident on every page.
- David Hash for the design elements in this text, including one of the most beautiful textbook covers in the business.
- Dawnelle Krouse, Lauren Timmer, and Jane Hoover who acted as my proofreaders and copyeditor for this edition.
- Jane Peden for her behind the scenes work that keeps us all functioning.
- Inkling for providing a dynamic authoring platform, and Aptara for all of their technical assistance.

As both an educator and an author, communicating the importance of science represents one of my greatest passions. Our modern society is based largely on advances in science and technology over the past few decades. As I present in this text, there are many challenges facing humans, and an understanding of how science can help analyze, and offer solutions to, these problems is critical to our species' health and survival.

I also want to acknowledge my family for all of their support. My wife and partner Sandy has never wavered in her energy and support of my projects. The natural curiosity of my children, Devin and Kayla, has provided me with the motivation to make this world a better place for everyone.

Michael Windelspecht, Ph.D.

Blowing Rock, NC

Ancillary Authors

Appendix Answer Bank: Betsy Harris, *Ricochet Creative Productions*

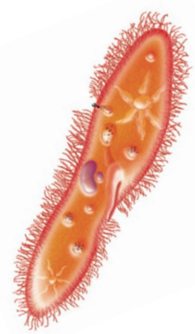
Connect Question Bank: Alex James, *Ricochet Creative Productions*

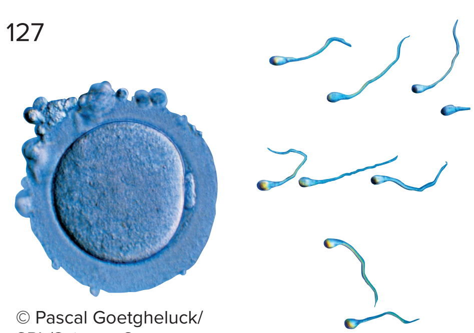
Connect Test Bank: Carrie Wells, *University of North Carolina,Charlotte;* Jennifer Wiatrowski, *Pasco-Hernando Community College*

Tutorial Development: *Ricochet Creative Productions*

SmartBook with Learning Resources: Alex James, *Ricochet Creative Productions;* Patrick Galliart, *North Iowa Area Community College*

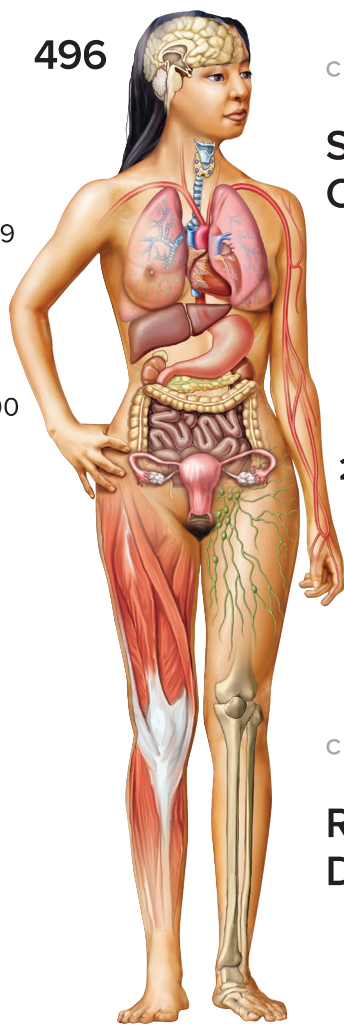
Contents

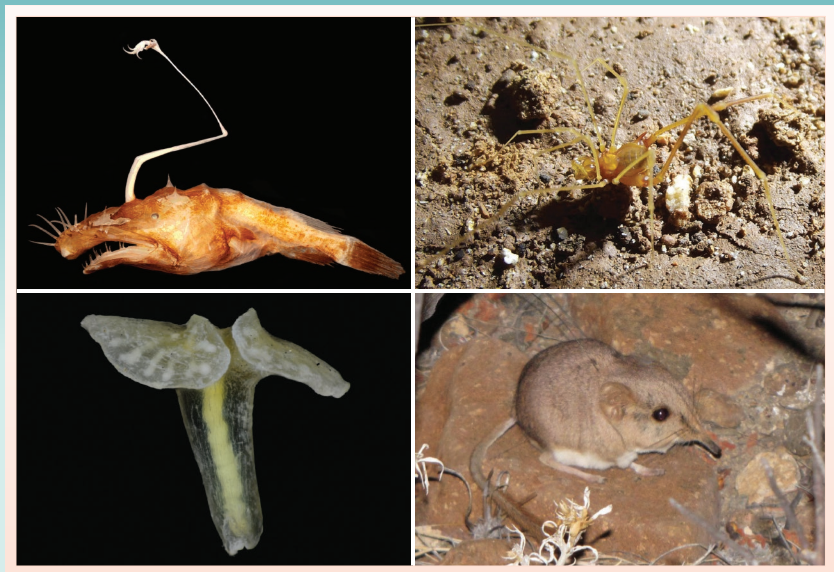




© Pascal Goetgheluck/ SPL/Science Source

© Eye of Science/Science Source





(anglerfish): © Theodore Pietsch/University of Washington; (spider): © MSc. Rafael Fonseca-Ferreira; (*Dendrogramma*): © Jean Just, Reinhardt Mobjerg Kristensen and Jorgen Olesen; (elephant shrew): © Dr. Galen Rathbun and Dr. Jack Dumbacher

1

Biology: The Science of Life

OUTLINE

The Diversity of Life

Life on Earth takes on a staggering variety of forms, often with appearances and behaviors that may be strange to humans. As we will see in this chapter, one of the ways that biologists classify life is by species. So how many species are there on the planet? The truth is, we really don't know. Recent estimates suggest that there may be around 8.7 million species on the planet, but many scientists believe that number is probably much higher, especially when the bacteria are factored in. So far, less than 2 million species have been identified, and most of those are insects.

However, new species, such as those shown here, are being discovered all the time. While investigating the impacts of the 2010 oil spills in the Gulf of Mexico, researchers discovered the anglerfish *Lasiognathus dinema* (*top, left*). Recently, two new species of *Dendrogramma* were discovered off the coast of Australia (*bottom, left*). This genus is so unique that it does not fit into any current classification. A new eyeless cave spider, *Iandumoema smeagol,* named after the Lord of the Rings character, is so specialized that it is believed to be found in a limited number of caves (*top, right*). New mammals have also recently been discovered, such as the world's smallest elephant shrew, *Macroscelides micus* (*bottom, right*).

As we will learn in this chapter, although life is diverse, it also shares a number of important characteristics.

As you read through this chapter, think about the following questions:

1. What are the general characteristics that separate living organisms from nonliving things?
2. How do species fit into the biological levels of organization?
3. What are some of the challenges facing science today?

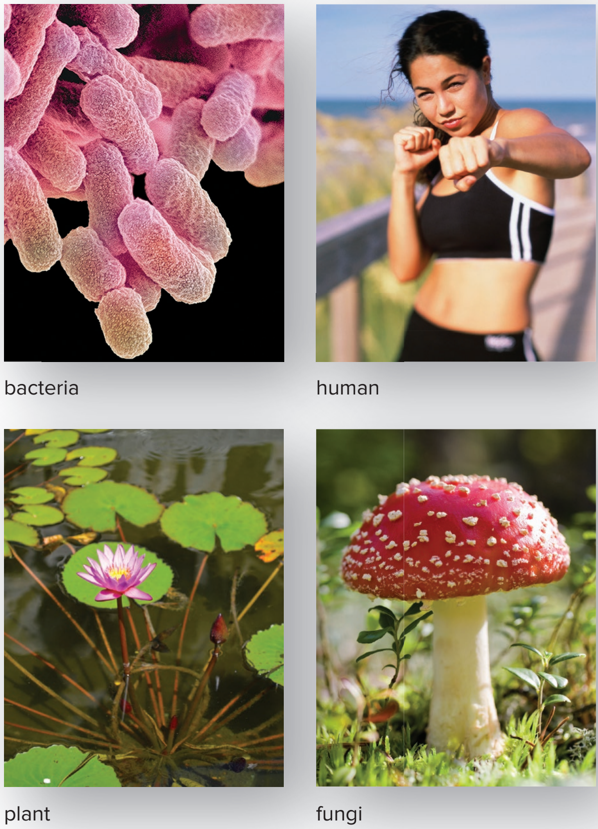


Figure 1.1 **Diversity of life.**

Biology is the study of life in all of its diverse forms.

(bacteria): © Science Photo Library RF/Getty Images; (human): © Purestock/Superstock RF; (plant): © McGraw-Hill Education; (fungi): © Jorgen Bausager/Getty RF

1.1 The Characteristics of Life

Learning Outcomes

Upon completion of this section, you should be able to

1. Explain the basic characteristics that are common to all living organisms.
2. Distinguish between the levels of biological organization.
3. Summarize how the terms *homeostasis, metabolism,* and *adaptation* relate to all living organisms.
4. Contrast chemical cycling and energy flow within an ecosystem.

As we observed in the chapter opener, life is diverse (**Fig. 1.1**). Life may be found everywhere on the planet, from thermal vents at the bottom of the ocean to the coldest reaches of Antarctica. **Biology** is the scientific study of life. Biologists study not only life's diversity but also the characteristics that are shared by all living organisms. These characteristics include levels of organization, the ability to acquire materials and energy, the ability to maintain an internal environment, the ability to respond to stimuli, the ability to reproduce and develop, and the ability to adapt and evolve to changing conditions. By studying these characteristics, we gain insight into the complex nature of life, which helps us distinguish living organisms from nonliving things. In the next sections, we will explore these characteristics in more detail.

The complex organization of life begins with atoms, the basic units of matter. Atoms combine to form small molecules, which join to form larger molecules within a **cell,** the smallest, most basic unit of life. Although a cell is alive, it is made from nonliving molecules (**Fig. 1.2**).

The majority of the organisms on the planet, such as the bacteria and most protists, are single-celled. Plants, fungi, and animals are **multicellular** organisms and are therefore composed of many types of cells, which often combine to form **tissues.** Tissues make up **organs,** as when various tissues combine to form a heart or a leaf. Organs work together in **organ systems;** for example, the heart and blood vessels form the cardiovascular system. Various organ systems work together within complex organisms.

The organization of life extends beyond the individual organism. A **species** is a group of similar organisms that are capable of interbreeding. All of the members of a species within a particular area belong to a **population.** When populations interact, such as the humans, zebras, and trees in Figure 1.2, they form a **community.** At the **ecosystem** level, communities interact with the physical environment (soil, atmosphere, etc.). Collectively, the ecosystems on the planet are called the **biosphere,** the zone of air, land, and water at the surface of the Earth where living organisms are found.

Life Requires Materials and Energy

Life from single cells to complex organisms cannot maintain organization or carry on necessary activities without an outside source of materials and energy. Food provides nutrient molecules, which are used as building blocks or energy sources. **Energy** is the capacity to do work, and it takes work to maintain the organization of the cell and the organism. When cells use nutrient molecules to make their parts and products, they carry out a sequence of chemical reactions. The term **metabolism** encompasses all the chemical reactions that occur in a cell.

Figure 1.2 **Levels of biological organization.**

All life is connected by levels of biological organization that extend from atoms to the biosphere.

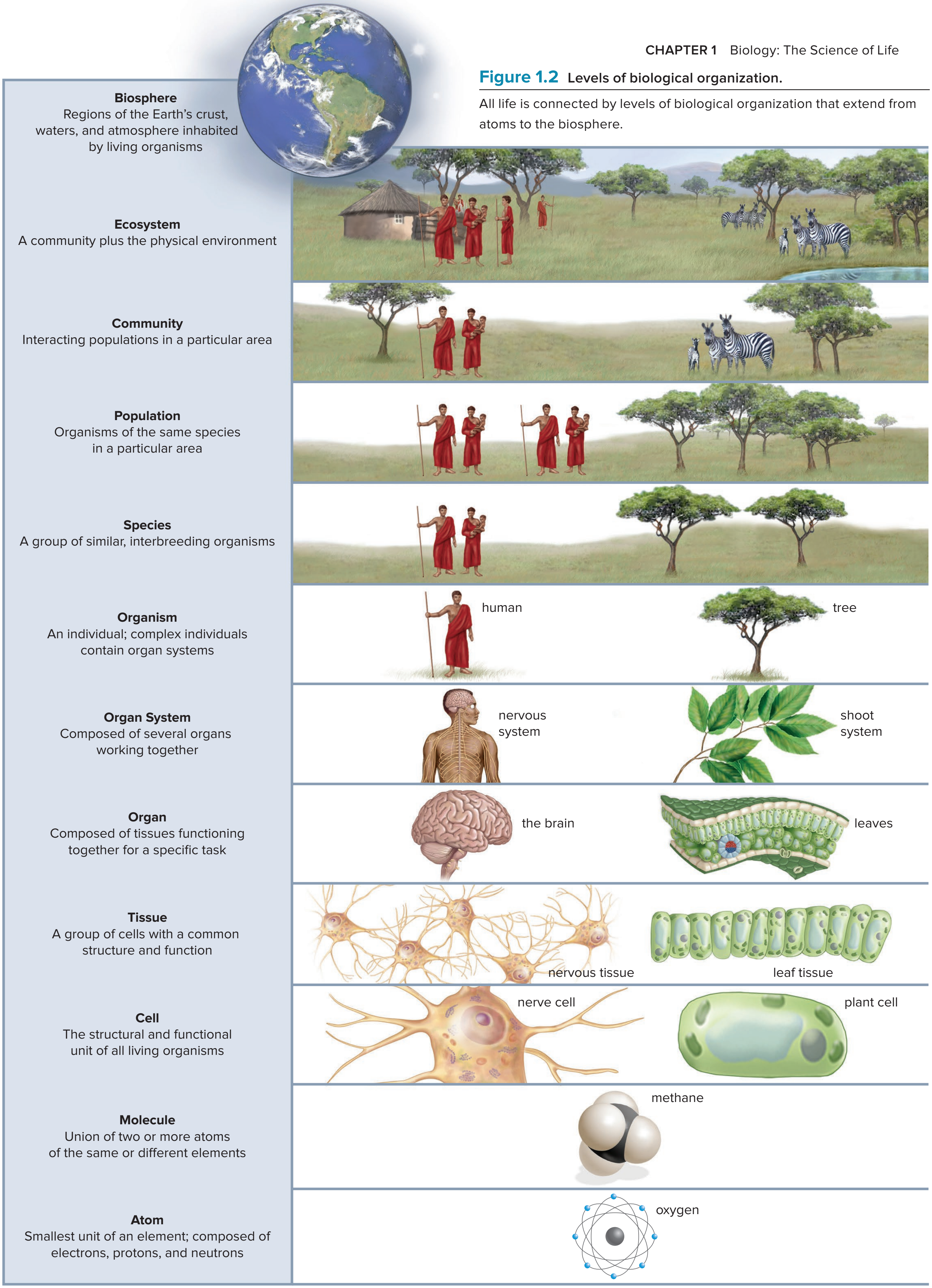


Figure 1.3 **Acquiring nutrient materials and energy.**

All organisms, including this mongoose eating a snake, require nutrients and energy.

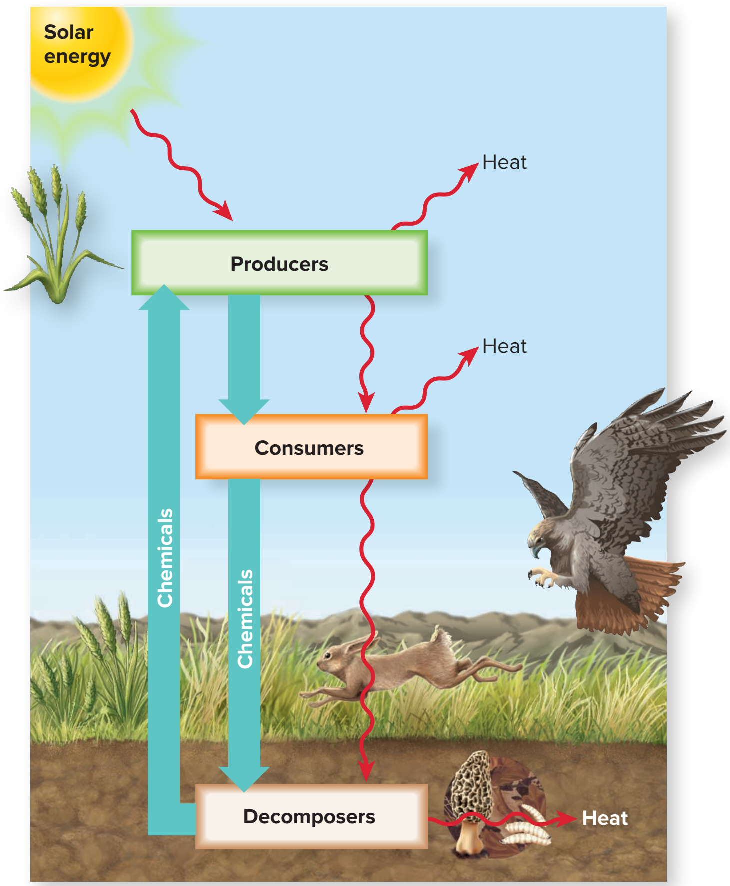


Figure 1.4 **Chemical cycling and energy flow in an ecosystem.**

In an ecosystem, chemical cycling (aqua arrows) and energy flow (red arrows) begin when plants use solar energy and inorganic nutrients to produce their own food. Chemicals and energy are passed from one population to another in a food chain. Eventually, energy dissipates as heat. With the death and decomposition of organisms, chemicals are returned to living plants once more.

The ultimate source of energy for nearly all life on Earth is the sun. Plants and certain other organisms are able to capture solar energy and carry on **photosynthesis,** a process that transforms solar energy into the chemical energy of nutrient molecules. For this reason, these organisms are commonly called producers. Animals and plants get energy by metabolizing (**Fig. 1.3**), or breaking down, the nutrient molecules made by the producers.

The energy and chemical flow between organisms also defines how an ecosystem functions (**Fig. 1.4**). Within an ecosystem, chemical cycling and energy flow begin when producers, such as grasses, take in solar energy and inorganic nutrients to produce food (organic nutrients) by photosynthesis. Chemical cycling (aqua arrows) occurs as chemicals move from one population to another in a food chain, until death and decomposition allow inorganic nutrients to be returned to the producers once again. Energy (red arrows), on the other hand, flows from the sun through plants and the other members of the food chain as they feed on one another. The energy gradually dissipates and returns to the atmosphere as heat. Because energy does not cycle, ecosystems could not stay in existence without solar energy and the ability of photosynthetic organisms to absorb it.

Energy flow and nutrient cycling in an ecosystem largely determine where different ecosystems are found in the biosphere. The two most biologically diverse ecosystems—tropical rain forests and coral reefs—occur where solar energy is very abundant and nutrient cycling is continuous.

The availability of energy and nutrients also determines the type of biological communities that occur within an ecosystem. One example of an ecosystem in North America is the grasslands, which are inhabited by populations of rabbits, hawks, and various types of grasses, among many others. The energy input and nutrient cycling of a grassland are less than those of a rain forest, so the community structure and food chains of these ecosystems differ.

Living Organisms Maintain an Internal Environment

For metabolic processes to continue, living organisms need to keep themselves stable with regard to temperature, moisture level, acidity, and other factors critical to maintaining life. This is called **homeostasis,** or the maintenance of internal conditions within certain physiological boundaries.

Many organisms depend on behavior to regulate their internal environment. A chilly lizard may raise its internal temperature by basking in the sun on a hot rock. When it starts to overheat, it scurries for cool shade. Other organisms have control mechanisms that do not require any conscious activity. When you are studying and forget to eat lunch, your liver releases stored sugar to keep your blood sugar level within normal limits. Many of the organ systems of our bodies are involved in maintaining homeostasis.

Living Organisms Respond

Living organisms find energy and/or nutrients by interacting with their surroundings. Even single-celled organisms can respond to their environment. The beating of microscopic hairs or the snapping of whiplike tails moves them toward or away from light or chemicals. Multicellular organisms can manage more complex responses. A monarch butterfly can sense the approach of fall and begin its flight south, where resources are still abundant. A vulture can smell meat a mile away and soar toward dinner.

The ability to respond often results in movement: The leaves of a plant turn toward the sun, and animals dart toward safety. Appropriate responses help ensure survival of the organism and allow it to carry on its daily activities. Altogether, we call these activities the *behavior* of the organism.

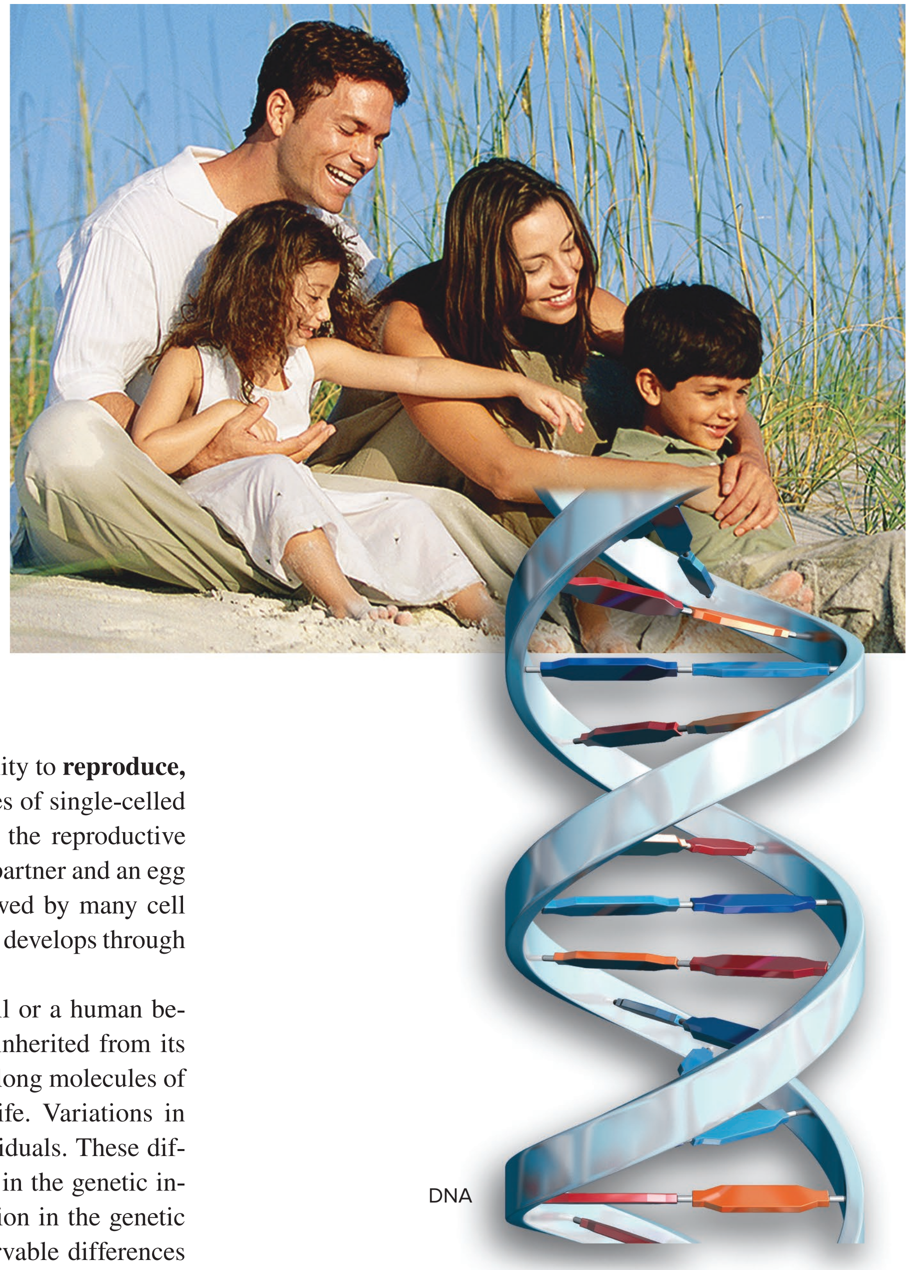


Figure 1.5 Reproduction is a characteristic of life. Whether they are single-celled or multicellular, all organisms reproduce. Offspring receive a copy of their parents' DNA and therefore a copy of the parents' genes.

(photo): © Purestock/Superstock RF; (DNA): © David Mack/SPL/Science Source

Living Organisms Reproduce and Develop

Life comes only from life. Every living organism has the ability to **reproduce,** or make another organism like itself. Bacteria and other types of single-celled organisms simply split in two. In multicellular organisms, the reproductive process usually begins with the pairing of a sperm from one partner and an egg from the other partner. The union of sperm and egg, followed by many cell divisions, results in an immature individual, which grows and develops through various stages to become an adult.

An embryo develops into a whale or a yellow daffodil or a human because of the specific set of **genes,** or genetic instructions, inherited from its parents (**Fig. 1.5**). In all organisms, the genes are located on long molecules of **DNA (deoxyribonucleic acid),** the genetic blueprint of life. Variations in genes account for the differences between species and individuals. These differences are the result of **mutations,** or inheritable changes in the genetic information. Mutation provides an important source of variation in the genetic information. However, not all mutations are bad—the observable differences in eye and hair color are examples of mutations.

By studying DNA, scientists are able to understand not only the basis for specific traits, like susceptibility for certain types of cancer, but also the evolutionary history of the species. Reproduction involves the passing of genetic information from a parent to its offspring. Therefore, the information found within the DNA represents a record of our molecular heritage. This includes not only a record of the individual's lineage, but also how the species is related to other species.

DNA provides the blueprint or instructions for the organization and metabolism of the particular organism. All cells in a multicellular organism contain the same set of genes, but only certain ones are turned on in each type of specialized cell. Through the process of **development,** cells express specific genes to distinguish themselves from other cells, thus forming tissues and organs.

Living Organisms Have Adaptations

Adaptations are modifications that make organisms suited to their way of life. Some hawks have the ability to catch fish; others are best at catching rabbits. Hawks can fly, in part, because they have hollow bones to reduce their weight and flight muscles to depress and elevate their wings. When a hawk dives, its strong feet take the first shock of the landing, and its long, sharp claws reach out and hold onto the prey. Hawks have exceptionally keen vision, which enables them not only to spot prey from great heights but also to estimate distance and speed.

Humans also have adaptations that allow them to live in specific environments. Humans who live at extreme elevations in the Himalayas (over 13,000 feet, or 4,000 meters) have an adaptation that reduces the amount of hemoglobin produced in the blood. Hemoglobin is important for the transport of oxygen. Normally, as elevation increases, the amount of hemoglobin increases, but too much hemoglobin makes the blood thick, which can cause health problems. In some high-elevation populations, a mutation in a single gene reduces the risk.

Evolution, or the manner in which species become adapted to their environment, is discussed in the next section of this chapter.

1.1 CONNECTING THE CONCEPTS

All living organisms, from bacteria to humans, share the same basic characteristics of life.

Check Your Progress 1.1

1. List the basic characteristics common to all life.
2. List, in order starting with the least organized, the levels of biological organization.
3. Explain how chemical cycling and energy flow occur at both the organism and the ecosystem levels of organization.

1.2 Evolution: The Core Concept of Biology

Learning Outcomes

Upon completion of this section, you should be able to

1. Define the term *evolution*.
2. Explain the process of natural selection and its relationship to evolutionary processes.
3. Summarize the general characteristics of the domains and major kingdoms of life.

Despite diversity in form, function, and lifestyle, organisms share the same basic characteristics. As mentioned, they are all composed of cells organized in a similar manner. Their genes are composed of DNA, and they carry out the same metabolic reactions to acquire energy and maintain their organization. The unity of living organisms suggests that they are descended from a common ancestor—the first cell or cells.

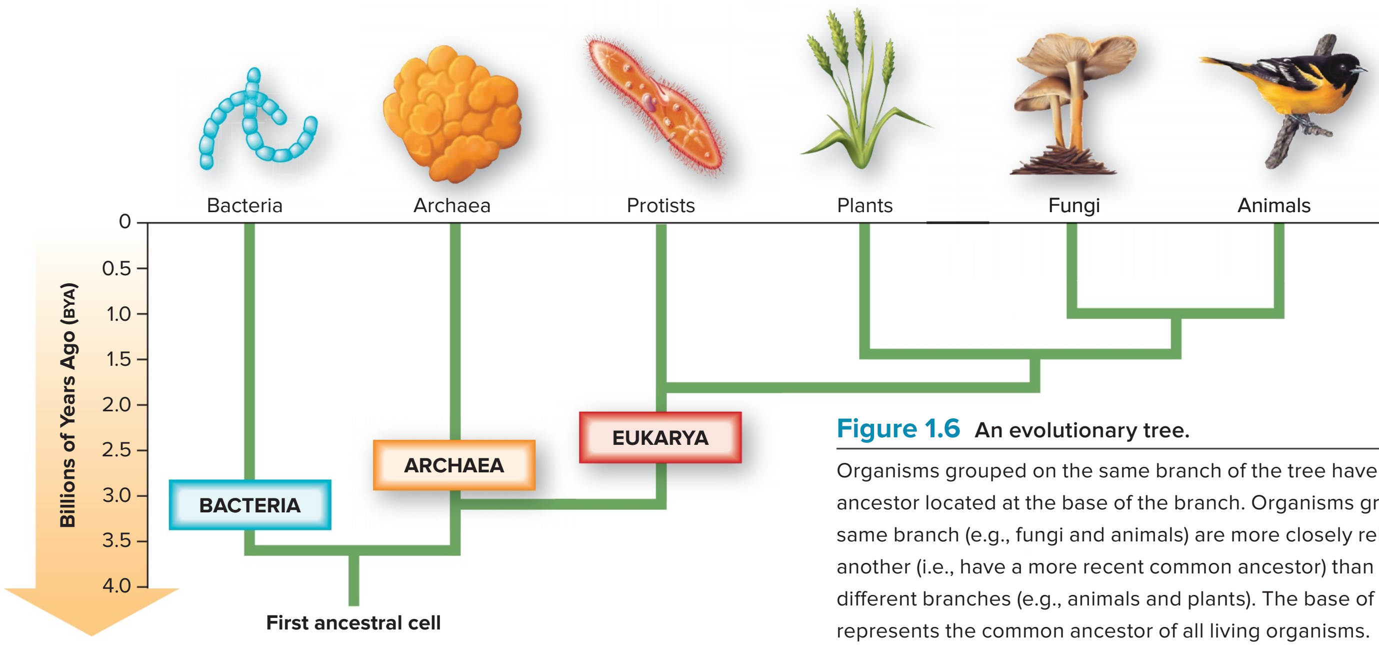


Figure 1.6 An evolutionary tree.

Organisms grouped on the same branch of the tree have a common ancestor located at the base of the branch. Organisms grouped on the same branch (e.g., fungi and animals) are more closely related to one another (i.e., have a more recent common ancestor) than organisms on different branches (e.g., animals and plants). The base of the tree itself represents the common ancestor of all living organisms.

An evolutionary tree is like a family tree (**Fig. 1.6**). Just as a family tree shows how a group of people have descended from one couple, an evolutionary tree traces the ancestry of life on Earth to a common ancestor. One couple can have diverse children, and likewise a population can be a common ancestor to several other groups, each adapted to a particular set of environmental conditions. **Evolution** is the process in which populations change over time to adapt to their environment, and pass on these changes to the next generation. Evolution is considered the unifying concept of biology because it explains so many aspects of biology, including how living organisms arose from a single ancestor and the tremendous diversity of life on the planet.

Natural Selection and Evolutionary Processes

In the nineteenth century, two naturalists—Charles Darwin and Alfred Russel Wallace—came independently to the conclusion that evolution occurs by means of a process called natural selection. Charles Darwin is the more famous of the two because he wrote a book called *On the Origin of Species,* which presented much data to substantiate the occurrence of evolution by natural selection. Since that time, evolution has become the core concept of biology because the theory explains so many different types of observations in every field of biology.

The process of **natural selection** is the mechanism of evolutionary change and is based on how a population changes in response to its environment. Environments may change due to the influence of living factors (such as a new predator) or nonliving factors (such as temperature). As the environment changes over time, some individuals of a species may possess certain adaptations that make them better suited to the new environment. Individuals of a species that are better adapted to their environment tend to live longer and produce more offspring than other individuals. This differential

Connections: Health

How does evolution affect me personally?

In the presence of an antibiotic, resistant bacteria are selected to reproduce over and over again, until the entire population of bacteria becomes resistant to the antibiotic. In 1959, a new antibiotic called methicillin became available to treat bacterial (staph) infections that were already resistant to penicillin. In 1974, 2% of the staph infections were classified as MRSA (methicillin-resistant *Staphylococcus aureus*), but by 2004 the number had risen to 63%. In response, the Centers for Disease Control and Prevention conducted an aggressive campaign to educate health-care workers about preventing MRSA infections. The program was very successful, and between 2005 and 2008 the number of MRSA infections in hospitals declined by 28%. However, MRSA remains an important concern of the medical community.

reproductive success, called natural selection, results in changes in the characteristics of a population over time. That is, adaptations that result in higher reproductive success tend to increase in frequency in a population from one generation to the next. This change in the frequency of traits in populations is called evolution.

The phrase "common descent with modification" sums up the process of evolution because it means that, as descent occurs from common ancestors, modifications occur that cause the organisms to be adapted (suited) to the environment. As a result, one species can be a common ancestor to several species, each adapted to a particular set of environmental conditions. Specific adaptations allow species to play particular roles in their environment.

The Hawaiian honeycreepers are a remarkable example of this process (**Fig. 1.7**). The more than 50 species of honeycreepers all evolved from one species of finch, which likely originated in North America and arrived in the Hawaiian islands between 3 and 5 million years ago. Modern honeycreepers have an assortment of bill shapes adapted to different types of food. Some honeycreeper species have curved, elongated bills used for drinking flower nectar. Others have strong, hooked bills suited to digging in tree bark and seizing wood-boring insects or short, straight, finchlike bills for feeding on small seeds and fruits. Even with such dramatic differences in feeding habits and bill shapes, honeycreepers still share certain characteristics, which stem from their common finch ancestor. The various honeycreeper species are similar in body shape and size, as well as mating and nesting behavior.

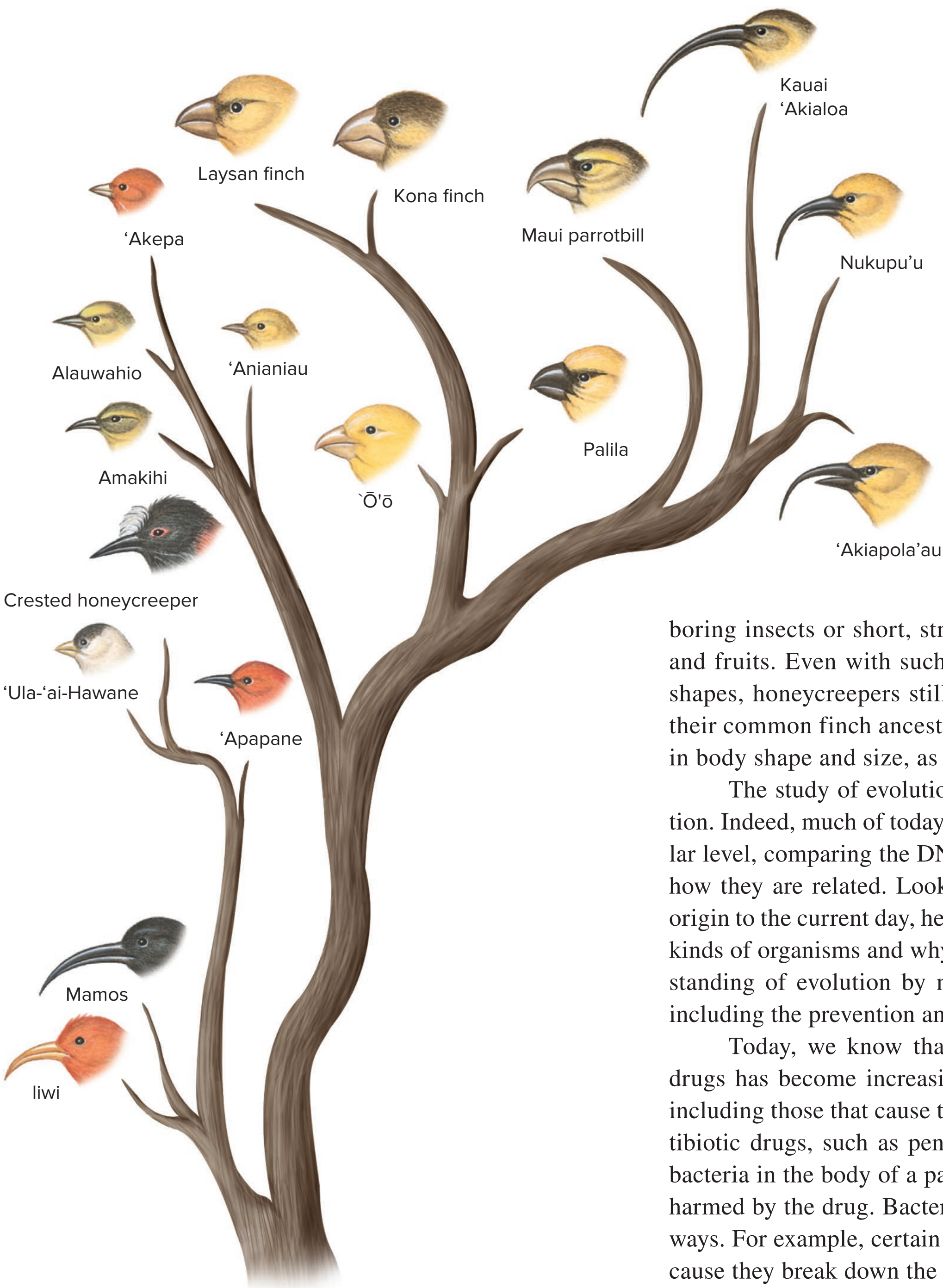


Figure 1.7 **Evolution of Hawaiian honeycreepers.**

Hawaiian honeycreepers, descendants of a single ancestral species, display an amazing diversity of bill shapes and sizes.

The study of evolution encompasses all levels of biological organization. Indeed, much of today's evolution research is carried out at the molecular level, comparing the DNA of different groups of organisms to determine how they are related. Looking at how life has changed over time, from its origin to the current day, helps us understand why there are so many different kinds of organisms and why they have the characteristics they do. An understanding of evolution by natural selection also has practical applications, including the prevention and treatment of disease.

Today, we know that, because of selection, resistance to antibiotic drugs has become increasingly common in a number of bacterial species, including those that cause tuberculosis, gonorrhea, and staph infections. Antibiotic drugs, such as penicillin, kill susceptible bacteria. However, some bacteria in the body of a patient undergoing antibiotic treatment may be unharmed by the drug. Bacteria can survive antibiotic drugs in many different ways. For example, certain bacteria can endure treatment with penicillin because they break down the drug, rendering it harmless. If even one bacterial cell lives because it is antibiotic-resistant, then its descendants will inherit this drug-defeating ability. The more antibiotic drugs are used, the more natural selection favors resistant bacteria, and the more often antibiotic-resistant infections will occur.

Organizing the Diversity of Life

Think of an enormous department store, offering thousands of different items for sale. The various items are grouped in departments—electronics, apparel, furniture, and so on—to make them easy for customers to find. Because life is so diverse, it is helpful to have a system that groups organisms into categories. Two areas of biology help us group organisms into categories: **Taxonomy** is the discipline of identifying and naming organisms according to certain rules, and **systematics** makes sense out of the bewildering variety of life on Earth by classifying organisms according to their presumed evolutionary relationships. As systematists learn more about evolutionary relationships between species, the taxonomy of a given organism may change. Systematists are even now making observations and performing experiments that will one day bring about changes in the classification system adopted by this text.

Categories of Classification

The classification categories, from least inclusive to most inclusive, are species, **genus, family, order, class, phylum, kingdom,** and **domain** (**Table 1.1**). Each successive category above species contains more types of organisms than the preceding one. Species placed within one genus share many specific characteristics and are the most closely related, while species placed in the same domain share only general characteristics. For example, all species in the genus *Pisum* look pretty much the same—that is, like pea plants—but species in the plant kingdom can be quite varied, as is evident when we compare grasses with trees. By the same token, only modern humans are in the genus *Homo,* but many types of species, from tiny hydras to huge whales, are members of the animal kingdom. Species placed in different domains are the most distantly related. For now, we will focus on the general characteristics of the domains and kingdoms of life.

Domains

The most inclusive and general levels of classification are the domains (**Table 1.2**). Biochemical evidence (obtained from the study of DNA and proteins) suggests that there are only three domains of life: **domain Bacteria, domain Archaea,** and **domain Eukarya.** Both domain Archaea and domain Bacteria contain prokaryotes. Prokaryotes are single-celled, and they lack the membrane-bound nucleus found in the eukaryotes of domain Eukarya.

Prokaryotes are structurally simple but metabolically complex. Archaea live in aquatic environments that lack oxygen or are too salty, too hot, or too acidic for most other organisms. Perhaps these environments are similar to those of the primitive Earth and archaea are representative of the first cells that evolved. Bacteria are found almost everywhere—in the water, soil, and atmosphere, as well as on our skin and in our mouths and large intestines. Although some bacteria cause diseases, others perform useful services, both environmental and commercial. For example, they are used to conduct genetic research in our laboratories (the *E. coli* in Table 1.2 is one example), to produce innumerable products in our factories, and to purify water in our sewage treatment plants.

Kingdoms

Systematicists are just beginning to understand how to categorize domain Archaea and domain Bacteria into kingdoms. Currently, there are four kingdoms

Table 1.1 Levels of Biological Organization

Category	Human	Corn
Domain	Eukarya	Eukarya
Kingdom	Animalia	Plantae
Phylum	Chordata	Anthophyta
Class	Mammalia	Liliopsida
Order	Primates	Commelinales
Family	Hominidae	Poaceae
Genus	*Homo*	*Zea*
Species*	*H. sapiens*	*Z. mays*

* To specify an organism, you must use the full binomial name, such as *Homo sapiens.*