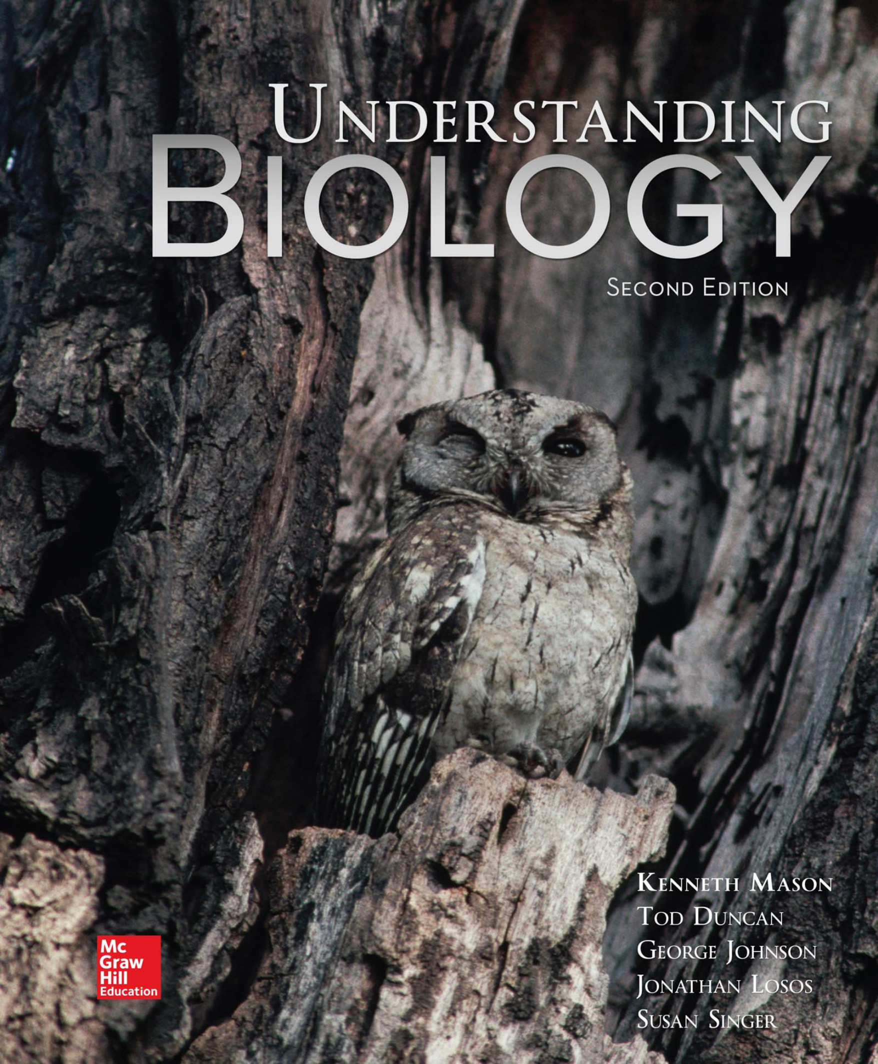

UNDERSTANDING BIOLOGY

SECOND EDITION

KENNETH MASON
TOD DUNCAN
GEORGE JOHNSON
JONATHAN LOSOS
SUSAN SINGER

Mc Graw Hill Education

Understanding Biology

Second Edition

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UNDERSTANDING BIOLOGY, SECOND EDITION

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Brief Contents

About the Authors

© Kenneth Mason

Kenneth Mason maintains an association with the University of Iowa, Department of Biology after having served as a faculty member for eight years. His academic positions, as a teacher and researcher, include the faculty of the University of Kansas, where he designed and established the genetics lab, and taught and published on the genetics of pigmentation in amphibians. At Purdue University, he successfully developed and grew large introductory biology courses and collaborated with other faculty in an innovative biology, chemistry, and physics course supported by the National Science Foundation. At the University of Iowa, where his wife served as president of the university, he taught introductory biology and human genetics. His honor society memberships include Phi Sigma, Alpha Lambda Delta, and, by vote of Purdue pharmacy students, Phi Eta Sigma Freshman Honors Society.

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Tod Duncan is a Clinical Assistant Professor at the University of Colorado Denver. He currently teaches first semester general biology and coordinates first and second semester general biology laboratories. Previously, he taught general microbiology, virology, the biology of cancer, medical microbiology, and cell biology. A bachelor's degree in cell biology with an emphasis on plant molecular and cellular biology from the University of East Anglia in England led to doctoral studies in cell cycle control, and postdoctoral research on the molecular and biochemical mechanisms of DNA alkylation damage *in vitro* and in *Drosophila melanogaster*. Currently, he is interested in factors affecting retention and success of incoming first-year students in diverse demographics. He lives in Boulder, Colorado, with his two Great Danes, Eddie and Henry.

© George Johnson

George Johnson is professor emeritus of biology at Washington University in Saint Louis, where he taught genetics to biology majors and freshman biology to nonmajors for 35 years. Also professor of genetics at Washington University School of Medicine, his research in population genetics focused on genetic variation in alpine butterflies. He has published more than 40 scientific articles and authored six college texts, including *Biology, The Living World,* and *Essentials of the Living World,* as well as the widely used high school biology textbook *Holt Biology.* In the 30 years he has been authoring biology texts, over 3 million students have been taught from textbooks he has written.

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Jonathan Losos is the Monique and Philip Lehner Professor for the Study of Latin America in the Department of Organismic and Evolutionary Biology and curator of herpetology at the Museum of Comparative Zoology at Harvard University. Losos's research has focused on studying patterns of adaptive radiation and evolutionary diversification in lizards. He is the recipient of several awards, including the prestigious Theodosius Dobzhanksy and David Starr Jordan Prizes, the Edward Osborne Wilson Naturalist Award, and the Daniel Giraud Elliot Medal from the National Academy of Sciences. Losos has published more than 100 scientific articles.

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Susan Rundell Singer is the Laurence McKinley Gould Professor of Natural Sciences in the Department of Biology at Carleton College in Northfield, Minnesota, where she has taught introductory biology, plant biology, genetics, and plant development for 26 years. Her research focuses on the development and evolution of flowering plants and genomics learning. Singer has authored numerous scientific publications on plant development and co-authored education reports, including *Vision and Change* and "America's Lab Report." She received the American Society of Plant Biology's Excellence in Teaching Award and the Botanical Society's Bessey Award, is an AAAS fellow, served on the National Academies Board on Science Education, and chaired several National Research Council study committees, including the committee that produced *Discipline-Based Education Research*.

© Ian J. Quitadamo, Ph.D.

Ian Quitadamo Lead Digital Author is a Professor with a dual appointment in Biological Sciences and Science Education at Central Washington University in Ellensburg, Washington. He teaches introductory and majors biology courses and cell biology, genetics, and biotechnology, as well as science teaching methods courses for future science teachers and interdisciplinary content courses in alternative energy and sustainability. Dr. Quitadamo was educated at Washington State University and holds a BA in biology, Masters degree in genetics and cell biology, and an interdisciplinary Ph.D. in science, education, and technology. Previously a researcher of tumor angiogenesis, he now investigates the behavioral and neurocognitive basis of critical thinking and has published numerous studies of factors that improve student critical thinking performance. He has led multiple initiatives in critical thinking and assessment, and is active nationally in helping transform university faculty practice.

Note to the Student

More than most subjects, biology is at its core a set of ideas and if you can master these basic ideas, you have a framework to fit in the increasingly detailed information that will continue to accumulate. This book has been designed to help you do just that. We have focused *Understanding Biology,* second edition, right where you need help—on the core ideas.

In keeping with that goal, the book provides a clear pathway through the forest of facts that can bog down your understanding of biology. Each chapter begins with a Learning Path that introduces the major concepts for the chapter. Then within each section these larger concepts are broken down into their supporting, more specific concepts. Each of these comes with a learning objective that tells you what you should be able to do upon completing the section, and each section has a brief review with a question to help you think about the concepts.

The key to this organization, and more important, to the content, is that you now have a book that presents the important concepts of biology and supporting detail, but with a greater focus on understanding. The organization also lends itself well to the digital tools that accompany the text. *Understanding Biology,* second edition, is part of a family of learning tools, both print and digital, that are designed to help you understand biology and be successful in your studies.

Note to the Professor

Everyone teaching biology has been affected by the wave of change sweeping over college instruction these days. Digital technologies have set off a revolution in how we teach, from online course management to interactive and adaptive assessment; almost everything we do as instructors has changed. Yet the textbook itself has not changed significantly. In fact, over the last 25 years we have seen the evolution of the encyclopedic text. These tomes of biology were wonderful to catalog information but not necessarily to teach or learn biology in the ever-changing classroom. This book represents an attempt to rethink how to present biology to the modern student.

Rather than remove context and supporting information, we have simply removed material that is not taught in most classes. This allows us to focus on the concepts that are actually taught. In deciding what to include and what to eliminate, we didn’t rely solely on our own experiences. Rather, we asked instructors across the country what chapters in a majors biology text they taught, and what chapters they did not. Through a combination of an analysis of course syllabi, custom orders, surveys, and reviews of preliminary versions of the text, you, the professors, have helped us identify course topics. It may come as no surprise that most majors biology courses cover much of the material in the first half of the book: the basic concepts of cell biology, genetics, and evolution. Professors who teach the second half of the course pick and choose from chapters in the last half of the book. In this text we have also made strategic decisions on content, retaining or expanding treatment in these basic areas to provide the context to facilitate student learning. The rest of the text we have shortened. Whole chapters from a traditional text have not been eliminated, but the treatments have become more focused on the key concepts, with unnecessary detailed reduced.

We also focused on helping students develop critical-thinking skills that will serve them well into the future. *Understanding Biology,* second edition, provides two features that help develop critical thinking: end-of-chapter Inquiry & Analysis and end-of-part Connecting the Concepts. While texts may present graphs and descriptions of experiments, they rarely give students a taste of what it is like to “think” like a scientist. The Inquiry & Analysis feature contains full-page scientific investigation based on real experiments carried out by laboratory scientists and published in major journals. They walk the students through the scientific process, from formulating hypotheses and experimentation through data analysis and forming conclusions. Connecting the Concepts is an end-of-part feature that help students see how topics are related under unifying concepts. Seemingly unrelated topics are unified by the same fundamental concepts that provide a framework to build knowledge upon knowledge.

We wrote this book because we have come to feel that while today’s biology textbooks reflect new content, they do little to take advantage of new instructional opportunities. What sort of text would best serve a student taking an online course? A course where classroom time is devoted to discussion rather than lecture? A course delivered by computer, with interactive learning its mode of delivery? It is to address these diverse course offerings that we have undertaken this new majors text. While *Understanding Biology,* second edition, will serve an instructor very well in a traditional lecture course supporting the lectures with detailed explanations, its aim is broader: to provide a tool that will support new teaching methods and online delivery methods as well.

Changes to This Edition

The goal of the first edition of this book was to produce a text containing the topics actually covered in the majority of introductory biology classes at the depth that these topics are being taught. The second aim was to make the text as approachable to the student as possible. In this revision, we have not changed the material covered, as our research for the first edition already indicated what is being taught. Instead, we have tried to improve the readability for the student. One particular focus was cleaning up loose use of language in discussing chemical topics, especially those related to energy and chemical bonds. We have attempted to make the treatment of chemical and physical concepts as accurate as possible, as well as presented for maximum readability for the student.

Part I The Molecular Basis of Life

Chapter 1 The chapter was updated to clarify the relationship between modern domains and traditional kingdoms. The section on important concepts to biology was rewritten to reflect new use of these concepts in the Connecting the Concepts feature presented at the end of every Part. Other edits were made for clarity and readability for students.

Chapter 2 Minor edits were made for clarity. Most edits were related to the nature of chemical bonds, and to the role of water in living systems.

Chapter 3 Edits were made to clarify the nature of energy in living systems, including the role of ATP. The text was edited to clarify the behavior of lipids in water. The figure on the formation of peptide bonds was modified to show amino acids in ionized form as they would be under physiological conditions. All changes increase accuracy and readability for students.

Part II Biology of the Cell

Chapter 4 The discussion of the structure and role of proteasome were updated, including evolutionary implications. The section on cell junctions was edited to reduce confusing language and increase consistency.

Chapter 5 The material on transmembrane domains was completely rewritten to reduce confusing language and improve readability. The material on the role of membrane proteins was edited to improve accuracy and clarity.

Chapter 6 The chapter was rewritten to improve the presentation of concepts of energy. Material was edited to present the material in more chemically appropriate language. Material on thermodynamics was rewritten to increase accuracy and readability for students. A new figure on entropy was included to remove confusion introduced by the old figure.

Chapter 7 The chapter was rewritten to clarify concepts about energy metabolism and make the discussions more chemically accurate. Edits were also made to improve clarity and readability.

Chapter 8 Material was rewritten to clarify the nature of energy transactions during photosynthesis. Editing improves clarity and readability of presentation.

Chapter 9 The material on the nature of receptors was rewritten for clarity and accuracy. Material on RTKs and GPCRs was rewritten for clarity and accuracy.

Chapter 10 The material on chromosome compaction was rewritten for clarity and accuracy. The section on cancer was completely rewritten to introduce new material on genomics of cancer and provide a more modern view.

Part III Genetics and Molecular Biology

Chapter 11 The material on the synaptonemal complex throughout the chapter was updated and rewritten for clarity. This includes a new drawing of the synaptonemal complex, replacing an EM image that was more difficult to see. The nature of monopolar attachment to the spindle was clarified.

Chapter 12 The figure showing the relationship of genotype to phenotype was moved from chapter 15 to this chapter, where it provides a much better context for students. The section on extensions to Mendel was rewritten for clarity.

Chapter 13 The section on linkage was rewritten to improve clarity of this difficult concept. The material on genetic mapping was also rewritten to improve readability for students. Information about SNPs in humans was updated, as was the material on source of changes in chromosome number. The section on human genetic diseases and prenatal screening was rewritten and updated. The material on genomic imprinting was updated to reflect new information.

Chapter 14 The section on DNA structure was rewritten to clarify the organic chemistry terminology used to describe nucleotides. The description of the Watson–Crick structure of DNA was edited for clarity. The description of how telomerase functions was updated and rewritten to clarify action of the enzyme. The discussion of *E. coli* polymerases was updated and rewritten for clarity.

Chapter 15 The Beadle and Tatum experiment and presentation of the central dogma were rewritten for clarity and readability. The material on eukaryotic transcription was updated to reflect new information from genome-wide scans providing a new view of polymerase pausing and promoter usage. The material on the integration of transcription and splicing was updated to provide a more modern view. The section on mutations was completely rewritten to reflect new data on human mutation rates.

Chapter 16 The material on eukaryotic promoters and transcription factors was updated to provide a more modern view of the control of transcription. The section on the relationship between chromatin structure and the control of gene expression was

	completely rewritten to incorporate new data and present a more modern view of this critical topic.
Chapter 17	The material on PCR was updated to include reverse-transcription PCR (RT-PCR) and quantitative RT-PCR. New sections were added to provide a more contemporary perspective on molecular techniques used in biotechnology. Modern techniques for investigating gene function were added, including RNA interference, knockin mice, and the CRISPR genome editing technology. Two new sections on modern applications of biotechnology were added, which include the use of fluorescent *in-situ* hybridization and gene chips in medical diagnostics.
Chapter 18	The section on genome sequencing was updated to reflect current high-throughput technologies. The material on the Human Genome Project was updated to include information about the Cancer Genome Project, and new material on the wheat genome project reveals the challenges of sequencing larger, repetitive genomes. The section on bioinformatics was updated to include material on the use of mass spectrometry in proteomics.

Part IV Evolution

Chapter 19	The section on variation in natural populations was completely rewritten to take into account new data. This includes extensive material on variation in human populations. Learning objectives throughout were rewritten for consistency and clarity.
Chapter 20	The chapter was edited throughout for clarity and consistency. The material on biogeography was updated and rewritten for clarity.
Chapter 21	The chapters was edited throughout for increased readability for students. The material on biological species concept and speciation was rewritten to improve clarity.

Part V The Diversity of Life

Chapter 22	The material on cladistics was edited for clarity and readability. The material on the evolution of multicellularity was edited for clarity.
Chapter 23	The prokaryotic genetics section was rewritten for clarity and to provide a modern perspective to complement the historical material. The material on human diseases caused by infectious agents was updated. A section on giant viruses was added to provide information on this exciting new area.
Chapter 24	The chapter was updated for accuracy, with new material added on control and treatment of malaria.
Chapter 25	Updates focused on emphasizing the relationships between structure and function in fungal forms. The chapter was restructured, moving the more applied aspects of mycology to the front of the chapter. Changes to the Chytridiomycota section reflect current thinking in terms of fungal phylogeny. The chapter was also edited for readability and clarity.
Chapter 26	Edits throughout emphasize the adaptations made by plants as they transitioned from an aquatic existence to a terrestrial one. The chapter was edited for clarity and readability.
Chapter 27	The chapter was edited throughout for clarity and readability.

Part VI Plant Form and Function

Chapter 29	Changes were made to section headings to emphasize the key message of the section. The chapter was edited for clarity and readability.
Chapter 30	The chapter was edited throughout for clarity and readability.
Chapter 31	The chapter was edited throughout for clarity and readability.

Part VII Animal Form and Function

Chapter 32	The material on tissue types was rewritten to improve readability, and a new figure was added showing the different types of epithelial tissue. The table showing different types of neurons was changed to a new figure to improve clarity. The material on animal locomotion was edited for accuracy and clarity.
Chapter 33	The material on supporting cells was updated to include new information. The description of membrane potential and action potentials was rewritten to improve clarity and readability.
Chapter 34	The chapter throughout was edited for clarity and readability.
Chapter 35	The material on distinctions between receptor types was rewritten for clarity. A discussion of the ability of steroid hormones to act via membrane receptors was added to update the material in this section. The section on the action and control of G proteins in signaling was updated and rewritten. Material on osmoregulation in fresh- and saltwater fish was added.
Chapter 36	The material on blocks to polyspermy was updated for clarity and accuracy. The section on embryonic stem cells and the the reversal of determination was extensively updated to include new data and provide context for the student.

Part VIII Ecology and Behavior

Chapter 37	The chapter was edited throughout for clarity and readability.
Chapter 38	The chapter was edited for clarity and accuracy. The data on human populations was updated.
Chapter 39	The material on mimicry was rewritten for clarity and accuracy. The material on keystone predator and succession was updated for accuracy and readability.
Chapter 40	The chapter was edited throughout for clarity and readability.

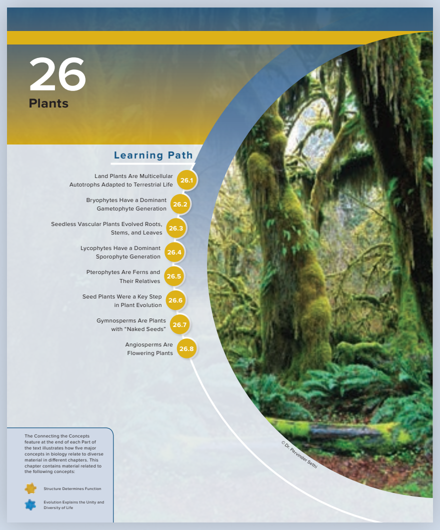
A Learning Path to *Understanding Biology*

Understanding Biology and its online assets have been carefully thought out and crafted to help students and professors work efficiently and effectively through the material in the course, making the most of study time and instructional goals.

The Learning Path

Each chapter is organized in a way that guides the student through the key concepts.

Every chapter opens with a Learning Path that walks through the main concepts in the chapter. This helps you understand where the material fits in the context of other concepts in the chapter.



26

Plants

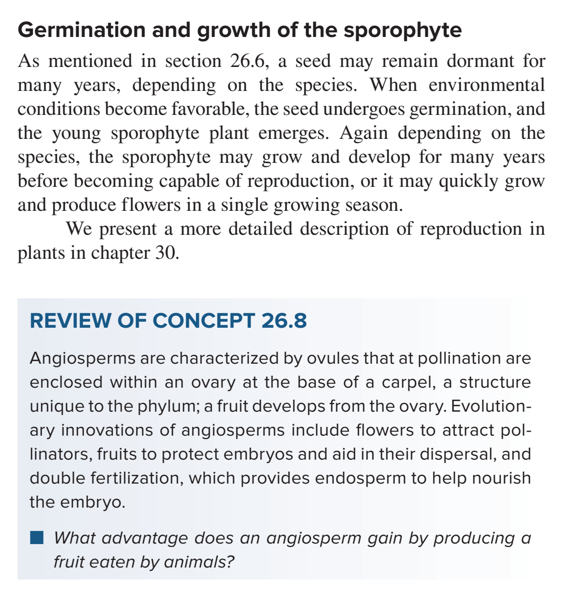
Learning Path

- 26.1 Land Plants Are Multicellular Autotrophs Adapted to Terrestrial Life
- 26.2 Bryophytes Have a Dominant Gametophyte Generation
- 26.3 Seedless Vascular Plants Evolved Roots, Stems, and Leaves
- 26.4 Lycophytes Have a Dominant Sporophyte Generation
- 26.5 Pterophytes Are Ferns and Their Relatives
- 26.6 Seed Plants Were a Key Step in Plant Evolution
- 26.7 Gymnosperms Are Plants with "Naked Seeds"
- 26.8 Angiosperms Are Flowering Plants

The Connecting the Concepts feature at the end of each Part of the text illustrates how five major concepts in biology relate to diverse material in different chapters. This chapter contains material related to the following concepts:

- Structure Determines Function
- Evolution Explains the Unity and Diversity of Life

The chapter opening pages contain icons that link to the "Connecting the Concepts" feature that follow each Part in the text. The Connecting the Concepts show how concepts presented in different chapters are related, connected by unifying concepts in biology. These icons indicate what unifying concepts are illustrated by the content in the chapter.



Germination and growth of the sporophyte

As mentioned in section 26.6, a seed may remain dormant for many years, depending on the species. When environmental conditions become favorable, the seed undergoes germination, and the young sporophyte plant emerges. Again depending on the species, the sporophyte may grow and develop for many years before becoming capable of reproduction, or it may quickly grow and produce flowers in a single growing season.

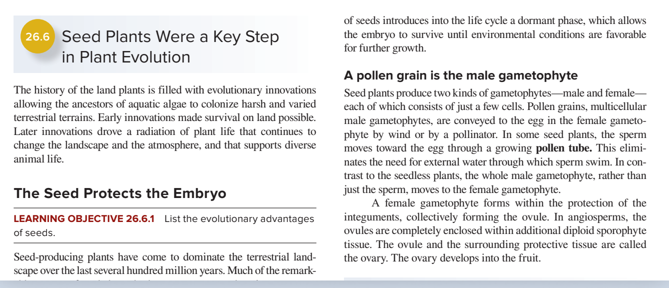
We present a more detailed description of reproduction in plants in chapter 30.

REVIEW OF CONCEPT 26.8

Angiosperms are characterized by ovules that at pollination are enclosed within an ovary at the base of a carpel, a structure unique to the phylum; a fruit develops from the ovary. Evolutionary innovations of angiosperms include flowers to attract pollinators, fruits to protect embryos and aid in their dispersal, and double fertilization, which provides endosperm to help nourish the embryo.

- *What advantage does an angiosperm gain by producing a fruit eaten by animals?*

At the end of each section, Review of Concept questions allow you to check your understanding before moving on to the next concept.



26.6 Seed Plants Were a Key Step in Plant Evolution

The history of the land plants is filled with evolutionary innovations allowing the ancestors of aquatic algae to colonize harsh and varied terrestrial terrains. Early innovations made survival on land possible. Later innovations drove a radiation of plant life that continues to change the landscape and the atmosphere, and that supports diverse animal life.

The Seed Protects the Embryo

LEARNING OBJECTIVE 26.6.1 List the evolutionary advantages of seeds.

Seed-producing plants have come to dominate the terrestrial landscape over the last several hundred million years. Much of the remark-

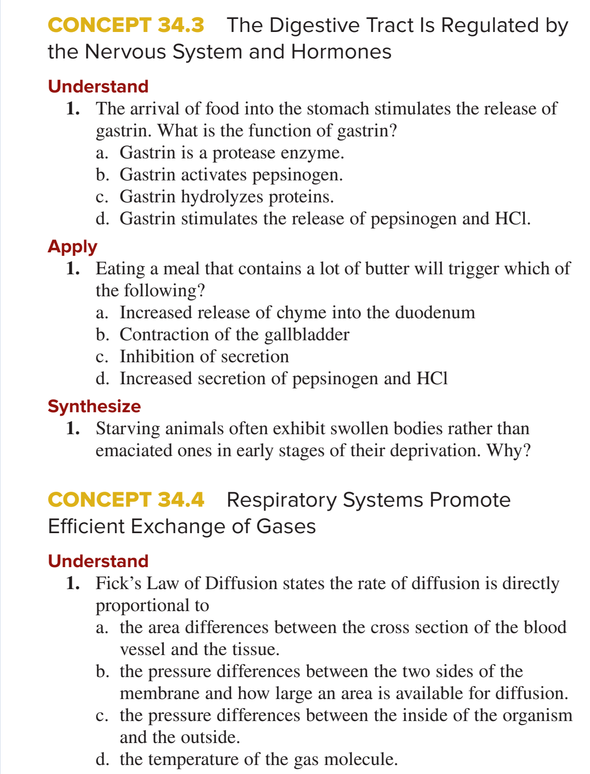
of seeds introduces into the life cycle a dormant phase, which allows the embryo to survive until environmental conditions are favorable for further growth.

A pollen grain is the male gametophyte

Seed plants produce two kinds of gametophytes—male and female—each of which consists of just a few cells. Pollen grains, multicellular male gametophytes, are conveyed to the egg in the female gametophyte by wind or by a pollinator. In some seed plants, the sperm moves toward the egg through a growing **pollen tube.** This eliminates the need for external water through which sperm swim. In contrast to the seedless plants, the whole male gametophyte, rather than just the sperm, moves to the female gametophyte.

A female gametophyte forms within the protection of the integuments, collectively forming the ovule. In angiosperms, the ovules are completely enclosed within additional diploid sporophyte tissue. The ovule and the surrounding protective tissue are called the ovary. The ovary develops into the fruit.

Every concept is broken down into sections that cover skills or ideas you should master. Learning objectives at the beginning of each section help you identify important concepts.



CONCEPT 34.3 The Digestive Tract Is Regulated by the Nervous System and Hormones

Understand

1. The arrival of food into the stomach stimulates the release of gastrin. What is the function of gastrin?
   a. Gastrin is a protease enzyme.
   b. Gastrin activates pepsinogen.
   c. Gastrin hydrolyzes proteins.
   d. Gastrin stimulates the release of pepsinogen and HCl.

Apply

1. Eating a meal that contains a lot of butter will trigger which of the following?
   a. Increased release of chyme into the duodenum
   b. Contraction of the gallbladder
   c. Inhibition of secretion
   d. Increased secretion of pepsinogen and HCl

Synthesize

1. Starving animals often exhibit swollen bodies rather than emaciated ones in early stages of their deprivation. Why?

CONCEPT 34.4 Respiratory Systems Promote Efficient Exchange of Gases

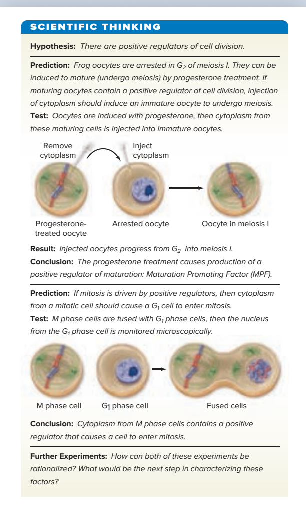
Understand

1. Fick's Law of Diffusion states the rate of diffusion is directly proportional to
   a. the area differences between the cross section of the blood vessel and the tissue.
   b. the pressure differences between the two sides of the membrane and how large an area is available for diffusion.
   c. the pressure differences between the inside of the organism and the outside.
   d. the temperature of the gas molecule.

At the end of the chapter, each concept is assessed at three different levels. On your first pass through the chapter prior to class, you will want to focus on questions at the "Understand" level. As you gain greater mastery, you can challenge yourself with Apply and Synthesize questions that require higher cognitive skills.

Think Like a Scientist

Scientific Thinking figures throughout the text walk you through a scientific experiment, laying out the Hypothesis, Predictions, Test Procedures, Results, and Conclusion. Some also challenge you to devise further experiments.



SCIENTIFIC THINKING

Hypothesis: *There are positive regulators of cell division.*

Prediction: *Frog oocytes are arrested in G_2 of meiosis I. They can be induced to mature (undergo meiosis) by progesterone treatment. If maturing oocytes contain a positive regulator of cell division, injection of cytoplasm should induce an immature oocyte to undergo meiosis.*

Test: *Oocytes are induced with progesterone, then cytoplasm from these maturing cells is injected into immature oocytes.*

Result: *Injected oocytes progress from G_2 into meiosis I.*

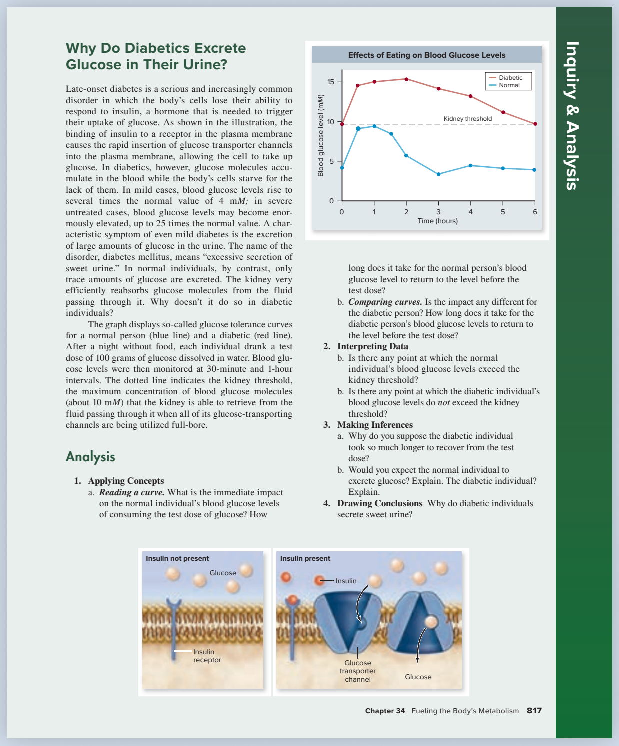
Conclusion: *The progesterone treatment causes production of a positive regulator of maturation: Maturation Promoting Factor (MPF).*

Prediction: *If mitosis is driven by positive regulators, then cytoplasm from a mitotic cell should cause a G_1 cell to enter mitosis.*

Test: *M phase cells are fused with G_1 phase cells, then the nucleus from the G_1 phase cell is monitored microscopically.*

Conclusion: *Cytoplasm from M phase cells contains a positive regulator that causes a cell to enter mitosis.*

Further Experiments: *How can both of these experiments be rationalized? What would be the next step in characterizing these factors?*



Why Do Diabetics Excrete Glucose in Their Urine?

Late-onset diabetes is a serious and increasingly common disorder in which the body's cells lose their ability to respond to insulin, a hormone that is needed to trigger their uptake of glucose. As shown in the illustration, the binding of insulin to a receptor in the plasma membrane causes the rapid insertion of glucose transporter channels into the plasma membrane, allowing the cell to take up glucose. In diabetics, however, glucose molecules accumulate in the blood while the body's cells starve for the lack of them. In mild cases, blood glucose levels rise to several times the normal value of 4 m*M;* in severe untreated cases, blood glucose levels may become enormously elevated, up to 25 times the normal value. A characteristic symptom of even mild diabetes is the excretion of large amounts of glucose in the urine. The name of the disorder, diabetes mellitus, means "excessive secretion of sweet urine." In normal individuals, by contrast, only trace amounts of glucose are excreted. The kidney very efficiently reabsorbs glucose molecules from the fluid passing through it. Why doesn't it do so in diabetic individuals?

The graph displays so-called glucose tolerance curves for a normal person (blue line) and a diabetic (red line). After a night without food, each individual drank a test dose of 100 grams of glucose dissolved in water. Blood glucose levels were then monitored at 30-minute and 1-hour intervals. The dotted line indicates the kidney threshold, the maximum concentration of blood glucose molecules (about 10 m*M*) that the kidney is able to retrieve from the fluid passing through it when all of its glucose-transporting channels are being utilized full-bore.

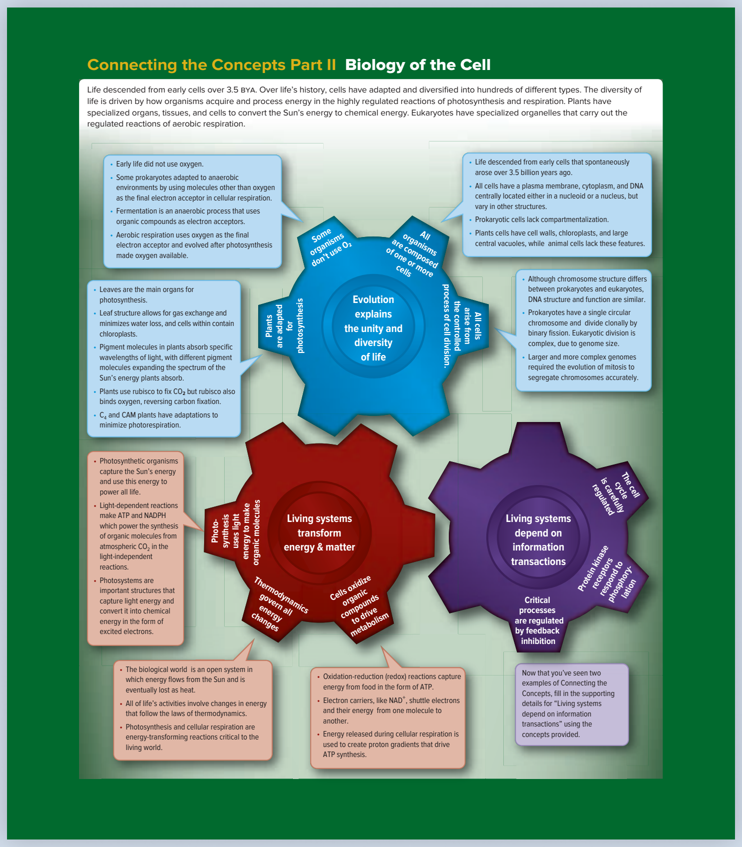
Analysis

1. **Applying Concepts**
   a. ***Reading a curve.*** What is the immediate impact on the normal individual's blood glucose levels of consuming the test dose of glucose? How long does it take for the normal person's blood glucose level to return to the level before the test dose?
   b. ***Comparing curves.*** Is the impact any different for the diabetic person? How long does it take for the diabetic person's blood glucose levels to return to the level before the test dose?
2. **Interpreting Data**
   b. Is there any point at which the normal individual's blood glucose levels exceed the kidney threshold?
   b. Is there any point at which the diabetic individual's blood glucose levels do *not* exceed the kidney threshold?
3. **Making Inferences**
   a. Why do you suppose the diabetic individual took so much longer to recover from the test dose?
   b. Would you expect the normal individual to excrete glucose? Explain. The diabetic individual? Explain.
4. **Drawing Conclusions** Why do diabetic individuals secrete sweet urine?

Chapter 34 Fueling the Body's Metabolism **817**

Inquiry & Analysis features at the end of every chapter take you into a scientific investigation in more detail, presenting you with experimental results and challenging you to interpret the data. Associated online activities can help you practice your data analysis skills.

Uncovering Connections Between Concepts



Connecting the Concepts Part II Biology of the Cell

Life descended from early cells over 3.5 BYA. Over life's history, cells have adapted and diversified into hundreds of different types. The diversity of life is driven by how organisms acquire and process energy in the highly regulated reactions of photosynthesis and respiration. Plants have specialized organs, tissues, and cells to convert the Sun's energy to chemical energy. Eukaryotes have specialized organelles that carry out the regulated reactions of aerobic respiration.

- Early life did not use oxygen.
- Some prokaryotes adapted to anaerobic environments by using molecules other than oxygen as the final electron acceptor in cellular respiration.
- Fermentation is an anaerobic process that uses organic compounds as electron acceptors.
- Aerobic respiration uses oxygen as the final electron acceptor and evolved after photosynthesis made oxygen available.

- Life descended from early cells that spontaneously arose over 3.5 billion years ago.
- All cells have a plasma membrane, cytoplasm, and DNA centrally located either in a nucleoid or a nucleus, but vary in other structures.
- Prokaryotic cells lack compartmentalization.
- Plants cells have cell walls, chloroplasts, and large central vacuoles, while animal cells lack these features.

- Leaves are the main organs for photosynthesis.
- Leaf structure allows for gas exchange and minimizes water loss, and cells within contain chloroplasts.
- Pigment molecules in plants absorb specific wavelengths of light, with different pigment molecules expanding the spectrum of the Sun's energy plants absorb.
- Plants use rubisco to fix CO_2 but rubisco also binds oxygen, reversing carbon fixation.
- C_4 and CAM plants have adaptations to minimize photorespiration.

- Although chromosome structure differs between prokaryotes and eukaryotes, DNA structure and function are similar.
- Prokaryotes have a single circular chromosome and divide clonally by binary fission. Eukaryotic division is complex, due to genome size.
- Larger and more complex genomes required the evolution of mitosis to segregate chromosomes accurately.

- Photosynthetic organisms capture the Sun's energy and use this energy to power all life.
- Light-dependent reactions make ATP and NADPH which power the synthesis of organic molecules from atmospheric CO_2 in the light-independent reactions.
- Photosystems are important structures that capture light energy and convert it into chemical energy in the form of excited electrons.

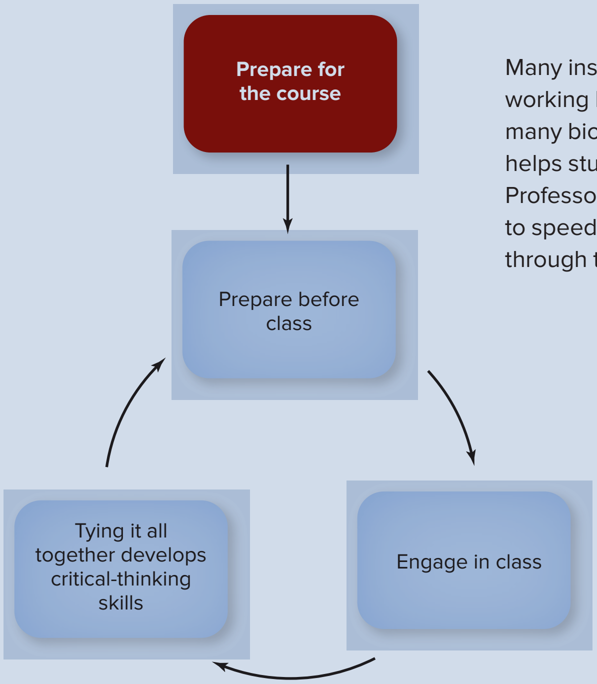
- The biological world is an open system in which energy flows from the Sun and is eventually lost as heat.
- All of life's activities involve changes in energy that follow the laws of thermodynamics.
- Photosynthesis and cellular respiration are energy-transforming reactions critical to the living world.

- Oxidation-reduction (redox) reactions capture energy from food in the form of ATP.
- Electron carriers, like NAD^+, shuttle electrons and their energy from one molecule to another.
- Energy released during cellular respiration is used to create proton gradients that drive ATP synthesis.

Now that you've seen two examples of Connecting the Concepts, fill in the supporting details for "Living systems depend on information transactions" using the concepts provided.

A "Connecting the Concepts" feature at the end of each Part in the text shows how seemingly isolated concepts in different chapters are connected by unifying concepts of biology.

Using Connect® and *Understanding Biology*, 2nd Edition



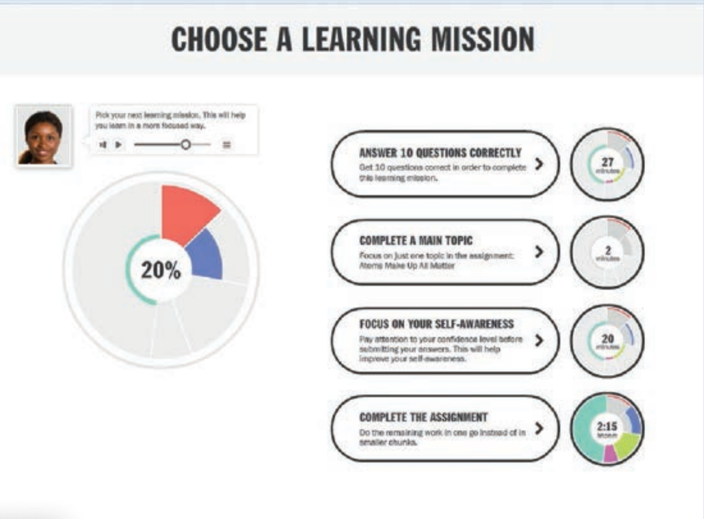
Prepare for the Course

Many institutions expect students to start a course in majors biology with a working knowledge of basic chemistry and cellular biology. For this reason, many biology students struggle the first few weeks of class. *LearnSmart Prep* helps students with this prerequisite knowledge and is now available in Connect. Professors can assign modules in LearnSmart Prep to help students get up to speed on core concepts, or students can access LearnSmart Prep directly through the LearnSmart Prep link.

Mc Graw Hill Education LEARNSMART PREP®

LearnSmart Prep is an adaptive learning tool designed to increase student success and aid retention through the first few weeks of class. Using this digital tool, majors biology students can master some of the most fundamental and challenging principles of biology before they begin to struggle in the first few weeks of class.

1 A diagnostic establishes your baseline comprehension and knowledge; then the program generates a learning plan tailored to your academic needs and schedule.



CHOOSE A LEARNING MISSION

Pick your next learning mission. This will help you learn in a more focused way.

ANSWER 10 QUESTIONS CORRECTLY
Get 10 questions correct in order to complete this learning mission.

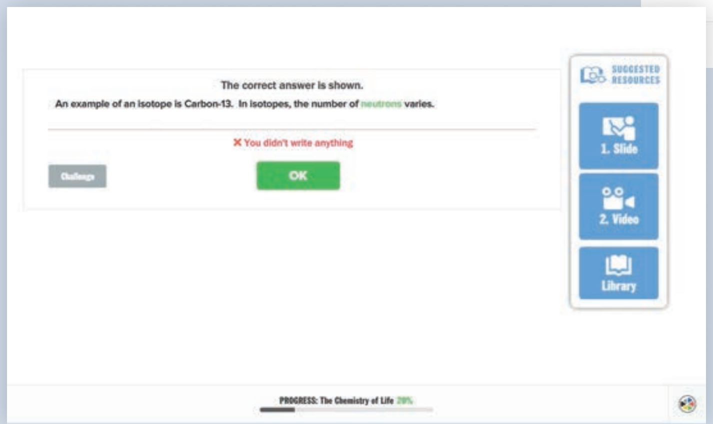
COMPLETE A MAIN TOPIC
Focus on just one topic in the assignment: Atoms Make Up All Matter

FOCUS ON YOUR SELF-AWARENESS
Pay attention to your confidence level before submitting your answers. This will help improve your self-awareness.

COMPLETE THE ASSIGNMENT
Do the remaining work in one go instead of in smaller chunks.

PROGRESS: The Chemistry of Life 20%

2 As you work through the learning plan, the program asks you questions and tracks your mastery of concepts. If you answer questions about a particular concept incorrectly, the program will provide a learning resource (e.g., animation or tutorial) on that concept, then will ensure that you understand the concept by asking you more questions. Didn't get it the first time? Don't worry—LearnSmart Prep will keep working with you!



The correct answer is shown.

An example of an isotope is Carbon-13. In isotopes, the number of neutrons varies.

✗ You didn't write anything

PROGRESS: The Chemistry of Life 20%

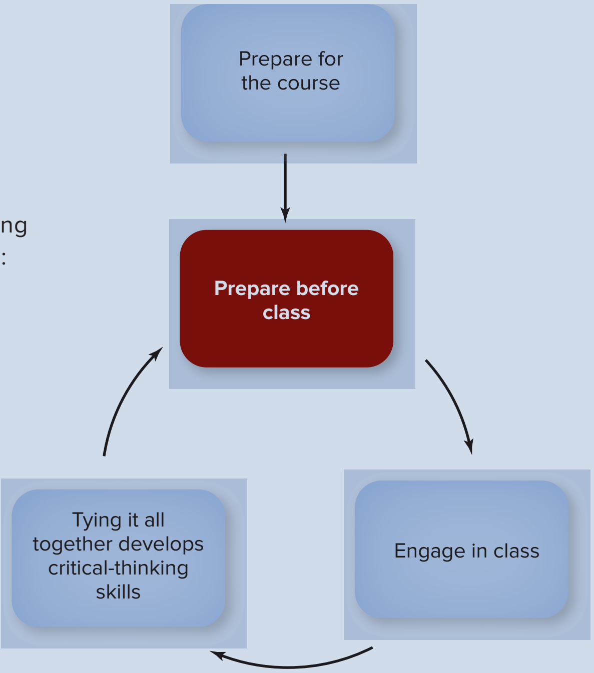
3 Using LearnSmart Prep, you can identify the content you don't understand, focus your time on content you need to know but don't, and therefore improve your chances of success in the majors biology course.

Prepare Before Class

Students who are most successful in college are those who have developed effective study skills, and who use those skills before, during, and after class.

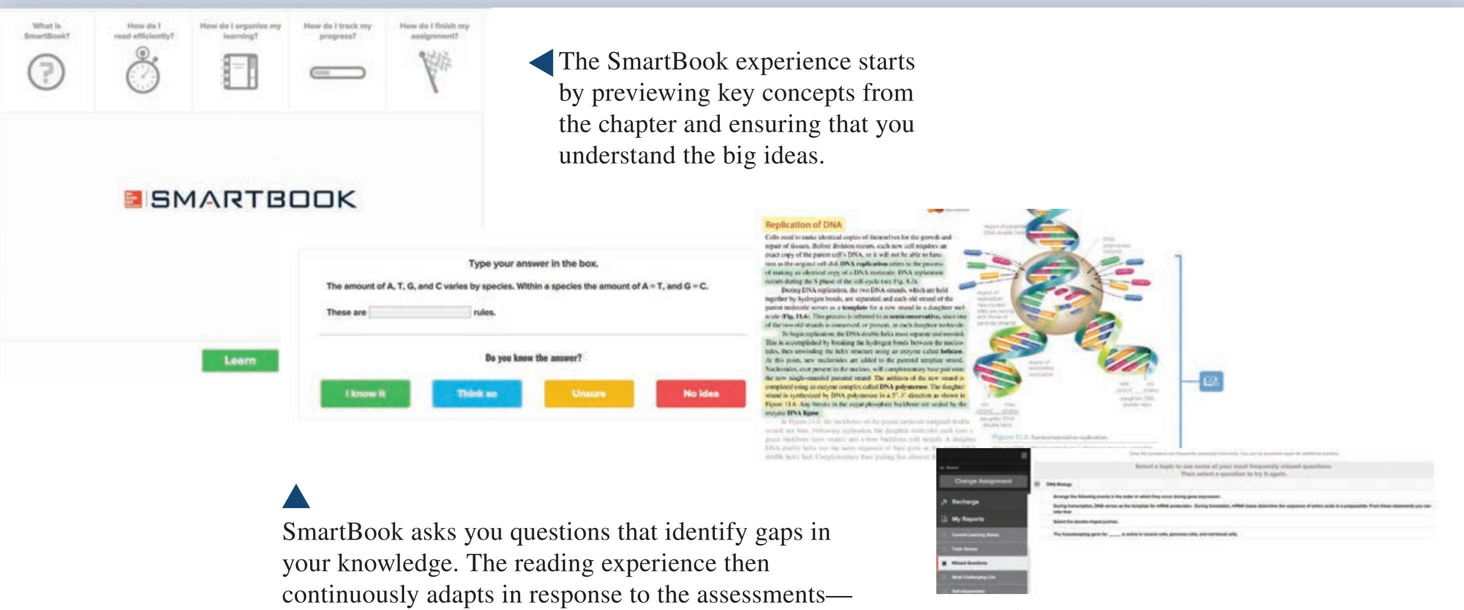
Students can maximize time in class by previewing the material before stepping into the lecture hall. *Understanding Biology,* 2nd edition, is available in two formats: the printed text as well as the online SmartBook. Students can use either of these options to preview the material before lecture. Becoming familiar with terminology and basic concepts will allow students to follow along in class and engage in the content in a way that allows for better retention.

Professors can help students prepare for class by making preclass assignments. SmartBook assignments are effective for introducing terminology and general concepts. They provide a personalized, adaptive reading experience.



SMARTBOOK®

Powered by an intelligent diagnostic and adaptive engine, **SmartBook** facilitates the reading process by identifying what content a student knows and doesn't know through adaptive assessments.



Type your answer in the box.

The amount of A, T, G, and C varies by species. Within a species the amount of A = T, and G = C.

These are ______ rules.

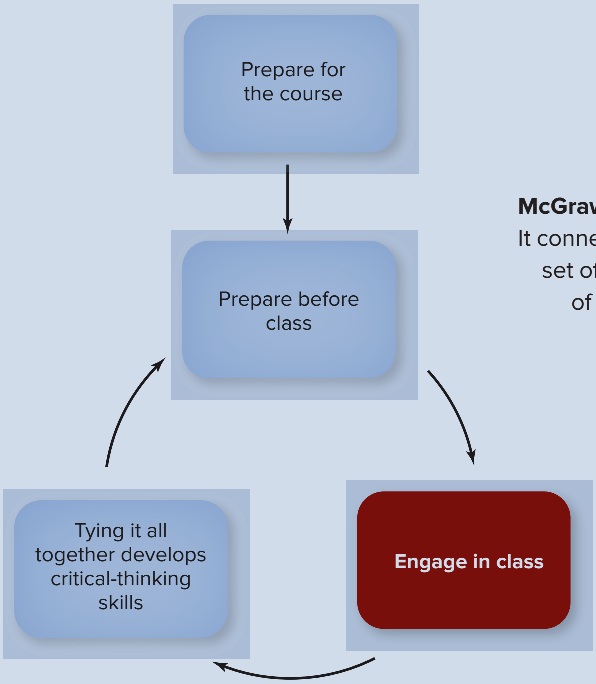
Do you know the answer?

I know it | Think so | Unsure | No idea

The SmartBook experience starts by previewing key concepts from the chapter and ensuring that you understand the big ideas.

SmartBook asks you questions that identify gaps in your knowledge. The reading experience then continuously adapts in response to the assessments—highlighting the material you need to review based on what you don't know.

The reports in SmartBook help identify topics where you need more work.

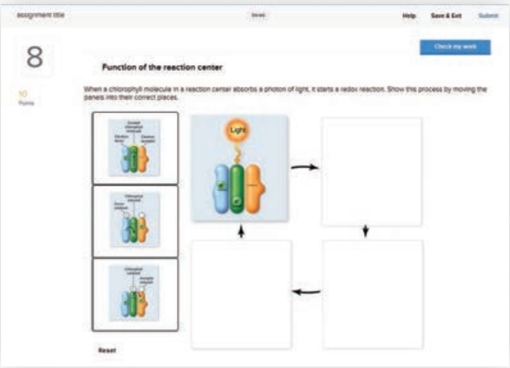


Engage in Class

McGraw-Hill Connect provides online presentation, assignment, and assessment solutions. It connects student with the tools and resources they'll need to achieve success. A robust set of questions and activities is presented in the Question Bank, and a separate set of questions to use for exams is presented in the Test Bank. Professors can track individual student performance—by question, by assignment, or in relation to the class overall—with detailed grade reports.

1 Pre-class assignments help students engage in the content during class.

Assignments are accessed through Connect and could include homework assignments, quizzes, SmartBook assignments, and other resources.

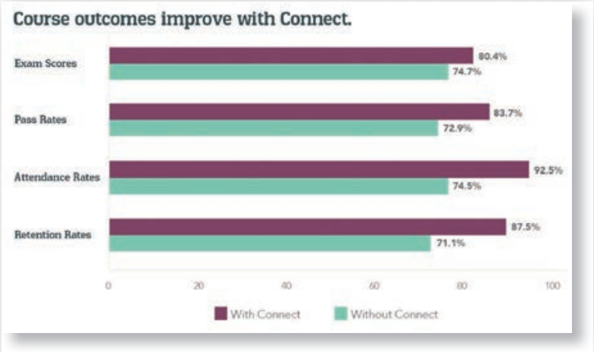


Function of the reaction center

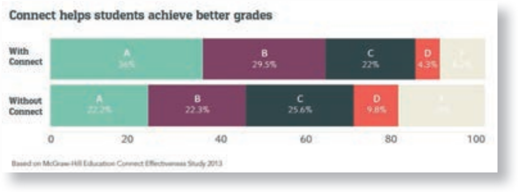
When a chlorophyll molecule in a reaction center absorbs a photon of light, it starts a redox reaction. Show this process by moving the panels into their correct places.

Interactive and traditional questions help assess students' knowledge of the material.

2 Connect Insight is Connect's visual analytics dashboard for instructors and students.



Provides at-a-glance student performance on assignments. Instructors can use the information for a just-in-time approach to teaching.



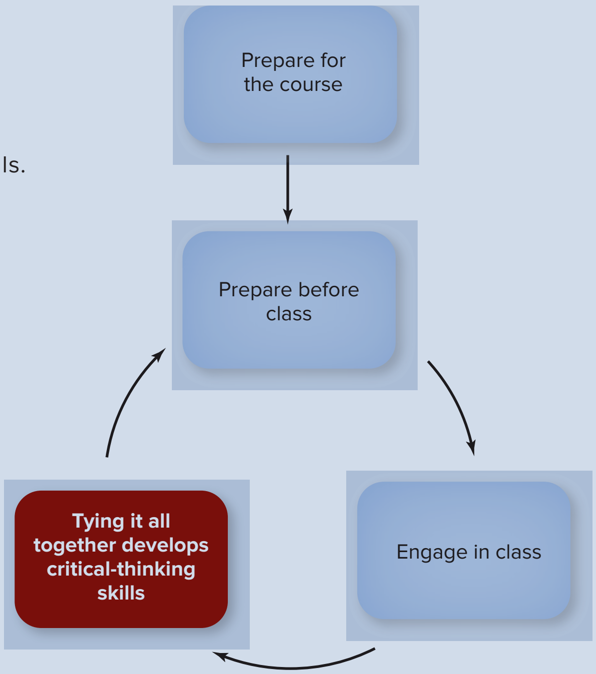
Based on McGraw-Hill Education Connect Effectiveness Study 2013

Presents data that empower students to improve performance that is efficient and effective.

Tying it all together develops critical-thinking skills

Follow up class with assessment that helps students develop critical-thinking skills. Set up assignments from the various assessment banks in Connect.

The Question and Test Banks contain higher-order critical-thinking questions that require students to demonstrate a more in-depth understanding of the concepts; instructors can quickly and easily filter the banks for these questions using higher-level Bloom's tags.

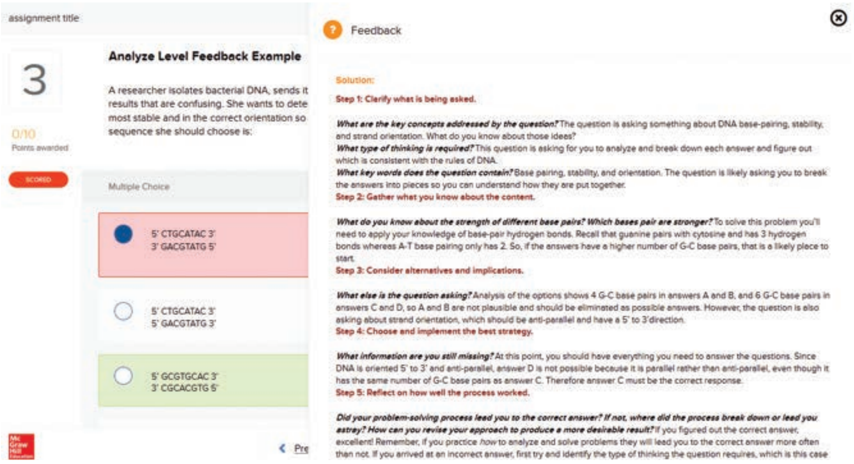

Prepare for the course

Prepare before class

Engage in class

Tying it all together develops critical-thinking skills

① Working through problems and questions that develop critical-thinking skills is key to understanding the concepts at a higher level.



Analyze Level Feedback Example

A researcher isolates bacterial DNA, sends it
results that are confusing. She wants to dete
most stable and in the correct orientation so
sequence she should choose is:

Multiple Choice

● 5' CTGCATAC 3'
3' GACGTATG 5'

○ 5' CTGCATAC 3'
5' GACGTATG 3'

○ 5' GCGTGCAC 3'
3' CGCACGTG 5'

Feedback

Solution:

Step 1: Clarify what is being asked.

What are the key concepts addressed by the question? The question is asking something about DNA base-pairing, stability, and strand orientation. What do you know about those ideas?
What type of thinking is required? This question is asking for you to analyze and break down each answer and figure out which is consistent with the rules of DNA.
What key words does the question contain? Base pairing, stability, and orientation. The question is likely asking you to break the answers into pieces so you can understand how they are put together.

Step 2: Gather what you know about the content.

What do you know about the strength of different base pairs? Which bases pair are stronger? To solve this problem you'll need to apply your knowledge of base-pair hydrogen bonds. Recall that guanine pairs with cytosine and has 3 hydrogen bonds whereas A-T base pairing only has 2. So, if the answers have a higher number of G-C base pairs, that is a likely place to start.

Step 3: Consider alternatives and implications.

What else is the question asking? Analysis of the options shows 4 G-C base pairs in answers A and B, and 6 G-C base pairs in answers C and D, so A and B are not plausible and should be eliminated as possible answers. However, the question is also asking about strand orientation, which should be anti-parallel and have a 5' to 3' direction.

Step 4: Choose and implement the best strategy.

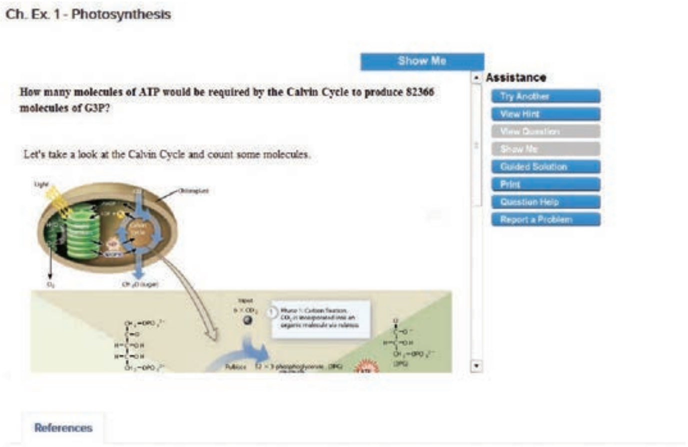
What information are you still missing? At this point, you should have everything you need to answer the questions. Since DNA is oriented 5' to 3' and anti-parallel, answer D is not possible because it is parallel rather than anti-parallel, even though it has the same number of G-C base pairs as answer C. Therefore answer C must be the correct response.

Step 5: Reflect on how well the process worked.

Did your problem-solving process lead you to the correct answer? If not, where did the process break down or lead you astray? How can you revise your approach to produce a more desirable result? If you figured out the correct answer, excellent! Remember, if you practice *how* to analyze and solve problems they will lead you to the correct answer more often than not. If you arrived at an incorrect answer, first try and identify the type of thinking the question requires, which is this case

Detailed Feedback All higher level Bloom's questions that involve problem solving contain detailed feedback in Connect. The feedback walks students through the steps of the problem-solving process and helps them evaluate their scientific-thinking skills.

Many chapters also contain a **Quantitative Question Bank**. These are more challenging algorithmic questions, intended to help your students practice their quantitative reasoning skills. Hints and guided solution options step students through a problem.



Ch. Ex. 1 - Photosynthesis

How many molecules of ATP would be required by the Calvin Cycle to produce 82366 molecules of G3P?

Let's take a look at the Calvin Cycle and count some molecules.

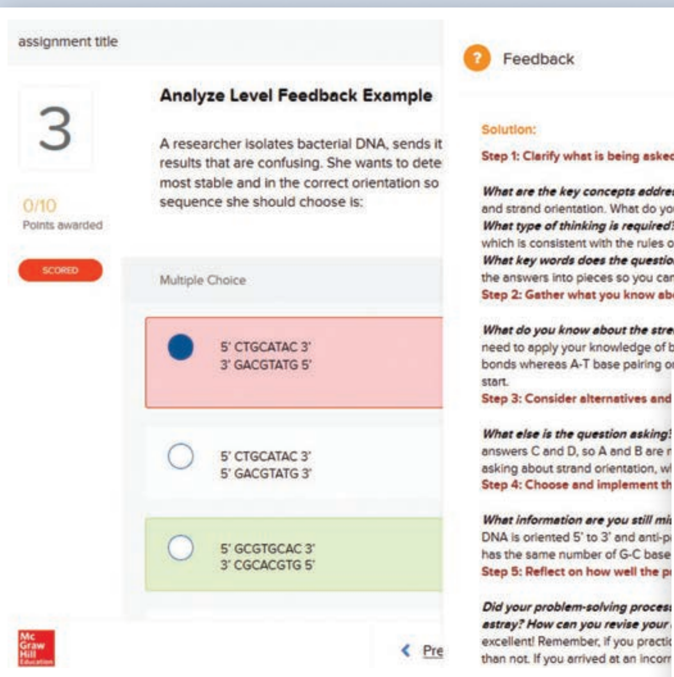
Strengthen Problem-Solving Skills and Key Concept Development with Connect

Detailed Feedback Learning is a process of iterative development, of making mistakes, reflecting, and adjusting over time. The Question and Test Banks in Connect™ for *Understanding Biology,* 2nd edition, are more than direct assessments; they are self-contained learning experiences that systematically build student learning over time.

For many students, choosing the right answer is not necessarily based on applying content correctly; it is more a matter of increasing their statistical odd of guessing. A major fault with this approach is that students don't learn how to process the questions correctly, mostly because they are repeating and reinforcing their mistakes rather than reflecting and learning from them. To help students develop problem-solving skills, all higher-level Bloom's questions in Connect are supported with hints, to help students focus on important information for answering questions, and detailed feedback that walks students through the problem-solving process, using Socratic questions in a decision-tree-style framework to scaffold learning. The feedback for every higher-level Bloom's question (Apply, Analyze, Evaluate) follows a similar process: Clarify Question, Gather Content, Choose Answer, and Reflect on Process.

Unpacking the Concept We've taken problem solving a step further. In each chapter, two or three higher-level Bloom's questions in the Question Bank are broken out by the steps of the detailed feedback. Rather than leaving it up to the students to work through the detailed feedback, a second version of the question is presented in a separate bank following a sequential step format. Students need to answer questions such as "What is the key concept addressed by the question?" before proceeding to answer the question, walking them through the problem-solving process. The professor can choose which version of the question to include in the assignment based on the problem-solving skills of the students.

▼



assignment title

3

0/10
Points awarded

SCORED

Analyze Level Feedback Example

A researcher isolates bacterial DNA, sends it
results that are confusing. She wants to dete
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sequence she should choose is:

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3' GACGTATG 5'

○ 5' CTGCATAC 3'
5' GACGTATG 3'

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3' CGCACGTG 5'

< Pre

Feedback

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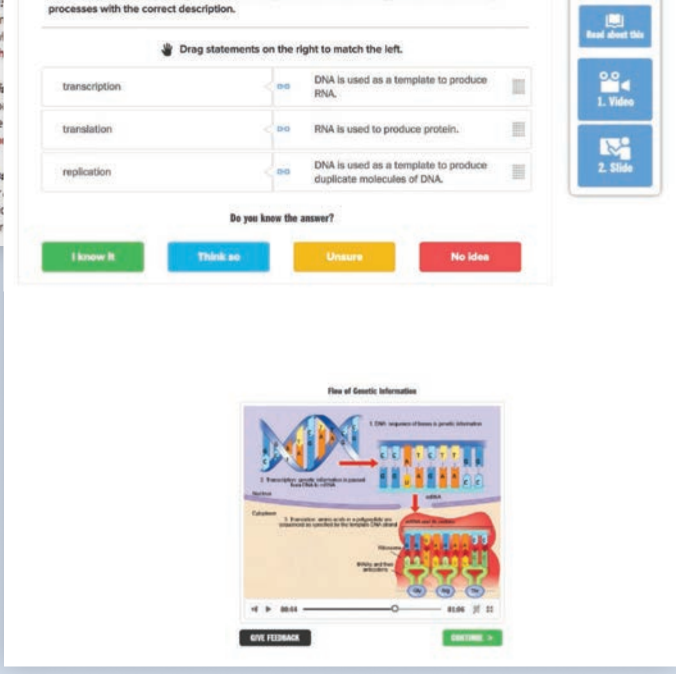
Did your problem-solving proces
astray? How can you revise your
excellent! Remember, if you practic
than not. If you arrived at an incorr

SmartBook with Learning Resources To help students understand key concepts, SmartBook® for *Understanding Biology*, 2nd edition, is enhanced with Learning Resources. Based on student usage data, derived from thousands of SmartBook users of the first edition, concepts that proved more challenging for students are supported with Learning Resources to enhance the textbook presentation. Learning Resources, such as animations or tutorials, are indicated in SmartBook adjacent to the textbook content. If a student is struggling with a Learning Resource concept, the student is directed to the Learning Resource, or he or she can click on the Learning Resource at any time. ▶



Based on your understanding of the central dogma of molecular biology, match the following processes with the correct description.

Drag statements on the right to match the left.

transcription — DNA is used as a template to produce RNA.
translation — RNA is used to produce protein.
replication — DNA is used as a template to produce duplicate molecules of DNA.

Do you know the answer?

Connect

Required=Results

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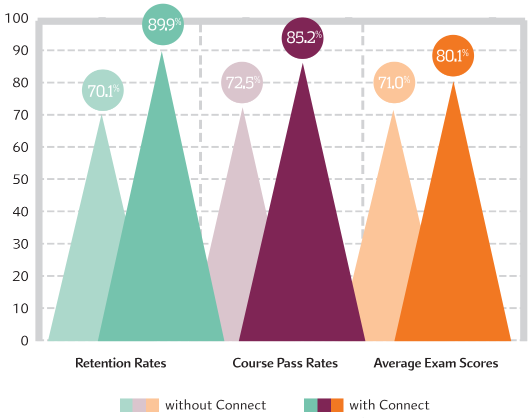

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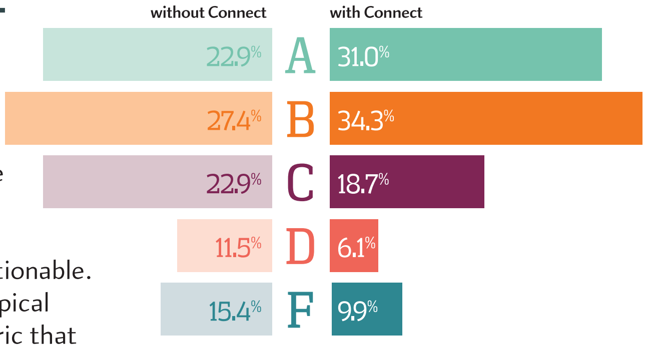

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Accounting week 1 quiz

CH 02 - Quiz Intermediate

Chapter 4

Ch 05. En casa: Vocabulario

CH 05 States of Consciousness

Quiz - Extra Credit

Ch 02. En la universidad: Vocabulario

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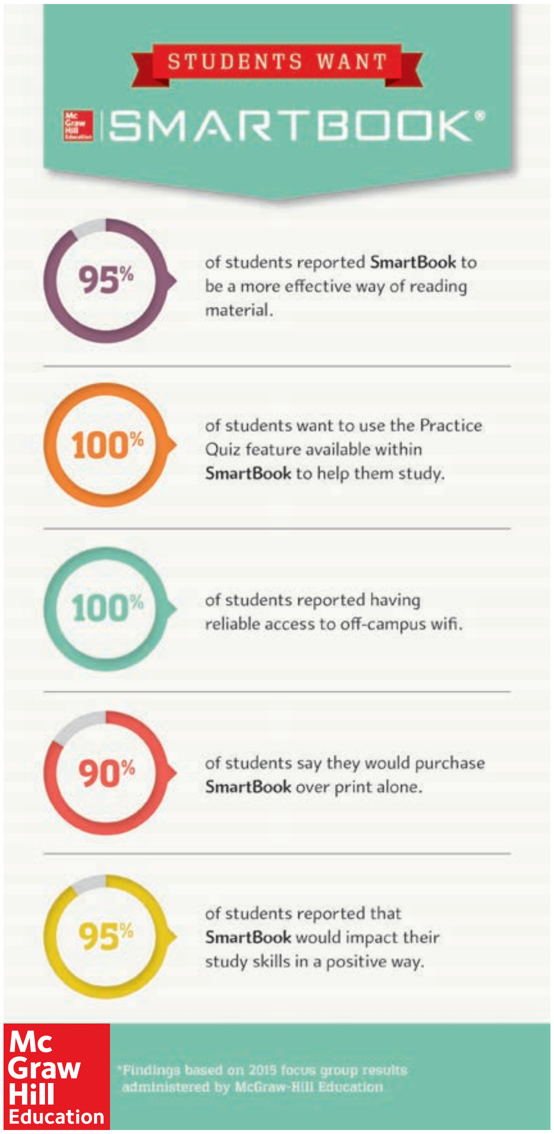

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*Findings based on 2015 focus group results administered by McGraw-Hill Education

Acknowledgments

A revision of this scope relies on the talents and efforts of many people working behind the scenes and we have benefited greatly from their assistance.

The copy editor, Deb DeBord, labored many hours and always improved the clarity and consistency of the text. She has made a tremendous contribution to the quality of the final product. We were fortunate to work with MPS Limited to update the art program and improve the layout of the pages. Our close collaboration resulted in a text that is pedagogically effective as well as more beautiful than any other biology text on the market.

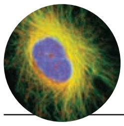
We have the continued support of an excellent team at McGraw-Hill Education. Justin Wyatt, the Brand Manager for Biology, has been a steady leader during a time of change. The Lead Product Developer, Liz Sievers, provided support in so many ways it would be impossible to name them all. April Southwood, Lead Content Project Manager, and Matt Backhous, Designer, ensured our text was elegantly designed. Patrick Reidy, Marketing Manager, is always a sounding board for more than just marketing, and many more people behind the scenes have all contributed to the success of our text. This includes the digital team, whom we owe a great deal for their efforts to help us move toward the future.

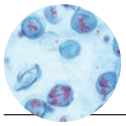
Digital Team: Ian Quitadamo, *Central Washington University,* serves as the Lead Digital Author in Majors Biology, directing the development plan for the digital content. Scott Cooper, *University of Wisconsin–LaCrosse,* serves as the Lead Connect digital content team, and Michelle Pass, *University of North Carolina–Charlotte,* serves as the Lead for the SmartBook development team.

Throughout this edition we have had the support of spouses and children, who have seen less of us than they might have liked because of the pressures of getting this revision completed. They have adapted to the many hours this book draws us away from them, and, even more than us, looked forward to its completion.

In the end, the people we owe the most are the generations of students who have passed through our lecture halls. They have taught us at least as much as we have taught them, and their questions and suggestions continue to improve the text and supplementary materials.

Contents





1

The Science of Biology

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Learning Path

1.1 The Diversity of Life Is Overwhelming

1.2 Biology Is the Science of Life

1.3 Science Is Based on Both Observation and Reasoning

1.4 The Study of Evolution Is a Good Example of Scientific Inquiry

1.5 A Few Important Concepts Form the Core of Biology

The Connecting the Concepts feature at the end of each Part of the text illustrates how five major concepts in biology relate to diverse material in different chapters. This chapter contains material related to the following concepts:

- Life Is Subject to Chemical and Physical Laws
- Evolution Explains the Unity and Diversity of Life

Introduction

You are about to embark on a journey—a journey of discovery about the nature of life. Almost two centuries ago, a young English naturalist named Charles Darwin set sail on a similar journey on board H.M.S. *Beagle;* a replica of this ship is pictured here. What Darwin learned on his five-year voyage led directly to his development of the theory of evolution by natural selection, a theory that has become the core of the science of biology. Darwin's voyage seems a fitting place to begin our exploration of biology—the scientific study of living organisms and how they have evolved. Before we begin, however, let's take a moment to think about what biology is and why it's important.

1.1 The Diversity of Life Is Overwhelming

Biology is the study of living things—literally the science of life. The living world is teeming with a breathtaking variety of creatures—whales, butterflies, mushrooms, plants, bacteria—which despite their obvious differences share features common to all living organisms. In this chapter, we will introduce the science of biology beginning with this diversity.

Biological Diversity Can Be Organized by Evolutionary History

LEARNING OBJECTIVE 1.1.1 Describe the three domains of life.

Faced with the bewildering diversity of life, biologists originally classified organisms based on shared characteristics. However, as they learned how evolution by natural selection shapes diversity, problems arose with these classifications. Now classification is optimally based on shared evolutionary history, which often but not always produces results similar to shared characteristics (see chapter 22).

When we look far back into the history of life, we find three lineages we now call domains: Bacteria, Archaea, and Eukarya. These three domains include all organisms on the planet. The bacteria and archaea include only single-celled organisms (figure 1.1) and are called prokaryotes due to their both lacking a membrane-bounded nucleus (see chapter 4). The eukarya contain most of the organisms familiar to you and can be divided into four kingdoms: Protista, Fungi, Plantae, and Animalia (figure 1.2). There are other ways to divide the early roots of the eukaryotic tree, which we will consider in chapter 22. The best way to classify all organisms is an area of active research and remains hotly debated.

Domain Archaea. This prokaryotic domain includes this methanogen, which manufactures methane as a result of its metabolic activity.

Domain Bacteria. This prokaryotic domain includes this purple sulfur bacteria, which can use light energy to drive the synthesis of organic compounds.

Figure 1.1 The two prokaryotic domains. Bacteria and archaea share the feature of lacking a membrane-bounded nucleus. Organisms from both of these domains are single-celled.

(Archaea): © Power and Syred/Science Source; (Bacteria): © Alfred Pasieka/SPL/Science Source

Protista. Most of the unicellular eukaryotes (those whose cells contain a nucleus) are grouped into this kingdom, as well as the multicellular algae like the one pictured here.

Fungi. This kingdom contains mostly multicellular nonphotosynthetic organisms that digest their food externally, such as mushrooms.

Plantae. This kingdom contains photosynthetic multicellular organisms that are terrestrial, such as the flowering plant pictured here.

Animalia. Organisms in this kingdom are nonphotosynthetic multicellular organisms that digest their food internally, such as this ram.

Figure 1.2 The eukaryotic domain. Eukaryotes consist of most familiar organisms and many that are not. The eukaryotes can be divided into four kingdoms: Protista, Fungi, Plantae, and Animalia.

(Protista): © Elmer Frederick Fischer/Corbis RF; (Fungi): © Russell Illig/Getty Images RF; (Plantae): © Iconotec/Glow Images RF; (Animalia): © Alan and Sandy Carey/Getty Images RF

The work of biologists affects your everyday life: what you eat, what happens to you when you go to the hospital, and how our society will handle environmental issues such as climate change. Unifying the diverse systems studied by biologists are the shared characteristics of all living things that have been shaped by the process of evolution by natural selection. Keeping this theme in mind will help you to manage the complexity and diversity of biology.

REVIEW OF CONCEPT 1.1

The living world is incredibly diverse. The oldest branching of the tree of life is into bacteria, archaea, and eukarya.

- *What are some shared features of living systems?*

1.2 Biology Is the Science of Life

In its broadest sense, biology is the study of living things. So it would seem that biologists would have no problem defining life. In fact, it is quite difficult to provide a simple definition of life.

Life Defies Simple Definition

LEARNING OBJECTIVE 1.2.1 Describe five fundamental properties of life.

What does it mean to be alive? What are the properties that define a living organism? These questions are not as simple as they appear, because some of the most obvious properties of living organisms are also properties of many nonliving things—for example, *complexity* (a computer is complex), *movement* (clouds move in the sky), and *response to stimulation* (a soap bubble pops if you touch it). To appreciate why these three properties, so common among living things, do not help us to define life, imagine a mushroom standing next to a television: The television seems more complex than the mushroom, the picture on the television screen is moving while the mushroom just stands there, and the television responds to a remote control device while the mushroom continues to just stand there—yet it is the mushroom that is alive.

All living things also share five more fundamental properties, passed down over millions of years from the first organisms to evolve on Earth: *cellular organization; energy utilization; homeostasis; growth, development, and reproduction;* and *heredity.*

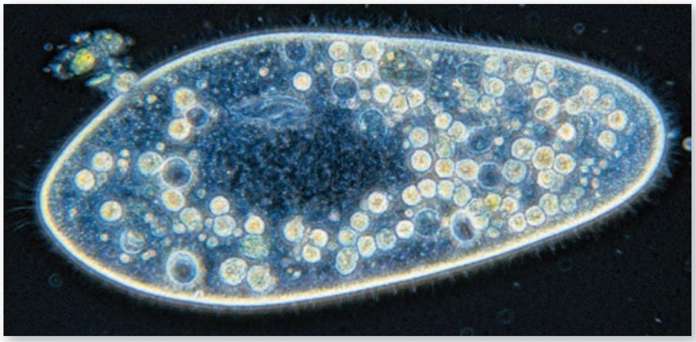

Figure 1.3 Cellular organization. These paramecia are complex single-celled protists that have just ingested several yeast cells. Like these paramecia, many organisms consist of just a single cell, while others are composed of trillions of cells.

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1. **Cellular organization.** All living things are composed of one or more cells. Often too tiny to see, cells carry out the basic activities of living. Some cells have simple interiors, whereas others have complex organization, but all are able to grow and reproduce. Many organisms possess only a single cell, like the paramecia in figure 1.3; your body contains about 10 trillion to 100 trillion cells (depending on how big you are).
2. **Energy utilization.** All living things use energy. Moving, growing, thinking—everything you do requires energy. Where does all this energy come from? It is captured from sunlight by plants and algae through photosynthesis. To get the energy that powers our lives, we extract it from plants or from plant-eating animals. That's what the kingfisher is doing in figure 1.4, eating a fish that ate algae.
3. **Homeostasis.** All living things maintain relatively constant internal conditions so that their complex processes can be better coordinated. Although the environment often varies a lot, organisms act to keep their interior conditions relatively constant, a process called *homeostasis*. Your body acts to maintain an internal temperature of 37°C (98.6°F), however hot or cold the weather might be.
4. **Growth, development, and reproduction.** All living things grow and reproduce. Bacteria increase in size and simply split in two, as often as every 15 minutes. More complex organisms grow by increasing the number of cells, and they develop by producing different kinds of cells.
5. **Heredity.** All organisms possess a genetic system that is based on the replication and duplication of a long molecule called *DNA (deoxyribonucleic acid)*. The information that

Figure 1.4 Energy utilization. This kingfisher obtains the energy it needs to move, grow, and carry out its body processes by eating fish. It harvests the energy from food using chemical processes that occur within cells.

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determines what an individual organism will be like is contained in a code dictated by the order of the subunits making up the DNA molecule. Because DNA is copied from one generation to the next, any change in a gene is also preserved and passed on to future generations. The transmission of characteristics from parent to offspring is a process called *heredity*. All organisms interact with other organisms and the nonliving environment in ways that influence their survival, and as a consequence, organisms evolve adaptations to their environments.

Living Systems Show Hierarchical Organization

LEARNING OBJECTIVE 1.2.2 Describe the hierarchical nature of living systems.

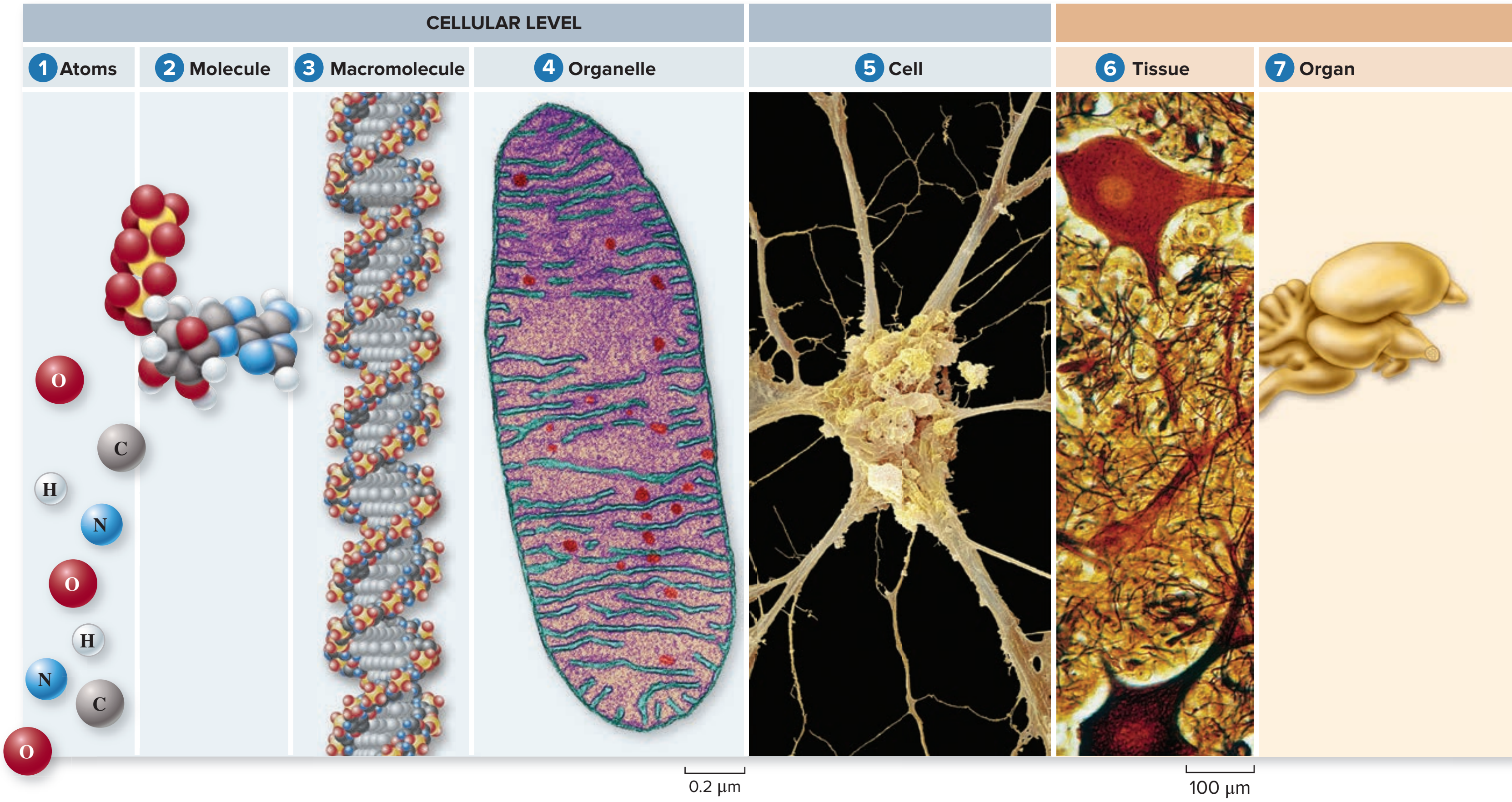
Life's organisms interact with each other at many levels, in ways simple and complex. A key factor organizing these interactions is their degree of complexity. The organization of the biological world is hierarchical—that is, each level builds on the level below it, from the very simplest level of individual atoms to the vastly complex level of interacting ecosystems (figure 1.5):

The Cellular Level. At the cellular level, **atoms** ①, the fundamental elements of matter, are joined together by chemical bonds into stable assemblies called **molecules** ②. Large, complex molecules are called **macromolecules** ③. DNA, which stores the hereditary information, is a macromolecule. Complex biological molecules are assembled into tiny structures called **organelles** ④, within which cellular activities are organized. A mitochondrion is an organelle within which the cell extracts energy from food molecules. Membrane-bounded units called **cells** ⑤ are the basic units of life. Bacteria are composed of single cells. Animals, plants, and many other organisms are multicellular—composed of many cells.

The Organismal Level. Cells of multicellular organisms exhibit three levels of organization. The most basic level is that of **tissues** ⑥, which are groups of similar cells that act as a functional unit. Nerve tissue is one kind of tissue, specialized to carry electrical signals. Tissues, in turn, are grouped into **organs** ⑦ —body

Figure 1.5 **Hierarchical organization of living systems.** Life is highly organized, from the simplest atoms to complex, multicellular organisms. Along this hierarchy of structure, atoms form molecules, which are used to form organelles, which in turn form the functional subsystems within cells. Cells are organized into tissues, then into organs and organ systems such as the nervous system. This organization extends beyond individual organisms to populations, communities, ecosystems, and finally the entire biosphere.

(organelle): © Keith R. Porter/Science Source; (cell): © Steve Gschmeissner/Getty Images; (tissue): © Ed Reschke/Getty Images; (organism): © Russell Illig/Getty Images RF; (population): © George Ostertag/agefotostock; (species top, bottom): © PhotoLink/Getty Images RF; (community): © Ryan McGinnis/Alamy; (ecosystem): © McGraw-Hill Education. Steven P. Lynch, photographer; (biosphere): NASA Goddard Space Flight Center, Image by Reto Stöckli (land surface, shallow water, clouds). Enhancements by Robert Simmon (ocean color, compositing, 3D globes, animation)



structures composed of several different tissues that act as a structural and functional unit. Your brain is an organ composed of nerve cells and cells that nourish and support them, as well as a variety of associated connective tissues that form both protective coverings and a network of blood vessels to bring oxygen and nutrients to the brain. At the third level of organization, organs are grouped into **organ systems** ⑧. The nervous system, for example, consists of sensory organs, the brain and spinal cord, and a network of neurons that convey signals between the brain and the other organs and tissues of the body.

The Populational Level. Individual **organisms** ⑨ occupy several hierarchical levels within the living world. The most basic of these is the **population** ⑩—a group of organisms of the same species living in the same place. All populations of a particular kind of organism together form a **species** ⑪, its members similar in appearance and able to interbreed. At a higher level of biological organization, a **biological community** ⑫ consists of all the populations of different species living together in one place.

The Ecosystem Level. At the highest tier of biological organization, a biological community and the physical habitat (soil composition, available water, temperature range, wind, and a host of other environmental influences) within which it lives together constitute an ecological system, or **ecosystem** ⑬. The entire planet can be thought of as a global ecosystem we call the **biosphere** ⑭.

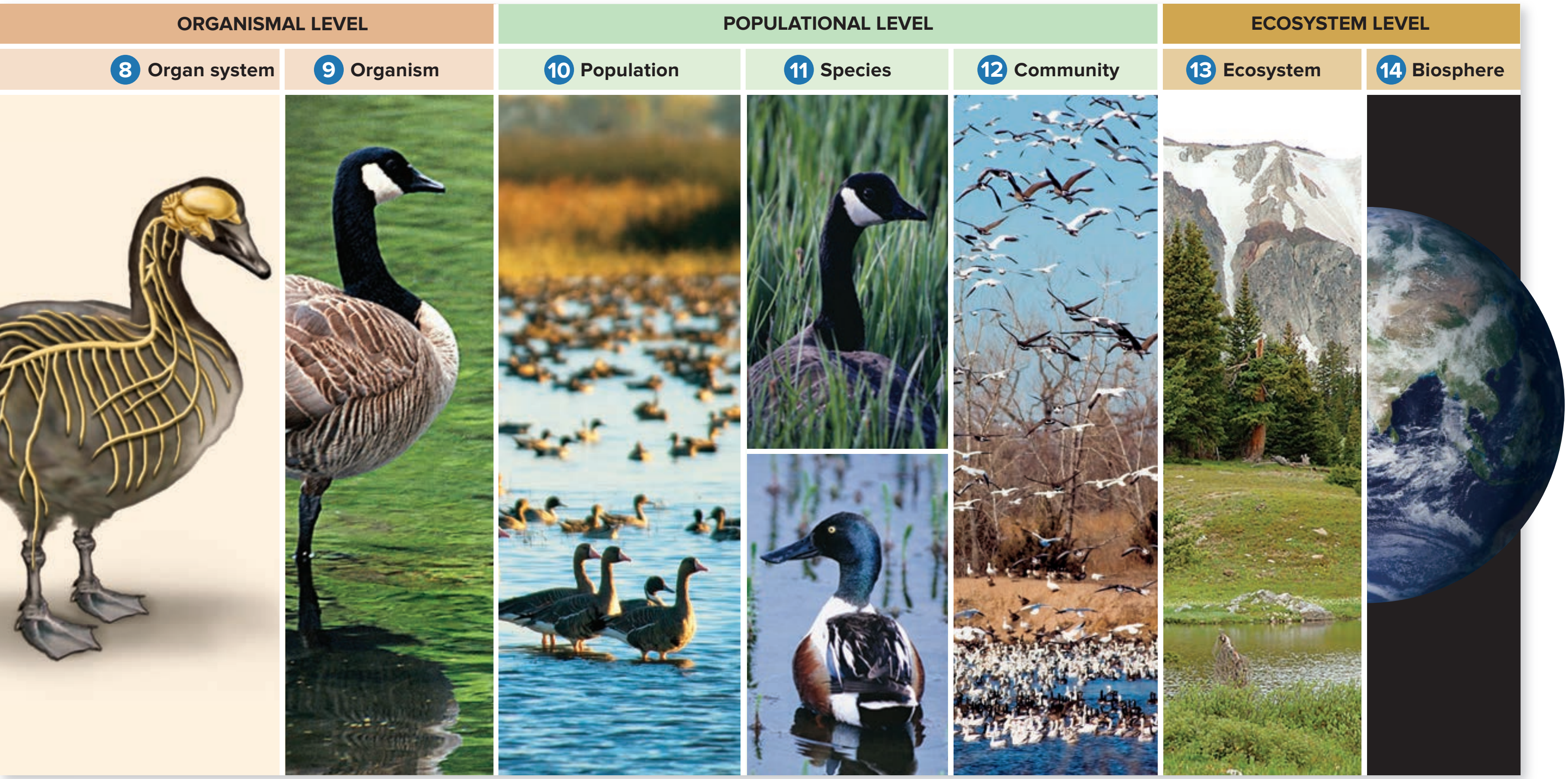
Novel Properties Emerge from More Complex Organization

LEARNING OBJECTIVE 1.2.3 Discuss how living systems display emergent properties.

At each higher level in the living hierarchy, novel properties emerge, properties that were not present at the simpler level of organization. These **emergent properties** result from the way in which components interact and often cannot be guessed just by looking at the parts themselves. You have the same array of cell types as a giraffe, for example—so examining a collection of its individual cells gives little clue of what your body is like.

The emergent properties of life are not magical or supernatural. They are the natural consequences of the hierarchy or structural organization that is the hallmark of life. Both water (which makes up 50 to 75% of your body's weight) and ice are made of H_2O molecules, but one is liquid and the other is solid, because the H_2O molecules in ice are more organized. Two proteins—long chains of amino acids—may contain the same number of each amino acid, yet one might act as an enzyme to promote a chemical reaction while the other might not; the enzymatic activity is an emergent property, reflecting the information contained in the *sequence* of the amino acids.

Functional properties emerge from more complex organization. Metabolism is an emergent property of life. The chemical reactions within a cell arise from interactions between molecules that are orchestrated by the orderly environment of the cell's interior. Consciousness is an emergent property of the brain that results from the interactions of many neurons in different parts of the brain.



This description of the common features and organization of living systems begins to get at the nature of what it is to be alive. The rest of this book illustrates and expands on these basic ideas to provide you with a more complete account of living systems.

REVIEW OF CONCEPT 1.2

Biology is a unifying science that brings together all branches of science to study living systems. Life does not have a simple definition, but living systems share a number of properties that together describe life. Biologists organize living systems hierarchically, from the subcellular level to the entire biosphere, with emerging properties arising at each stage that cannot be guessed from studying its parts.

- *Can you name an emergent property at the population level?*

1.3 Science Is Based on Both Observation and Reasoning

Much like life itself, the nature of science defies simple description. For many years scientists have written about the "scientific method" as though there were a single way of doing science. This oversimplification has contributed to nonscientists' confusion about the nature of science.

At its core, science is concerned with developing an increasingly accurate understanding of the world by using observation and reasoning. To begin with, we assume that natural forces acting now have always acted, that the fundamental nature of the universe has not changed since its inception, and that it is not changing now.

The Scientific Process Involves Description and Both Deductive and Inductive Reasoning

LEARNING OBJECTIVE 1.3.1 Distinguish between deductive and inductive reasoning.

Scientists attempt to be as objective as possible in interpreting their results. Because scientists are human, this is not completely possible, but because science is a collective endeavor subject to scrutiny, it is self-correcting. One person's results are verified by others, and if the results cannot be repeated, they are rejected.

Descriptive science

The classic vision of the scientific process is that observations lead to hypotheses, which in turn make experimentally testable predictions. In this way, scientists dispassionately evaluate new ideas to arrive at an increasingly accurate view of nature. We discuss this way of doing science later in this section, but it is important to understand that much of science is purely descriptive: In order to understand anything, the first step is to describe it completely. Much of biology is concerned with arriving at an increasingly accurate description of nature.

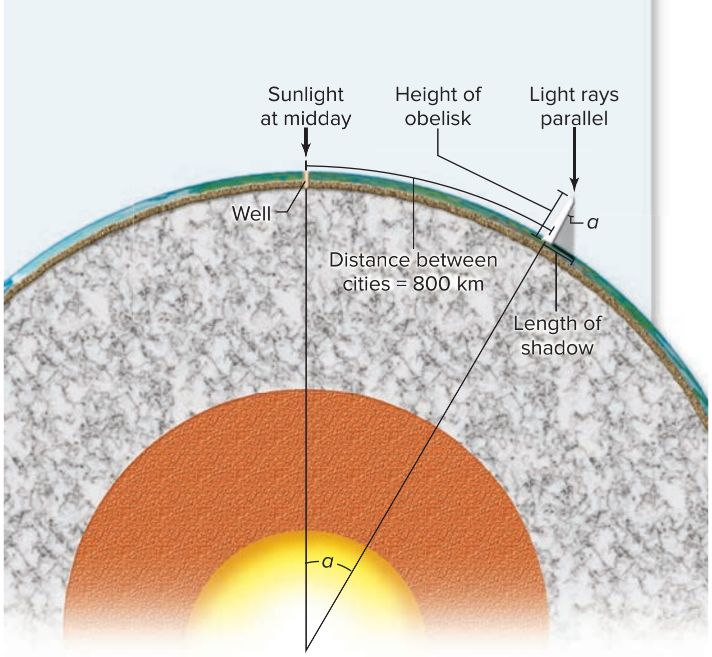


Figure 1.6 Deductive reasoning: How Eratosthenes estimated the circumference of the Earth using deductive reasoning. ***1.*** On a day when sunlight shone straight down a deep well at Syene in Egypt, Eratosthenes measured the length of the shadow cast by a tall obelisk in the city of Alexandria, about 800 kilometers (km) away. ***2.*** The shadow's length and the obelisk's height formed two sides of a triangle. Using the recently developed principles of Euclidean geometry, Eratosthenes calculated the angle, *a*, to be 7° and 12´, exactly 1/50 of a circle (360°). ***3.*** If angle *a* is 1/50 of a circle, then the distance between the obelisk (in Alexandria) and the well (in Syene) must be equal to 1/50 the circumference of the Earth. ***4.*** Eratosthenes had heard that it was a 50-day camel trip from Alexandria to Syene. Assuming that a camel travels about 18.5 km per day, he estimated the distance between the obelisk and well as 925 km (using different units of measure, of course). ***5.*** Eratosthenes thus deduced the circumference of the Earth to be 50 × 925 = 46,250 km. Modern measurements put the distance from the well to the obelisk at just over 800 km. Employing a distance of 800 km, Eratosthenes's value would have been 50 × 800 = 40,000 km. The actual circumference is 40,075 km.

The study of biodiversity is an example of descriptive science that has implications for other aspects of biology, in addition to societal implications. Efforts are currently under way to classify all life on Earth. This ambitious project is purely descriptive, but it will lead to a greater understanding of biodiversity and of the effect our species is having on biodiversity.

One of the most important accomplishments of molecular biology at the dawn of the 21st century was completing the sequencing of the human genome. Many new hypotheses about human biology will be generated by this knowledge, and many experiments will be needed to test these hypotheses, but the determination of the sequence itself was descriptive science.

The study of logic recognizes two opposite ways of arriving at logical conclusions: deductive and inductive reasoning. Science makes use of both, although induction is the primary way of reasoning in hypothesis-driven science.

Deductive reasoning

Deductive reasoning applies general principles to predict specific results. Deductive reasoning is the reasoning of mathematics and philosophy, and it is used to test the validity of general ideas in all branches of knowledge. For example, if all mammals by definition have hair, and you find an animal that does not have hair, then you may conclude that this animal is not a mammal. A biologist uses deductive reasoning to infer the species of a specimen from its characteristics. More than 2200 years ago, the Greek scientist Eratosthenes used Euclidean geometry and deductive reasoning to accurately estimate the circumference of the Earth (figure 1.6).

Inductive reasoning

In **inductive reasoning,** the logic flows in the opposite direction, from the specific to the general. Inductive reasoning uses specific observations to construct general scientific principles. For example, if poodles have hair and terriers have hair, and every dog that you observe has hair, then you may conclude that all dogs have hair. Inductive reasoning leads to generalizations that can then be tested. Inductive reasoning first became important to science in the 1600s in Europe, when Francis Bacon, Isaac Newton, and others began to use the results of particular experiments to infer general principles about how the world operates.

Hypothesis-Driven Science Makes and Tests Predictions

LEARNING OBJECTIVE 1.3.2 Illustrate how experimentation can be used to test hypotheses.

Experimental scientists use inductive reasoning to establish which general principles are true from among the many that might be true, systematically testing alternative proposals. If these proposals prove inconsistent with experimental observations, they are rejected as untrue, as illustrated in figure 1.7.

After making careful observations, scientists construct a **hypothesis,** which is a suggested explanation that accounts for those observations. A hypothesis is a proposition that might be true. Those hypotheses that have not yet been disproved are retained. They are useful because they fit the known facts, but they are always subject to future rejection if, in the light of new information, they are found to be incorrect.

This process can also be *iterative;* that is, a hypothesis can be changed and refined with new data. For instance, geneticists George Beadle and Edward Tatum studied the nature of genetic information to arrive at the "one-gene/one-enzyme" hypothesis. This hypothesis states that a gene represents the genetic information necessary to make a single enzyme. As investigators learned more about the molecular nature of genetic information, the hypothesis was refined to "one-gene/one-polypeptide," because enzymes can be made up of more than one polypeptide. With still more discoveries about the nature of genetic information, other investigators found that a single gene can specify more than one polypeptide, and the hypothesis was refined again.

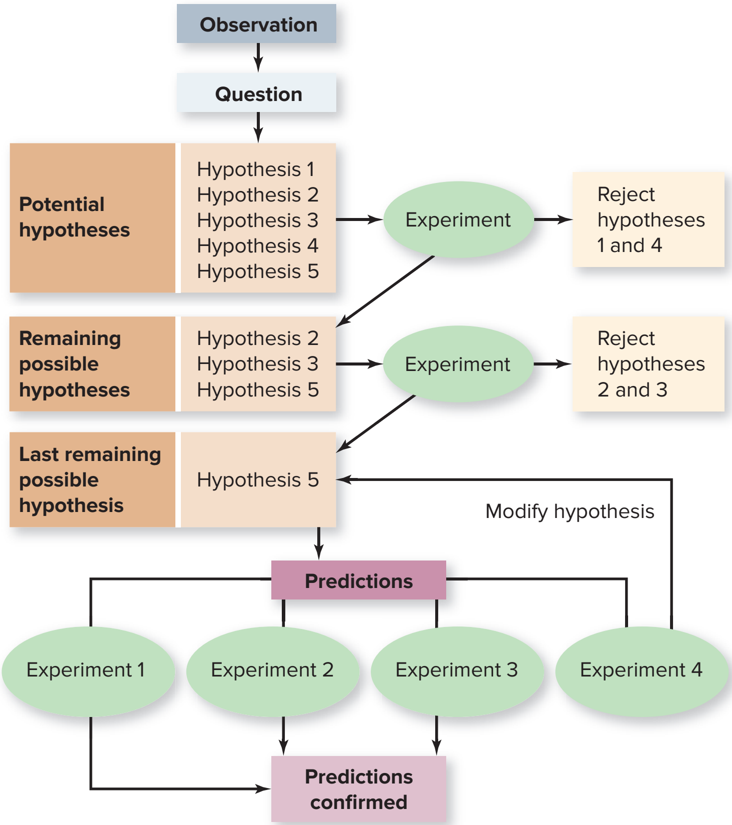


Figure 1.7 How experimental science is done. This diagram illustrates how scientific investigations proceed. First, scientists make observations that raise a particular question. They develop a number of potential explanations (hypotheses) to answer the question. Next, they carry out experiments in an attempt to eliminate one or more of these hypotheses. Then, they make predictions based on the remaining hypotheses and carry out further experiments to test these predictions. The process can also be iterative. As experimental results are performed, the information can be used to modify the original hypothesis to fit each new observation.

Testing hypotheses

We call the test of a hypothesis an **experiment.** Suppose that a room appears dark to you. To understand why it appears dark, you propose several hypotheses. The first might be "There is no light in the room because the light switch is turned off." An alternative hypothesis might be "There is no light in the room because the light bulb is burned out." And yet another hypothesis might be "I am going blind." To evaluate these hypotheses, you would conduct an experiment designed to eliminate one or more of the hypotheses.

For example, you might test your hypotheses by flipping the light switch. If you do so and the room is still dark, you have disproved the first hypothesis: Something other than the setting of the light switch must be the reason for the darkness. Note that a test such as this does not prove that any of the other hypotheses are true; it merely demonstrates that the one being tested is not. A successful experiment is one in which one or more of the alternative hypotheses are demonstrated to be inconsistent with the results and are thus rejected.

As you proceed through this text, you will encounter many hypotheses that have withstood the test of experiment. Many will continue to do so; others will be revised as biologists make new observations. Biology, like all science, is in a constant state of change, with new ideas appearing and replacing or refining old ones.

Establishing controls

Often scientists are interested in learning about processes that are influenced by many factors, or **variables.** To evaluate alternative hypotheses about one variable, all other variables must be kept constant. This is done by carrying out two experiments in parallel: an experiment treatment or group and a control treatment or group. In the **experiment treatment,** one variable is altered in a known way to test a particular hypothesis. In the **control treatment,** that variable is left unaltered. In all other respects the two experiments are identical, so any difference in the outcomes of the two experiments must result from the influence of the variable that was changed.

Much of the challenge of experimental science lies in designing control experiments that isolate a particular variable from other factors that might influence a process.

Theories Are the Solid Conclusions of Science

LEARNING OBJECTIVE 1.3.3 Discuss how scientists use models to describe, explain, and test theories.

A successful scientific hypothesis needs to be not only valid but also useful—it needs to tell us something we want to know. A hypothesis is most useful when it makes predictions, because those predictions provide a way to test the validity of the hypothesis. If an experiment produces results inconsistent with predictions, the hypothesis must be rejected or modified. In contrast, if the predictions are supported by experimental testing, the hypothesis is supported. The more experimentally supported predictions a hypothesis makes, the more valid it is.

Reductionism

Scientists often use the philosophical approach known as **reductionism** to understand a complex system by reducing it to its working parts. Reductionism has limits when applied to living systems, however—the complex interworking of many interconnected functions leads to emergent properties that cannot be predicted based on the workings of the parts. For example, ribosomes—complex cellular machines that make proteins—can be disassembled into their constituent parts. However, examination of the parts in isolation would not lead to predictions about the nature of protein synthesis. On a higher level, understanding the physiology of a single Canada goose would not lead to predictions about flocking behavior. Biologists are just beginning to come to grips with this problem and to think about ways of dealing with the whole as well as the workings of the parts. The emerging field of systems biology focuses on this different approach.

Biological models

Biologists construct models in many different ways for a variety of uses. Geneticists construct models of interacting networks of proteins that control gene expression, often even drawing cartoon figures to represent that which we cannot see. Population biologists build models of how evolutionary change occurs. Cell biologists build models to explain cell communication and the events leading from an external signal to internal events. Structural biologists build models of the structure of proteins and macromolecular complexes in cells.

Models provide a way to organize how we think about a problem. Models can also get us closer to the larger picture and away from the extreme reductionist approach. The working parts are provided by the reductionist analysis, but the model shows how they fit together. Often these models suggest other experiments that can be performed to refine or test the model.

The nature of scientific theories

Scientists use the word **theory** in two main ways. The first meaning of *theory* is essentially deductive, a proposed explanation for some natural phenomenon, based on general principles. Thus, we speak of the principle first proposed by Newton as the “theory of gravity.” Such theories often bring together concepts that were previously thought to be unrelated.

The second meaning of *theory* is essentially inductive: a body of interconnected concepts, supported by inductive scientific reasoning and experimental evidence, that explains the facts in some area of study. For example, quantum theory in physics brings together a set of ideas about the nature of the universe derived from diverse experimental observations and serves as a guide to further questions and experiments.

To scientists, theories are the solid ground of science, expressing ideas of which they are most certain. By contrast, to the general public the word *theory* usually implies the opposite—a *lack* of knowledge or a guess (“it’s only a *theory* . . .”). Not surprisingly, this difference often results in confusion. In this text, *theory* will always be used in its scientific sense, in reference to an accepted general principle or body of knowledge.

The “scientific method”

In the past it was fashionable to speak of the “scientific method” as consisting of an orderly sequence of logical, “either/or” steps. Each step would reject one of two mutually incompatible alternatives, as though trial-and-error testing would inevitably lead a researcher through the maze of uncertainty to the ultimate scientific answer. If this were the case, a computer would make a good scientist. But science is not done this way.

As the British philosopher Karl Popper has pointed out, successful scientists without exception design their experiments with an idea of how the results are going to come out. They have what Popper calls an “imaginative preconception” of what the truth might be. Because insight and imagination play such a large role in scientific progress, some scientists are better at science than others—just as Bob Dylan and the Beatles stand out among songwriters or Mozart and Beethoven among composers.

Research results are written up and submitted for publication in scientific journals, where other scientists review the experiments and conclusions. This process of careful evaluation, called *peer review,* lies at the heart of modern science. It helps to ensure that faulty research or false claims are not given the authority of scientific fact. It also provides other scientists with a starting point for testing the reproducibility of experimental results. Results that cannot be reproduced are not taken seriously for long.

REVIEW OF CONCEPT 1.3

Much of science is descriptive, amassing observations to gain an accurate view. Both deductive and inductive reasoning are used in science. Scientific hypotheses are suggested explanations for observed phenomena. When a hypothesis has been extensively tested and no contradictory information has been found, it becomes an accepted theory. Theories are coherent explanations of observed data, and they may be modified by new information.

- *How does a scientific theory differ from a hypothesis?*

1.4 The Study of Evolution Is a Good Example of Scientific Inquiry

Darwin's theory of evolution explains and describes how organisms on Earth have changed over time and acquired a diversity of new forms. This famous theory provides a good example of how a scientist develops a hypothesis and how a scientific theory is tested and gains acceptance.

The Idea of Evolution Existed Prior to Darwin

LEARNING OBJECTIVE 1.4.1 Describe ideas about evolution proposed before Darwin.

Charles Robert Darwin (1809–1882; figure 1.8) was an English naturalist who, after 30 years of study and observation, wrote one of the most famous and influential books of all time. This book, *On the Origin of Species by Means of Natural Selection,* created a sensation when it was published, and the ideas Darwin expressed in it have played a central role in the development of human thought.

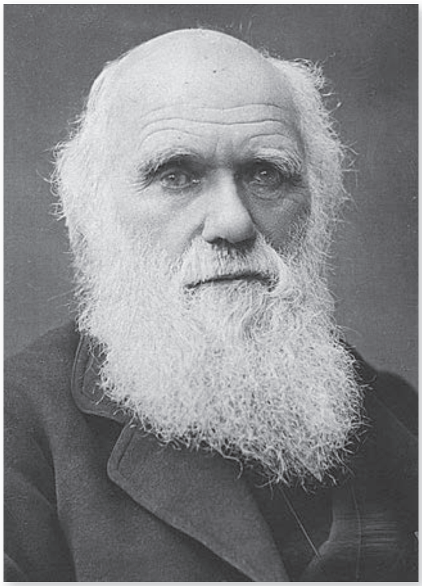


Figure 1.8 **Charles Darwin.** This newly rediscovered photograph, taken in 1881, the year before Darwin died, appears to be the last ever taken of the great biologist.

© Huntington Library/SuperStock

Birth of the idea of evolution

In Darwin's time, most people believed that the different kinds of organisms and their individual structures resulted from direct actions of a Creator (many people still believe this). Species were thought to have been specially created and to be unchangeable over the course of time. This was the view of Carolus Linnaeus (1708–1778), the Swedish biologist who established the system of naming organisms that is still in use.

By the first part of the 18th century, many more kinds of organisms were being discovered than previously, as well as many fossil animals and plants. These discoveries gradually began to trigger discussions of evolution, the possibility that living things have changed during the history of life on Earth. The great French biologist Georges-Louis Leclerc, Comte de Buffon (1707–1788), spoke explicitly, a century before Darwin, of natural affinities between kinds of organisms, writing of "the universal kinship of all generations born from a common mother." He could see no explanation for the common features of all mammals except their evolution from a common ancestor.

Within 50 years these ideas led Jean Baptiste de Lamarck (1744–1829) to explicitly propose evolution as a theory to account for the patterns observed in nature. In 1801 he suggested that all species, including human beings, were descended from other species. Lamarck thought of life as having evolved progressively from simple to more complex forms, and he was the first to propose a coherent theory of evolution.

Lamarck's theory was based on the incorrect idea that organs and structures became stronger through use, and that the strengthened character was then passed on to offspring—the **theory of inheritance of acquired characteristics.** Although incorrect, Lamarck's theory called wide attention to the possibility of evolution and, by doing so, set the stage for the acceptance of the correct, and much simpler, explanation proposed by Charles Darwin half a century later.

Darwin attributed evolution to what he called *natural selection,* which he proposed as a coherent, logical explanation. His book *On the Origin of Species* was a best seller in its day and brought his ideas to wide public attention.

Darwin Gathered Information During the Voyage of the *Beagle*

LEARNING OBJECTIVE 1.4.2 Identify important observations made by Darwin on the *Beagle*.

The story of Darwin and his theory of evolution begins in 1831, when Darwin was 22 years old. He was part of a five-year navigational mapping expedition around the coasts of South America (figure 1.9), aboard H.M.S. *Beagle*. During this long voyage, Darwin had the chance to study a wide variety of plants and animals on continents, islands, and distant seas. Repeatedly, Darwin saw that the characteristics of similar species varied somewhat from place