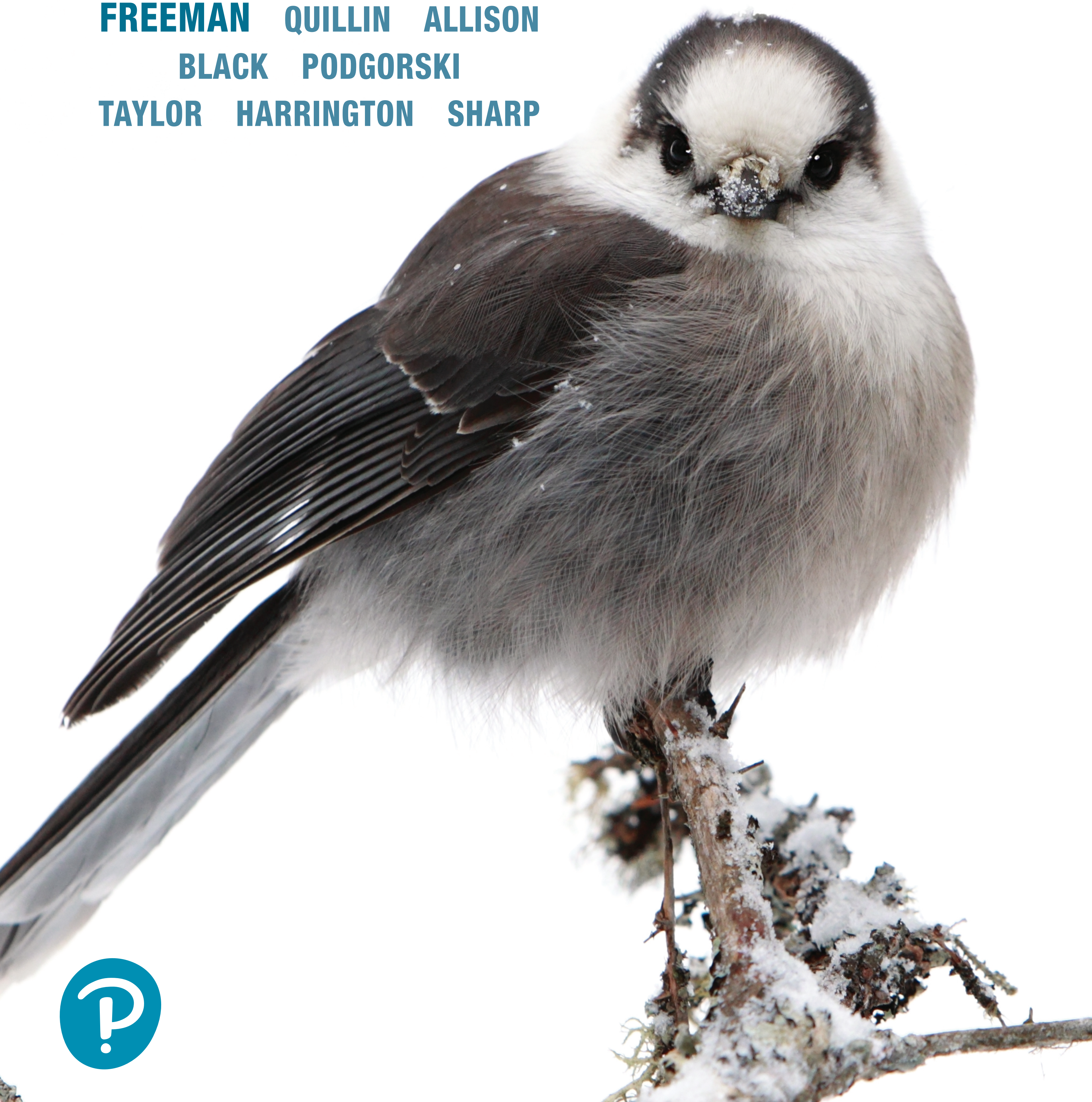
THIRD CANADIAN EDITION

BIOLOGICAL SCIENCE

FREEMAN QUILLIN ALLISON
BLACK PODGORSKI
TAYLOR HARRINGTON SHARP



Brief Contents

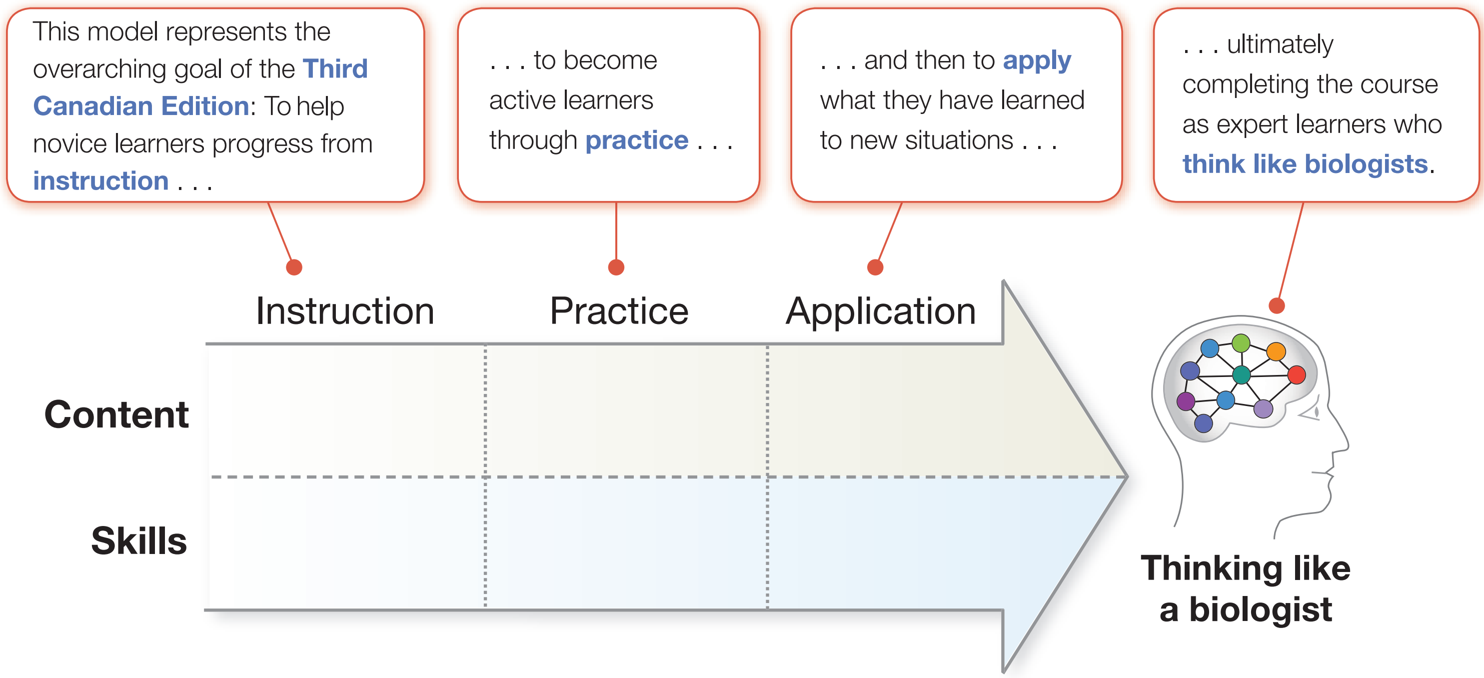
Canadian Research and Canadian Issues

CANADIAN RESEARCH

CANADIAN ISSUES

A Student-Centred Approach to the Study of Biology

Since its trailblazing First Edition, ***Biological Science*** has delivered numerous biology teaching innovations that emphasize higher-order thinking skills and conceptual understanding rather than an encyclopedic grasp of what is known about biology. With each edition, this approach has grown and improved to better help students make the shift from being novice learners to expert learners. Central to this shift is a student-centred approach that provides deep support for the learning of core content and the development of key skills that help students learn and practise biology.



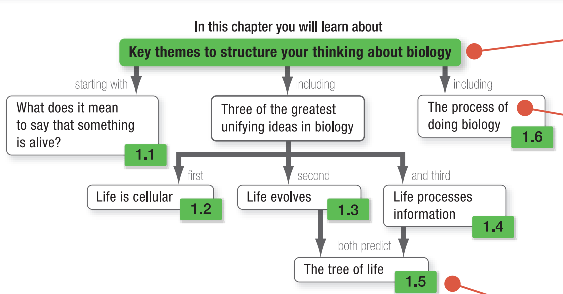
On the pages that follow, we will show how the text and **Mastering Biology** *resources work together to achieve this goal.*

Develop a Conceptual Understanding of Biology

Unique Chapter-Opening Roadmaps set the table for learning by visually grouping and organizing information to help students anticipate key ideas as well as recognize meaningful relationships and connections that are explored in the chapter that follows.

1 Biology and the Tree of Life

This whisky jack looks like it is waiting for a kindly hiker to give it some food. It represents one of the key characteristics of life introduced in this chapter—energy.



Each **Roadmap** begins with a statement of why the chapter topic is important.

Key topics from each chapter are previewed, and related ideas are connected through **linking words**.

Chapter section numbers help students find key ideas easily in the chapter.

In essence, biological science is the study of life. It searches for ideas and observations that unify our understanding of the diversity of life—from bacteria living in hot springs to humans and majestic sequoia trees.

The goals of this chapter are to introduce the nature of life and explore how biologists go about studying it. The chapter also introduces themes that will resonate throughout this book:

- Analyzing how organisms work at the molecular level.
- Understanding organisms in terms of their evolutionary history.
- Helping you learn to think like a biologist.

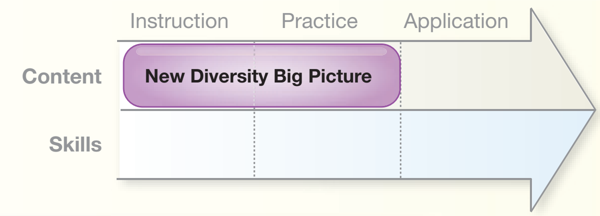
Let's begin with what may be the most fundamental question of all: What is life?

BIG PICTURE

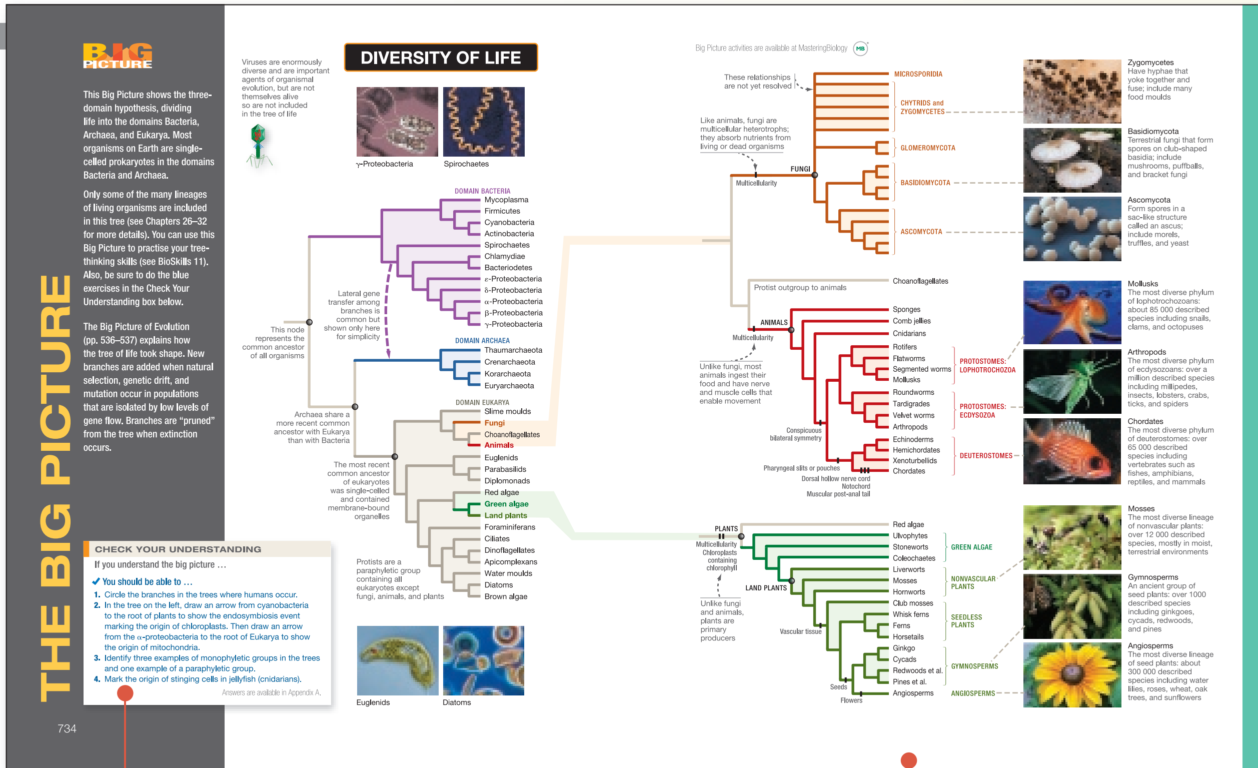
This chapter is part of the Big Picture. See how on pages 16–17.

1

Big Picture Concept Maps are referenced on the opening page of related chapters, pointing students to summary pages that help them synthesize challenging topics.



Big Picture Concept Maps integrate visuals and words to help students synthesize information about challenging topics in biology that span multiple chapters and units.



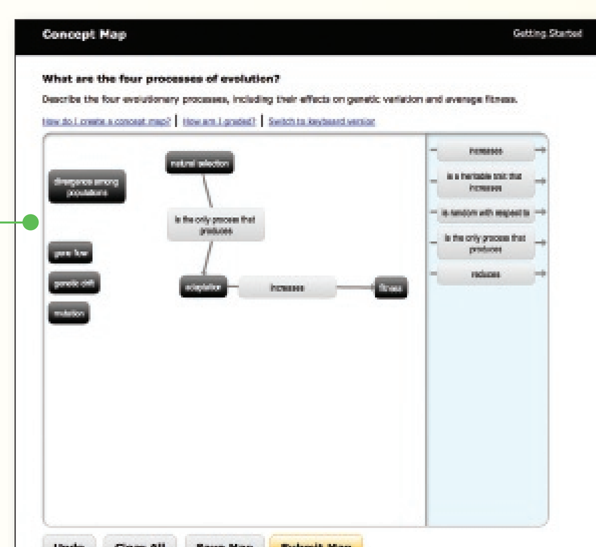
"You should be able to…" activities encourage students to analyze important patterns within each Big Picture concept map.

Big Picture topics include:

- **NEW!** Doing Biology, pp. 16–17
- Macromolecules, pp. 138–139
- Energy for Life, pp. 234–235
- Genetic Information, pp. 408–409
- Evolution, pp. 536–537
- **NEW!** Diversity of Life, pp. 734–735
- How Vascular Plants Work, pp. 856–857
- How Humans Work, pp. 1082–1083
- Ecology, pp. 1232–1233

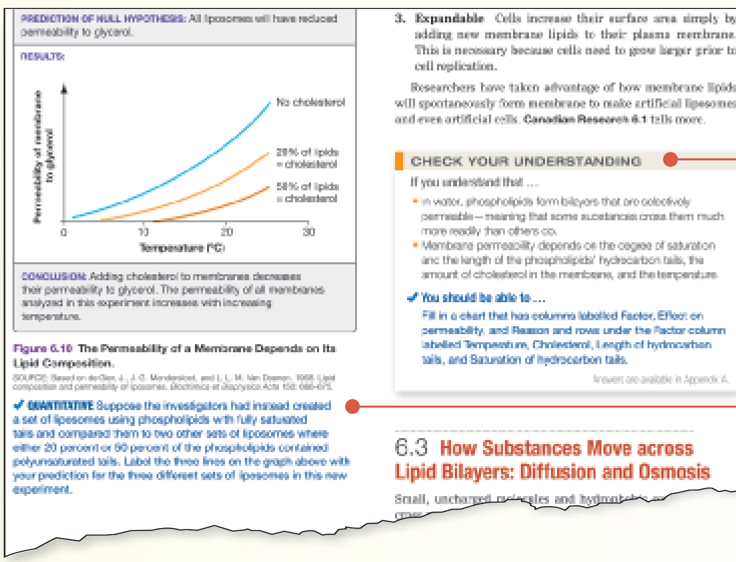
Mastering Biology

Big Picture concept map tutorials are challenging, higher-level activities that require students to build their own concept map and to answer questions about the content. They are automatically graded to make it easy for professors to assign. New to the **Third Canadian Edition** are tutorials on diversity.



Engage in Scientific Inquiry and Active Problem Solving

A wide variety of practice questions and exercises are designed to encourage readers to pause and test their understanding as they proceed through each chapter. All questions and exercises are highlighted in blue throughout the text.

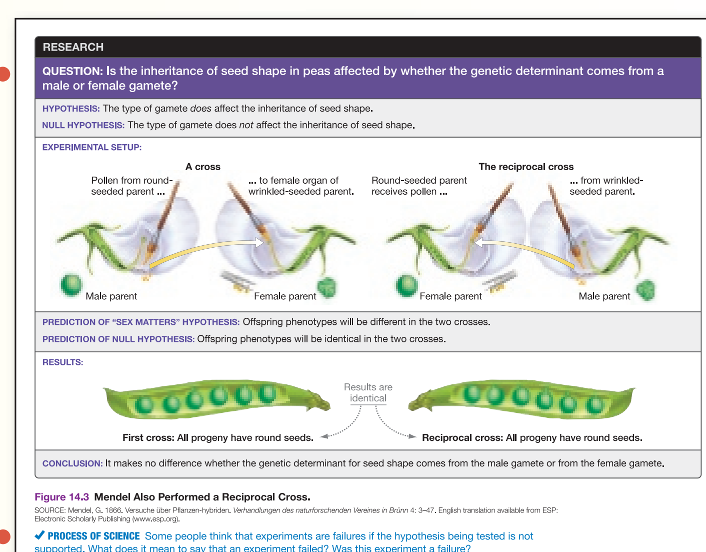


Check Your Understanding activities ask students to work with important concepts in the chapter.

Figure and table caption questions and exercises ask students to critically examine information in figures and tables.

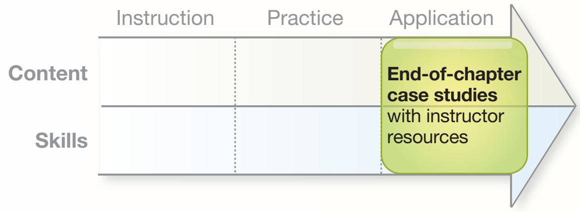
Research boxes teach students how we know what we know about biology by using current and classic research to model the observational and hypothesis-testing process of scientific discovery.

Each Research box concludes with a **question or exercise** that asks students to think critically about experimental design by predicting outcomes, analyzing the setup used to test a hypothesis, or interpreting data found in experimental results



Mastering Biology

"Solve It" Tutorials engage learners in a multi-step investigation of a "mystery" or open question in which students must analyze real data.



Steps to Building Understanding

Each chapter ends with three groups of questions that build in difficulty.

✔ TEST YOUR KNOWLEDGE

Begin by testing your basic knowledge of new information.

✔ TEST YOUR UNDERSTANDING

Once you're confident with the basics, demonstrate your deeper understanding of the material.

✔ TEST YOUR PROBLEM-SOLVING SKILLS

Work toward mastery of the content by answering questions that challenge you at the highest level of competency.

NEW! "Put It All Together" case studies appear at the end of every chapter and provide a brief summary of contemporary biology research in action. Each case study connects what students learn in class with current, real-world biology research questions. At least one question requires students to **analyze real data** or apply **quantitative skills**.

Mastering Biology

NEW! Case study questions from the end of chapter are assignable in MasteringBiology.

NEW! Classroom activity questions about the case study are available for clickers to help instructors easily incorporate the case studies into their classroom teaching.

✔ PUT IT ALL TOGETHER: Case Study

Have human species hybridized in the past?

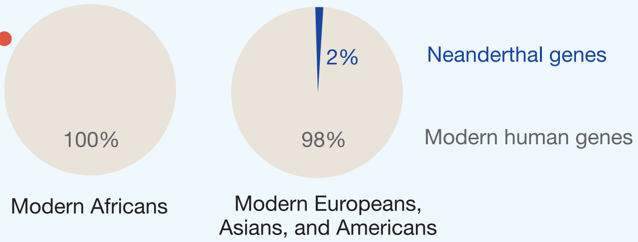
A revolution in the study of human evolution is under way due to the invention of techniques that enable DNA sequencing not only of modern humans but also of ancient humans (introduced in Chapter 20).

11. Human populations today are *not* considered separate species under the biological species, morphospecies, ecological species, and phylogenetic species concepts. Explain what kind of evidence supports this statement.

12. Before the application of DNA sequencing to fossils, which species concept was most useful for distinguishing human fossils? What is one disadvantage of this approach?

13. Modern humans (*Homo sapiens*) and archaic humans called Neanderthals (*H. neanderthalensis*) shared a common ancestor in Africa but diverged in different geographic areas. When modern humans migrated out of Africa and dispersed around the world starting about 70 000 years ago, they overlapped with Neanderthals in Europe. This scenario is best described as:
a. species living in sympatry following allopatric speciation
b. species living in sympatry following sympatric speciation
c. species living in allopatry following allopatric speciation
d. species living in allopatry following sympatric speciation

14. Swedish biologist Svante Pääbo and colleagues sequenced the Neanderthal genome from fossils and compared the sequences to modern humans. According to the data shown here, did the two species interbreed when their ranges overlapped? Explain.

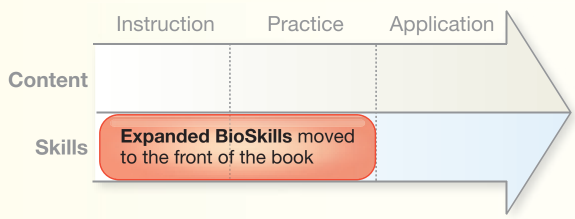


Source: Prüfer, K., et al. 2014. *Nature* 505: 43–49.

15. **PROCESS OF SCIENCE** Is it legitimate to use the DNA of humans living today to determine if mating occurred among human species in the past? Explain.

16. Neanderthals disappeared about 40 000 years ago when the modern human population increased. This is an example of what outcome(s) of secondary contact (see Table 24.3)? Predict one way this result might have come about.

Develop Skills for Success in Biology and Beyond...



NEW! Unique BioSkills reference section is now placed earlier in the text to draw attention to key skills students need to succeed in biology. Previously located in an appendix at the end of the text, this easy-to-find reference material now follows Chapter 1 to better support the development of skills throughout the course. Each BioSkill includes practice exercises.

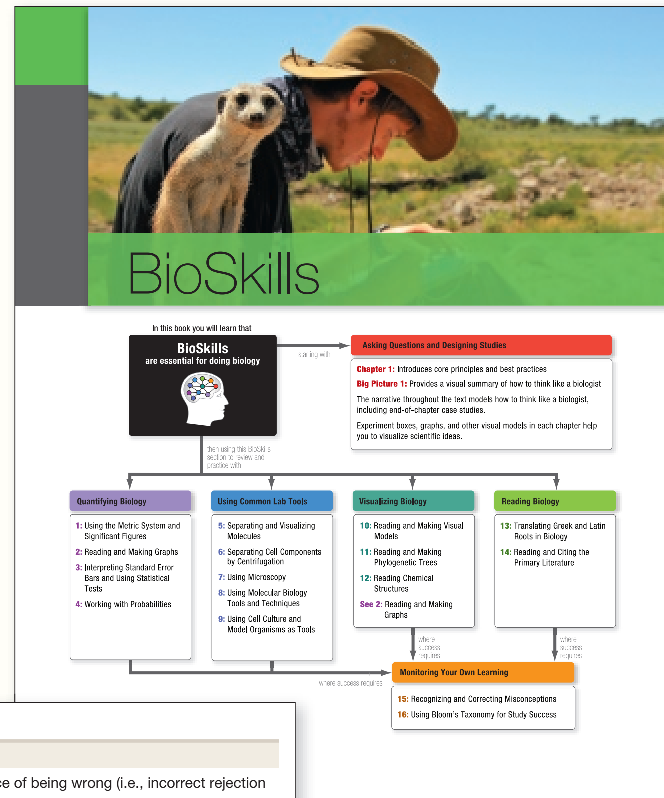


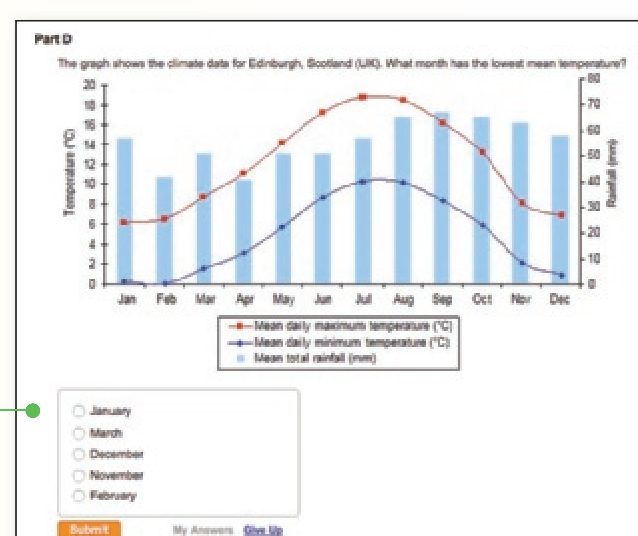
Table B3.1 Asterisk Rating System for *P* Values and Statistical Significance

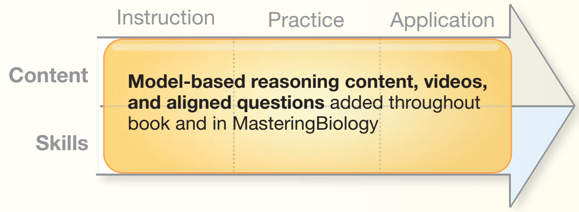
P Value	Asterisk Rating	Statistical Significance Level	Meaning
$P > 0.05$	None	Not significant	Greater than a 1 in 20 chance of being wrong (i.e., incorrect rejection of the null hypothesis)
$P < 0.05$	*	Statistically significant	Less than a 1 in 20 chance of being wrong
$P < 0.01$	**	Statistically significant	Less than a 1 in 100 chance of being wrong
$P < 0.001$	***	Statistically significant	Less than a 1 in 1000 chance of being wrong

EXPANDED! BioSkill on Interpreting Standard Error Bars and Using Statistical Tests includes a new discussion of commonly used tests, such as chi-square, t-test, and analysis of variance (ANOVA). A new section discusses interpreting *P* values and statistical significance.

Mastering Biology

BioSkills review questions are available in the Study Area for self-paced learning and practice. Additional BioSkills questions in the item library are assignable for homework.





Concept Maps

Concept maps are devices for organizing and expressing what you know about a topic. They have been proven to be an effective studying and learning tool.

Concept maps have two main elements: **(1)** concepts that are identified by words or short phrases and placed in a box or circle (you can think of these as the "nouns"), and **(2)** labelled arrows that physically link two or more concepts and explain the relationship between them (you can think of these as the "verbs"). The concepts can be arranged in different patterns on the page depending on the content. Concept maps may be organized as a hierarchy starting with the big idea at the top and moving down to details, or they may be organized in a time sequence or cycle.

One example of a simple concept map is shown in **Figure B10.1**. Other types of concept maps that you will encounter in this

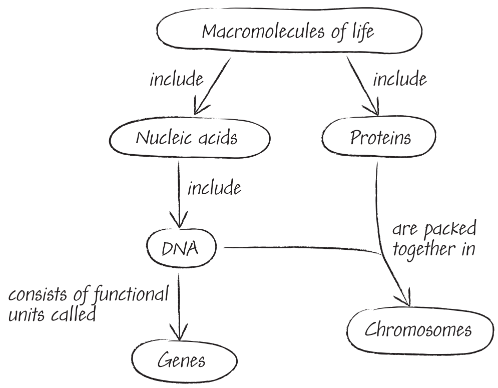
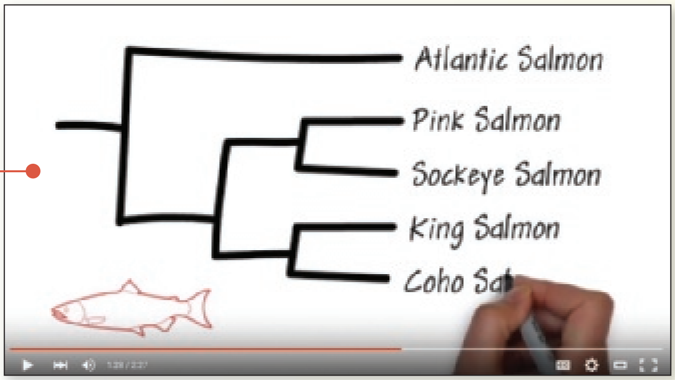
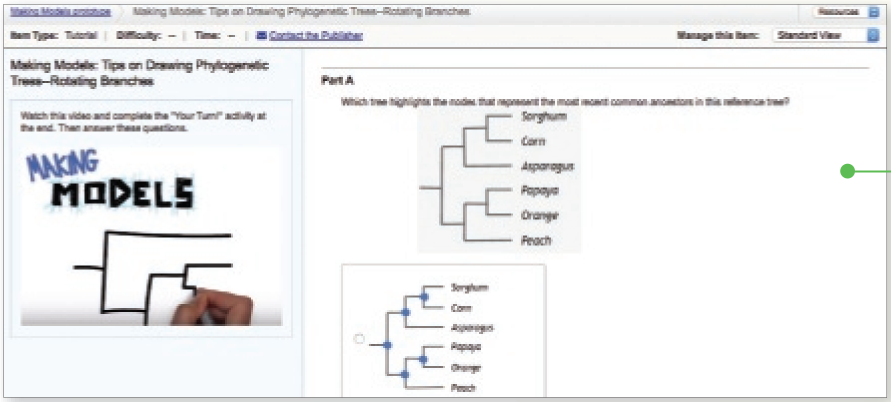


Figure B10.1 A Concept Map of the Relationships between Nucleic Acids and Proteins.

NEW! BioSkill 10: Reading and Making Visual Models is a guide for developing a deeper understanding of biology concepts by interpreting and creating visual models.

NEW! Interactive whiteboard videos about Making Models to reinforce learning and to demonstrate how to build visual models.





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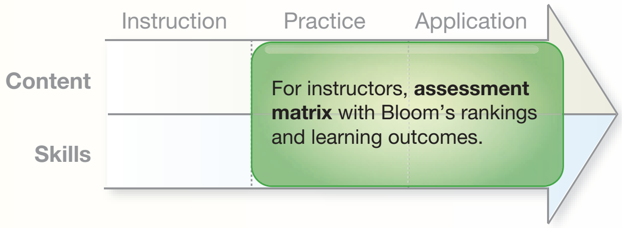
NEW! Making Models activities are assignable for homework and include the whiteboard videos plus application questions that help in developing the skills of interpreting visual models.

For Instructors: Easily Align Assessment with Your Course Goals

Informed by current science education research and curriculum reform strategies, the Third Canadian Edition instructor resources provide a broad range of easy-to-use assessment options.



BLOOM'S TAXONOMY RANKING

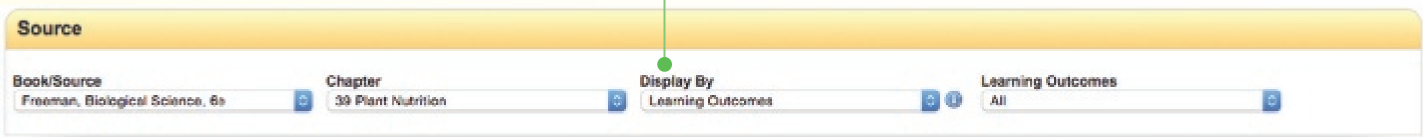
"Blue Thread" questions, including some end-of-chapter problems, are ranked according to **Bloom's taxonomy** and are assignable in MasteringBiology.

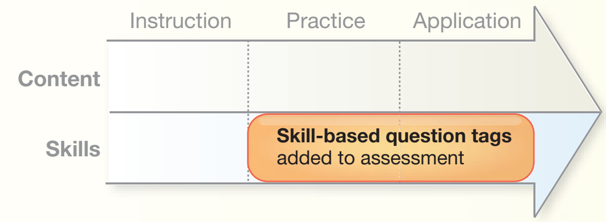
LEARNING OUTCOMES

Each question is tagged to a publisher-provided **Learning Outcome**. Instructors may also track their own Learning Outcomes using MasteringBiology.

Mastering Biology

EXPANDED! Questions, activities, and tutorials are tagged by Bloom's ranking and Learning Outcome.





An extensive selection of mid- and high-level assessment questions are provided throughout each chapter to help students learn, practise, and prepare for tests.

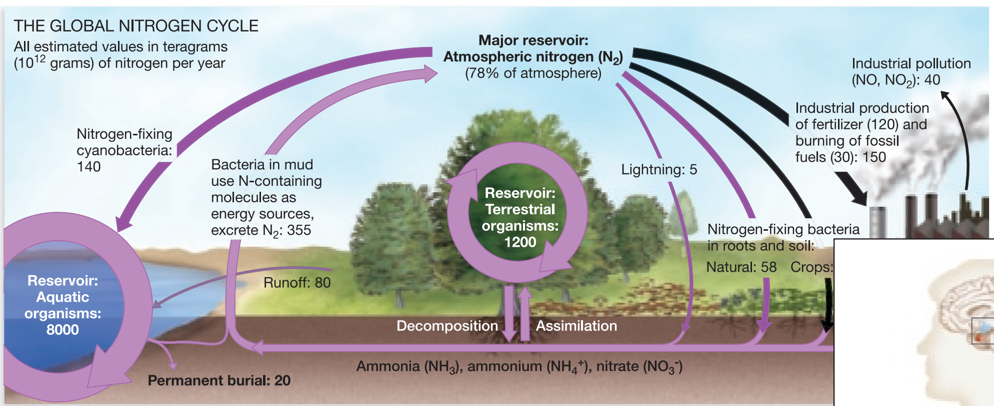


Figure 53.17 The Global Nitrogen Cycle. Nitrogen enters ecosystems as ammonia or nitrate via fixation from atmospheric nitrogen. It is exported in runoff and as nitrogen gas given off by bacteria that use nitrogen-containing compounds as an electron acceptor.

DATA: Fowler, D., et al. 2013. *Philosophical Transactions of the Royal Society B* 368 (1621): 20130165.

✔ **QUANTITATIVE** Calculate the percentage of total nitrogen fixation (all downward-pointing arrows) that is caused by human activities (black arrows).

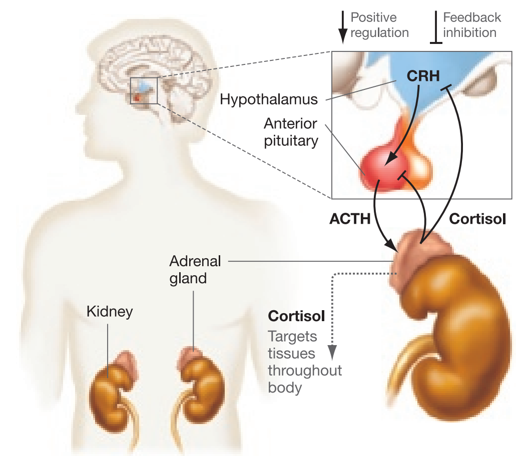


Figure 46.15 The Interaction between Cortisol, ACTH, and CRH Is an Example of Feedback Inhibition.

✔ **PROCESS OF SCIENCE** Use the figure to devise a test for adrenal failure in humans.

NEW! Question labels call attention to questions that require **quantitative skills**, an understanding of the **process of science**, connecting biology and **society**, making **models**, and more.

NEW! Caution questions address topics for which students often hold common misconceptions. Answers to Caution questions include information that addresses the misconception.

5. CAUTION According to data presented in this chapter, which one of the following statements is correct?

a. When individuals change in response to challenges from the environment, their altered traits are passed on to offspring.

b. Species are created independently of each other and do not change over time.

c. Populations—not individuals—change when natural selection occurs.

d. The traits of populations become more perfect over time.

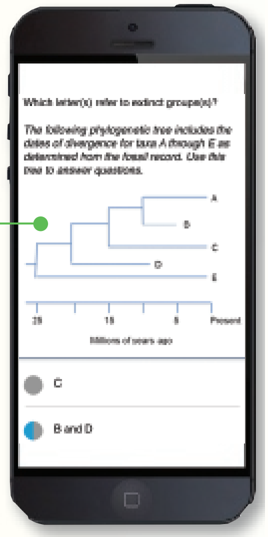
Succeed with Mastering Biology

Mastering Biology is a powerful online learning and assessment system proven to improve results by engaging students before, during, and after class with a deep library of helpful activities. Mastering brings learning full circle by continuously adapting to each student and making learning more personal than ever—before, during, and after class.

Before Class

NEW! Dynamic Study Modules provide students with multiple sets of questions with extensive feedback so that they can test, learn, and retest until they achieve mastery of the textbook material.

NEW! More mobile-friendly pre-class reading quizzes help students pinpoint concepts that they understand and concepts with which they need more help. By identifying topics that are most difficult for them, students are better prepared to ask questions and more likely to listen actively.



During Class

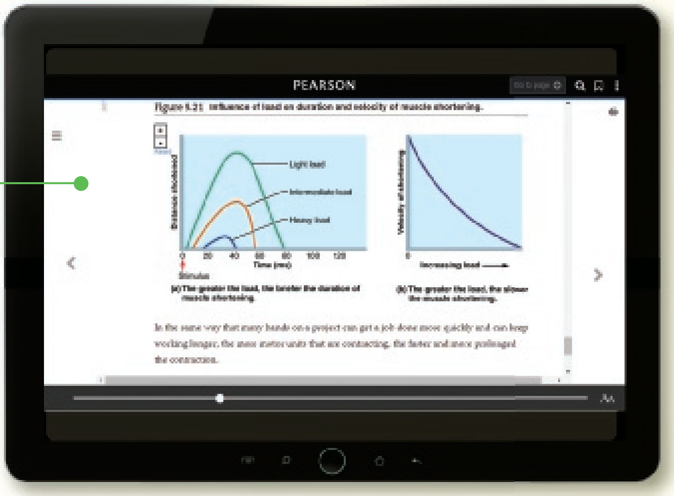
NEW! Learning Catalytics™ allows students to use their smartphone, tablet, or laptop to respond individually or in groups to questions in class. Visit learningcatalytics.com to learn more.

After Class

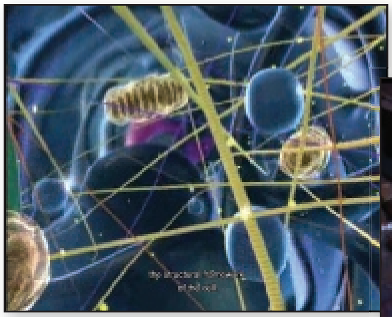
NEW! Optional Adaptive Follow-up Assignments are based on each student's performance on the original MasteringBiology assignment and provide additional questions and activities tailored to each student's needs.

Hundreds of self-paced tutorials and coaching activities provide students with individualized coaching with specific hints and feedback on the toughest topics in the course.

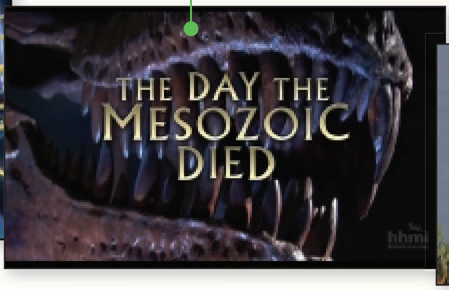
NEW! Pearson eText 2.0 Features include student and instructor note-taking, highlighting, bookmarking, search, and hotlinked glossary.



Mastering Biology offers a wide variety of tutorials that can be assigned as homework. Examples include:



BioFlix® Tutorials use 3-D, movie-quality animations and coaching exercises to help students master tough topics outside of class. Animations can also be shown in class.



NEW! HHMI Short Films, documentary-quality movies from the Howard Hughes Medical Institute, engage students in topics from the discovery of the double helix to evolution, with assignable questions.

NEW! Galapagos Evolution Videos, filmed by Peter and Rosemary Grant, bring to life the dynamic evolutionary processes that impact Darwin's finches on Daphne Major Island.

INSTRUCTOR AND STUDENT RESOURCES

For Instructors

Instructor's Guide (Download only)
Includes learning objectives, lecture outlines, vocabulary, active learning lecture activities, and clicker questions.

TestGen Test Bank (Download Only)
All of the exam questions in the Test Bank have been peer reviewed, providing questions that set the standard for quality and accuracy. Questions have been improved by evaluating user data from **Mastering Biology**. Test questions are ranked according to Bloom's taxonomy.

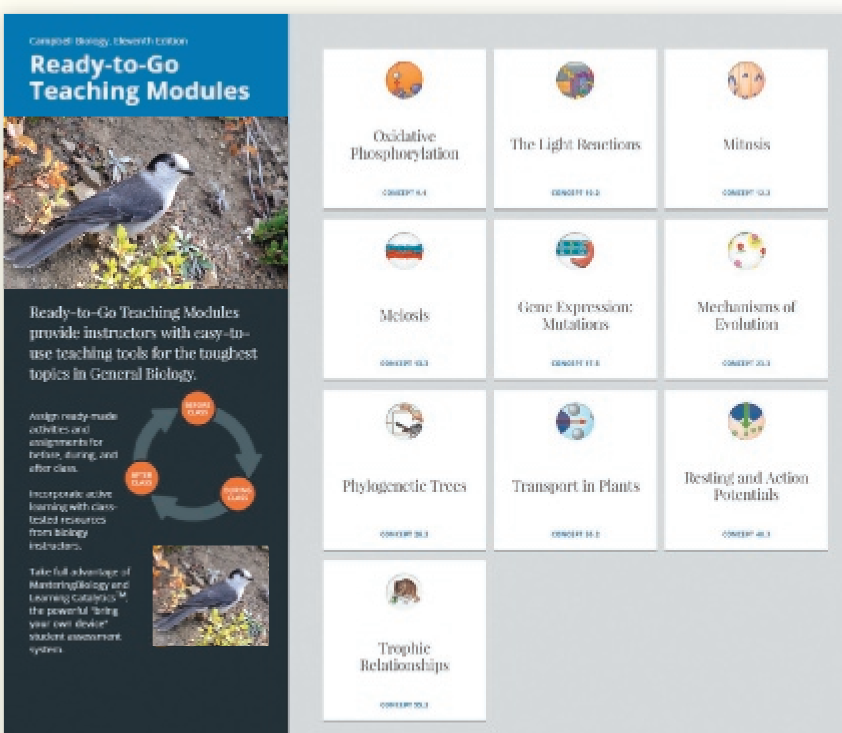
PowerPoint Presentations (Download Only)
A set of PowerPoint presentations offers lectures outlines for each chapter, augmented by key text illustrations and hyperlinks to animations.

For Students

Study Guide by Warren Burggren et. al.
© 2019 | 013451324X / 9780134513249
The Study Guide presents a breakdown of key biological concepts, difficult topics, and quizzes to help students prepare for exams.

Practicing Biology: A Student Workbook
© 2017 | 0134261941/9780134261942
This workbook provides a variety of hands-on activities such as mapping and modelling to suit different learning styles and help students discover which topics they need more help on. Students learn biology by doing biology.

NEW! Ready-to-Go Teaching Modules help instructors efficiently make use of the best teaching tools before, during, and after class.



The **Ready-to-Go Teaching Modules** incorporate the best that the text, MasteringBiology, and Learning Catalytics have to offer, along with new ideas for in-class activities. The modules can be accessed through the Instructor Resources area of MasteringBiology.

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Whisky jack, *Perisoreus canadensis*

The whisky jack or grey jay is native to every Canadian province and territory, living year-round in boreal and alpine coniferous forests. A mated pair of these intelligent and curious corvids prepare for a northern winter by gluing perishable food items to tree branches with their sticky saliva. Whisky jacks nest in late winter, incubating eggs at temperatures as low as −20°C. Their thick, fluffy plumage keeps them warm. Feathers cover their legs and feet and even line their nostrils.

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JOAN SHARP Simon Fraser University

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"I would like to dedicate this book to my grandparents, the best teachers one could hope for."
—Mike Harrington

"For Yusef, who finds the world a fascinating place, and in memory of Yasmin, who found comfort in nature."
—Joan Sharp

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Detailed Contents

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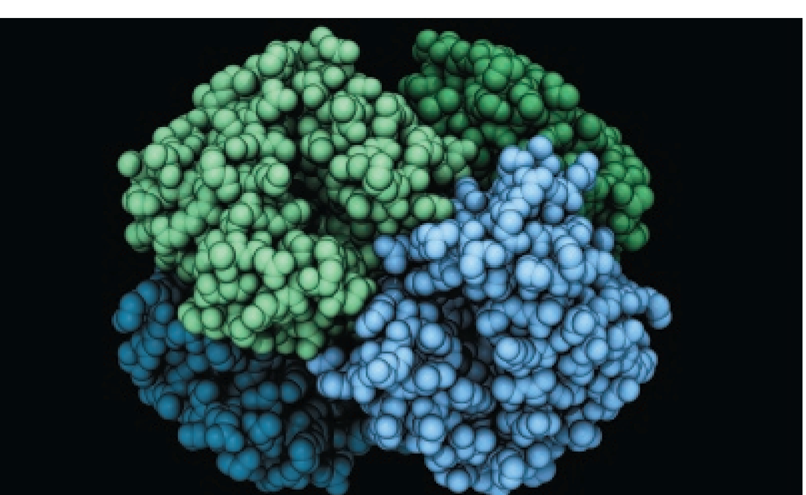

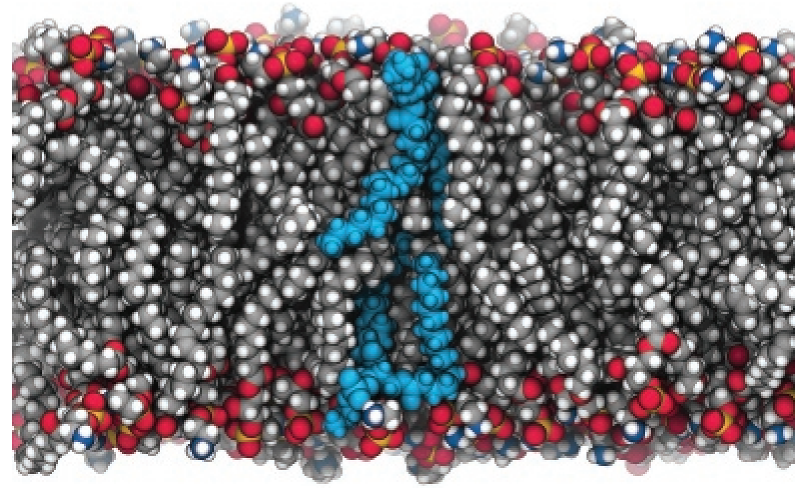

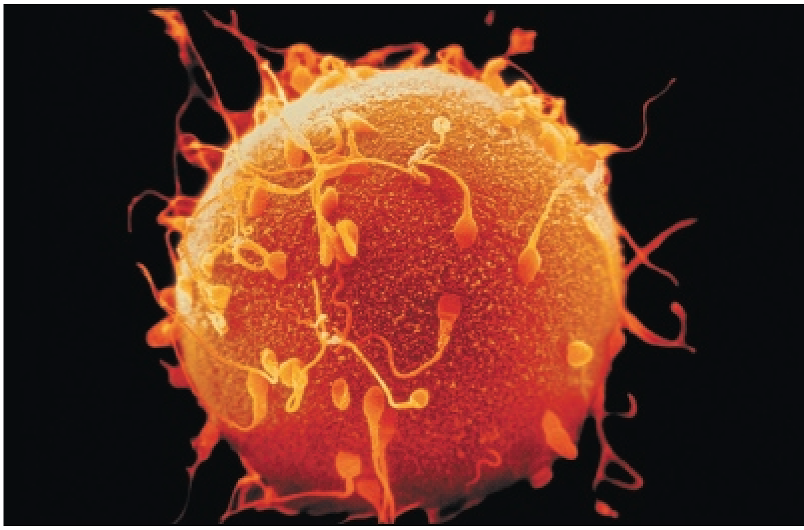

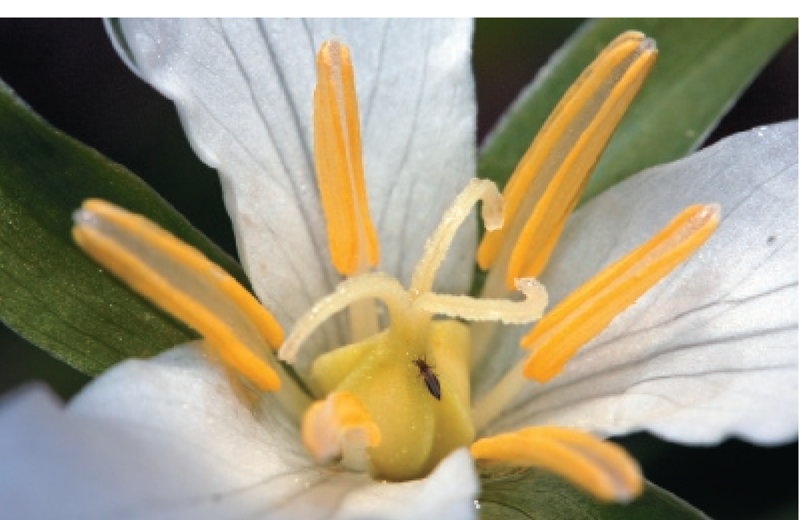

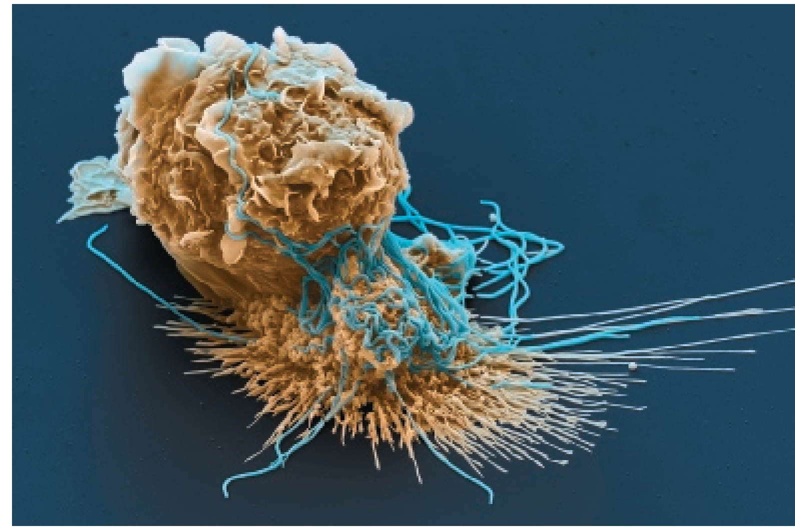

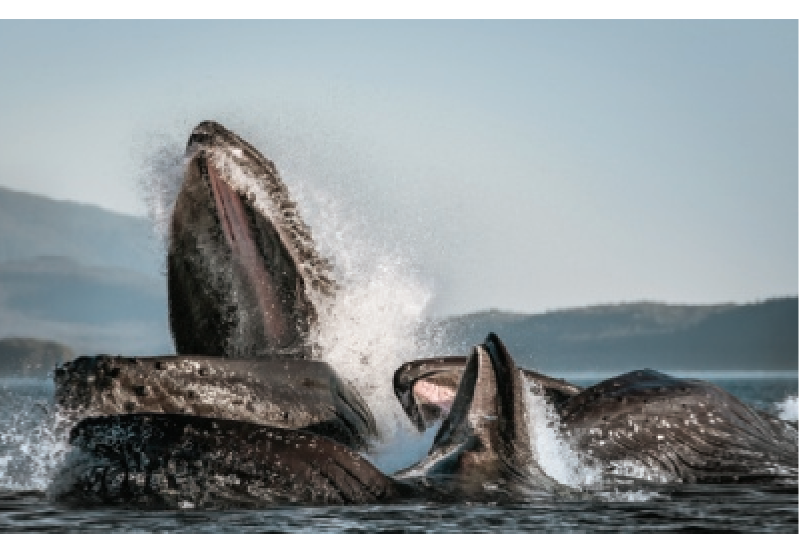

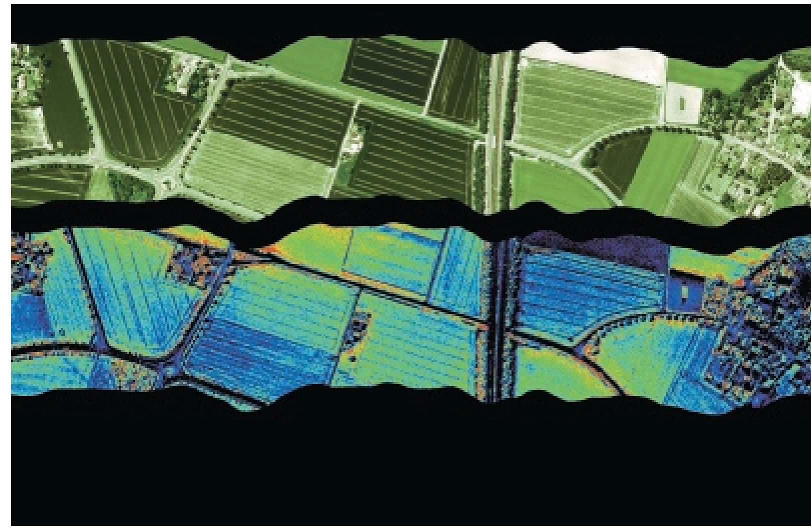

About the Authors

A Letter from Scott:

I started working on *Biological Science* in 1997 with a simple goal: To help change the way biology is taught. After just shy of 20 000 hours of work on four editions of this text, that goal still gets me out of bed in the morning. But instead of focusing my energies on textbook writing, I've decided to devote myself full-time to research on student learning and developing new courses for undergraduate and graduate students at the University of Washington.

I have passed the torch to an all-star cast of leading scientists and educators who have enthusiastically taught from, and contributed to, previous editions of *Biological Science*. The new team brings their passion, talent, and creativity to the book, with expertise that spans the breadth of the life sciences. Just as important, they work beautifully together because they think alike. They are driven by a shared concern for student learning, a commitment to the craft of writing, and a background in evidence-based teaching.

These pages provide a brief introduction to Liz Allison, Michael Black, Greg Podgorski, Kim Quillin, Jeff Carmichael, Emily Taylor, Mike Harrington, and Joan Sharp. As a group, they've built on the book's existing strengths and infused this edition with fresh energy, perspective, and ideas. I'm full of admiration for what they have accomplished, and excited about the impact this edition will have on biology students from all over the world.

—Scott Freeman

Scott Freeman received a Ph.D. in Zoology from the University of Washington and was subsequently awarded an Alfred P. Sloan Postdoctoral Fellowship in Molecular Evolution at Princeton University. He has done research in evolutionary biology on topics ranging from nest parasitism to the molecular systematics of the blackbird family and is coauthor, with Jon Herron, of the standard-setting undergraduate text *Evolutionary Analysis*. Scott is the recipient of a Distinguished Teaching Award from the University of Washington and is currently a Principal Lecturer in the UW Department of Biology, where he teaches introductory biology for majors, a writing-intensive course for majors called The Tree of Life, and a graduate seminar in college science teaching. Scott's current research focuses on how active learning affects student learning and academic performance.

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Michael Black received his Ph.D. in Microbiology & Immunology from Stanford University School of Medicine as a Howard Hughes Predoctoral Fellow. After graduation, he studied cell biology as a Burroughs Wellcome Postdoctoral Fellow at the MRC Laboratory of Molecular Biology in Cambridge, England. His current research focuses on the use of molecules to identify and track the transmission of microbes in the environment. Michael is a professor of Cell & Molecular Biology at California Polytechnic State University in San Luis Obispo, where he teaches introductory and advanced classes for majors in cell biology and microbiology. In addition to his teaching and research activities, Michael serves as the director of the Undergraduate Biotechnology Lab, where he works alongside Undergraduate technicians to integrate research projects and inquiry-based activities into undergraduate classes.

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Kim Quillin received her B.A. in Biology at Oberlin College summa cum laude and her Ph.D. in Integrative Biology from the University of California, Berkeley as a National Science Foundation Graduate Fellow. Kim has worked in the trenches with Scott Freeman on every edition of *Biological Science*, starting with the ground-up development of the illustrations in the first edition in 1999 and expanding her role in each edition, always with the focus of helping students to think like biologists. Kim currently teaches introductory biology at Salisbury University, a member of the University System of Maryland, where she is actively involved in the ongoing student-centered reform of the concepts-and-methods course for biology majors. Her current research focuses on the scholarship of teaching and learning with an emphasis on visual model-based reasoning as a science process skill.
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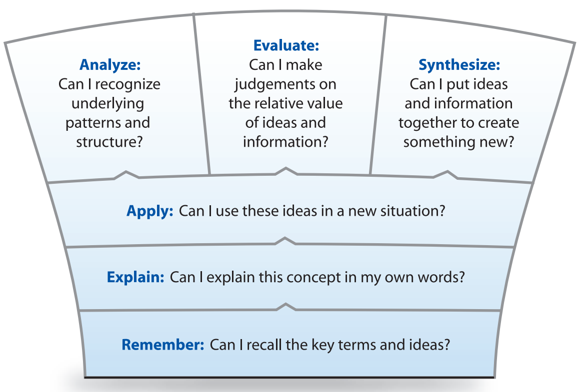
Mike Harrington completed his B.Sc. and Ph.D. in the Zoology Department of the University of British Columbia. His graduate work on *Drosophila* chromatin structure combined classical and molecular genetics. He is presently a Faculty Lecturer in the Biological Sciences department at the University of Alberta. He teaches cell biology at the first- and second-year levels and genetics at the second-, third-, and fourth-year levels. His teaching goals are (1) to find ways to incorporate current scientific research into introductory courses, (2) to develop new ways to expand a course's boundaries with online material, and (3) to use clicker classroom response systems to teach content with questions.

Joan Sharp received her B.A. and B.Sc. from McGill University and her M.Sc. from the University of British Columbia. She is a Teaching Professor at Simon Fraser University, where she teaches Biology of Everyday Life, Introduction to Biology, General Biology, and Vertebrate Biology. Her teaching and research interests include a number of areas: (1) Argumentation is a key component of critical thinking and scientific reasoning. Effective argumentation requires the selection and evaluation of evidence in order to articulate and defend a carefully thought-out position. Development of this essential scientific skill may benefit from a supportive learning environment in which students are prompted with a controversial question and provided with explicit instruction on argumentation. (2) Case studies engage students with key concepts by using meaningful real-world scenarios. The use of clickers allows the implementation of case studies in large lecture courses, facilitating small group discussion and increasing student learning. (3) Prior or newly acquired misconceptions interfere with student success in building meaningful biological understanding. It is important to understand common misconceptions and to develop activities that allow students to address and correct their misconceptions. Concept inventories can be used to measure students' learning gains to assess the success of teaching strategies targeting student misconceptions. Students' written work can serve as a starting point to address areas of misunderstanding and to help students refine and express biological ideas.

Preface to Instructors

Biological Science emphasizes the process of scientific discovery and guides students to think like a biologist. Our students need to learn the language of biology and to construct their own understanding of fundamental biological concepts. They also need to actively apply these concepts to new situations; evaluate experimental design, hypotheses, and data; synthesize results; and make and interpret models.

We wrote this book for instructors who embrace this challenge—who want to help their students learn how to think like a biologist. The essence of higher education is to promote higher order thinking. Our job is to help students understand biological science at all six levels of Bloom's taxonomy of learning. For instructors, resources are provided to help align course activities and learning goals with their assessment strategies.



Bloom's Taxonomy

Core Values

For the Third Canadian Edition, the coauthor team strives to extend the vision and maintain the core values of *Biological Science*—to provide a book and online resources for instructors who embrace the challenge of boosting students to higher levels of learning and to provide a book that helps students each step of the way in learning to think like a scientist, regardless of their starting point in the process.

Dedicated instructors have high expectations of their students. The Third Canadian Edition provides tools to help students to learn at the level called for by the American Association for the Advancement of Science report, *Vision and Change in Undergraduate Biology Education*. This report and others place a premium on fundamental concepts and skills and emphasize the importance of connecting core ideas across all levels of biology.

What's New in this Edition

The Third Canadian Edition contains many new or expanded features, all of them designed to provide students with initial instruction in content and skills, followed by opportunities for lots of practice in applying knowledge and skills to new contexts. The ultimate goal is for students to learn to construct their own knowledge and think like biologists.

- **Relocated and Expanded BioSkills Section** Instructors recognize that biology students need to develop foundational science skills in addition to content knowledge. Since the First Canadian Edition, *Biological Science* has provided a unique, robust set of materials and activities in an appendix to guide students who need extra help with the skills emphasized in the book. In the Third Canadian Edition, the BioSkills materials have been placed between Chapters 1 and 2 to emphasize their importance as a resource for success in doing biology, and to make it easier for students to access them throughout the course. The BioSkills are grouped within five broad categories depicted in a new opening road map: Quantifying Biology, Using Common Lab Tools, Visualizing Biology, Reading Biology, and Monitoring Your Own Learning. Five new BioSkills have been added: Using Molecular Biology Tools and Techniques, Reading and Making Visual Models, Reading and Citing the Literature, Recognizing and Correcting Misconceptions, and Using Bloom's Taxonomy for Study Success. Existing BioSkills have been updated to support new features in the Third Canadian Edition. For example, the explanation of statistical tests has been expanded, and *P* values are introduced to provide students with essential quantitative skills for interpreting data in the end-of-chapter case studies. BioSkills include practice questions, are cross-referenced throughout the text, and can be assigned online in MasteringBiology®.
- **Put It All Together Case Studies** The end-of-chapter question sets for every chapter now include a case study. Case studies briefly introduce contemporary biology research in action, followed by questions that ask students to apply the chapter's content and skills to the research topic. A constant hallmark of this text is its emphasis on experimental evidence—on teaching how we know what we know. The case studies expand this emphasis, requiring students to evaluate real data and to see how ongoing scientific research is related to core biological ideas.
- **Integrated Chapters** Three newly consolidated chapters reorganize and integrate information to better serve instructors and students. Chapter 20 (The Molecular Revolution: Biotechnology and Beyond) merges the most essential information on genome analysis that was previously discussed in separate chapters, while moving details of fundamental techniques to the BioSkills. Core material on the general principles of development, particularly those related to genetics and evolution, now forms the closing chapter of a streamlined unit on Gene Structure and Expression (Chapter 21). Content on plant and animal development has been moved from the former

developmental biology unit to the respective reproduction and development chapters of the How Plants Work (Chapter 38) and How Animals Work (Chapter 47) units.

- **Skill-Based Question Tags** *Biological Science* has long emphasized skill development, and reports like *Vision and Change* also encourage this focus for introductory majors. To help students and instructors identify opportunities to practise key skills, questions are tagged to indicate the following: Process of Science questions explore the application of the scientific process; Model questions ask students to interpret or construct visual models; Society questions explore the relationship between science and society; Quantitative questions help students perform quantitative analysis and mathematical reasoning; and Caution questions address topics for which students often hold common misconceptions. Answers to Caution questions include information that addresses the misconception.
- **Expanded Use of Summary Tables** The art program is further enhanced in this edition by additional illustrated summary tables that deliver content in a streamlined way and facilitate comparison and analysis by students. For example, the diversity boxes from the Second Canadian Edition's The Diversification of Life unit have been redesigned as photographic summary tables. These tables make subject areas more accessible to visual learners and reinforce a chapter's key concepts.

Hallmark Features of the Text

We are excited to introduce new features to the Third Canadian Edition. At the same time, we are committed to strengthening the hallmark features that make this book unique.

- **Road Maps** Each chapter now opens with a concept map that visually groups and organizes information to help students anticipate key ideas as well as recognize meaningful relationships and connections among ideas. While the Road Maps help students look forward as they engage with a chapter, Big Picture concept maps integrate words and visuals to help students synthesize information about challenging topics that span multiple chapters or units. Together, these two features help students navigate chapter content and see the forest for the trees.
- **Opportunities for Practice** "Blue Thread" questions, integrated throughout the text, are designed to help students identify what they do and do not understand. The idea is that if students really understand a piece of information or a concept, they should be able to do something with it. As in the Second Canadian Edition, all questions in the text are assigned a Bloom's taxonomy level to help both students and instructors understand whether a question requires higher-order or lower order cognitive skills.
    - **In-text "You Should Be Able To" questions** focus on topics and concepts that professors and students have identified as most key or difficult in each chapter.
    - **Caption questions and exercises** challenge students to examine the information in a figure or table critically—not just absorb it.
    - **Check Your Understanding boxes** present two to three tasks that students should be able to complete in order to demonstrate a mastery of summarized key ideas.
    - **End-of-chapter questions** are organized in three levels of increasing difficulty so students can build from lower- to higher-order cognitive levels of assessment.
- **Focus on Real Data** Students now have expanded opportunities to develop skills at working with real data from the primary literature. Sources of the data presented in Research Boxes, graphs, and end-of-chapter Case Studies are cited to model good practice for students and to provide a resource for students and instructors who wish to evaluate the original data more deeply.

Integration of Media

The textbook continues to be supported by MasteringBiology, the most powerful online homework, tutorial, and assessment system available. Tutorials follow the Socratic method, coaching students to the correct answer by offering feedback specific to a student's errors or misconceptions as well as supplying hints that students can access if they get stuck. Instructors can associate content with publisher-provided learning outcomes or create their own. Content highlights include the following:

- **Making Models Activities** Whiteboard videos—accessible online via the Study Area in MasteringBiology help students develop their visual modelling skills. The videos are also included in assignable activities that allow students to practise modelling and to apply their understanding to new situations.
- **Case Study Questions** Put It All Together Case Study questions are assignable in MasteringBiology. Additional clicker questions are also provided in instructor resources to facilitate classroom activities.
- **Solve It Tutorials** These activities allow students to act like scientists in simulated investigations. Each tutorial presents an interesting, real-world question that students will answer by analyzing and interpreting data.
- **Experimental Inquiry Tutorials** The call to teach students about the process of science has never been louder. To support such teaching, there are 10 interactive tutorials on classic scientific experiments—ranging from Meselson–Stahl on DNA replication to the Grants' work on Galápagos finches and Connell's work on competition. Students who use these tutorials should be better prepared to think critically about experimental design and evaluate the wider implications of the data—preparing them to do the work of real scientists in the future.
- **BioFlix® Animations and Tutorials** BioFlix are movie-quality, 3-D animations that focus on the most difficult core topics and are accompanied by in-depth, online tutorials that provide hints and feedback to guide student learning. BioFlix animations and tutorials tackle topics such as meiosis, mitosis, DNA replication, photosynthesis, homeostasis, and the carbon cycle.

- **HHMI Short Films Activities** Documentary-quality movies from HHMI are available in MasteringBiology with assignable questions to make sure students understand key ideas.
- **Galápagos Evolution Video Activities** These incredible videos, filmed on the Galápagos Islands by Peter and Rosemary Grant, bring to life the dynamic evolutionary processes that have an impact on Darwin's finches on Daphne Major Island. Six videos explore important concepts and data from the Grants' field research, and assignable activities keep students focused on the important take-away points.
- **End-of-Chapter Questions** A broad range of end-of-chapter questions are available to assign in MasteringBiology.
- **Blue Thread Questions** Over 500 questions based on the Blue Thread questions in the textbook are assignable in MasteringBiology.
- **Big Picture Concept Map Tutorials** A new, more engaging concept mapping tool is the basis for highly interactive, challenging concept map activities based on the Big Picture figures in the textbook. Students build their own concept maps, which are auto-graded, and then answer questions to make sure they understand key ideas and make important connections.
- **BioSkills Activities** Activities based on the BioSkills content in the textbook are assignable in MasteringBiology, including activities to support the new BioSkills.
- **Reading Quiz Questions** Every chapter includes reading quiz questions that can be assigned to ensure students read the textbook and understand the basics. These quizzes are perfect as a pre-lecture assignment to get students into the content before class, allowing instructors to use class time more effectively.

Acknowledgments

Supplements Contributors

We are grateful for the hard work and creativity of the contributors who worked on an impressive array of print and online support materials.

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Book Team

As coauthors on the Third Canadian edition of *Biological Science*, we would like to thank all the talented people who were involved in the production of our textbook. This very professional team was headed by Anne Williams, Vice President and Editorial Director. We are grateful for the guidance of Cathleen Sullivan, Executive Acquisitions Editor.

Developmental Editor Joanne Sutherland patiently and expertly provided guidance and encouragement throughout the process, while the final version of the text was effectively and efficiently managed by Project Manager Jessica Mifsud and Copyeditor Charlotte Morrison-Reed, directed by Lead Project Manager Avinash Chandra.

Pearson Canada's talented sales team, who listen to educators, advise the editorial staff, and get the book into students' hands, are supported by the boundless energy of Marketing Specialist Erica Willer and Senior Marketing Manager Kim Teska.

Serving a Community of Teachers

Biology instructors share a deep commitment to students and their learning. While we all have our own personal teaching styles, these styles are built as we test and refine ideas learned through discussing biology instruction with our colleagues and through interacting with—and listening to—our students.

Research on biology education is gathering momentum, bringing the same level of rigour to our classrooms that we bring to our lab benches and field sites. We bring the spirit and practice of evidence-based teaching into this textbook and we welcome your comments, suggestions, and questions.

Thank you for considering this text and for your work on behalf of your students. We have the best jobs in the world.

Content Highlights of the Third Canadian Edition

As discussed in the preface, a major focus of this revision is to introduce unique, innovative features designed to provide students with initial instruction in content and skills, as well as lots of practice in applying knowledge and skills to new contexts—with the ultimate goal of helping students learn to construct their own knowledge and think like biologists. As in each edition, to ensure that the content reflects the current state of science and is accurate, the author team has scrutinized every chapter to add new, relevant content, update descriptions when appropriate, and adjust the approach to certain topics to enhance student comprehension. New content emphasizes overarching themes—including how advances in understanding gene expression and genome structure inform all of biology from development to evolution to physiology to ecology and the profound impact of global climate change on life on Earth. In this section, some of the key content improvements to the textbook are highlighted.

Chapter 1 Biology and the Tree of Life New section titles emphasize the theme of five characteristics of life, within a framework of three unifying theories: the cell theory, the theory of evolution, and new coverage of the chromosome theory of inheritance. A brief introduction to the central dogma of molecular biology is added to provide students with a framework for understanding the connections between genes and phenotype early on in the book.

Chapter 2 Water and Carbon: The Chemical Basis of Life A stronger emphasis on chemical evolution is treated throughout the chapter to bring chemistry to life for the student reader. Two prominent models for chemical evolution are introduced; the historic Miller prebiotic soup experiment was moved here. Advanced discussion of energy and chemical reactions was moved to a new chapter (see Chapter 8). A new Canadian Research box describes searching for life 2.4 km beneath Timmins, Ontario.

Chapter 3 Protein Structure and Function The chapter is reorganized to discuss protein structure before protein function. This has allowed for a discussion on how proteins have the shapes necessary for their cellular roles. Details of how enzymes work were moved to Chapter 8. New Canadian content includes research on prion diseases in domestic cattle and wild deer at the University of Alberta and the design of light-responsive proteins at the University of Toronto.

Chapter 4 Nucleic Acids and the RNA World New experimental results concerning the synthesis of nucleotides and nucleic acids in a prebiotic environment are discussed. The art and text are updated to present the geometry of nitrogenous bases relative to the sugar–phosphate backbone in double-stranded DNA. There are new sections on how nucleotides are named and on the pathogenic coconut cadang-cadang viroid.

Chapter 5 An Introduction to Carbohydrates The impact of carbohydrate structure is emphasized by discussing the breakdown of maltose, lactose, and cellulose. The chapter is reorganized to better distinguish between disaccharides, oligosaccharides, and polysaccharides. The glycolipids and glycoproteins that serve as the ABO blood group antigens are introduced. Canadian Research 5.1 describes human milk carbohydrates and Canadian Issues 5.1 is updated to present the hypothesis that artificial sweeteners cause obesity by changing gut bacteria.

Chapter 6 Lipids, Membranes, and the First Cells Illustrations of fats and phospholipids are revised to emphasize similarity in structure. New content on lipid and membrane evolution and the proposed characteristics of the first protocell is introduced. There are new figures of aquaporin and the CFTR channel. New Canadian research includes the invention of artificial cells at McGill University and research done on membrane proteins at the Universities of Guelph and Manitoba, and Western University.

Chapter 7 Inside the Cell A new figure is added to better depict the pulse–chase assay used to identify the secretory pathway. Several topics have been revised including nuclear transport, the smooth endoplasmic reticulum, vesicle transport, endocytosis, and intermediate filaments. A list of student misconceptions about cells has been added as has research from Simon Fraser University and the University of British Columbia.

Chapter 8 Energy and Enzymes: An Introduction to Metabolism This new chapter pulls together concepts in energy, chemical reactions, and enzymes that previously were covered in three different chapters. Oxidation and reduction reactions are emphasized to prepare students for Chapters 9 and 10. Illustrations of chemical bonds are updated to more accurately represent the correlation between bond length and chemical energy. The role of energetic coupling in converting endergonic reactions into exergonic reactions is clarified. A new Canadian Research box describes protein processing using insulin as an example. Insulin and diabetes mellitus are also discussed in Canadian Research 11.2, 21.2, and 41.1.

Chapter 9 Cellular Respiration and Fermentation Two new summary tables for glycolysis and the citric acid cycle are added. Figures and text are updated to track the number of intermediates and products in each of the metabolic pathways. Coverage of the Cori cycle and anaerobic respiration have been added and expanded, respectively, to address student misconceptions on these processes. The Canadian research on ATP synthase has been updated.

Chapter 10 Photosynthesis Greater emphasis is placed on the events responsible for converting the kinetic energy in light to potential energy stored in chemical bonds. Content is revised to address the misconceptions that the products of photosynthesis are used only to manufacture carbohydrates and that chloroplasts supply the ATP necessary for all other cellular functions. Figures and text are updated to more easily track the inputs and outputs in the photosynthetic reactions. Canadian Research 10.1 has been expanded to distinguish between carbon concentrating mechanisms and CO_2 trapping mechanisms.

Chapter 11 Cell–Cell Interactions Coverage of extracellular matrix structure and function is expanded, including its role in intercellular adhesion and cell signalling. New content has been added on intercellular communication by yeast cells to find mating partners. Canadian content now includes the role of insulin signalling in insects, the identification of Canadian camels on Ellesmere Island, and a case study based upon research done at Université de Montréal and McGill University.

Chapter 12 The Cell Cycle Figures are updated to clearly distinguish differences between replicated and unreplicated chromosomes. A new figure helps explain the pulse–chase assay for identifying phases of the cell cycle. The description of mitosis has been revised to focus on the proteins that are causing each event to occur and why these events are necessary for the cell. Canadian Research 12.2 describes how MPF brings about chromosome condensation.

Chapter 13 Meiosis To improve the flow of the chapter, the section on advantages of sexual reproduction was moved earlier. Increased attention is paid to topics students are known to struggle with, such as the distinctions between sister chromatids and homologous chromosomes, reproduction in animals and plants, and interchromosomal and intrachromosomal recombination. A new study that supports the changing-environment hypothesis of sexual reproduction is added. The chapter now introduces standard human karyotype nomenclature and uses it to expand on the mechanisms and consequences of chromosome nondisjunction in humans.

Chapter 14 Mendel and the Gene There is a sharper focus on challenging concepts, including the relationship between genotype and phenotype and the ability to consider phenotypes at levels that range from the molecular to the organismal. There are new examples to illustrate pleiotrophy and multiple allelism. New figures and a summary table on pedigree analysis bring together this topic.

Chapter 15 DNA and the Gene: Synthesis and Repair Coverage is expanded on the Okazaki experiment and on the Nobel Prize–winning experiments of Greider and colleagues on telomeres and telomerase, so that students can more easily understand these investigations and their significance. New Canadian research has been added on the relationships between telomere length and cancer cells and on DNA repair and the cell cycle.

Chapter 16 How Genes Work Greater emphasis is placed on illustrating how the central dogma links genotype to phenotype. A stronger point is made that mutations can occur anywhere in the genome, not just in protein-coding sequences. The description of point mutations now distinguishes between base-pair substitutions and insertion-deletion mutations.

Chapter 17 Transcription, RNA Processing, and Translation For each part of the chapter, bacteria and eukaryotes are now discussed separately. This has meant adding details on eukaryotic transcription termination, translation initiation, and translation termination. Three existing figures and one table are modified to improve clarity. Research at the University of Lethbridge illustrates how RNAs are modified.

Chapter 18 Control of Gene Expression in Bacteria Regulation of the *lac* operon has been updated and two new examples, the *ara* operon and the ToxR regulon have been added. Canadian Research 18.1 describes how gene expression changes in a pathogenic bacterium when it invades human cells.

Chapter 19 Control of Gene Expression in Eukaryotes Coverage of chromatin structure, histone modifications, microRNAs, and RNA longevity have been updated. New figures show how transcription factors read DNA sequences, how alternative splicing occurs, and the role of p53 in healthy cells. New Canadian Research boxes describe the roles of DNA methylation on carpenter ant size and of alternative splicing on an important human RNA.

Chapter 20 The Molecular Revolution: Biotechnology and Beyond Material previously spread across two chapters is merged to provide a more focused overview of major aims and techniques of genomics and related fields, including recent innovations such as CRISPR genome editing. Specific details of fundamental techniques are relocated to the BioSkills section for students and instructors who desire this level of coverage. New Canadian content includes the discovery of the *CFTR* gene at the University of Toronto as well as several current research projects.

Chapter 21 Genes, Development, and Evolution Essential concepts previously spread across several chapters are brought together in this chapter, and it now links the Gene Structure and Expression unit to the Evolutionary Patterns and Processes unit by using molecular and cellular aspects of developmental biology as a bridge. Canadian Research 21.2 now includes experimental stem cell–based therapies to treat spinal cord injuries and diabetes mellitus.

Chapter 22 Evolution by Natural Selection The historical introduction is simplified and illustrated in a new figure that compares different conceptual models of life's diversity. The homology section is updated to include developmental processes, and the three levels of homology are highlighted in a new summary table. More practice is provided in applying Darwin's postulates and reading phylogenetic trees. There is increased focus on overcoming common evolutionary misconceptions throughout the chapter. More plant examples are included. Focus on the ecological context of evolution is increased.

Chapter 23 Evolutionary Processes The introduction to the Hardy–Weinberg principle is simplified and updated with new examples. Increased attention is given to students' struggle to distinguish gene flow and genetic drift, and there are new follow-up questions. The summary table on evolutionary processes now includes icons to help students distinguish evolutionary processes, effect on genetic variation, and effect on fitness.

Chapter 24 Speciation New examples emphasize the origin of biodiversity, variation in rate of speciation, and biogeography, and illustrate the role of sexual selection and genetic mechanisms in speciation. Icons are now included in three summary tables to help students visualize mechanisms of reproductive isolation, species concepts, and outcomes of secondary contact between populations.

Chapter 25 Phylogenies and the History of Life The terms "microevolution" and "macroevolution" are now defined in the introduction. The phylogenetics section is updated to include more diverse examples. There is increased emphasis on avoiding common misconceptions in interpreting and drawing trees. The fossil review is reorganized into a photographic summary table. Canadian Research 25.1 is updated with information about the recently discovered Marble Canyon fossil assemblage from Kootenay National Park, British Columbia. Dates in the history of lifetime line are updated. New evidence regarding causes of the end-Cretaceous extinction is introduced.

Chapter 26 Bacteria and Archaea New content is included on the role of endospores in the prokaryote life cycle, and recent studies on the human microbiome are highlighted. The section on themes in diversification is expanded to include mechanisms of gene transfer (e.g., transformation, transduction, and conjugation). Recent ideas that call into question the traditional three-domain tree of life hypothesis are presented.

Chapter 27 Protists Discussion of the role of endosymbiosis in the origin of mitochondria and chloroplasts is streamlined to focus on key concepts. The coverage of euglenids now includes a description of the flexible pellicle of this group, to underscore the point that most protist lineages are characterized by distinct microscopic features. Coverage of slime moulds is expanded to include more on the structure and movement of plasmodial slime moulds. Greater attention is paid to guiding students step-by-step through complex protist life cycles.

Chapter 28 Green Algae and Land Plants The updated discussion of the origin of plants now recognizes the conjugating algae (Zygnematophyceae) as one of the closest living relatives to land plants. Alternation of generations—the fundamental life cycle of all land plants—is now emphasized and presented with greater clarity.

Chapter 29 Fungi Content is updated to emphasize the important role of asexual spores (conidia) in the reproductive cycle of fungi. The unique relationship between a fungus and ants resulting in "zombie ants" is highlighted to illustrate the diversity of fungal lifestyles. Canadian Research 29.1 describes the work of University of British Columbia botanist Suzanne Simard and her colleagues on the interactions among ectomycorrhizal fungal networks and forest trees.

Chapter 30 An Introduction to Animals The chapter is updated to include insights gleaned from new genetic and developmental data, emphasizing that evolution is not a straightforward march from simple to complex. Canadian Issues 30.1 introduces CHONe, the Canadian Healthy Oceans Network, which worked with the First Census of Marine Life to establish a biodiversity database for Canada's Pacific, Arctic, and Atlantic oceans and is now tasked with making recommendations for the establishment of Marine Protected Areas in Canadian waters.

Chapter 31 Protostome Animals The revised introduction is organized as a walk-through of a phylogeny to provide context from the previous chapter. Characteristics traditionally used to distinguish protostome development are deemphasized in light of recent research showing many exceptions. A new figure shows the phylogeny of arthropods, including insects within the Crustacea. Canadian Research 31.1 introduces exciting new fossil finds of Cambrian mollusks.

Chapter 32 Deuterostome Animals The echinoderm section has an increased emphasis on ecology and process of science, including Paine's keystone predator study. The invertebrate chordate section is expanded to include ascidians, thalaceans, and larvaceans. The key innovations section is revised and streamlined as a walk-through of the chordate phylogeny. The section on early vertebrates introduces *Metaspriggina*, the best-preserved Cambrian fish. The human evolution section is updated, including reference to new hominin species and an image of a Neanderthal woman.

Chapter 33 Viruses Canadian Research 33.1 discusses University of British Columbia oceanographer Curtis Suttle's work on the tremendous diversity, abundance, and importance of marine viruses. A new section on the role of viruses in shaping the evolution of organisms is introduced. A discussion of the SARS-CoV and MERS-CoV outbreaks is included to illustrate the international network of researchers that works to identify and control emerging viral infections. New content on how viruses impact society is included, along with new material covering recent discoveries on how the Ebola virus infects cells.

Chapter 34 Plant Form and Function The chapter is reorganized to discuss the structure and function of cells and tissues before placing them in the context of primary and secondary growth. Practice is provided on calculating and comparing the relationship between surface area and volume in different types of plant structures. Content on secondary growth is expanded to emphasize how trees make the transition from primary to secondary growth.

Chapter 35 Water and Sugar Transport in Plants The discussion of water potential and water movement is streamlined to bring key concepts into sharper focus. Recent work on the role of the *SWEET* genes in sugar transport is introduced.

Chapter 36 Plant Nutrition Discussion of parasitic plants is broadened and now includes dodder and ghost plants as examples.

Chapter 37 Plant Sensory Systems, Signals, and Responses The discussion of phototropins is streamlined to focus on key concepts. The role of phytochrome in circadian rhythms and etiolation is introduced. A summary table on key plant growth regulators is now illustrated with photographs to show the impact of hormones on plant growth and development.

Chapter 38 Plant Reproduction and Development The chapter is reorganized to merge essential information previously spread across several chapters and bring flowering plant reproduction and development together in a single, integrated story. Discussions of flower structure, pollination, fertilization, the formation of seeds and fruits, and embryogenesis are updated and streamlined. Coverage of vegetative development emphasizes the roles of apical meristems and genes involved in embryogenesis and leaf formation.

Chapter 39 Animal Form and Function The discussion of mammalian thermoregulation is moved into the section on homeostasis. In the introduction to animal tissue types, more explicit structure–function examples are given for each tissue type. The section on regulatory homeostasis is updated, and the idea that regulation and conformation are two ends of a spectrum is introduced. The expressions "warm-blooded" and "cold-blooded" are addressed to explain why these terms are problematic to use in biology. The section on countercurrent multipliers is simplified. Canadian Research 39.1 on Carleton University's Ken Storey's work on freeze-tolerant animals has been updated.

Chapter 40 Water and Electrolyte Balance in Animals The chapter is reorganized to better integrate the relationship between excretion and water and electrolyte balance. Osmoregulatory strategies are now organized according to the challenges presented by marine, freshwater, and terrestrial habitats. Coverage of osmoregulation in bony fishes versus cartilaginous fishes, mammalian kidney function, and how nonmammalian vertebrates concentrate their urine is expanded and clarified.

Chapter 41 Animal Nutrition Information on diabetes mellitus has been updated and now includes discoveries and therapies from Mount Sinai Hospital. New research is presented on how fruit flies taste food and how bees choose pollen from the Universities of British Columbia and Ottawa, respectively.

Chapter 42 Gas Exchange and Circulation Oxygen–hemoglobin dissociation figures are redrawn more accurately, and new content helps students understand the meaning of a sigmoidal curve. The open circulatory system common to most invertebrates is illustrated with a new figure showing circulation in a spider.

Chapter 43 Animal Nervous Systems A new figure shows the relationships among sensory neurons, motor neurons, and interneurons. Review of material from earlier chapters on how ions are transported across membranes is streamlined. The discussion of the magnitude of action potentials and how action potentials propagate down an axon is clarified. Revisions emphasize that new action potentials are continuously generated along the entire length of an axon, addressing the misconception that a single action potential travels from one end to the other. Updated information is included on the hippocampus, the enteric nervous system, and the technique of optogenetics, a major breakthrough in neuroscience.

Chapter 44 Animal Sensory Systems The section on taste is updated to reflect new knowledge about the structure and function of gustation, and the likely existence of more than just five taste sensations. The role of mechanoreception in taste—by providing information about texture—is introduced. New content highlights one of the chapter's key ideas: Animals do not rely on senses independently and instead integrate information from multiple sensory modalities.

Chapter 45 Animal Movement A new figure shows examples of hydrostatic skeletons, endoskeletons, and exoskeletons. A brief section is added addressing the misconception that muscles grow by adding new cells during weight-lifting/training. In fact, the cells simply grow. A new section discusses the role of bone in calcium storage and the process of bone remodelling. Osteoblasts and osteoclasts are introduced, and osteoporosis is discussed briefly. Canadian Research 45.1 describes how University of Alberta's Scott Persons and Philip Currie have reconstructed the tail muscles of *Tyrannosaurus rex*, providing a new interpretation of the movement of this iconic dinosaur.

Chapter 46 Chemical Signals in Animals Content is rearranged to flow more logically: first introducing cell signalling, next discussing how hormones stimulate cells, then giving examples of what hormones can do, and finally describing how hormones are regulated overall. Discussion of the discovery of hormones is updated for historical accuracy and includes a new research box on Berthold's classic experiment on roosters, which shows that a chemical blood-borne messenger (later characterized as testosterone) can affect behaviour and anatomy. Control of blood-glucose levels by insulin and glucagon is now used to illustrate how hormones maintain homeostasis. Canadian Issues 46.1, which explores the consequences of releasing estrogens into the environment, has been updated. A new research box, Canadian Research 46.1, describes the role of cortisol in mediating stress in wildlife.

Chapter 47 Animal Reproduction and Development Material previously spread across several chapters is merged to bring reproduction and development together to tell a single, integrated story. Coverage of fertilization is now integrated with egg development; coverage of cleavage, gastrulation, and organogenesis is combined into a new, descriptive section on embryonic development. The chapter now focuses more on the physiology of reproduction in mammals, but retains a comparative approach by including examples ranging from insects to marsupials. Canadian Issues 47.1 is updated to include mitochondrial replacement therapy, also known as three-parent babies.

Chapter 48 The Immune System in Animals Updated content on inappropriate immune responses (autoimmunity and allergies) and inadequate responses (immunodeficiency) is grouped together in one section. The hygiene hypothesis is introduced to explain the growing trend of inappropriate immune responses in populations that have reduced exposure to common pathogens and parasites. The description on the ABO blood antigens is expanded and includes research at the University of British Columbia toward eliminating these antigens from donated blood cells.

Chapter 49 An Introduction to Ecology The introduction is revised to clarify the relationship between traditional ecology and the study of human impacts. The niche concept is introduced as a tool to relate organisms to environmental conditions. The theory of plate tectonics and a figure showing continental drift are added to the section on biogeography. The Coriolis effect, prevailing winds, ocean gyres, and El Niño are added to the climate section. Information from the Second Canadian Edition biome boxes is integrated into the text and included in new photographic summary tables on terrestrial and aquatic biomes. The temperate coniferous forest biome has been added, to include all of Canada's major terrestrial biomes.

Chapter 50 Behavioural Ecology The introduction includes increased emphasis on fitness trade-offs and variation among organisms in a population (population thinking). Section case studies are updated, including a new opportunity for students to practise with optimal foraging in bees, a new data graphic on sexual selection in *Anolis* lizards, and a new photo of monkeys engaged in reciprocal grooming. Canadian Issues 50.1 introduces the whisky jack, which *Canadian Geographic* has proposed as Canada's national bird. A new section addresses the misconception that individuals act for the good of the species.

Chapter 51 Population Ecology The mark—recapture Quantitative Methods box is expanded. The figure and discussion of the life-history continuum are expanded. The exponential growth section is revised for a clearer walk-through of the equations and more direct assistance with common misconceptions. A new photographic summary table of density-dependent factors is added. Human population content is updated. Applications to conservation are expanded.

Chapter 52 Community Ecology More plant examples are included. The case studies on species interactions are updated and clarified. The community structure section now begins with a discussion of how pairwise interactions combine to form webs of interactions, introducing the food web as an example. A discussion of bottom-up and top-down influences on community structure is now included.

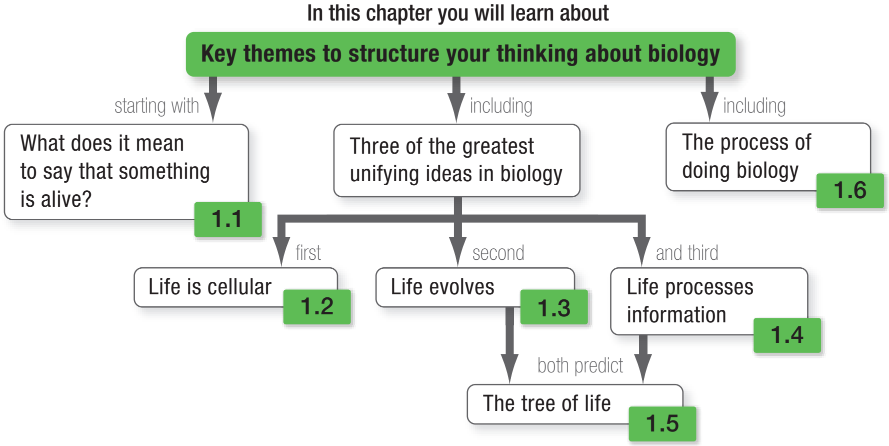
Chapter 53 Ecosystems and Global Ecology Updates and clarifications are made throughout the chapter, particularly in the section on climate change, including updated data graphics. Nutrient cycle figures are modified to distinguish natural and human-caused processes. A section on phosphorus cycling is added. Canadian Issues 53.1 has been updated with new information about the threat that mountain pine beetles may pose to Canada's vast boreal forests. The concept of tipping points is added, and the interaction of multiple variables is emphasized.

Chapter 54 Biodiversity and Conservation Biology Updates and clarifications are made throughout the chapter. A new figure contrasts resistance and resilience. A new data graphic emphasizes the resource intensity of beef. Overall, more emphasis is placed on the positive effects of conservation action, including a new full-page photographic summary table of conservation strategies. A number of Canadian examples of threats to biodiversity and conservation initiatives have been included.

Marina Vdovkina/123RF

1 Biology and the Tree of Life

This whisky jack looks like it is waiting for a kindly hiker to give it some food. It represents one of the key characteristics of life introduced in this chapter—energy.



In essence, biological science is the study of life. It searches for ideas and observations that unify our understanding of the diversity of life—from bacteria living in hot springs to humans and majestic sequoia trees.

The goals of this chapter are to introduce the nature of life and explore how biologists go about studying it. The chapter also introduces themes that will resonate throughout this book:

- Analyzing how organisms work at the molecular level.
- Understanding organisms in terms of their evolutionary history.
- Helping you learn to think like a biologist.

Let's begin with what may be the most fundamental question of all: What is life?

BIG PICTURE

This chapter is part of the Big Picture. See how on pages 16–17.

1.1 What Does It Mean to Say That Something Is Alive?

An **organism** is a life-form—a living entity made up of one or more cells. Although there is no simple definition of life that is endorsed by all biologists, most agree that organisms share a suite of five fundamental characteristics. You can think of this text as one long exploration of these five traits.

- ***Cells*** Organisms are made up of membrane-bound units called **cells.** The membrane of a cell regulates the passage of materials between exterior and interior spaces.
- ***Replication*** One of the great biologists of the twentieth century, François Jacob, said that the "dream of a bacterium is to become two bacteria." Almost everything an organism does contributes to one goal: replicating itself.
- ***Evolution*** Organisms are the products of evolution, and their populations continue to evolve today.
- ***Information*** Organisms process hereditary, or genetic, information encoded in units called **genes.** Organisms also respond to information from the environment and adjust to maintain stable internal conditions. Right now, cells throughout your body are using information to make the molecules that keep you alive, your eyes and brain are decoding information on this page that will help you learn some biology, and if your room is too hot you might be sweating to cool off.
- ***Energy*** To stay alive and reproduce, organisms have to acquire and use energy. To give just two examples: plants absorb sunlight; animals ingest food.

Three of the greatest unifying ideas in all of science, which depend on the five characteristics just listed, laid the groundwork for modern biology: the cell theory, the theory of evolution, and the chromosome theory of inheritance. Formally, scientists define a **theory** as an explanation for a very general class of phenomena or observations that is supported by a wide body of evidence. Note that this definition contrasts sharply with the everyday usage of the word "theory," which often carries meanings such as "speculation" or "guess."

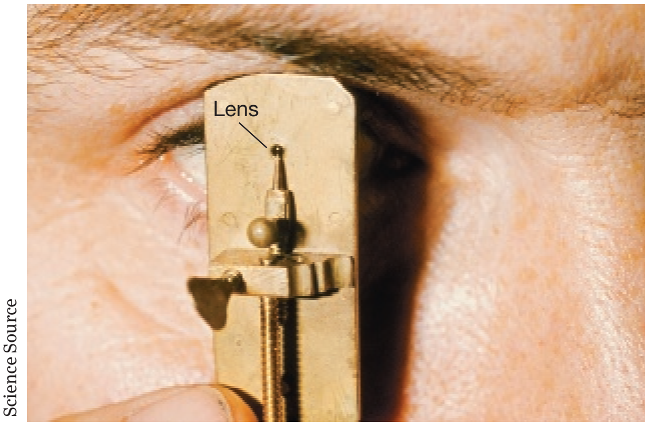
The cell theory, the theory of evolution, and the chromosome theory of inheritance address fundamental questions: What are organisms made of? Where do they come from? How is hereditary information transmitted from one generation to the next?

When these theories began to emerge in the mid-1800s, they revolutionized the way biologists think about the world. None of these insights came easily, however. The cell theory, for example, emerged after some 200 years of work. Let's examine some of the pivotal discoveries made along the way.

1.2 Life Is Cellular

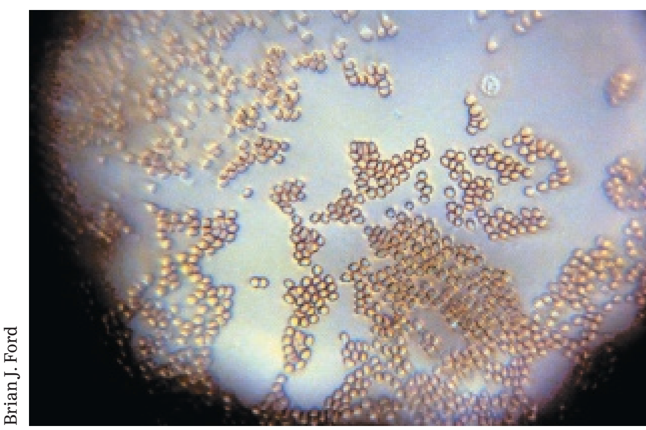
In 1665 the Englishman Robert Hooke devised a crude microscope to examine the structure of cork (a bark tissue) from an oak tree. The instrument magnified objects to just 30× (30 times) their normal size, but it allowed Hooke to see something

(a) Van Leeuwenhoek built his own microscopes—which, while small, were powerful. They allowed him to see, for example ...



Biophoto Associates/Photo Researchers, Inc./ Science Source

(b) ... human blood cells (this modern photo was shot through one of van Leeuwenhoek's original microscopes).



Brian J. Ford

Figure 1.1 Van Leeuwenhoek's Microscope Made Cells Visible.

extraordinary. In the cork he observed small, pore-like compartments that were invisible to the naked eye. Hooke coined the term "cells" for these structures because he thought they resembled the cells inhabited by monks in a monastery.

Soon after Hooke published his results, the Dutch scientist Anton van Leeuwenhoek developed much more powerful microscopes, some capable of magnifications up to 300× (**Figure 1.1**). With these instruments, Van Leeuwenhoek inspected samples of pond water and made the first observations of a dazzling collection of single-celled organisms that he called "animalcules."

In the 1670s an Italian researcher studying the leaves and stems of plants with a microscope concluded that plant tissues were composed of many individual cells. By the early 1800s, enough data had accumulated for a German biologist to claim that *all* organisms consist of cells. Did this claim hold up?

All Organisms Are Made of Cells

Advances in microscopy have made it possible to examine the amazing diversity and complexity of **cells** at higher and higher magnifications. Microscopes tens of thousands of times more powerful than Van Leeuwenhoek's have revealed that cells are highly organized compartments separated from their environment by a membrane barrier. With these instruments, biologists have examined many new species. The basic conclusion made in the 1800s remains intact: All organisms are made of cells.

The smallest organisms known today are bacteria that are barely 200 nanometres wide, or 200 *billionths* of a metre. (See **BioSkills 1** to review the metric system.[1]) It would take 5000 of these organisms lined up side by side to span a millimetre. In contrast, sequoia trees can be over 100 metres tall, the equivalent of a 20-storey building. Bacteria and sequoias are composed of the same fundamental building block, however—the cell. Bacteria consist of a single cell; sequoias are made up of trillions of cells.

The realization that all organisms are made of cells was fundamentally important, but it formed only the first part of the cell theory. In addition to understanding what organisms are made of, scientists wanted to understand how cells come to be.

Where Do Cells Come From?

In 1858, a German scientist named Rudolph Virchow proposed that all cells arise from cells already in existence. The complete **cell theory** builds on this concept: All organisms are made of cells, and all cells come from preexisting cells.

Two Hypotheses The cell theory was a direct challenge to the prevailing explanation of where cells come from, called spontaneous generation. In the mid-1800s, most biologists believed that organisms could arise spontaneously under certain conditions. The bacteria and fungi that spoil foods such as milk and wine were thought to appear in these nutrient-rich media of their own accord—springing to life from nonliving materials. In contrast, the cell theory maintained that cells do not arise spontaneously but are produced only when preexisting cells grow and divide. The all-cells-from-cells explanation was a **hypothesis:** a testable statement to explain a phenomenon or a set of observations.

Biologists usually use the word "theory" to refer to proposed explanations for broad patterns in nature and prefer "hypothesis" to refer to explanations for more tightly focused questions. A theory serves as a framework for developing new hypotheses.

An Experiment to Settle the Question Soon after Virchow's all-cells-from-cells hypothesis appeared in print, a French scientist named Louis Pasteur set out to test its predictions in an **experiment.** Experiments are a powerful scientific tool because they allow researchers to test the effect of a single, well-defined factor on a particular phenomenon. An experimental **prediction** describes a measurable or observable result that must be correct if a hypothesis is valid.

Pasteur wanted to determine whether organisms could arise spontaneously in a nutrient broth or whether they appear only when a broth is exposed to a source of preexisting cells. To address the question, he created two treatments that were identical in every respect but one: the factor being tested—in this case, a broth's exposure to preexisting cells.

Both treatments used glass flasks filled with the same amount of the same nutrient broth (**Figure 1.2**). Both flasks were boiled for the same amount of time to kill any existing organisms. After sterilization by boiling, however, any bacteria and fungi that cling to dust particles in the air could drop into the broth in the flask shown in Figure 1.2a because the neck of this flask was straight.

[1]**BioSkills** are located after Chapter 1. They focus on general skills that you'll use throughout this course. More than a few students have found them to be a lifesaver. Please use them!

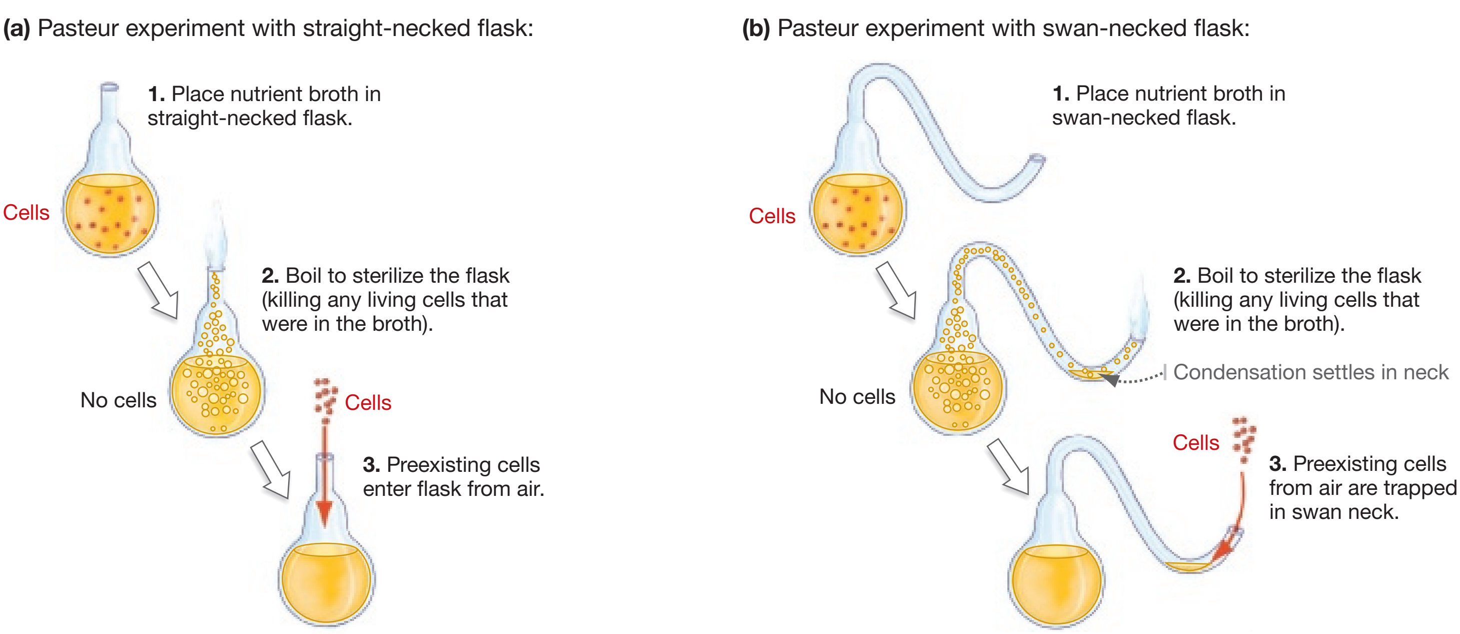


Figure 1.2 The Spontaneous Generation and All-Cells-from-Cells Hypotheses Were Tested Experimentally.

✔ **PROCESS OF SCIENCE** What problem would arise in interpreting these results if Pasteur had (1) put different types of broth in the two treatments, or (2) used a ceramic flask for one treatment and a glass flask for the other?

In contrast, in the flask with a long swan neck (Figure 1.2b), water would condense in the crook of the swan neck after boiling and this pool of water would trap any bacteria or fungi that entered on dust particles. Thus, the contents of the swan-necked flask were isolated from any source of preexisting cells even though they were still open to the air.

The spontaneous generation hypothesis predicted that cells would appear in both treatment groups. The all-cells-from-cells hypothesis predicted that cells would appear only in the treatment exposed to a source of preexisting cells.

And Pasteur's results? The broth in the straight-necked flask exposed to preexisting cells quickly filled with bacteria and fungi. This observation was important because it showed that the sterilization step had not altered the nutrient broth's capacity to support growth. The broth in the swan-necked flask remained sterile, however. Even when the flask was left standing for months, no organisms appeared in it. This result was inconsistent with the hypothesis of spontaneous generation.

Because Pasteur's data were so conclusive—meaning that there was no other reasonable explanation for them—the results persuaded most biologists that the all-cells-from-cells hypothesis was correct.

If all cells come from existing cells, where did the first cells come from? Biologists now have evidence that life arose from nonlife early in Earth's history, through a process called **chemical evolution.**

Life Replicates through Cell Division

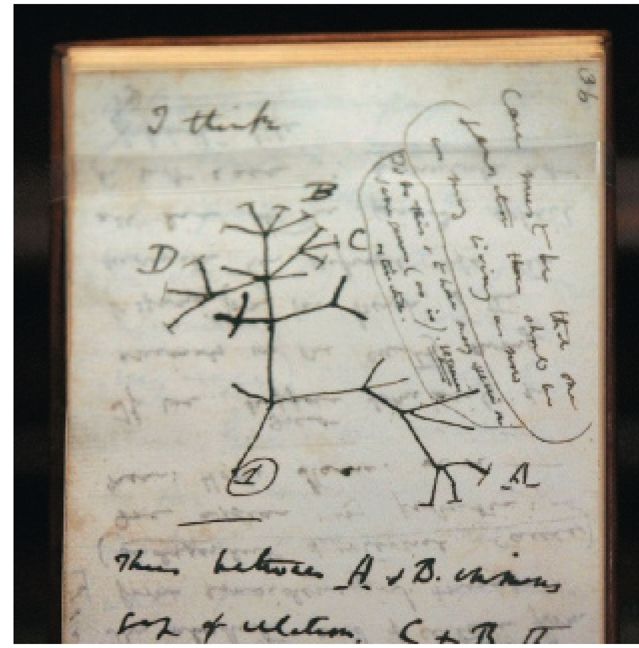
For life on Earth to continue to exist, cells must replicate. Most cells are capable of reproducing by dividing—in effect, by making a copy of themselves. As predicted by the cell theory, all the cells present in your body and in most other multicellular individuals are descended from preexisting cells, tracing back to a fertilized egg. A fertilized egg is a cell created by the fusion of sperm and egg—cells that formed in individuals of the previous generation.

New cells arise when preexisting cells split. In multicellular organisms they become specialized for particular functions by intricate processes. In this way, all the cells in a multicellular organism are connected by a common lineage. Is the tremendous diversity among organisms also related to common ancestry?

The second great founding idea in biology, published the same year as the all-cells-from-cells hypothesis, provided an answer. This was the realization, made independently by the English scientists Charles Darwin and Alfred Russel Wallace, that all the diverse **species**—all distinct, identifiable types of organisms—are connected by common ancestry.

1.3 Life Evolves

In 1858, short papers written separately by Darwin and Wallace were read to a small group of scientists attending a meeting of the Linnean Society of London. A year later, Darwin published a book that expanded on the idea summarized in those brief papers. The book was called *On the Origin of Species by Means of Natural Selection*. The first edition sold out in a day.



Rebecca Letz/Sipa Press/Newscom

Figure 1.3 Sketch from Darwin's Notebook Dated 1837. Darwin wrote this in the notes that follow: "Thus genera would be formed. Bearing relation to ancient types with several extinct forms."

What Is Evolution?

Darwin and Wallace's theory made two important claims concerning patterns that exist in the natural world:

1. Species are related by common ancestry (**Figure 1.3**). This idea contrasted with the prevailing view in science at the time, which was that species represent independent entities created separately by a divine being.
2. The characteristics of species can be modified from generation to generation. Darwin called this process descent with modification. This claim argued against the popular view at the time that species do not change.

Evolution is a change in the characteristics of a population over time. A **population** is defined as a group of individuals of the same species living in the same area at the same time. To put it another way, species are related to one another and can change through time.

What Is Natural Selection?

Several other scientists had already come to the same conclusions as Darwin and Wallace about the relationships between species. The great insight by Darwin and Wallace was in proposing a process, called **natural selection,** that explains *how* evolution occurs.

Two Conditions of Natural Selection

Natural selection occurs whenever two conditions are met:

1. Individuals within a population vary in characteristics that are **heritable**—meaning, traits that can be passed on to offspring.

2. In a particular environment, certain versions of these heritable traits help individuals survive better or reproduce more than other versions.

If certain heritable traits lead to increased success in producing offspring, then those traits become more common in the population over time. In this way, the population's characteristics change as a result of natural selection acting on individuals. This is a key insight: Natural selection acts on individuals, but evolutionary change occurs in populations.

Evolution occurs when heritable variation leads to differential success in reproduction. Individual populations change through time in response to natural selection. But over the past several decades, biologists have also documented dozens of cases in which natural selection has caused populations of one species to diverge and form new species. This divergence process is called **speciation.**

Research on speciation has two important implications: All species come from preexisting species, and all species, past and present, trace their ancestry back to a single common ancestor.

Fitness and Adaptation Darwin also introduced some new terminology to identify what happens during natural selection.

- In everyday English, "fitness" means "health and well-being." But in biology, **fitness** means "an individual's ability to produce viable offspring." Individuals with high fitness produce many surviving offspring.
- In everyday English, "adaptation" means that an individual is adjusting and changing to function in new circumstances. But in biology, an **adaptation** is a trait that increases the fitness of an individual in a particular environment.

Darwin and Wallace's ideas arose from their observations of nature. For example, in finches from the Galápagos Islands Darwin noted the remarkable variation in beak size and shape in species that otherwise appeared similar. He proposed that the birds on different islands in the chain were similar because they descended from a common ancestor, but the finch populations that colonized different islands had changed through time and formed new species with distinct beaks.

Long-term studies by biologists over the past several decades have documented dramatic changes in a population of finches on one of the Galápagos Islands (you will learn more about this study in Chapter 22). When small, soft seeds were abundant there due to increased rainfall, finches with small, pointed beaks produced more offspring and had higher fitness than individuals with large, deep beaks. In this population and with this food source, a small, pointed beak was an adaptation that allowed certain individuals to thrive, and the incidence of finches with such beaks increased in the population.

Note that during this process, the beak shape of any individual finch did not change within its lifetime—the change occurred in the characteristics of the population over time. Darwin's finches continue to evolve today in response to changes in the environment.

Together, the cell theory and the theory of evolution provided the young science of biology with two central, unifying ideas:

1. The cell is the fundamental structural unit in all organisms.
2. All species are related by common ancestry and have changed over time in response to natural selection.

But what was the source of the heritable variation in traits? And how was information stored and transmitted from one generation to the next? The third unifying idea—the chromosome theory of inheritance—provided the foundation for biologists to answer these questions.

CHECK YOUR UNDERSTANDING

If you understand that …

- Natural selection occurs when heritable variation in certain traits leads to improved success in reproduction. Because individuals with these traits produce many offspring with the same traits, the traits increase in frequency and evolution occurs.
- Evolution is a change in the characteristics of a population over time.

✔ You should be able to …

Discuss the following statement: "Various species of Galápagos finches are adapted to their particular habitats."

Answers are available in Appendix A.

1.4 Life Processes Information

After Walter Sutton and Theodor Boveri proposed the **chromosome theory of inheritance** in 1902, the pieces of the genetic puzzle began to fall into place. The key point? Inside cells, hereditary or genetic information is encoded in genes, the units located on chromosomes.

But it wasn't until experiments were carried out in the 1950s that biologists figured out the molecular nature of the genetic material—a **chromosome** consists of a molecule of **deoxyribonucleic acid,** or **DNA.** To sum up, DNA is the heredity material. Genes consist of specific segments of DNA that code for products in the cell.

The Central Dogma

In what is considered one of the greatest scientific breakthroughs of biology, James Watson and Francis Crick proposed that DNA is a double-stranded helix (**Figure 1.4**). Crucial insights that led to this model came from structural analyses performed by Rosalind Franklin in Maurice Wilkins' laboratory.

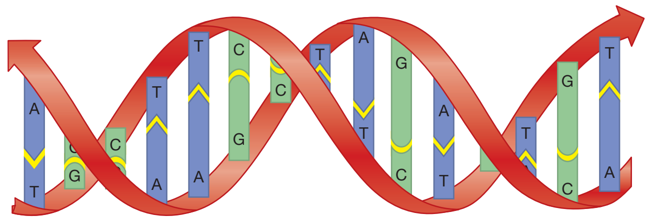


Figure 1.4 DNA Is a Double Helix.

Each strand of the **double helix** is made up of varying sequences of four different kinds of building blocks. In terms of structure, on each strand of the helix the building blocks of DNA are connected one to another linearly. In terms of function, they are like letters of the alphabet—the four different kinds of molecular building blocks are symbolized by the letters A, T, C, and G. A sequence of this letter code is like the sequence of letters in a word—it has meaning. In this way, DNA carries, or encodes, the information required for an organism's growth and reproduction.

The two strands of the double helix are joined by connections between the building blocks that occur only between certain letters: A always pairs with T, and C always pairs with G (see Figure 1.4). This pairing is key: DNA can be copied, and the information encoded in the DNA is faithfully preserved. The pairs are arranged much like the rungs on a ladder, with the strands acting as the sides of the ladder.

How is this information transmitted? The **central dogma**—first articulated by Crick—describes the flow of information in cells. In this context, the term "dogma" means a framework for understanding. Put simply, DNA codes for RNA, which codes for proteins (**Figure 1.5**).

Molecular machinery in cells makes a copy of a particular gene's information in the form of a closely related molecule called **ribonucleic acid,** or **RNA.** RNA molecules carry out a number of specialized functions in cells. For example, molecular machinery reads a messenger RNA molecule to determine what building blocks to use to make a **protein.** Proteins are crucial to most tasks required for a cell to exist, from forming structural components to promoting the chemical reactions that sustain life.

Understanding the structure of DNA provided insight into how genetic information is passed from cell to cell or from one organism to its offspring. Making a copy of DNA in a cell is a highly accurate process, but mistakes can occur. What happens when a mistake is made? Differences in DNA sequences may lead to differences in the sequence of building blocks of proteins.

The implications are profound: The outward appearance of an organism is a product of the proteins produced by its molecular machinery, so differences in DNA sequences might lead to a difference, for example, in finch beak size and shape, or in the length of a bighorn sheep's horns. At the level of individuals, such changes might increase or decrease fitness. At the population level, changes in sequence lead to the heritable variations that underlie the diversity of life and make evolution possible.

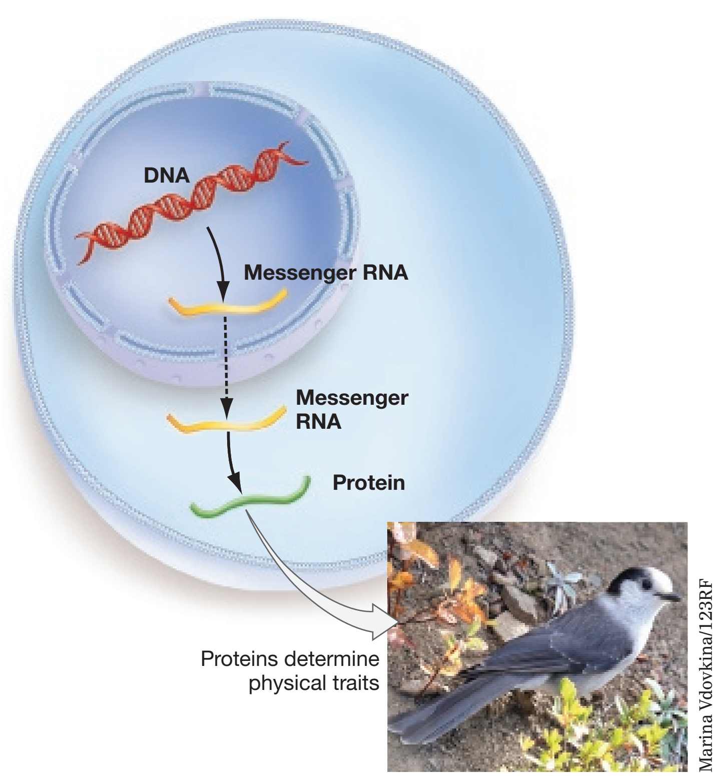


Figure 1.5 The Central Dogma Describes the Flow of Genetic Information. Genetic information flows from DNA to RNA to proteins. Differences in DNA sequences may lead to different physical traits.

Life Requires Energy

The chemical reactions that sustain the diversity of life take place inside cells. Transmitting genetic information, and the other work carried out by cells, requires energy. Organisms—whether single-celled or multicellular—are capable of living in a wide array of environments because they vary in cell structure and how they acquire and use energy.

Organisms have two fundamental nutritional needs—acquiring chemical energy in the form of a molecule called **ATP** (or **adenosine triphosphate**) and obtaining molecules that can be used as building blocks for the synthesis of DNA, RNA, proteins, the cell membrane, and other large, complex compounds required by the cell. How organisms do this—whether acquiring energy from the sun or through chemical compounds—is central to the tremendous diversification of life after it first arose on Earth.

1.5 The Tree of Life

The theory of evolution by natural selection predicts that biologists should be able to construct a **tree of life**—a family tree of organisms. If life on Earth arose just once, then such a diagram would describe the genealogical relationships among species with a single, ancestral species at its base. Has this task been accomplished? If the tree of life exists, what does it look like?

Using Molecules to Understand the Tree of Life

One of the great breakthroughs in research on the tree of life occurred when American biologist Carl Woese (pronounced *woze*) and colleagues began analyzing the molecular components of organisms as a way to understand their evolutionary relationships. Their goal was to understand the **phylogeny** of all organisms—their actual genealogical relationships. Translated literally, "phylogeny" means "tribe-source."

To understand which organisms are closely versus distantly related, Woese and co-workers needed to study a molecule found in all organisms. They selected a ribosomal RNA (rRNA). These are an essential part of ribosomes, which are cellular machinery that all cells use to grow and reproduce.

Although rRNA is a large and complex molecule, its underlying structure is simple. Much like DNA, an rRNA molecule is made up of sequences of four smaller chemical components called ribonucleotides. These ribonucleotides are symbolized by the letters A, U, C, and G. In rRNA, ribonucleotides are connected to one another linearly, like boxcars of a freight train (**Figure 1.6**).

Analyzing Genetic Variation Why might rRNA be useful for understanding the relationships between organisms? The answer is that the ribonucleotide sequence in rRNA is a trait that can change during the course of evolution. Although rRNA performs the same function in all organisms, the sequence of ribonucleotide building blocks in this molecule is not identical among species.

In land plants, for example, the molecule might start with the sequence A-U-A-U-C-G-A-G. In green algae, which are closely related to land plants, the same section of the molecule might contain A-U-A-U-G-G-A-G. But in brown algae, which are not closely related to green algae or to land plants, the same part of the molecule might consist of A-A-A-U-G-G-A-C.

The next step in analyzing genetic variation is to consider what the similarities and differences in the sequences imply about relationships among species. The goal is to produce a diagram that describes the phylogeny of the organisms being compared.

A diagram that depicts evolutionary history in this way is called a **phylogenetic tree.** (For help in learning how to read a phylogenetic tree, see **BioSkills 11**.) Just as a family tree shows relationships among individuals, a phylogenetic tree shows relationships among species. On a phylogenetic tree, branches that share a recent common ancestor—that is, an ancestral population—represent species that are closely related; branches that don't share recent common ancestors represent species that are more distantly related.

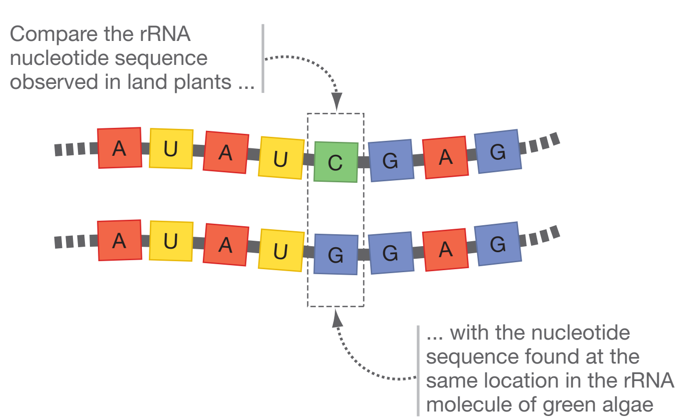


Figure 1.6 RNA Molecules Are Made Up of Smaller Molecules. The complete small subunit rRNA molecule contains about 2000 ribonucleotides; just 8 are shown in this comparison.

✔ **PROCESS OF SCIENCE** Suppose that in the same portion of rRNA, moulds and other fungi have the sequence A-U-A-U-G-G-A-C. According to these data, are fungi more closely related to green algae or to land plants? Explain your logic.

The Tree of Life Estimated from Genetic Data To construct a phylogenetic tree, such as the one shown in **Figure 1.7**, researchers

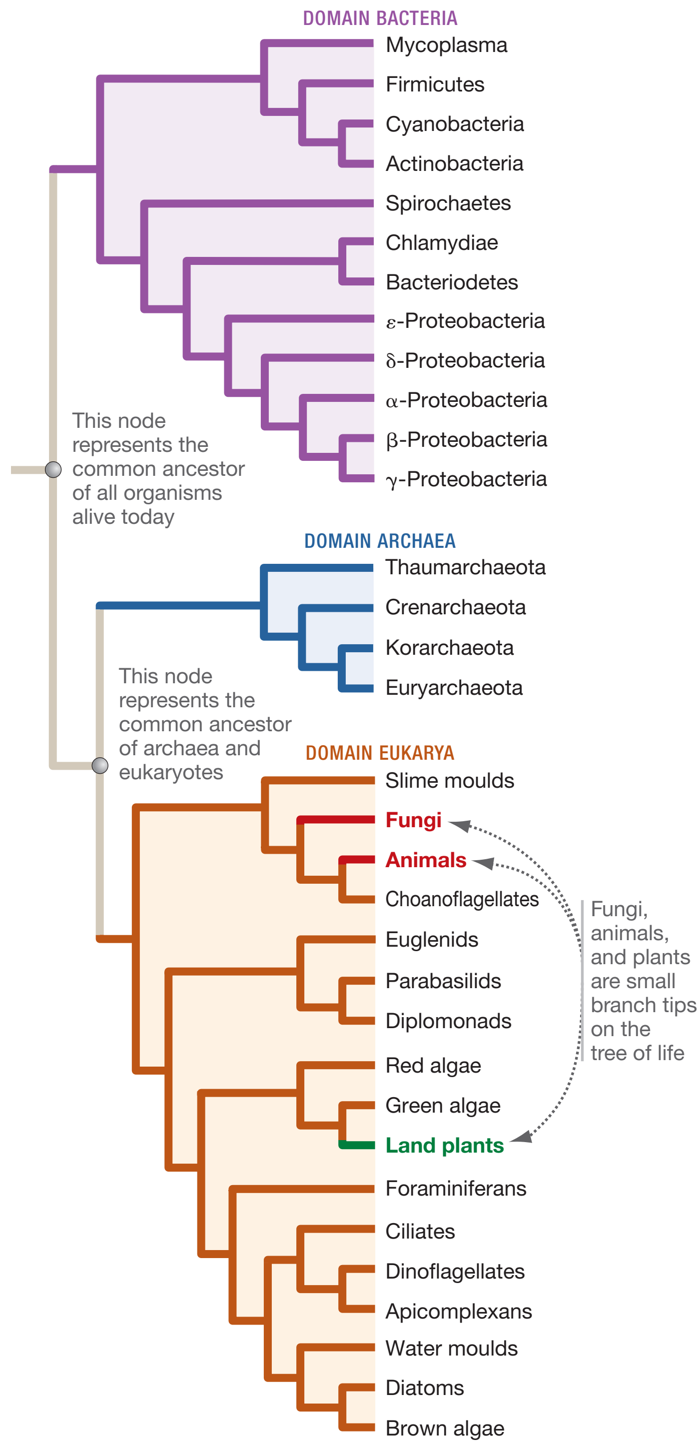


Figure 1.7 The Tree of Life Was Produced by Comparing Genetic Sequence Data. The three domains of life revealed by the analysis are labelled. Common names are given for lineages in the domains Bacteria and Eukarya. Phyla names are given for lineages in the domain Archaea, because most of them have no common names.

use sophisticated computer programs to find the arrangement of branches that is most consistent with the similarities and differences observed in the genetic data.

Because this tree includes such a diverse array of species, it is often called the universal tree, or the tree of life. Notice that the tree's main node is the common ancestor (ancestral population) of all living organisms. Researchers who study the origin of life propose that the tree's root extends even further back to the "*l*ast *u*niversal *c*ommon *a*ncestor" of cells, or **LUCA.**

The tree of life implied by genetic sequence data established that there are three fundamental groups or lineages of organisms: **(1)** the Bacteria, **(2)** the Archaea, and **(3)** the Eukarya. In all **eukaryotes** (literally, "true kernel"), cells have a prominent component called the nucleus (**Figure 1.8a**). Because the vast majority of bacterial and archaeal cells lack a nucleus, they are referred to as **prokaryotes** (literally, "before-kernel"; see **Figure 1.8b**). The vast majority of bacteria and archaea are unicellular ("one-celled"); many eukaryotes are multicellular ("many-celled").

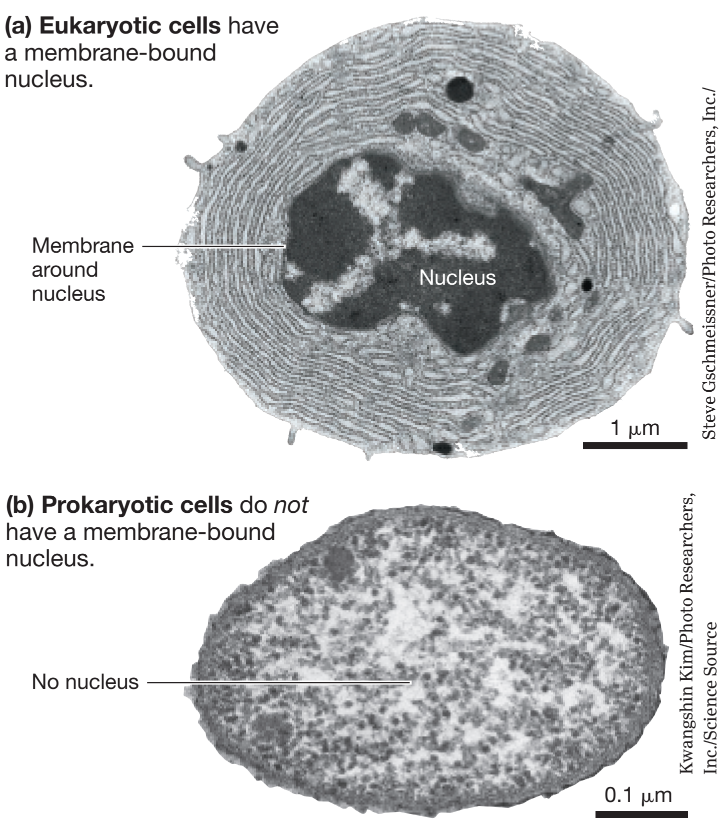


Figure 1.8 Eukaryotic and Prokaryotic Cells Differ in Structure. Dividing living organisms into two categories based on the presence or absence of a nucleus is convenient, but potentially misleading. In the next chapters, you will find that eukaryotic cells are very different from one another in their morphological appearance, while prokaryotic cells differ in their biochemical composition, particularly when comparing bacteria and archaea species.

✔ **QUANTITATIVE** How many times larger is the eukaryotic cell in this figure than the prokaryotic cell? (Hint: Study the scale bars.)

When results based on genetic data were first published, biologists were astonished. For example:

- Prior to Woese's work and follow-up studies, biologists thought that the most fundamental division among organisms was between prokaryotes and eukaryotes. The Archaea were virtually unknown—much less recognized as a major and highly distinctive branch on the tree of life.
- Fungi were thought to be closely related to plants. Instead, they are actually much more closely related to animals.
- Traditional approaches for classifying organisms—including the system of five kingdoms divided into various classes, orders, and families that you may have learned in high school—are inaccurate in many cases, because they do not reflect the actual evolutionary history of the organisms involved.

The Tree of Life Is a Work in Progress Just as researching your family tree can help you understand who you are and where you came from, so the tree of life helps biologists understand the relationships among species and evolutionary history of species. The discovery of the Archaea and the accurate placement of lineages such as the fungi qualify as exciting breakthroughs in our understanding of evolutionary history and life's diversity.

Work on the tree of life continues at a furious pace, however, and the location of certain branches on the tree is hotly debated. W. Ford Doolittle's work on this topic is presented in Canadian Research 26.1. As databases expand and as techniques for analyzing data improve, the shape of the tree of life will undoubtedly change. Our understanding of the tree of life, like our understanding of every other topic in biological science, is dynamic.

How Should We Name Branches on the Tree of Life?

In science, the effort to name and classify organisms is called **taxonomy.** Any named group is called a **taxon** (plural: **taxa**). Currently, biologists are working to create a taxonomy, or naming system, that accurately reflects the phylogeny of organisms. Based on the tree of life, Woese proposed a new taxonomic category called the **domain.** He designated Bacteria, Archaea, and Eukarya as the three domains of life.

Biologists often use the term **phylum** (plural: **phyla**) to refer to major lineages within each domain. Although the designation is somewhat arbitrary, each phylum is considered a major branch on the tree of life. Within the lineage called animals, biologists currently name 30–35 phyla—each of which is distinguished by distinctive aspects of its body structure as well as by distinctive gene sequences. For example, the mollusks (clams, squid, octopuses) constitute a phylum, as do chordates (the vertebrates and their close relatives).

Because the tree of life is so new, though, naming systems are still being worked out. For example, recent genetic data have fuelled an ongoing debate about whether there are only two domains of life: Bacteria as one domain, and the rest of life the other. One thing that hasn't changed for centuries, however, is the naming system for individual species.

Scientific (Latin) Names In 1735, a Swedish botanist named Carolus Linnaeus established a system for naming species that is still in use today. Linnaeus created a two-part name unique to each type of organism.

- ***Genus*** The first part indicates the organism's **genus** (plural: **genera**). A genus is made up of a closely related group of species. For example, Linnaeus put humans in the genus *Homo*. Although humans are the only living species in this genus, at least six extinct species, all of which walked upright and made extensive use of tools, were later also assigned to *Homo*.
- ***Species*** The second term in the two-part name identifies the organism's species. Linnaeus gave humans the species name *sapiens*. A species' name is always preceded by its genus.

An organism's genus and species designation is called its **scientific name** or Latin name. Scientific names are always italicized. Genus names are always capitalized, but species names are not—as in *Homo sapiens*.

Linnaeus maintained that different types of organisms should not be given the same genus and species names. Other species may be assigned to the genus *Homo* (from the Latin for "man"), and members of other genera may be named *sapiens* (from the Latin for "wise" or "knowing"), but only humans are named *Homo sapiens.* Each scientific name is unique.

Scientific Names Are Often Descriptive Scientific names and terms are often based on Latin or Greek word roots that are descriptive. For example, consider the yeast *Saccharomyces cerevisiae. Saccharomyces* is aptly named—the domesticated strains of yeast used in commercial baking and brewing are often fed sugar (Greek root *saccharo*), and yeast is a fungus (Greek root *myces*). The species name of this organism, *cerevisiae*, is Latin for "beer." Loosely translated, then, the scientific name of brewer's yeast means "sugar-fungus for beer."

Scientific names and terms often seem daunting at first glance. So, most biologists find it extremely helpful to memorize some of the common Latin and Greek roots. To aid you in this process, new terms in this text are often accompanied by a translation of their Latin or Greek word roots in parentheses. (A glossary of common root words with translations and examples is also provided in **BioSkills 13**.)

CHECK YOUR UNDERSTANDING

If you understand that ...

- A phylogenetic tree shows the evolutionary relationships between species.
- To infer where species belong on a phylogenetic tree, biologists examine their genetic and other characteristics. Closely related species should have similar characteristics, while less closely related species should be less similar.

✔ You should be able to ...

Examine the following DNA sequences and determine which two species would be closest on a phylogenetic tree:

Species A: A A C T A G C G C G A T
Species B: A A C T A G C G C C A T
Species C: T T C T A G C G G T A T

Answers are available in Appendix A.

1.6 Doing Biology

This chapter has introduced some of the great ideas in biology. The development of the cell theory, the theory of evolution, and the chromosome theory of inheritance provided cornerstones when the science was young. The central dogma explained the flow of information from DNA to physical traits of an organism, and the more recent insights of the tree of life have revolutionized our understanding of life's diversity.

These three unifying ideas are considered great because they explain fundamental aspects of nature, and because they have consistently been shown to be correct. They are considered correct because they have withstood extensive testing.

How do biologists go about testing their ideas? Let's consider two issues currently being addressed by researchers.

How Has Artificial Selection Affected Bighorn Sheep? An Introduction to Hypothesis Testing

In Section 1.3 we discussed how a population can change in response to natural selection. Individuals with the traits best suited to an environment have the most offspring. But what if humans are involved? This leads to **artificial selection**—changes in populations that occur when humans select certain individuals to produce the most offspring.

A familiar example involves dogs. Dogs were originally wolves. Over thousands of years, these animals came to live more and more closely with humans. Most obviously there was artificial selection to decrease the trait of aggression. There was also selection to increase behaviours that would be beneficial to the community, for example a willingness to guard against predators or to herd livestock. This gradual domestication turned a dangerous animal into a useful companion.

European and American researchers discovered in 2016 that dogs had been domesticated from wolves twice. They estimated this happened about 15 000 years ago in Western Eurasia and about 12 500 years ago in Eastern Eurasia. The populations were initially separate but, within a few thousand years, dogs were so plentiful across Eurasia that the two populations met and mixed.

This sort of change in the characteristics of a population over time is evolution. Humans have been practising artificial selection for thousands of years to improve agriculturally important plants and animals. But sometimes our actions have consequences that are neither intentional nor desirable. **Canadian Research 1.1** describes a troubling example of artificial selection on a wild organism—bighorn sheep. Researchers