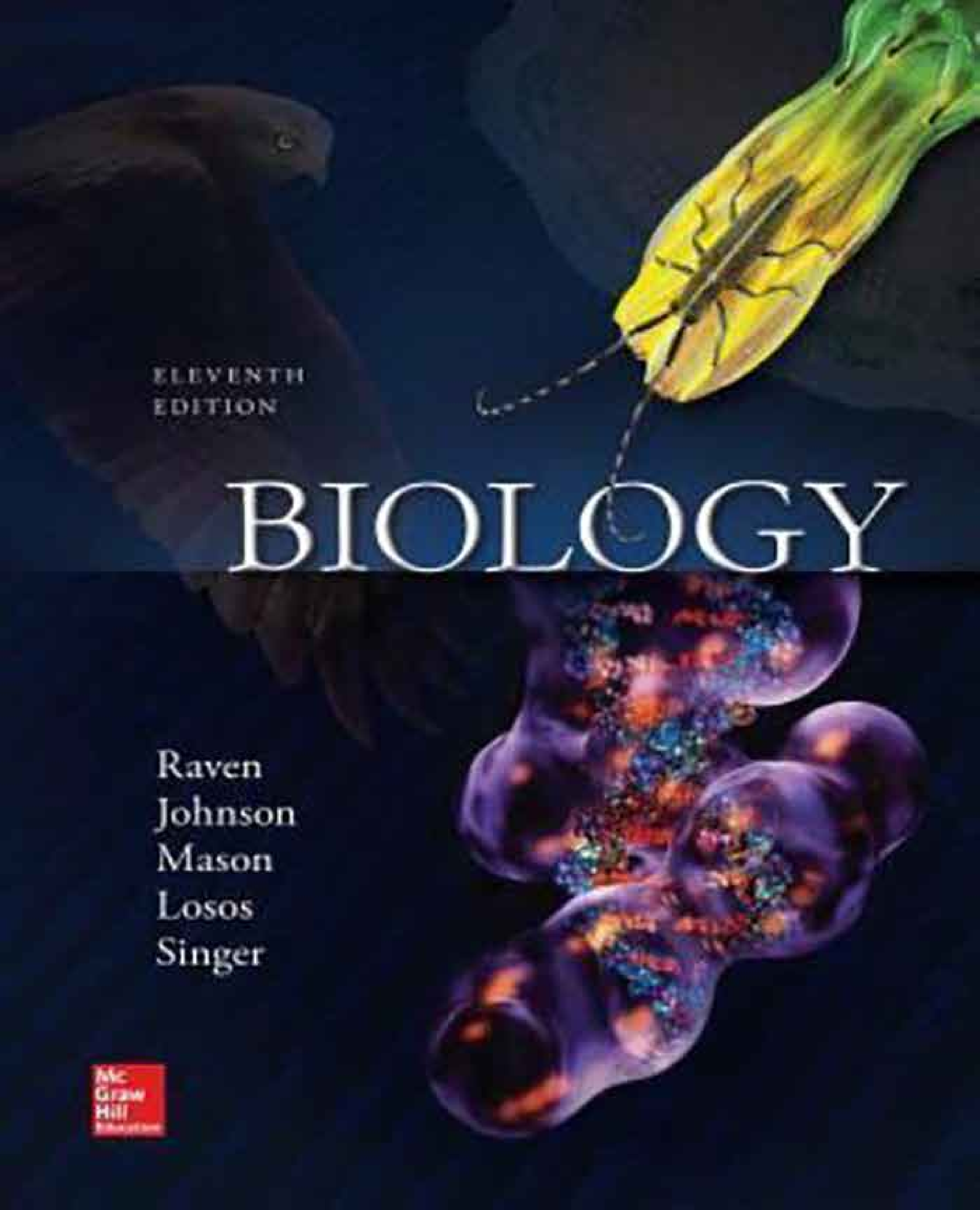

ELEVENTH
EDITION

BIOLOGY

Raven
Johnson
Mason
Losos
Singer

Mc
Graw
Hill
Education

Eleventh Edition

Biology

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BIOLOGY, ELEVENTH EDITION

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Brief Contents

About the Authors

Pictured left to right: Susan Rundell Singer, Jonathan Losos, Kenneth Mason

Kenneth Mason is currently associated with the University of Iowa, Department of Biology. 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 for eight years. His honor society memberships include Phi Sigma, Alpha Lambda Delta, and, by vote of Purdue pharmacy students, Phi Eta Sigma Freshman Honors Society.

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 150 scientific articles.

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 nearly 30 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 coauthored education reports including *Vision and Change* and "America's Lab Report." A fellow of the American Association for the Advancement of Science (AAAS), she has received the American Society of Plant Biology's Excellence in Teaching Award and the Botanical Society's Bessey Award, 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*.

Lead Digital Author

Ian Quitadamo is a Professor with a dual appointment in Biological Sciences and Science Education at Central Washington University in Ellensburg, WA. 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 bachelor's degree in biology, master's 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 received the Crystal Apple award for teaching excellence and led multiple initiatives in critical thinking and assessment. He is active nationally in helping transform university faculty practices. He is a coauthor of *Biology*, 11th ed., by Mader and Windelspecht (2013), and is the lead digital author for *Biology*, 3rd and 4th ed., by Brooker (2014 and 2017), *Biology*, 10th ed., by Raven (2014), *Understanding Biology* by Mason (2015), and *Principles of Biology* by Brooker (2015), all published by McGraw-Hill. For fun, Dr. Quitadamo practices Kyokushin full contact karate and is a 5th degree blackbelt.

Committed to Excellence

With the new 11th edition, Raven and Johnson's *Biology* continues the momentum built over the last three editions. This edition provides an unmatched comprehensive text fully integrated with a continually evolving, state-of-the-art digital environment. We have used this digital environment in the revision of *Biology*. The McGraw-Hill SmartBook© for the 10th edition provided data on student responses, and thus identify material that students find difficult. This "heat-mapping" technology is unique in the industry, and allows us to direct editing to difficult areas, or problem areas for students. The text continues to be a leader with an organization that emphasizes important biological concepts, while keeping the student engaged with learning outcomes that allow assessment of progress in understanding these concepts. An inquiry-based approach with robust, adaptive tools for discovery and assessment in both text and digital resources provides the intellectual challenge needed to promote student critical thinking and ensure academic success. A major strength of both text and digital resources is assessment across multiple levels of Bloom's taxonomy that develops critical-thinking and problem-solving skills in addition to comprehensive factual knowledge. McGraw-Hill's Connect® platform offers a powerful suite of online tools that are linked to the text and now include new quantitative assessment tools. The adaptive learning system helps students learn faster, study efficiently, and retain more knowledge of key concepts.

The 11th edition continues our tradition of providing the student with clear learning paths that emphasize data analysis and quantitative reasoning. Additional embedded eBook resources link to asides that delve more deeply into quantitative aspects.

As a team, we continually strive to improve the text by integrating the latest cognitive and best practices research with methods that are known to positively affect learning. We have multiple features that are focused on scientific inquiry, including an increased quantitative emphasis in the Scientific Thinking figures. We continue to use the concise, accessible, and engaging writing style of past editions while maintaining the clear emphasis on evolution and scientific inquiry that have made this a leading textbook of choice for majors biology students. Our emphasis on evolution combined with integrated cell and molecular biology and genomics offers our readers a student-friendly text that is modern and well balanced.

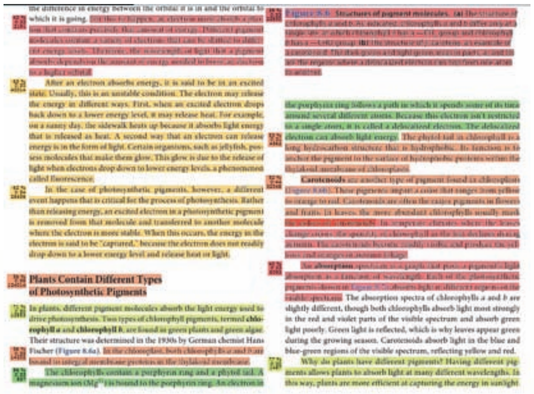
The 11th edition continues to employ the aesthetically stunning art program that the Raven and Johnson *Biology* text is known for. Complex topics are represented clearly and succinctly, helping students to build the mental models needed to understanding biology.

Insights into the diversity of life that are provided by molecular tools have led to a continued updating of these topics in the 11th edition. The diversity unit reflects the most current research on eukaryotic phylogenies, blending molecular, morphological, and development viewpoints. The biotechnology and genomics chapters have been completely revised to reflect changes in these fast-moving areas of modern biology. These are just a few examples of the many changes in the 11th edition of *Biology* that provide students with scientifically accurate context, historical perspective, and relevant supporting details essential to a modern understanding of life science.

As the pace of scientific discovery continues to provide new insights into the foundation of life on Earth, our author team will continue to use every means possible to ensure students are as prepared as possible to engage in biological topics. Our goal now, as it has always been, is to ensure student success. To that end, we approached this revision differently. To help guide our revision for this 11th edition, we were able to incorporate student usage data and input, derived from thousands of our SmartBook® users. SmartBook "heat maps" provided a quick visual snapshot of chapter usage data and the relative difficulty students experienced in mastering the content. With these data, we were able to hone not only our text content but also the SmartBook probes.

- If the data indicated that the subject was more difficult than other parts of the chapter, as evidenced by a high proportion of students responding incorrectly to the probes, we revised or reorganized the content to be as clear and illustrative as possible.
- In other cases, if one or more of the SmartBook probes for a section was not as clear as it might be or did not appropriately reflect the content, we edited the probe, rather than the text.

Below is an example of one of the heat maps from Chapter 8. The color-coding in highlighted sections indicate the various levels of difficulty students experienced in learning the material; topics highlighted in red being the most challenging for students.



We're excited about the 11th edition of this quality textbook providing a learning path for a new generation of students. All of us have extensive experience teaching undergraduate biology, and we've used this knowledge as a guide in producing a text that is up to date, beautifully illustrated, and pedagogically sound for the student. We've also worked to provide clear explicit learning outcomes, and more closely integrate the text with its media support materials to provide instructors with an excellent complement to their teaching.

Ken Mason, Jonathan Losos, Susan Rundell Singer

Cutting Edge Science

Changes to the 11th Edition

Part I: The Molecular Basis of Life

The revision for the 11th edition started with the end users—the students. As described earlier, the authors analyzed SmartBook student usage data collected over the life of the 10th edition. The data from SmartBook revealed content areas where students struggled and based on that information, the authors revised the text to improve clarity. All chapters were evaluated using the SmartBook heat-mapping data.

Other content-specific changes incude:

Part II: Biology of the Cell

Chapter 5—New information on how phospholipid composition differs in different membranes and how this can affect function was added. The chapter was reorganized and a new figure was added to highlight this material.

Chapter 6—Figures 6.4 and 6.5 were revised for clarity and accuracy.

Chapter 9—A new evolutionary aside on the Ras superfamily of small GTPases was added.

Part III: Genetic and Molecular Biology

The overall organization of this section remains the same. We have retained the split of transmission genetics into two chapters as it has proved successful for students.

Content changes in the molecular genetics portion of this section continue to update material that is the most rapidly changing in the entire book. We also continue to refine the idea that RNA plays a much greater role now than appreciated in the past.

Chapter 14—Extensive editing for clarity was done based on heat-map data.

Chapter 15—Extensive updating was done, including a rewritten section on eukaryotic transcription that emphasizes a more modern perspective. Extensive editing throughout the chapter for clarity was done based on heat-map data.

Chapter 16—Extensive updating was done, including a rewritten section on eukaryotic chromatin structure to emphasize a more modern view, taking new high-throughput data into account.

Chapter 17—The chapter was significantly revised to reflect advances in molecular biology techniques such as quantitative reverse-transcription PCR, the CRISPR/Cas9 and related gene-editing technologies, and genetic engineering approaches. Additional modifications include the revision or addition of relevant, engaging applications of biotechnology such as wastewater treatment, biofuel production, and disease detection and treatment.

Chapter 18—Changes to this chapter focus on updating content related to recent advances in sequencing technologies and include the addition of new comparative discussions on the human, wheat, and cancer genome projects. Also, a new analytical commentary on the ENCODE project helps students think critically about recent findings in the genomics field. The addition of a section on the applications of genomics helps students appreciate the social relevance of an often abstract subject area.

Part IV: Evolution

Chapter 20—The section on genetic variation was substantially revised to include recent genomic surveys quantifying the extent of genetic variation across the genome in humans. The text was clarified to say that "dominant" has no connotation of selective superiority. In addition, revisions were made to the information on the current cost in human lives of evolutionary change in microbes evolving resistance to antibiotics.

Chapter 21—The coverage of Darwin's finches and the peppered moth stories were revised to incorporate new information. A section on dating of fossils using radioactive decay was added.

Chapter 22—New additions include examples of geographic variation in the black rat snake incorporating recent phylogenetic analyses of DNA data; reproductive character displacement involving *Phlox* plants in Texas; and adaptive radiation in plants using the Hawaiian *Lobelia*. The phylogeny of Darwin's finches was modified based on current research. New data appear on the evolution of developmental regulation of beak shape in Darwin's finches, along with a new section on mass extinction.

Chapter 23—A new section was added on the relationship between phylogenetics and taxonomic classifications. The figures illustrating how phylogenetics works and how character evolution is interpreted on an evolutionary tree were revised.

New data are included on the evolution of saber-teeth in mammals.

Chapter 24—Updates include new data on comparative genomics. Consideration of primate genomes is expanded, including human and Neanderthal.

Chapter 25—The introduction was rewritten. The cichlid and stickleback examples were updated with new information.

Part V: Diversity of Life on Earth

Chapter 26—The information on geological dating and taxonomic classification was moved to other chapters where the discussions were more relevant.

Chapter 27—This chapter was extensively revised and updated, including a new section on giant viruses and material on the recent Ebola outbreak in Africa.

Chapter 28—Extensive updates include a new section on CRISPR systems, which provide adaptive immunity in bacteria.

Chapter 29—Updated discussions appear on microfossils, malaria vaccines, micronucleus, and *Chlamydomonas genome*. Changes in section headings more clearly describe section contents. Numerous figures were updated to reflect changes in the text.

Chapters 30—The introduction has been modified to provide an overview of land plant evolution. Major trends in the evolution of land plants are now emphasized. The discussion on the effects of mutations on diploid versus haploid bodies has been clarified. The difference between animal and plant life cycles has been emphasized. Throughout the chapter, distinctions between sporophyte and gametophyte generations are clearly described. The significance of hornworts in land plant evolution is described. Section headings were changed to more clearly describe section contents.

Chapter 31—The reduction in the complexity of the gametophyte generation in the evolution of land plants is emphasized. Distinctions between gamete and gametophyte, male and female gametophyte, zygote and embryo, and gymnosperms and angiosperms have been clarified. A discussion of the hypothesis for the rapid expansion of the world's biomes by the angiosperms has been added. The development of the female gametophyte has been described in more detail. The significance of double fertilization has been described.

Chapter 32—The development of hyphae during the evolution of fungi is described. The significance of above-ground spore dispersal structures is emphasized. The characteristics of each fungus group are clearly and concisely described. The significance of fungi in rumen biology has been described. Section headings were changed to more clearly describe section contents. Numerous figures were updated to reflect changes in the text.

Chapters 33–35—These chapters have been streamlined, eliminating extraneous information that was outside the scope of the main topics in the chapters. Throughout, changes were made in the species used as illustrative examples. Information on number of species in different taxa was updated.

Chapter 34—The information on medical infection rates to various invertebrate groups was updated.

Chapter 35—The phylogeny of chordates was updated. A discussion of evolution of tortoises and new information on the sensory abilities of the platypus were added. The phylogeny of primates was updated. New information was added on the genome of Neanderthals and understanding of the evolution of modern humans.

Part VI: Plant Form and Function

Throughout the plant chapters, corrections have been made so that $2n$ and n refer to the sporophyte and gametophyte generations, respectively, and x refers to the number of sets of chromosomes.

Chapter 36—The anatomical positions of components of plant tissues are more clearly presented. Structural differences between angiosperms and gymnosperms are emphasized. Distinctions between similar structures in different tissues—for example, pits in xylem versus pores in phloem—are made.

Chapter 37—The significance of water potential gradients in water transport is clarified and emphasized. The association between anaerobic conditions and poor root growth is described.

Chapter 38—The mechanism of closing in the Venus flytrap leaf has been updated.

Chapter 41—The concept of alternation of generations has been clarified and emphasized.

Part VII: Animal Form and Function

Chapter 46—A new illustration of hinge joints was added.

Chapter 47—The section on pancreas function was revised.

Chapter 48—Information on cutaneous respiration in turtles was added. The discussion of gas exchange in the capillaries was revised.

Chapter 49—The illustration and explanation of components of blood cells were revised, along with the explanation of how blood clotting works.

Chapter 52—New information on facultative parthenogenesis in vertebrates was added. Information on birth control was updated.

Part VIII: Ecology and Behavior

Chapter 54—Information on the social behaviors and brains of prairie and montane voles was updated. The discussion of orientation and migration, plus the section on evolution of mate choice in frogs were revised. Extraneous examples were eliminated to streamline the chapter.

Chapter 55—The information on human population growth and population demographics for several countries was updated using current statistics.

Chapter 56— Extraneous material was removed to streamline the chapter.

Chapter 57—Figures and explanations of trophic cascades, how effects move from one level of the food web to the next, and the discussions of trophic levels and island biogeography were revised. New ideas are presented on why the tropics are so biologically rich.

Chapter 58—Up-to-date information appears on global warming and global ozone levels, with an illustration of how the Earth revolves around the sun. A section was added on new human diseases that come from animals (zoonotic diseases).

Chapter 59—Information on human population growth in biodiversity hot spots, human health toll of West Nile Virus, and the recovery of the peregrine falcon was updated.

A Note From the Authors

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.

Beatrice Sussman was the copyeditor for this edition. She has labored many hours and always improves the clarity and consistency of the text. She has made significant contributions to the quality of the final product.

We were fortunate to work again with MPS 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. Justin Wyatt, preceded by Rebecca Olson, the brand managers for *Biology* have been steady leaders during a time of change. Lead Product Developer Liz Sievers, provided support in so many ways it would be impossible to name them all. April Southwood, content project manager, and David Hash, designer, ensured our text was on time and elegantly designed. Patrick Reidy, executive 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 continue improving our Connect assessment tools.

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 used the many editions of this text. 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.

Finally, we need to thank instructors from across the country who are continually sharing their knowledge and experience with us through market feedback and symposia. The feedback we received shaped this edition. All of these people took time to share their ideas and opinions to help us build a better edition of *Biology* for the next generation of introductory biology students, and they have our heartfelt thanks.

Preparing Students for the Future

Developing Critical Thinking with the Help of . . .

Detailed Feedback in Connect®

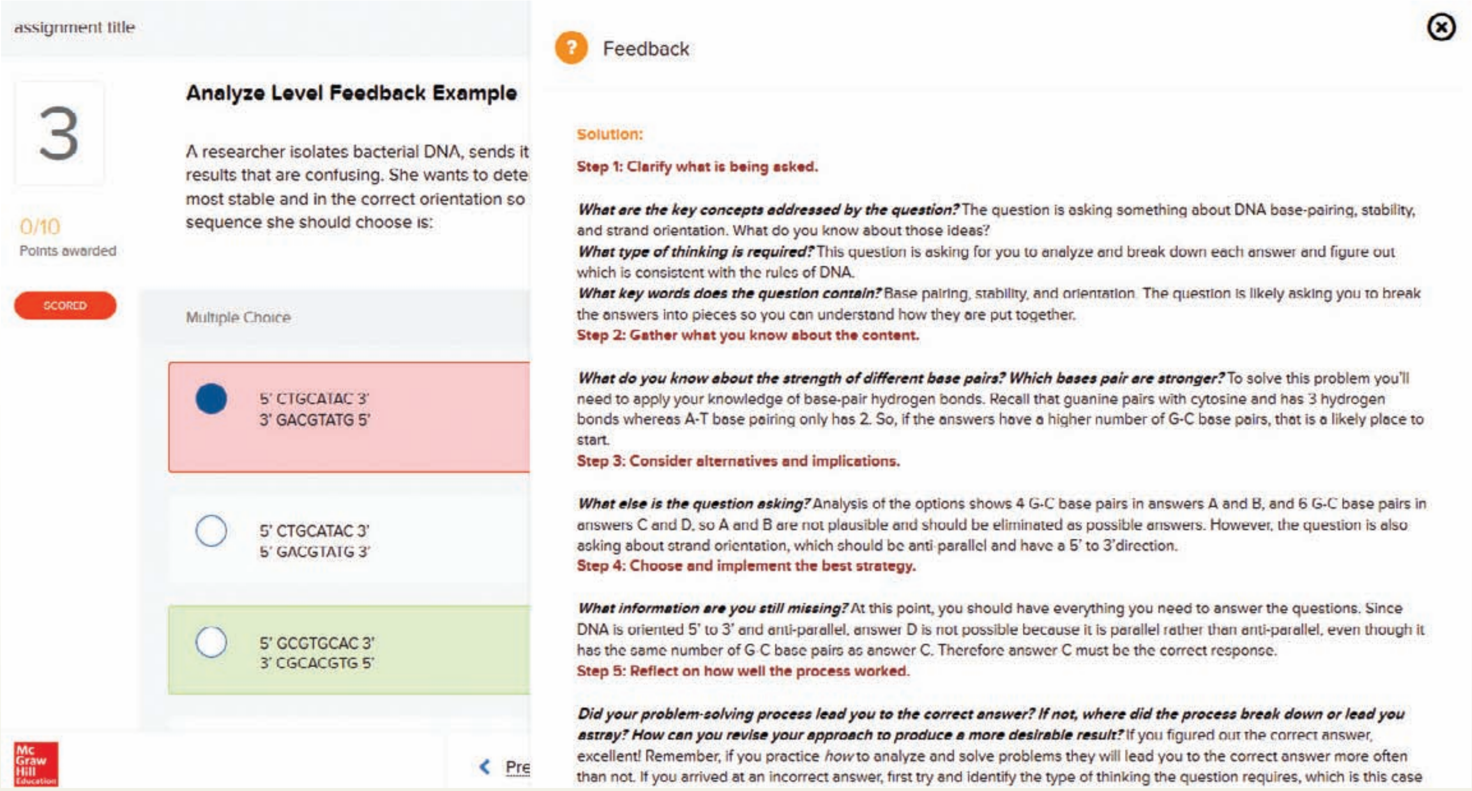
Learning is a process of iterative development, of making mistakes, reflecting, and adjusting over time. The question and test banks in Connect® for *Biology*, 11th edition, are more than direct assessments; they are self-contained learning experiences that systematically build student learning over 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 odds of guessing. A major fault with this approach is 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 Blooms questions in Connect are supported with hints, to help students focus on important information for answering the questions, and detailed feedback that walks students through the problem-solving process, using Socratic questions in a decision-tree-style framework to scaffold learning, where each step models and reinforces the learning process.

The feedback for each higher level Blooms question (Apply, Analyze, Evaluate) follows a similar process: Clarify Question, Gather Content, Choose Answer, Reflect on Process.

Unpacking the Concepts

We've taken problem solving a step further. In each chapter, three to five higher level Blooms questions in the question and test banks are broken out by the steps of the detailed feedback. Rather than leaving it up to the student to work through the detailed feedback, a second version of the question is presented in a stepwise format. Following the problem-solving steps, students need to answer questions about earlier steps, such as "What is the key concept addressed by the question?" before proceeding to answer the question. A 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

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.

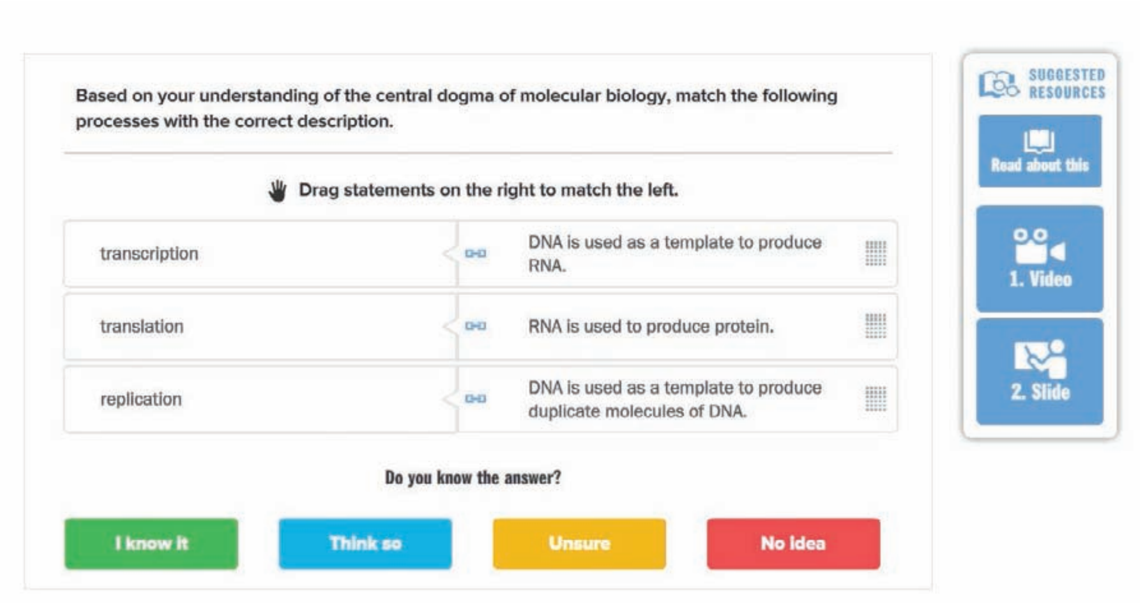
What information are you still missing? At this point, you should have everything you need to answer the questions. Since DNA is oriented 5' to 3' and anti-parallel, answer D is not possible because it is parallel rather than anti-parallel, even though it has the same number of G-C base pairs as answer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

Strengthen Problem Solving Skills and Key Concept Development with Connect®

SmartBook with Learning Resources

To help students understand key concepts, SmartBook® for *Biology*, 11th edition, is enhanced with Learning Resources. Based on student usage data, derived from thousands of SmartBook users of the tenth 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 concept based on his/her performance on the SmartBook questions, the student is given an option to review the Learning Resource or the student can click on the Learning Resources at any time.

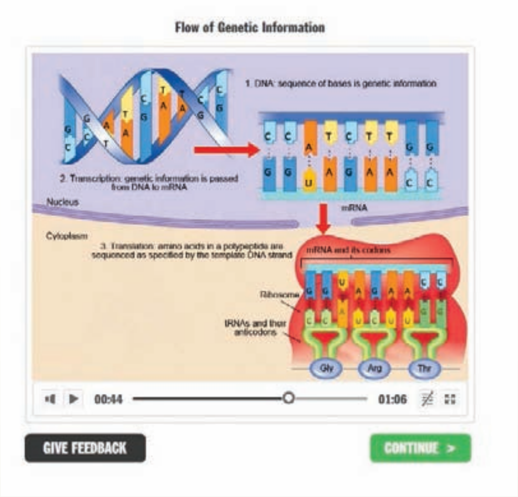


Based on your understanding of the central dogma of molecular biology, match the following processes with the correct description.

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?

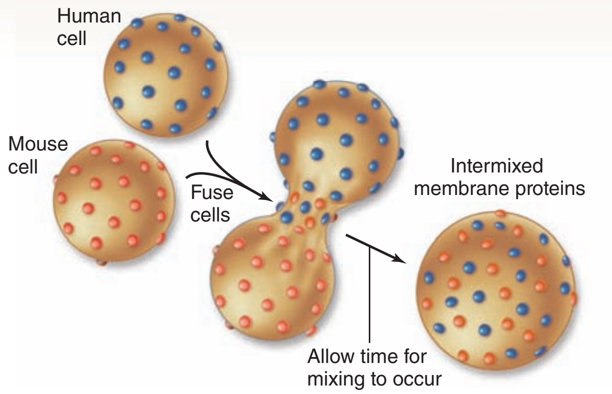


Scientific Thinking Art

Key illustrations in every chapter highlight how the frontiers of knowledge are pushed forward by a combination of hypothesis and experimentation. These figures begin with a hypothesis, then show how it makes explicit predictions, tests these by experiment and finally demonstrates what conclusions can be drawn, and where this leads. Scientific Thinking figures provide a consistent framework to guide the student in the logic of scientific inquiry. Each illustration concludes with open-ended questions to promote scientific inquiry.

SCIENTIFIC THINKING

Hypothesis: *The plasma membrane is fluid, not rigid.*
Prediction: *If the membrane is fluid, membrane proteins may diffuse laterally.*
Test: *Fuse mouse and human cells, then observe the distribution of membrane proteins over time by labeling specific mouse and human proteins.*



Result: *Over time, hybrid cells show increasingly intermixed proteins.*
Conclusion: *At least some membrane proteins can diffuse laterally in the membrane.*
Further Experiments: *Can you think of any other explanation for these observations? What if newly synthesized proteins were inserted into the membrane during the experiment? How could you use this basic experimental design to rule out this or other possible explanations?*

Figure 5.5 **Test of membrane fluidity.**

Data Analysis Questions

It's not enough that students learn concepts and memorize scientific facts, a biologist needs to analyze data and apply that knowledge. Data Analysis questions inserted throughout the text challenge students to analyze data and Interpret experimental results, which shows a deeper level of understanding.

Supporting Material Provided Online

Evolutionary Asides are inserted at relevant places in the book. The student links to this online content through the Evolutionary Aside icon found in the eBook. Evolutionary Asides provide additional examples or discussions of evolutionary topics related to the textual discussion.

Quantitative Asides are inserted at relevant places in the book. The student links to this online content through the Quantitative Aside icon found in the eBook. Quantitative Asides provide additional examples or expanded discussions of a quantitative aspect of the topic under discussion.

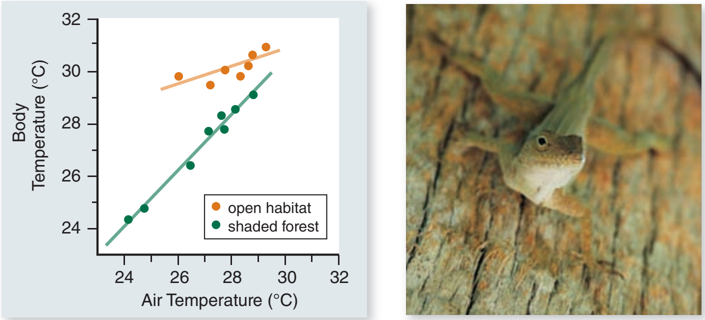


Figure 55.3 **Behavioral adaptation.** In open habitats, the Puerto Rican crested lizard, *Anolis cristatellus,* maintains a relatively constant temperature by seeking out and basking in patches of sunlight; as a result, it can maintain a relatively high temperature even when the air is cool. In contrast, in shaded forests, this behavior is not possible, and the lizard's body temperature conforms to that of its surroundings.

? **Inquiry question** When given the opportunity, lizards regulate their body temperature to maintain a temperature optimal for physiological functioning. Would lizards in open habitats exhibit different escape behaviors from lizards in shaded forest?

Data analysis Can the slope of the line tell us something about the behavior of the lizard?

Inquiry Questions

Questions that challenge students to think about and engage in what they are reading at a more sophisticated level.

Using Connect® and *Biology*, 11th edition

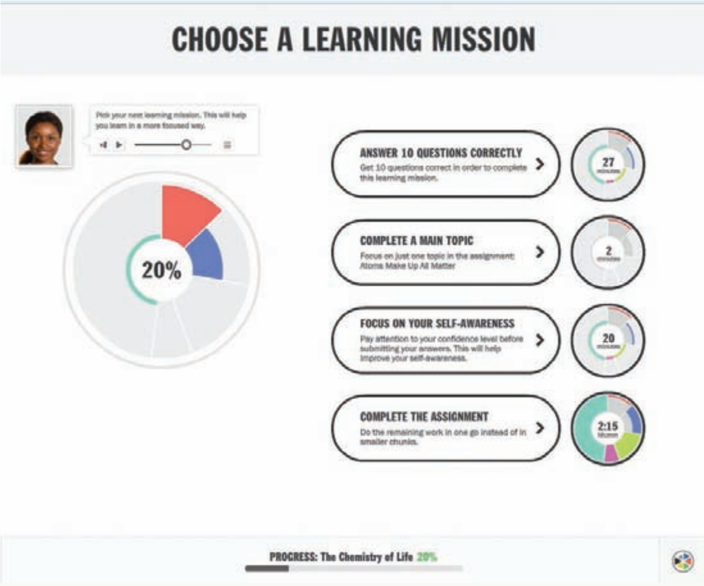
Biology 11th edition and its online assets have been carefully crafted to help professors and students work efficiently and effectively through the material in the course, making the most of instructional and study time.

Prepare for the Course

Many biology students struggle the first few weeks of class. Many institutions expect students to start majors biology having a working knowledge of basic chemistry and cellular biology. *LearnSmart Prep* 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.

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.

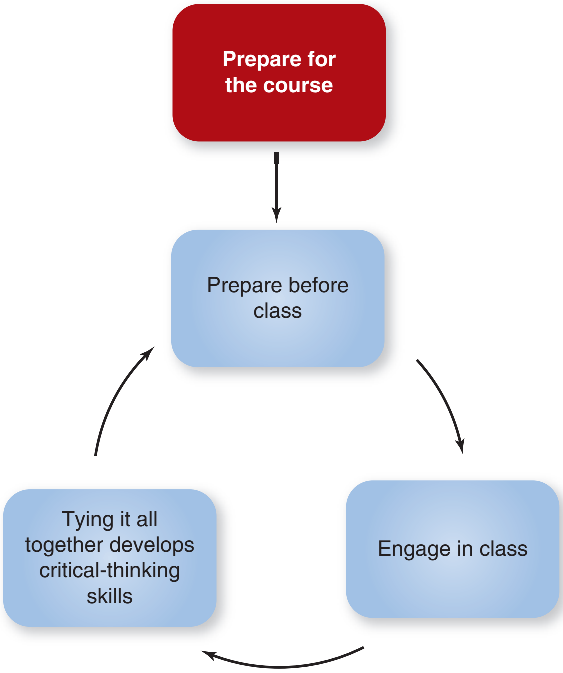
ANSWER 10 QUESTIONS CORRECTLY — Get 10 questions correct in order to complete this learning mission.

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 (ex. animation or tutorial) on that concept, then 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!

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 your majors biology course.


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%

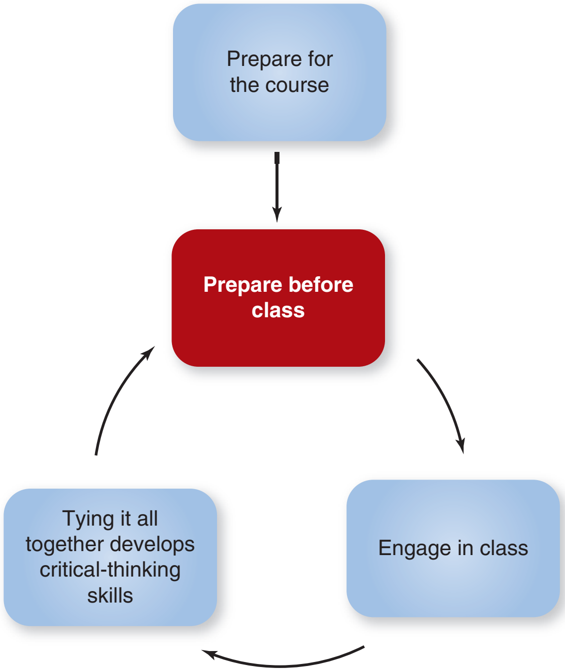
Prepare Before Class

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. *Biology*, 11th edition, is available in two formats: the printed text as well as the online SmartBook. Student 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.

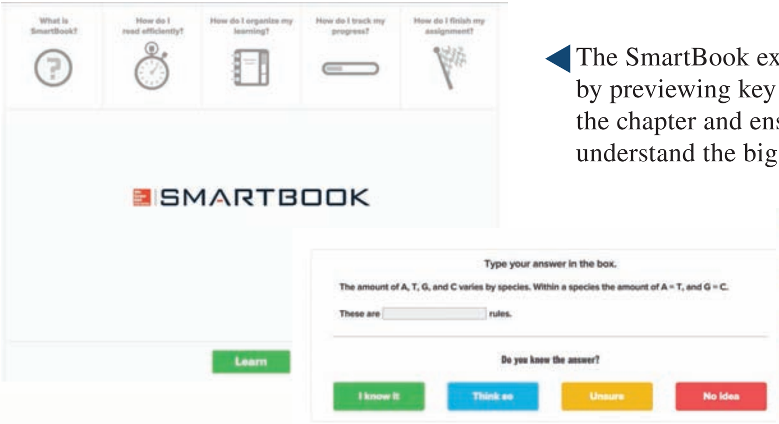
Professors can help students prepare for class by making preclass assignments. SmartBook assignments are effective for introducing terminology and general concepts.

SmartBook provides 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?

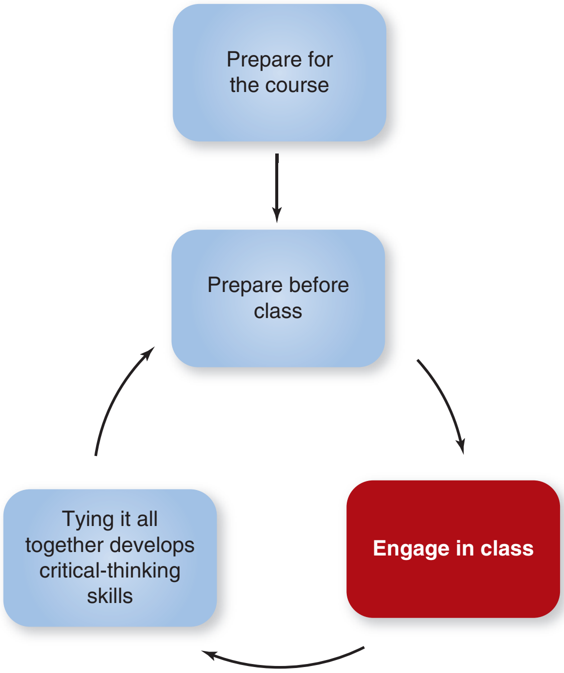
◀ The SmartBook experience starts by previewing key concepts from the chapter and ensuring that you understand the big ideas.

▲ 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.

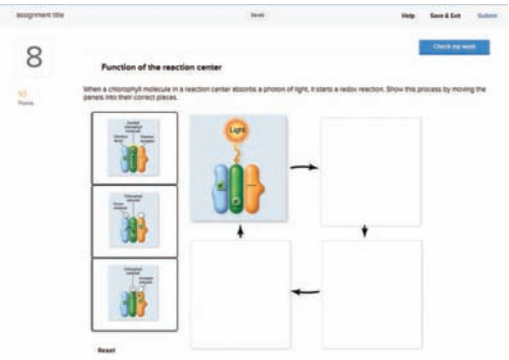
Engage in Class

McGraw-Hill Connect® provides online presentation, assignment, and assessment solutions. It connects students 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. Instructors can edit existing questions and author entirely new problems. They can track individual student performance—by question, assignment, or in relation to the class overall—with detailed grade reports.



① Preclass assignments to help students engage in the content during class.

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

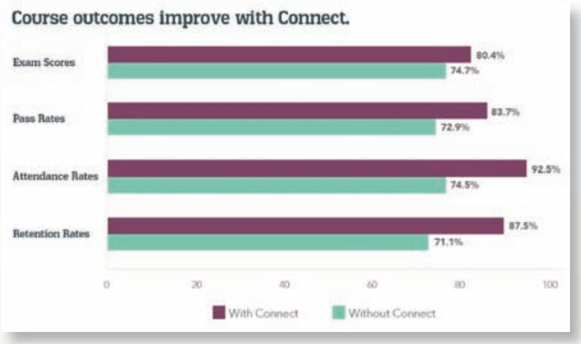


Function of the reaction center

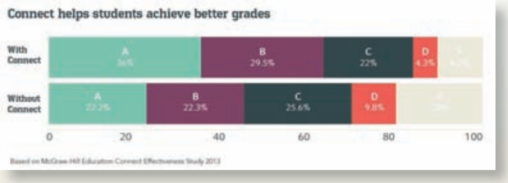
When a chlorophyll molecule in a reaction center absorbs a photon of light, it starts a redox reaction. Show this process by moving the panels into their correct places.

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.



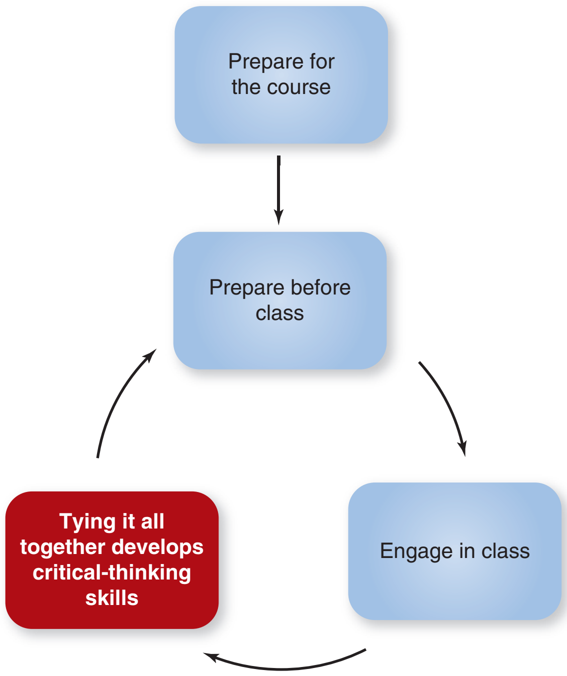
Based on McGraw-Hill Education Connect Effectiveness Study 2013

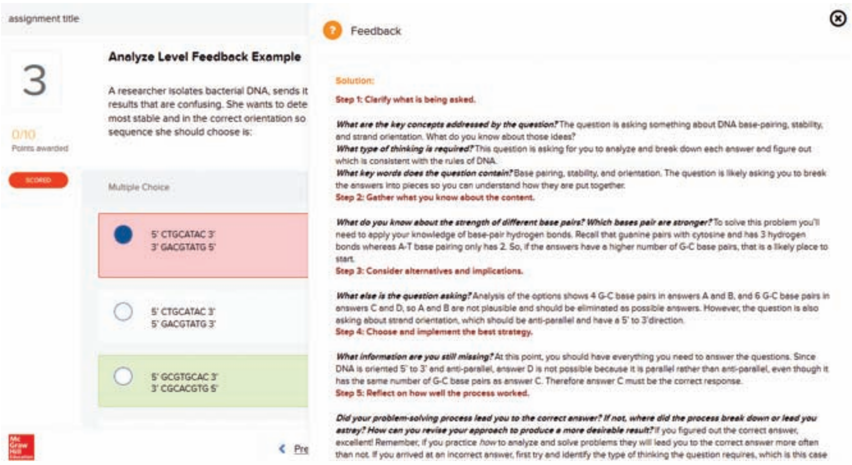
Presents data that empower students to improve performance that is efficient and effective.

Tying It All Together

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 Blooms tags.





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'

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.

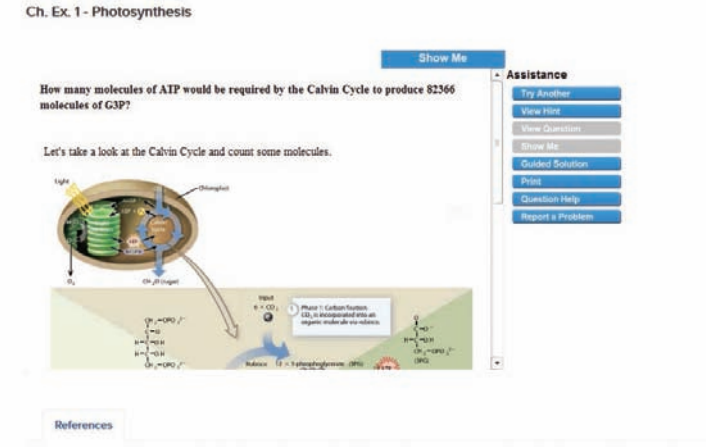
What else is the question asking? Analysis of the options shows 4 G-C base pairs in answers A and B, and 6 G-C base pairs in answers C and D, so A and B are not plausible and should be eliminated as possible answers. However, the question is also asking about strand orientation, which should be anti-parallel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



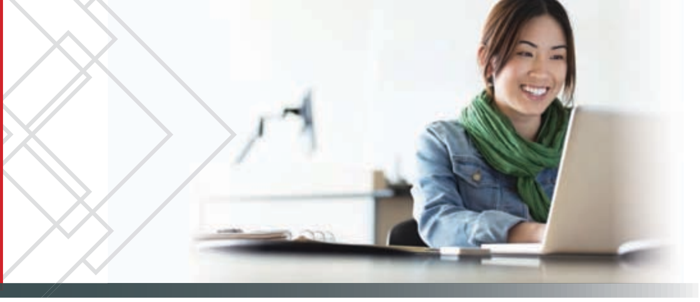
Ch. Ex. 1 - Photosynthesis

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.

Mc Graw Hill Education connect®

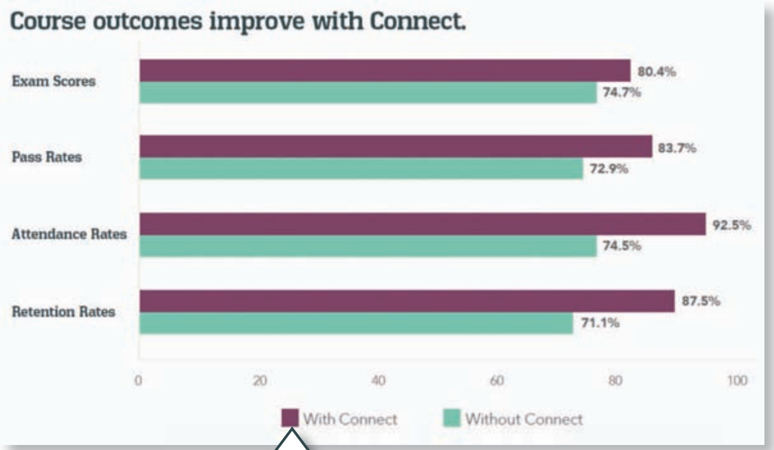
Required=Results



McGraw-Hill Connect® Learn Without Limits

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

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

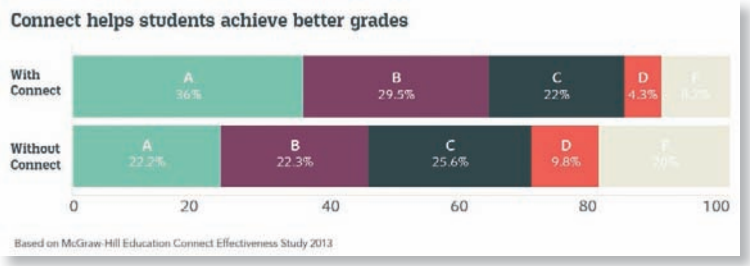


Using **Connect** improves passing rates by **10.8%** and retention by **16.4%.**

88% of instructors who use **Connect** require it; instructor satisfaction **increases** by 38% when **Connect** is required.

Analytics

Connect Insight®



Based on McGraw-Hill Education Connect Effectiveness Study 2013

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

Students can view their results for any **Connect** course.

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Connect's new, intuitive mobile interface gives students and instructors flexible and convenient, anytime–anywhere access to all components of the Connect platform.

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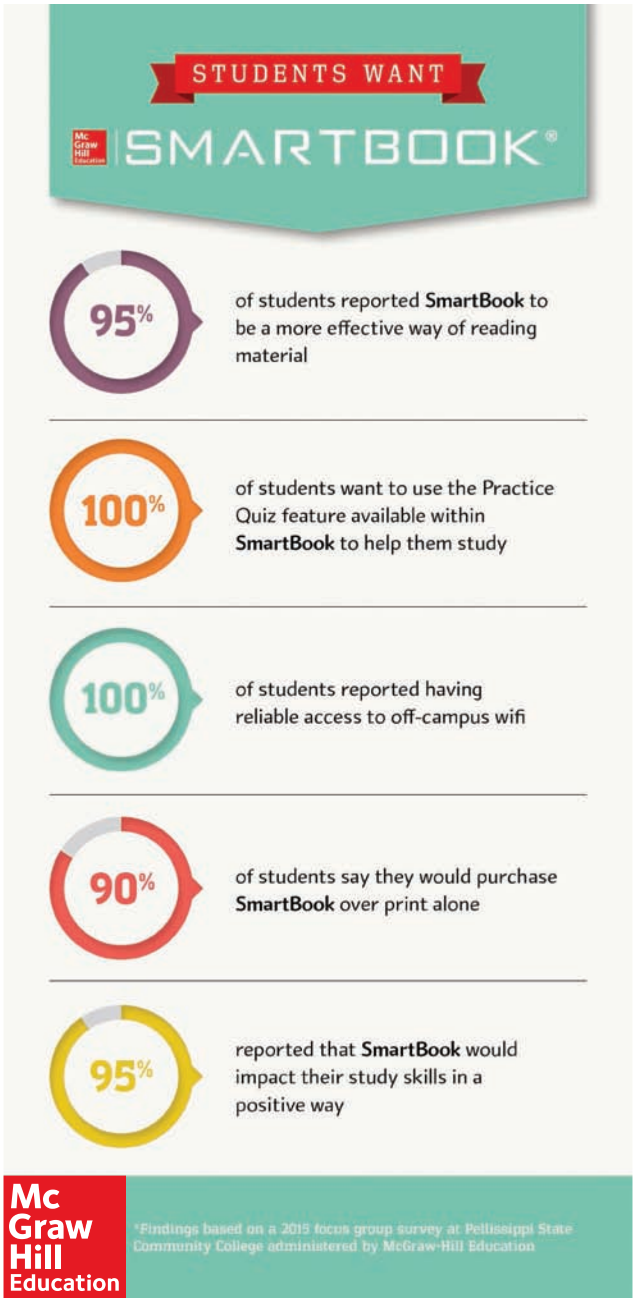

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100% of students want to use the Practice Quiz feature available within **SmartBook** to help them study

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

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

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*Findings based on a 2015 focus group survey at Pellissippi State Community College administered by McGraw-Hill Education

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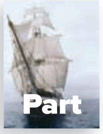
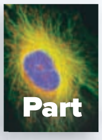
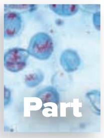


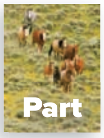
Part I The Molecular Basis of Life



Part II Biology of the Cell



Part III Genetic and Molecular Biology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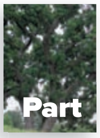
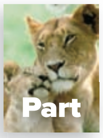


VI Plant Form and Function

VII Animal Form and Function



VIII Ecology and Behavior

Part I The Molecular Basis of Life

CHAPTER 1

The Science of Biology

Chapter Contents

Introduction

You are about to embark on a journey—a journey of discovery about the nature of life. More than 180 years 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 Science of Life

Learning Outcomes

1. *Compare biology to other natural sciences.*
2. *Describe the characteristics of living systems.*
3. *Characterize the hierarchical organization of living systems.*

This is the most exciting time to be studying biology in the history of the field. The amount of information available about the natural world has exploded in the last 42 years since the construction of the first recombinant DNA molecule. We are now in a position to ask and answer questions that previously were only dreamed of.

The 21st century began with the completion of the sequence of the human genome. The largest single project in the history of biology took about 20 years. Yet less than 15 years later, we can sequence an entire genome in a matter of days. This flood of sequence data and genomic analysis are altering the landscape of biology. These and other discoveries are also moving into the clinic as never before with new tools for diagnostics and treatment. With robotics, advanced imaging, and analytical techniques, we have tools available that were formerly the stuff of science fiction.

In this text, we attempt to draw a contemporary picture of the science of biology, as well as provide some history and experimental perspective on this exciting time in the discipline. In this introductory chapter, we examine the nature of biology and the foundations of science in general to put into context the information presented in the rest of the text.

Biology unifies much of natural science

The study of biology is a point of convergence for the information and tools from all of the natural sciences. Biological systems are the most complex chemical systems on Earth, and their many functions are both determined and constrained by the principles of chemistry and physics. Put another way, no new laws of nature can be gleaned from the study of biology—but that study does illuminate and illustrate the workings of those natural laws.

The intricate chemical workings of cells can be understood using the tools and principles of chemistry. And every level of biological organization is governed by the nature of energy transactions first studied by thermodynamics. Biological systems do not represent any new forms of matter, and yet they are the most complex organization of matter known. The complexity of living systems is made possible by a constant source of energy—the Sun. The conversion of this radiant energy into organic molecules by photosynthesis is one of the most beautiful and complex reactions known in chemistry and physics.

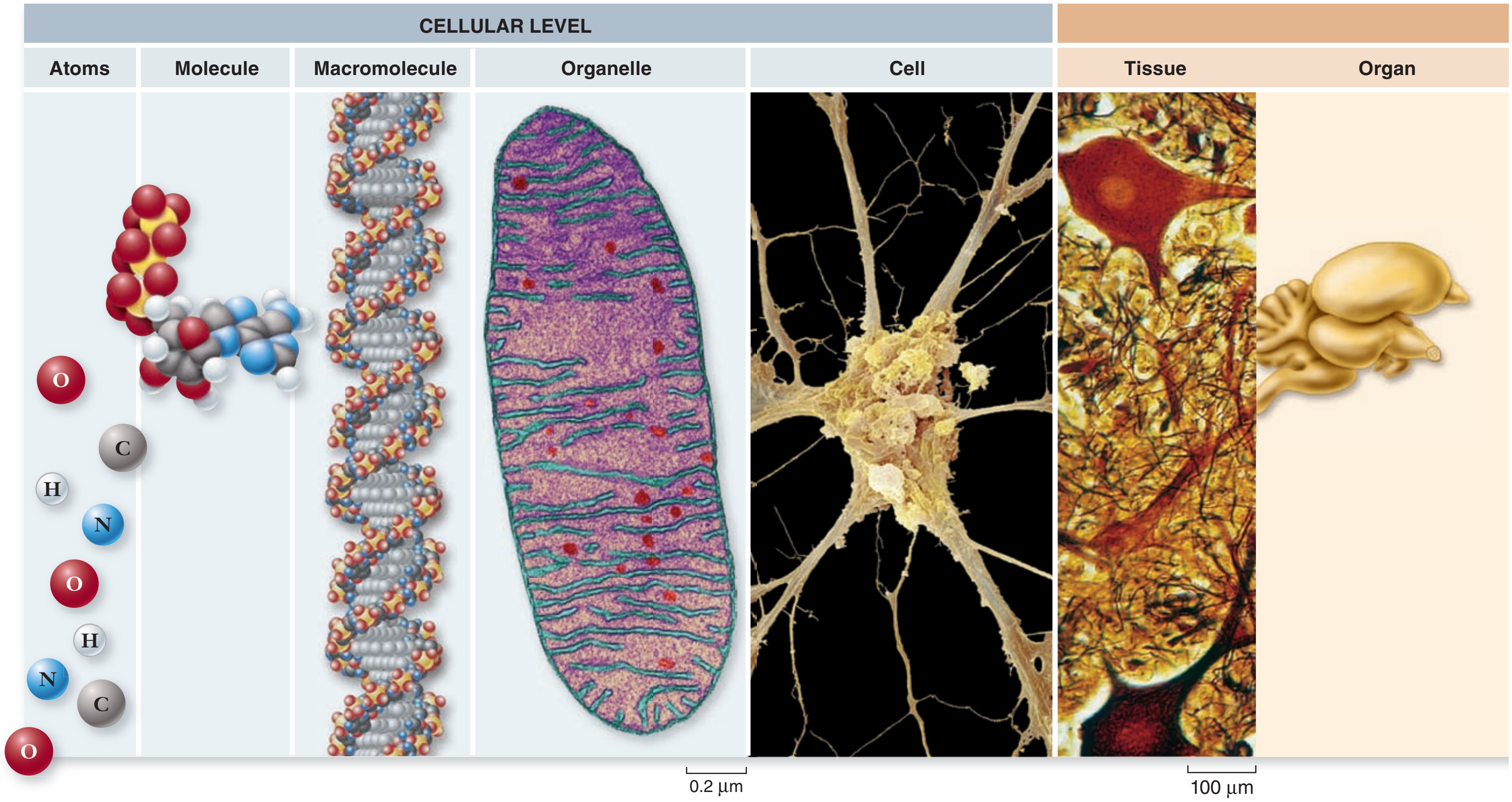
The way we do science is changing to grapple with increasingly difficult modern problems. Science is becoming more interdisciplinary, combining the expertise from a variety of traditional disciplines and emerging fields such as nanotechnology. Biology is at the heart of this multidisciplinary approach because biological problems often require many different approaches to arrive at solutions.

Life defies simple definition

In its broadest sense, biology is the study of living things—*the science of life.* Living things come in an astounding variety of shapes and forms, and biologists study life in many different ways. They live with gorillas, collect fossils, and listen to whales. They read the messages encoded in the long molecules of heredity and count how many times a hummingbird's wings beat each second.

What makes something "alive"? Anyone could deduce that a galloping horse is alive and a car is not, but why? We cannot say, "If it moves, it's alive," because a car can move, and gelatin can wiggle in a bowl. They certainly are not alive. Although we cannot define life with a single simple sentence, we can come up with a series of seven characteristics shared by living systems:

- **Cellular organization.** All organisms consist of one or more cells. Often too tiny to see, cells carry out the basic activities of living. Each cell is bounded by a membrane that separates it from its surroundings.
- **Ordered complexity.** All living things are both complex and highly ordered. Your body is composed of many different kinds of cells, each containing many complex molecular structures. Many nonliving things may also be



complex, but they do not exhibit this degree of ordered complexity.

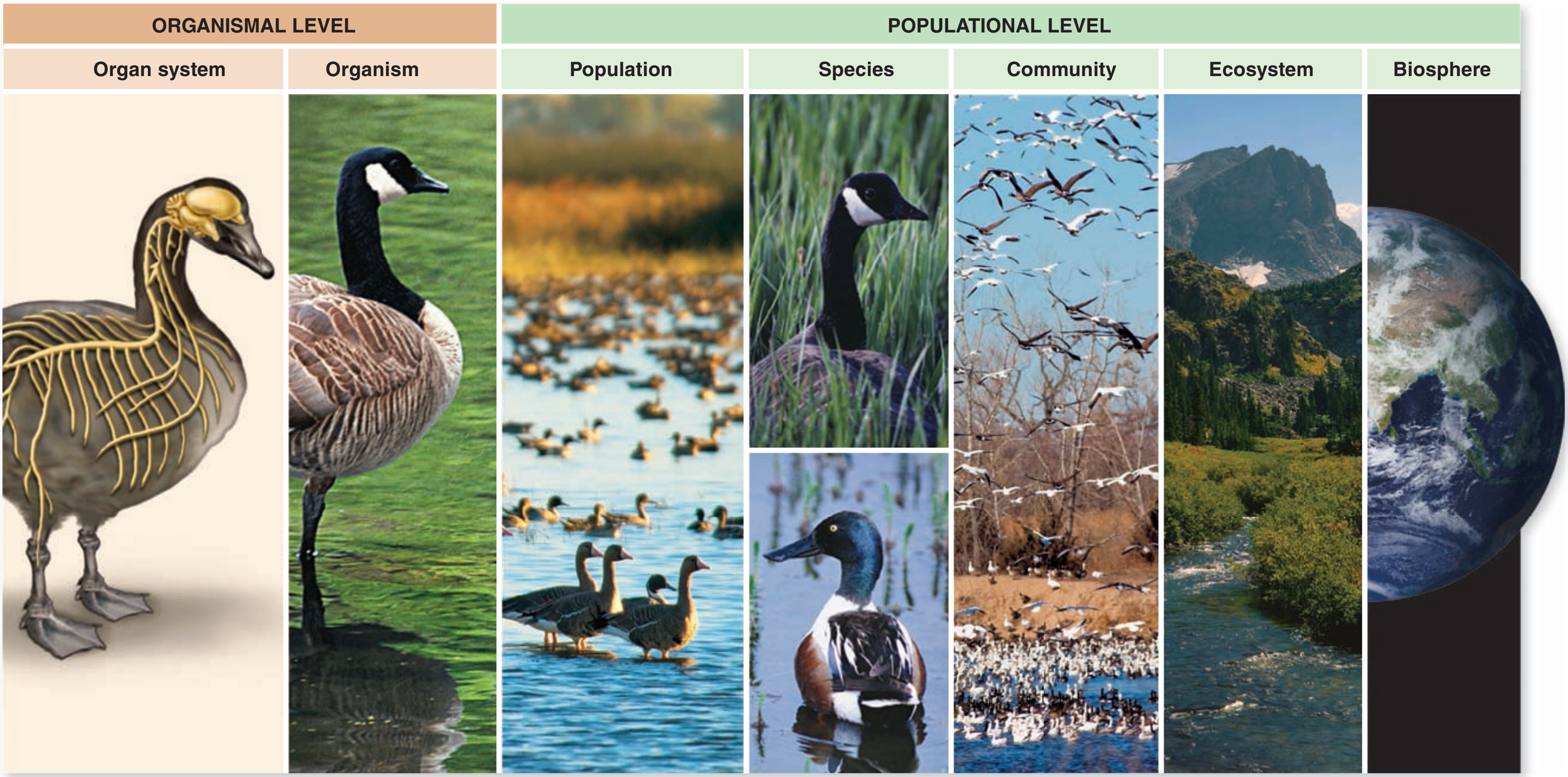
- **Sensitivity.** All organisms respond to stimuli. Plants grow toward a source of light, and the pupils of your eyes dilate when you walk into a dark room.
- **Growth, development, and reproduction.** All organisms are capable of growing and reproducing, and they all possess hereditary molecules that are passed to their offspring, ensuring that the offspring are of the same species.
- **Energy utilization.** All organisms take in energy and use it to perform many kinds of work. Every muscle in your body is powered with energy you obtain from your diet.
- **Homeostasis.** All organisms maintain relatively constant internal conditions that are different from their environment, a process called **homeostasis.** For example, your body temperature remains stable despite changes in outside temperatures.
- **Evolutionary adaptation.** 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

The organization of the biological world is hierarchical—that is, each level builds on the level below it:

1. **The cellular level.** At the cellular level (figure 1.1), **atoms,** the fundamental elements of matter, are joined together into clusters called **molecules.** Complex biological molecules are assembled into tiny structures called **organelles** within membrane-bounded units we call **cells.** The cell is the basic unit of life. Many independent organisms are composed only of single cells. Bacteria are single cells, for example. All animals and plants, as well as most fungi and algae, are multicellular—composed of more than one cell.
2. **The organismal level.** Cells in complex multicellular organisms exhibit three levels of organization. The most basic level is that of **tissues,** which are groups of similar cells that act as a functional unit. Tissues, in turn, are grouped into **organs—**body structures composed of several different tissues that act as a structural and functional unit. Your brain is an organ composed of nerve cells and a variety of associated tissues that form protective coverings and contribute blood. At the third level of organization, organs are grouped into **organ systems.** The nervous system, for example, consists of sensory organs, the brain and spinal cord, and neurons that convey signals.

Figure 1.1 Hierarchical organization of living systems. Life forms a hierarchy of organization from atoms to complex multicellular organisms. Atoms are joined together to form molecules, which are assembled into more complex structures such as organelles. These in turn form subsystems that provide different functions. Cells can be organized into tissues, then into organs and organ systems such as the goose's nervous system pictured. This organization then extends beyond individual organisms to populations, communities, ecosystems, and finally the biosphere.



3. **The populational level.** Individual organisms can be categorized into several hierarchical levels within the living world. The most basic of these is the **population—**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,** its members similar in appearance and able to interbreed. At a higher level of biological organization, a **biological community** consists of all the populations of different species living together in one place.
4. **The ecosystem level.** At the highest tier of biological organization, populations of organisms interact with each other and their physical environment. Together populations and their environment constitute an ecological system, or **ecosystem.** For example, the biological community of a mountain meadow interacts with the soil, water, and atmosphere of a mountain ecosystem in many important ways.
5. **The biosphere.** The entire planet can be thought of as an ecosystem that we call the biosphere.

As you move up this hierarchy, the many interactions occurring at lower levels can produce novel properties. These so-called **emergent properties** may not be predictable. Examining individual cells, for example, gives little hint about the whole animal. Many weather phenomena, such as hurricanes, are actually emergent properties of many interacting meteorological variables. It is because the living world exhibits many emergent properties that it is difficult to define "life."

The previous descriptions 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 try to provide a more complete account of living systems.

Learning Outcomes Review 1.1

Biology as a science brings together other natural sciences, such as chemistry and physics, to study living systems. Life does not have a simple definition, but living systems share a number of properties that together describe life. Living systems can be organized hierarchically, from the cellular level to the entire biosphere, with emergent properties that may exceed the sum of the parts.

- ***Can you study biology without studying other sciences?***

1.2 The Nature of Science

Learning Outcomes

1. ***Compare the different types of reasoning used by biologists.***
2. ***Demonstrate how to formulate and test a hypothesis.***

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

At its core, science is concerned with developing an increasingly accurate understanding of the world around us 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. A number of complementary approaches allow understanding of natural phenomena—there is no one "scientific method."

Scientists also attempt to be as objective as possible in the interpretation of the data and observations they have collected. Because scientists themselves 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.

Much of science is descriptive

The classic vision of the scientific method is that observations lead to hypotheses that in turn make experimentally testable predictions. In this way, we 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.

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 much greater understanding of biodiversity as well as the effect our species has on biodiversity.

One of the most important accomplishments of molecular biology at the dawn of the 21st century was the completion of the sequence 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.

Science uses both deductive and inductive reasoning

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

Deductive reasoning

Deductive reasoning applies general principles to predict specific results. More than 2200 years ago, the Greek scientist Eratosthenes used Euclidean geometry and deductive reasoning to accurately estimate the circumference of the Earth (figure 1.2). Deductive reasoning is the reasoning of mathematics and philosophy, and it is used to test the validity of general ideas in all branches of

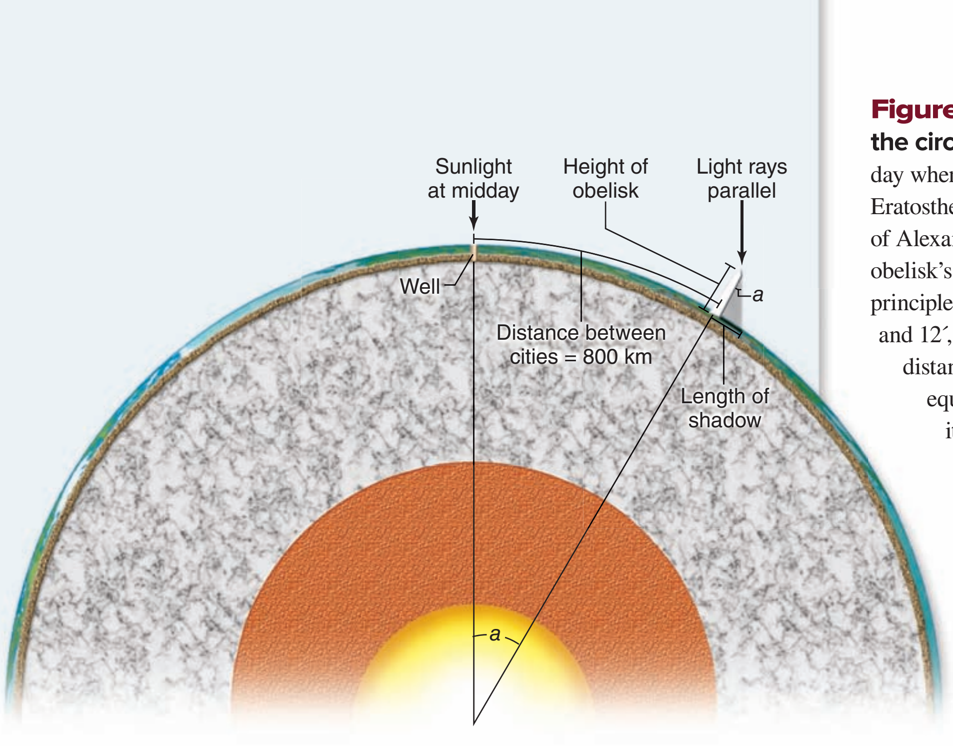


Figure 1.2 **Deductive reasoning: How Eratosthenes estimated the circumference of the Earth using deductive reasoning.** ***1.*** On a day when sunlight shone straight down a deep well at Syene in Egypt, Eratosthenes measured the length of the shadow cast by a tall obelisk in the city of Alexandria, 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 a camel travels about 18.5 km per day, he estimated the distance between 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. Using this distance Eratosthenes's value would have been 50 × 800 = 40,000 km. The actual circumference is 40,075 km.

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.

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.

An example from modern biology is the role of homeobox genes in development. Studies in the fruit fly, *Drosophila melanogaster,* identified genes that could cause dramatic changes in developmental fate, such as a leg appearing in the place of an antenna. These genes have since been found in essentially all multicellular animals analyzed. This led to the general idea that homeobox genes control developmental fate in animals.

Hypothesis-driven science makes and tests predictions

Scientists establish which general principles are true from among the many that might be true through the process of systematically testing alternative proposals. If these proposals prove inconsistent with experimental observations, they are rejected as untrue. Figure 1.3 illustrates the process.

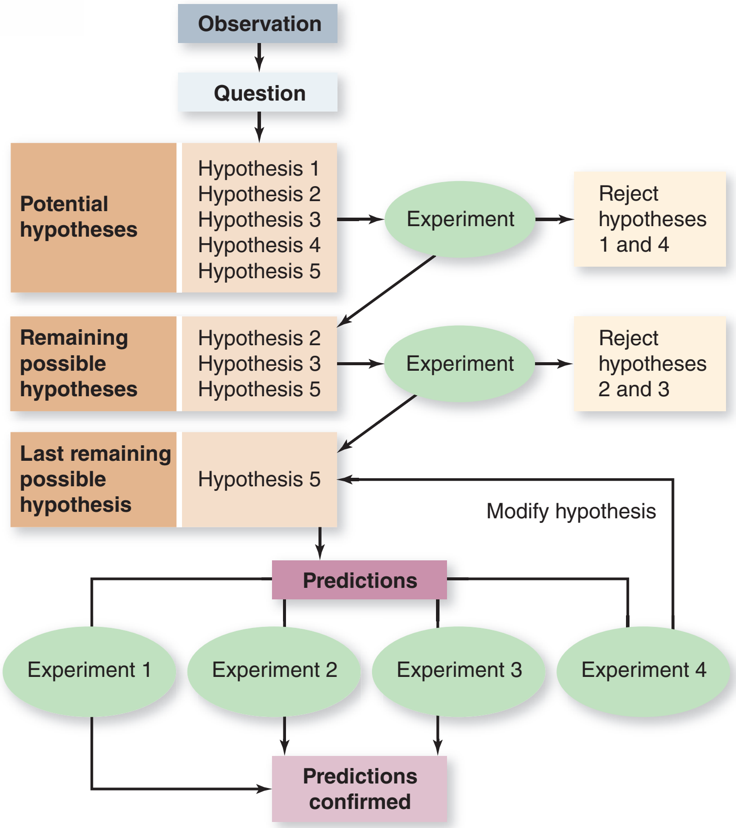


Figure 1.3 **How science is done.** This diagram illustrates how scientific investigations proceed. First, scientists make observations that raise a particular question. They develop a number of potential explanations (hypotheses) to answer the question. Next, they carry out experiments in an attempt to eliminate one or more of these hypotheses. Then, predictions are made based on the remaining hypotheses, and further experiments are carried out 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.

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 is usually an ongoing process with a hypothesis changing and being refined with new data. For instance, geneticists George Beadle and Edward Tatum studied the nature of genetic information to arrive at their "one-gene/one-enzyme" hypothesis (see chapter 15). 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 information 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.

Testing hypotheses

We call the test of a hypothesis an **experiment.** Suppose you enter a dark room. To understand why it is 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 lightbulb 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 is demonstrated to be inconsistent with the results and is 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 new observations are made by biologists. 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: a test experiment and a control experiment. In the **test experiment,** one variable is altered in a known way to test a particular hypothesis. In the **control experiment,** 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.

Using predictions

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 the 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 the hypothesis is.

As an example, in the early history of microbiology it was known that nutrient broth left sitting exposed to air becomes contaminated. Two hypotheses were proposed to explain this observation: spontaneous generation and the germ hypothesis. Spontaneous generation held that there was an inherent property in organic molecules that could lead to the spontaneous generation of life. The germ hypothesis proposed that preexisting microorganisms that were present in the air could contaminate the nutrient broth.

These competing hypotheses were tested by a number of experiments that involved filtering air and boiling the broth to kill any contaminating germs. The definitive experiment was performed by Louis Pasteur, who constructed flasks with curved necks that could be exposed to air, but that would trap any contaminating germs. When such flasks were boiled to sterilize them, they remained sterile, but if the curved neck was broken off, they became contaminated (figure 1.4).

SCIENTIFIC THINKING

Question: *What is the source of contamination that occurs in a flask of nutrient broth left exposed to the air?*

Germ Hypothesis: *Preexisting microorganisms present in the air contaminate nutrient broth.*

Prediction: *Sterilized broth will remain sterile if microorganisms are prevented from entering flask.*

Spontaneous Generation Hypothesis: *Living organisms will spontaneously generate from nonliving organic molecules in broth.*

Prediction: *Organisms will spontaneously generate from organic molecules in broth after sterilization.*

Test: *Use swan-necked flasks to prevent entry of microorganisms. To ensure that broth can still support life, break swan-neck after sterilization.*

Flask is sterilized by boiling the broth.

Unbroken flask remains sterile.

Broken flask becomes contaminated after exposure to germ-laden air.

Result: *No growth occurs in sterile swan-necked flasks. When the neck is broken off, and the broth is exposed to air, growth occurs.*

Conclusion: *Growth in broth is of preexisting microorganisms.*

Figure 1.4 **Experiment to test spontaneous generation versus germ hypothesis.**

This result was predicted by the germ hypothesis—that when the sterile flask is exposed to air, airborne germs are deposited in the broth and grow. The spontaneous generation hypothesis predicted no difference in results with exposure to air. This experiment disproved the hypothesis of spontaneous generation and supported the hypothesis of airborne germs under the conditions tested.

Reductionism breaks larger systems into their component parts

Scientists use the philosophical approach of **reductionism** to understand a complex system by reducing it to its working parts. Reductionism has been the general approach of biochemistry, which has been enormously successful at unraveling the complexity of cellular metabolism by concentrating on individual pathways and specific enzymes. By analyzing all of the pathways and their components, scientists now have an overall picture of the metabolism of cells.

Reductionism has limits when applied to living systems, however—one of which is that enzymes do not always behave exactly the same in isolation as they do in their normal cellular context. A larger problem is that 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 are the cellular factories that synthesize proteins, but this function could not be predicted based on analysis of the individual proteins and RNA that make up the structure. On a higher level, understanding the physiology of a single Canada goose would not lead to predictions about flocking behavior. The emerging field of systems biology uses mathematical and computational models to deal with the whole as well as understanding the interacting parts.

Biologists construct models to explain living systems

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 of signal transduction pathways and the events leading from an external signal to internal events. Structural biologists build actual 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.

As researchers gain more knowledge about the actual flow of molecules in living systems, more sophisticated kinetic models can be used to apply information about isolated enzymes to their cellular context. In systems biology, this modeling is being applied on a large scale to regulatory networks during development, and even to modeling an entire bacterial cell.

The nature of scientific theories

Scientists use the word **theory** in two main ways. The first meaning of theory is a proposed explanation for some natural phenomenon, often based on some general principle. 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 the body of interconnected concepts, supported by scientific reasoning and experimental evidence, that explains the facts in some area of study. Such a theory provides an indispensable framework for organizing a body of knowledge. For example, quantum theory in physics brings together a set of ideas about the nature of the universe, explains experimental facts, and serves as a guide to further questions and experiments.

To a scientist, theories are the solid ground of science, expressing ideas of which we are most certain. In contrast, to the general public, the word theory usually implies the opposite—a *lack* of knowledge, or a guess. 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.

Some critics outside of science attempt to discredit evolution by saying it is "just a theory." The hypothesis that evolution has occurred, however, is an accepted scientific fact—it is supported by overwhelming evidence. Modern evolutionary theory is a complex body of ideas, the importance of which spreads far beyond explaining evolution. Its ramifications permeate all areas of biology, and it provides the conceptual framework that unifies biology as a science. Again, the key is how well a hypothesis fits the observations. Evolutionary theory fits the observations very well.

Research can be basic or applied

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 a pretty fair 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 Bruce Springsteen stands out among songwriters or Claude Monet stands out among Impressionist painters.

Some scientists perform *basic research,* which is intended to extend the boundaries of what we know. These individuals typically work at universities, and their research is usually supported by grants from various agencies and foundations.

The information generated by basic research contributes to the growing body of scientific knowledge, and it provides the scientific foundation utilized by *applied research.* Scientists who conduct applied research are often employed in some kind of industry. Their work may involve the manufacture of food additives, the creation of new drugs, or the testing of environmental quality.

Research results are written up and submitted for publication in scientific journals, where the experiments and conclusions are reviewed by other scientists. 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.

Learning Outcomes Review 1.2

Much of science is descriptive, amassing observations to gain an accurate view. Both deductive reasoning and inductive reasoning are used in science. Scientific hypotheses are suggested explanations for observed phenomena. Hypotheses need to make predictions that can be tested by controlled experiments. Theories are coherent explanations of observed data, but they may be modified by new information.

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

1.3

An Example of Scientific Inquiry: Darwin and Evolution

Learning Outcomes

1. *Examine Darwin's theory of evolution by natural selection as a scientific theory.*
2. *Describe the evidence that supports the theory of evolution.*

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 grows and wins acceptance.

Charles Robert Darwin (1809–1882; figure 1.5) 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 ever since.

The idea of evolution existed prior to Darwin

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.

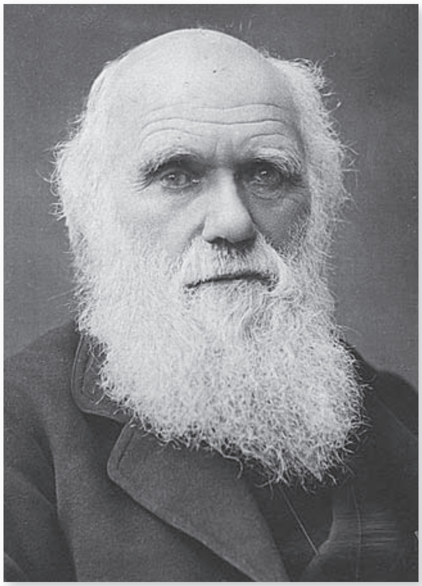


Figure 1.5 Charles Darwin. This newly rediscovered photograph taken in 1881, the year before Darwin died, appears to be the last ever taken of the great biologist.

In contrast to these ideas, a number of earlier naturalists and philosophers had presented the view that living things must have changed during the history of life on Earth. That is, **evolution** has occurred, and living things are now different from how they began. Darwin's contribution was a concept he called *natural selection,* which he proposed as a coherent, logical explanation for this process, and he brought his ideas to wide public attention.

Darwin observed differences in related organisms

The story of Darwin and his theory begins in 1831, when he was 22 years old. He was part of a five-year navigational mapping expedition around the coasts of South America (figure 1.6), aboard H.M.S. *Beagle.* During this long voyage, Darwin had the chance to study a wide variety of plants and animals on continents and islands and in distant seas. Darwin observed a number of phenomena that were of central importance to his reaching his ultimate conclusion.

Repeatedly, Darwin saw that the characteristics of similar species varied somewhat from place to place. These geographical patterns suggested to him that lineages change gradually as species migrate from one area to another. On the Galápagos Islands, 960 km (600 miles) off the coast of Ecuador, Darwin encountered a variety of different finches on the various islands. The 14 species, although related, differed slightly in appearance, particularly in their beaks (figure 1.7).

Darwin thought it was reasonable to assume that all these birds had descended from a common ancestor arriving from the South American mainland several million years ago. Eating different foods on different islands, the finches' beaks had changed during their descent—"descent with modification," or evolution. (These finches are discussed in more detail in chapters 21 and 22.)

Figure 1.6 **The five-year voyage of H.M.S. *Beagle*.** Most of the time was spent exploring the coasts and coastal islands of South America, such as the Galápagos Islands. Darwin's studies of the animals of the Galápagos Islands played a key role in his eventual development of the concept of evolution by means of natural selection.

In a more general sense, Darwin was struck by the fact that the plants and animals on these relatively young volcanic islands resembled those on the nearby coast of South America. If each one of these plants and animals had been created independently and simply placed on the Galápagos Islands, why didn't they resemble the plants and animals of islands with similar climates—such as those off the coast of Africa, for example? Why did they resemble those of the adjacent South American coast instead?

Darwin proposed natural selection as a mechanism for evolution

It is one thing to observe the results of evolution, but quite another to understand how it happens. Darwin's great achievement lies in his ability to move beyond all the individual observations to formulate the hypothesis that evolution occurs because of natural selection.

Woodpecker Finch *(Cactospiza pallida)*

Large Ground Finch *(Geospiza magnirostris)*

Cactus Finch *(Geospiza scandens)*

Figure 1.7 **Three Galápagos finches and what they eat.** On the Galápagos Islands, Darwin observed 14 different species of finches differing mainly in their beaks and feeding habits. These three finches eat very different food items, and Darwin surmised that the different shapes of their bills represented evolutionary adaptations that improved their ability to eat the foods available in their specific habitats.