The LIVING WORLD

9e

George Johnson

McGraw Hill Education

NINTH EDITION

The Living World

George B. Johnson

Washington University
St. Louis, Missouri

Mc Graw Hill Education

THE LIVING WORLD, NINTH EDITION

This book is printed on acid-free paper.

1 2 3 4 5 6 7 8 9 LWI 21 20 19 18 17 16

ISBN 978-1-259-69404-2
MHID 1-259-69404-6

Chief Product Officer, SVP Products & Markets: *G. Scott Virkler*
Vice President, General Manager, Products & Markets: *Marty Lange*
Vice President, Content Design & Delivery: *Betsy Whalen*
Managing Director: *Lynn Breithaupt*
Executive Brand Manager: *Michelle Vogler*
Director, Product Development: *Rose Koos*
Product Developer: *Anne Winch*
Marketing Manager: *Britney Hermsen*
Market Development Manager: *Jenna Paleski*
Director of Digital Content: *Michael G. Koot, PhD*
Digital Product Analyst: *Christine Carlson*
Director, Content Design & Delivery: *Linda Avenarius*
Program Manager: *Angela R. FitzPatrick*
Content Project Managers: *Vicki Krug/Brent dela Cruz*
Buyer: *Jennifer Pickel*
Design: *David W. Hash*
Content Licensing Specialists: *Lori Hancock/Lorraine Buczek*
Cover Image: © *Sue Demetriou/Offset.com* RF
Compositor: *MPS Limited*
Printer: *LSC Communications*

Library of Congress Cataloging-in-Publication Data

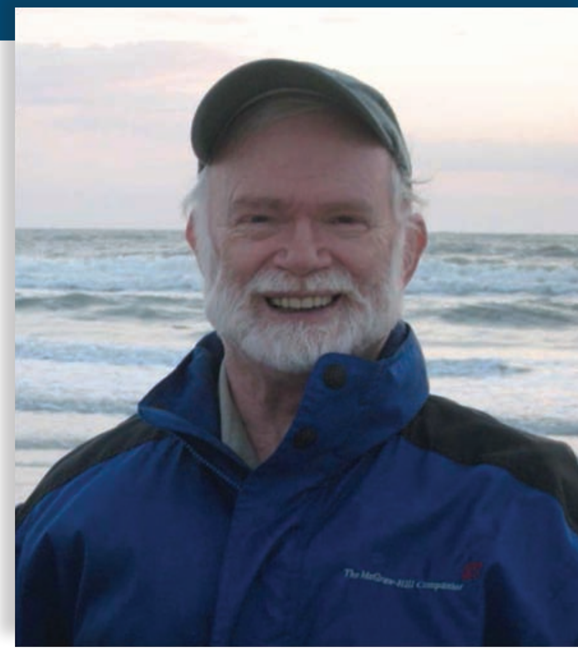
Names: Johnson, George B. (George Brooks), 1942-
Title: The living world / George B. Johnson, Washington University, St. Louis, Missouri.
Description: Ninth edition. | New York, NY : McGraw-Hill Education, [2018] |

Includes index.
Identifiers: LCCN 2016048185 | ISBN 9781259694042 (alk. paper)
Subjects: LCSH: Biology.
Classification: LCC QH308.2 .J62 2018 | DDC 570–dc23 LC record available at https://lccn.loc.gov/2016048185

mheducation.com/highered

Brief Contents

Preface



Courtesy George B. Johnson

Relevancy Is the Window

Biology is one of the most approachable of the sciences, yet many nonscience students look upon their first biology course with anxiety. Science courses are by their nature hard, these students believe, as they grit their teeth signing up for the course. A critical task facing any instructor, and any biology text for nonmajors, is to dispel this fear. Biology is in fact not difficult, and it is full of easy-to-grasp and fun ideas. No one who teaches biology today can fail to appreciate how important a subject it has become for our students. From global warming to stem cell initiatives to teaching "intelligent design" in classrooms, biology permeates the news and in large measure will define our students' futures. What the student needs right off the bat is a window into this world he or she is about to enter. In this ninth revision of *The Living World,* I have set out to address this issue head-on. Relevancy is the window. Every chapter of this revision is focused directly on the relevance of its content to today's students. When the discussion of a topic is linked to a student's own experience, it does not seem so unapproachable, and the utility of learning it is far easier to accept.

This text, *The Living World,* is my attempt to address this problem.

Focusing on the Essential Concepts

More than most subjects, biology is at its core a set of ideas, and if students can master these basic ideas, the rest comes easy. Unfortunately, while most of today's students are very interested in biology, the many terms get in the way, standing as a wall between students and science. With this text, I have tried to turn those walls into windows, removing those barriers so that readers can peer in and join the fun. Analogies have been my tool. In writing *The Living World,* I have searched for simple analogies that relate the matter at hand to things we all know. As science, analogies are not exact, but I do not count myself compromised. Analogies trade precision for clarity. If I do my job right, the key idea is not compromised by the analogy I use to explain it but rather revealed.

In addition, I have kept *The Living World* short enough to use in one semester, without a lot of technical details to intimidate wary students. I have tried to write it in an informal, friendly way, to engage as well as to teach. I have at every stage addressed ideas and concepts, rather than detailed information, trying to teach *how* things work and *why* things happen the way they do, rather than merely naming parts or giving definitions.

Key Biological Process Boxes There is no way to avoid the fact that some of the important ideas of biology are complex. No student encountering photosynthesis for the first time gets it all on the first pass. To aid in learning the more difficult material, I have given special attention to key concepts and processes such as photosynthesis and osmosis that form the core of biology. The essential processes of biology are not optional learning. A student must come to understand every one of them if he or she is to master biology as a science. With this goal in mind, I have prepared some four dozen "this is how it works" Key Biological Process boxes that walk the student through a complex process, one step at a time, so that the central idea is not lost in the details.

Linking Biology to Everyday Life

One of the principal roles of nonmajors' biology courses is to create educated citizens. In writing *The Living World,* I have endeavored wherever possible to connect what the students are learning to their own everyday lives.

Throughout *The Living World* are full-page features written by me that make connections between a chapter's contents and the everyday world: *Biology and Staying Healthy* discusses health issues that impact each student; *Today's Biology* examines advances that importantly affect society; *A Closer Look* examines interesting points in more detail; and *Author's Corner* takes a more personal view (mine) of how science relates to our personal lives.

Teaching Biology as an Evolutionary Journey

Evolutionary Explanations Evolution not only organizes biology, it explains it. It is not enough to say that a frog is an amphibian, transitional between fish and reptiles. This correctly organizes frogs on the evolutionary spectrum but fails to explain *why* frogs are the way they are, with a tadpole life stage and wet skin. Only when the student is taught that amphibians evolved as highly successful land animals, often as big as ponies and armor plated, can students get the point: of 37 families of amphibians, all but the two that lived in water (frogs and salamanders) were driven extinct with the advent of reptiles. A frog has evolved to *invade* water, not escape it. It is in this way that evolution explains biology, and that is how I have tried to use evolution in this text, to explain.

Confronting Evolution's Critics As evolution continues to be a controversial subject to the general public, I have provided students with an explicit consideration of the objections raised by evolution's critics, focusing in detail on the claims of so-called "intelligent design." I feel strongly that no student's education in biology is complete without a frank discussion of this contentious issue.

Helping Students Learn

Chapter Zero In over 30 years of teaching, I have seen students do well and others do poorly, and one of the best predictors of who would do well has been how well a student is prepared to learn. Entering a large freshman course, does a student know how to take notes? Does a student know how to use these notes effectively with the textbook? Can a student even read a graph? In *The Living World,* I have decided to tackle this problem head on and have added a Chapter 0 at the beginning of the text to help students with these very basic but essential learning tools. Learning to take effective notes during lecture, to recopy these notes promptly, and to key them to the text for efficient review when studying are skills that will improve students' performance not only in this course but throughout their college careers. Learning how to read a graph is a skill that will stand students in good stead throughout their lives.

Learning Objectives and Outcomes Students learn best when they are given a clear idea of what it is they are supposed to learn. With this in mind, *The Living World* begins each chapter with a list of specific learning objectives, keyed to that chapter's numbered segments. A **learning objective** is the intended result of study, a specific statement of what a student should be able to do when he or she successfully learns the material covered in that chapter segment. Learning objectives are typically discrete and quite specific—the small building blocks with which a student constructs understanding.

In this edition, each learning objective is repeated at the point that material appears in the text, again in the review at chapter's end, and again in the list of questions that end the chapter. This "learning path" guides the student through the key elements of each chapter, assessing how well each is mastered.

At the end of each numbered chapter segment, I have also placed one or more Key Learning Outcomes. Said simply, a **learning outcome** is a realized set of learning objectives, a

Biology and *Staying Healthy*

Anabolic Steroids in Sports

Among the most notorious of lipids in recent years has been the class of synthetic hormones known as anabolic steroids. Since the 1950s, some athletes have been taking these chemicals to build muscle and so boost athletic performance. Both because of the intrinsic unfairness of this and because of health risks, the use of anabolic steroids has been banned in sports for decades. Controversy over their use in professional baseball has recently returned anabolic steroids to the nation's front pages.

Anabolic steroids were developed in the 1930s to treat hypogonadism, a condition in which the male testes do not produce sufficient amounts of the hormone testosterone for normal growth and sexual development. Scientists soon discovered that by slightly altering the chemical structure of testosterone, they could produce synthetic versions that facilitated the growth of skeletal muscle in laboratory animals. The word *anabolic* means growing or building. Further tweaking reduced the added impact of these new chemicals on sexual development. More than 100 different anabolic steroids have been developed, most of which have to be injected to be effective. All require a prescription to be used legally in the United States, and all are banned in professional, college, and high school sports.

Another way to increase the body's level of testosterone is to use a chemical that is not itself anabolic but one that the body converts to testosterone. One such chemical is 4-androstenedione, more commonly called "andro." It was first developed in the 1970s by East German scientists to try to enhance their athletes' Olympic performances. Because andro does not have the same side effects as anabolic steroids, it was legally available until 2004. It was used by baseball slugger Mark McGwire, but it is now banned in all sports, and possession of andro is a federal crime.

Anabolic steroids work by signalling muscle cells to make more protein. They bind to special "androgenic receptor" proteins within the cells of muscle tissue. Like jabbing these proteins with a poker, the binding prods the receptors into action, causing them to activate genes on the cell's chromosomes that produce muscle tissue proteins, triggering an increase in protein synthesis. At the same time, the anabolic steroid molecules bind to so-called "cortisol receptor" proteins in the cell, preventing these receptors from doing their job of causing protein breakdown, the muscle cell's way of suppressing inflammation and promoting the use of proteins for fuel during exercise. By increasing protein production and inhibiting the breakdown of proteins in muscle cells after workouts, anabolic steroids significantly increase the mass of an athlete's muscle tissue.

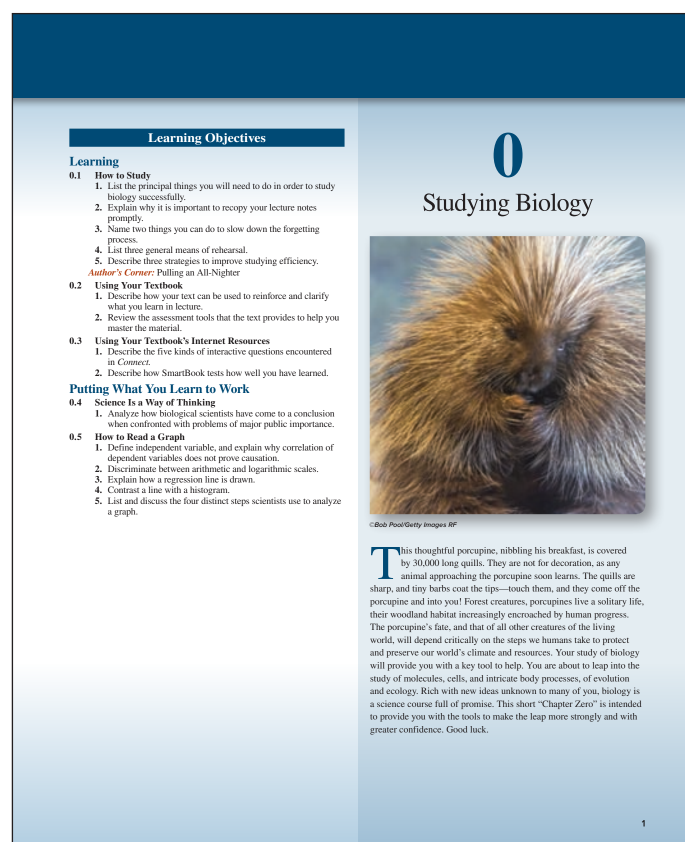
If the only effect of anabolic steroids on your body was to enhance your athletic performance by increasing your muscle mass, using them would still be wrong, for one very simple and important reason: fairness. To gain advantage in competition by concealed use of anabolic steroids—"doping"—is simply cheating. That is why these drugs are banned in sports.

The use of anabolic steroids by athletes and others is not only wrong but also illegal, because increased muscle mass is not the only effect of using these chemicals. Among adolescents, anabolic steroids can also lead to premature termination of the adolescent growth spurt, so that for the rest of their lives, users remain shorter than they would have been without the drugs. Adolescents and adults are also affected by steroids in the following ways. Anabolic steroids can lead to potentially fatal liver cysts and liver cancer (the liver is the organ of the body that attempts to detoxify the blood), cholesterol changes and hypertension (both of which can promote heart attack and stroke), and acne. Other signs of steroid use in men include reduced size of testicles, balding, and development of breasts. In women, signs include the growth of facial hair, lowering of the voice, and cessation of menstruation.

In the fall of 2003, athletic organizations learned that some athletes were using a new performance-enhancing anabolic steroid undetectable by standard antidoping tests, tetrahydrogestrinone (THG). And the practice continues. THG tends to break down when prepared for analysis by standard means, which explains why antidoping tests had failed to detect it. New urine tests for THG that were developed in 2004 have been used to catch several well-known sports figures. Olympic athlete Marion Jones and baseball sluggers Alex Rodriguez, Barry Bonds, and Mark McGwire have all been involved in steroid use. In 2016 all Russian athletes were barred from Track and Field competition in the Olympic Games because of wide-spread steroid use unreported by Russian sports authorities.

Home run slugger Alex Rodriguez was involved in a steroid controversy in 2013.
©Ron Antonelli/NY Daily News Archive via Getty Images

66 UNIT TWO THE LIVING CELL



Learning Objectives

Learning

0.1 How to Study
1. List the principal things you will need to do in order to study biology successfully.
2. Explain why it is important to recopy your lecture notes promptly.
3. Name two things you can do to slow down the forgetting process.
4. List three general means of rehearsal.
5. Describe three strategies to improve studying efficiency.

Author's Corner: Pulling an All-Nighter

0.2 Using Your Textbook
1. Describe how your text can be used to reinforce and clarify what you learn in lecture.
2. Review the assessment tools that the text provides to help you master the material.

0.3 Using Your Textbook's Internet Resources
1. Describe the five kinds of interactive questions encountered in *Connect.*
2. Describe how SmartBook tests how well you have learned.

Putting What You Learn to Work

0.4 Science Is a Way of Thinking
1. Analyze how biological scientists have come to a conclusion when confronted with problems of major public importance.

0.5 How to Read a Graph
1. Define independent variable, and explain why correlation of dependent variables does not prove causation.
2. Discriminate between arithmetic and logarithmic scales.
3. Explain how a regression line is drawn.
4. Contrast a line with a histogram.
5. List and discuss the four distinct steps scientists use to analyze a graph.

0

Studying Biology

©Bob Pool/Getty Images RF

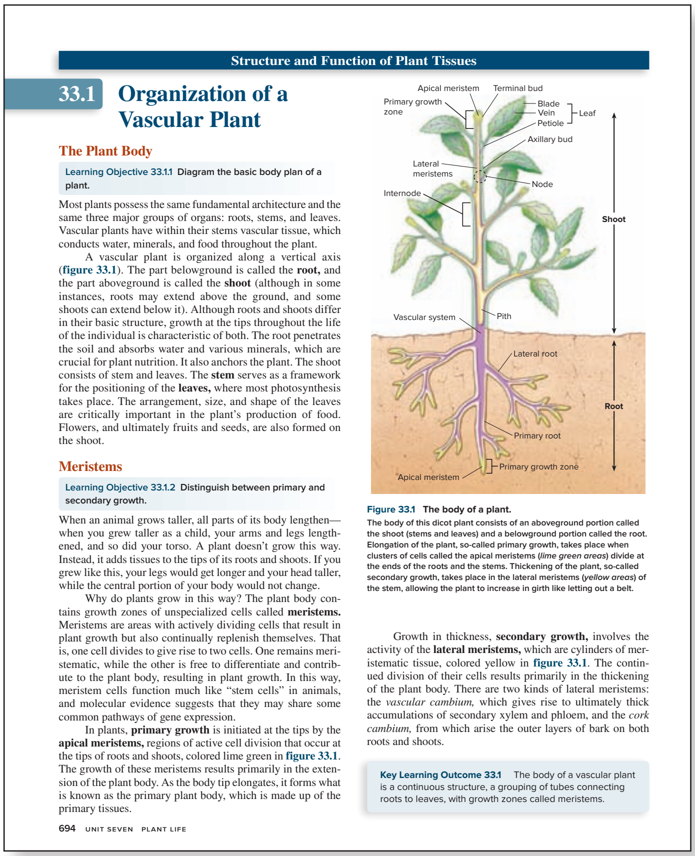
This thoughtful porcupine, nibbling his breakfast, is covered by 30,000 long quills. They are not for decoration, as any animal approaching the porcupine soon learns. The quills are sharp, and tiny barbs coat the tips—touch them, and they come off the porcupine and into you! Forest creatures, porcupines live a solitary life, their woodland habitat increasingly encroached by human progress. The porcupine's fate, and that of all other creatures of the living world, will depend critically on the steps we humans take to protect and preserve our world's climate and resources. Your study of biology will provide you with a key tool to help. You are about to leap into the study of molecules, cells, and intricate body processes, of evolution and ecology. Rich with new ideas unknown to many of you, biology is a science course full of promise. This short "Chapter Zero" is intended to provide you with the tools to make the leap more strongly and with greater confidence. Good luck.

1

concrete statement of what a student should have learned after mastering that chapter segment.

Learning objectives and outcomes together provide a student with a powerful learning tool. Learning objectives help the student focus on the important points as they read a chapter section, and end-of-chapter testing of each specific learning objective provides the student a very pointed indicator of how well he or she has mastered the objectives that were the target of their learning.

The series of questions that appears at the end of every chapter provides a student with a powerful assessment tool to see how well the learning objectives at the beginning of the chapter have been transformed into learning outcomes as a result of the student's study. The list includes questions written at three levels of sophistication, according to Bloom's taxonomy of learning categories: questions that evaluate knowledge and comprehension, questions that challenge the student to carry out application and analysis, and questions that require synthesis and evaluation.


Structure and Function of Plant Tissues

33.1 Organization of a Vascular Plant

The Plant Body

Learning Objective 33.1.1 Diagram the basic body plan of a plant.

Most plants possess the same fundamental architecture and the same three major groups of organs: roots, stems, and leaves. Vascular plants have within their stems vascular tissue, which conducts water, minerals, and food throughout the plant.

A vascular plant is organized along a vertical axis (figure 33.1). The part belowground is called the **root,** and the part aboveground is called the **shoot** (although in some instances, roots may extend above the ground, and some shoots can extend below it). Although roots and shoots differ in their basic structure, growth at the tips throughout the life of the individual is characteristic of both. The root penetrates the soil and absorbs water and various minerals, which are crucial for plant nutrition. It also anchors the plant. The shoot consists of stem and leaves. The **stem** serves as a framework for the positioning of the **leaves,** where most photosynthesis takes place. The arrangement, size, and shape of the leaves are critically important in the plant's production of food. Flowers, and ultimately fruits and seeds, are also formed on the shoot.

Meristems

Learning Objective 33.1.2 Distinguish between primary and secondary growth.

When an animal grows taller, all parts of its body lengthen—when you grew taller as a child, your arms and legs lengthened, and so did your torso. A plant doesn't grow this way. Instead, it adds tissues to the tips of its roots and shoots. If you grew like this, your legs would get longer and your head taller, while the central portion of your body would not change.

Why do plants grow in this way? The plant body contains growth zones of unspecialized cells called **meristems.** Meristems are areas with actively dividing cells that result in plant growth but also continually replenish themselves. That is, one cell divides to give rise to two cells. One remains meristematic, while the other is free to differentiate and contribute to the plant body, resulting in plant growth. In this way, meristem cells function much like "stem cells" in animals, and molecular evidence suggests that they may share some common pathways of gene expression.

In plants, **primary growth** is initiated at the tips by the **apical meristems,** regions of active cell division that occur at the tips of roots and shoots, colored lime green in figure 33.1. The growth of these meristems results primarily in the extension of the plant body. As the body tip elongates, it forms what is known as the primary plant body, which is made up of the primary tissues.

Figure 33.1 The body of a plant. The body of this dicot plant consists of an aboveground portion called the shoot (stems and leaves) and a belowground portion called the root. Elongation of the plant, so-called primary growth, takes place when clusters of cells called the apical meristems (*lime green areas*) divide at the ends of the roots and the stems. Thickening of the plant, so-called secondary growth, takes place in the lateral meristems (*yellow areas*) of the stem, allowing the plant to increase in girth like letting out a belt.

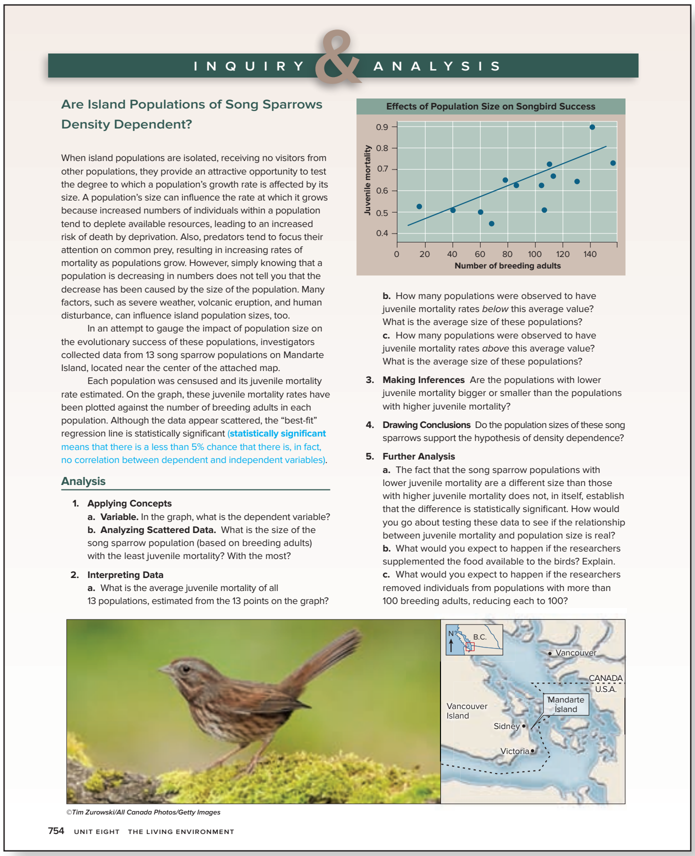
Growth in thickness, **secondary growth,** involves the activity of the **lateral meristems,** which are cylinders of meristematic tissue, colored yellow in figure 33.1. The continued division of their cells results primarily in the thickening of the plant body. There are two kinds of lateral meristems: the *vascular cambium,* which gives rise to ultimately thick accumulations of secondary xylem and phloem, and the *cork cambium,* from which arise the outer layers of bark on both roots and shoots.

Key Learning Outcome 33.1 The body of a vascular plant is a continuous structure, a grouping of tubes connecting roots to leaves, with growth zones called meristems.

694 UNIT SEVEN PLANT LIFE

Teaching Science as a Process

Inquiry and Analysis One of the most useful things a student can take away from his or her biology class is the ability to judge scientific claims that they encounter as citizens, long after college is over. As a way of teaching that important skill, every chapter now ends with an *Inquiry and Analysis* feature, a full-page presentation of an actual scientific investigation that requires the student to analyze the data and reach conclusions. Few pages in this text provide more bang for the buck in learning that lasts.


INQUIRY & ANALYSIS

Are Island Populations of Song Sparrows Density Dependent?

When island populations are isolated, receiving no visitors from other populations, they provide an attractive opportunity to test the degree to which a population's growth rate is affected by its size. A population's size can influence the rate at which it grows because increased numbers of individuals within a population tend to deplete available resources, leading to an increased risk of death by deprivation. Also, predators tend to focus their attention on common prey, resulting in increasing rates of mortality as populations grow. However, simply knowing that a population is decreasing in numbers does not tell you that the decrease has been caused by the size of the population. Many factors, such as severe weather, volcanic eruption, and human disturbance, can influence island population sizes, too.

In an attempt to gauge the impact of population size on the evolutionary success of these populations, investigators collected data from 13 song sparrow populations on Mandarte Island, located near the center of the attached map.

Each population was censused and its juvenile mortality rate estimated. On the graph, these juvenile mortality rates have been plotted against the number of breeding adults in each population. Although the data appear scattered, the "best-fit" regression line is statistically significant (statistically significant means that there is a less than 5% chance that there is, in fact, no correlation between dependent and independent variables).

Analysis

1. **Applying Concepts**
   a. **Variable.** In the graph, what is the dependent variable?
   b. **Analyzing Scattered Data.** What is the size of the song sparrow population (based on breeding adults) with the least juvenile mortality? With the most?
2. **Interpreting Data**
   a. What is the average juvenile mortality of all 13 populations, estimated from the 13 points on the graph?

   b. How many populations were observed to have juvenile mortality rates *below* this average value? What is the average size of these populations?
   c. How many populations were observed to have juvenile mortality rates *above* this average value? What is the average size of these populations?
3. **Making Inferences** Are the populations with lower juvenile mortality bigger or smaller than the populations with higher juvenile mortality?
4. **Drawing Conclusions** Do the population sizes of these song sparrows support the hypothesis of density dependence?
5. **Further Analysis**
   a. The fact that the song sparrow populations with lower juvenile mortality are a different size than those with higher juvenile mortality does not, in itself, establish that the difference is statistically significant. How would you go about testing these data to see if the relationship between juvenile mortality and population size is real?
   b. What would you expect to happen if the researchers supplemented the food available to the birds? Explain.
   c. What would you expect to happen if the researchers removed individuals from populations with more than 100 breeding adults, reducing each to 100?

©Tim Zurowski/All Canada Photos/Getty Images

754 UNIT EIGHT THE LIVING ENVIRONMENT

New to This Edition

Editing Your Genes. The most exciting advance since this text's last edition has been the introduction of a new easy-to-use tool called CRISPR that allows researchers to edit genes, a prospect both promising and a little scary. Like many advances in science, this one happened in stages, as described in Section 13.4 on page 270. The tool is based on a peculiar base sequence found in bacterial DNA that contains two elements. One element (the "I.D." sequence) is a short 30-base sequence identical to one found in a virus. The second element (the "kill" sequence), when transcribed into RNA, will fold back on itself, forming a loop to which a DNA-chopping nuclease binds. Bacteria use this system to combat infecting viruses: the "I.D." sequence binds its RNA transcript to the DNA of an invading virus, allowing the attached "kill" sequence to chop the virus DNA into pieces. What makes this a powerful tool for gene engineers? It is a simple matter to replace the virus "I.D." sequence with a different 30-base sequence that identifies some other gene that the researcher wishes to destroy or modify. Like changing the address on an envelope, the researcher can send the "kill" sequence to any address in the genome!

Can CRISPR Eliminate Malaria or Zika? Researchers in 2016 began to test the possibility of incorporating CRISPR in a so-called "gene drive." As described in Section 13.4

on page 271, the idea is to use CRISPR to replace an "I.D." sequence of an animal with a carefully constructed sequence containing both a new "I.D." and a copy of the CRISPR sequnce. If you were to do this, when the animal that possessed the modified version reproduced, its CRISPR chromosome would be paired in the zygote with the normal chromosome of the other parent—*and would convert it to the CRISPR-containing form!* In a chain reaction, CRISPR would spread through the entire population. If it were a mosquito population, this approach might be able to eliminate malaria or Zika in one stroke!

Geoengineering to Combat Global Warming. Important advances have also been made in attempts to combat global warming. With atmospheric CO_2 levels at a 2 million–year high and attempts to reduce emissions faltering, attempts to engineer the earth's climate offer what may be our best hope of combating global warming. Two so-called geoengineering approaches, described in Section 38.4 on page 809, are being evaluated seriously. One removes CO_2 from the atmosphere by fertilizing earth's oceans to induce massive photosynthesis. Earth's oceans are rich in marine algae, their growth limited primarily by lack of iron (Fe is a key component of chlorophyll). In the lab, every pound of iron added to ocean water could remove as much as 100,000 pounds of carbon from the air! Very controversial small-scale tests indicate that algal blooms are indeed produced by Fe fertilization and that the blooms sink to the ocean bottom, the carbon effectively returned to where it came from. The second geoengineering approach injects sulfate aerosol into the atmosphere to reflect sunlight away. The upper stratosphere is turned into a mirror, reflecting the sun's rays back into space. So even if CO_2 levels continue to rise, the world's climate does not warm because there is less light reaching CO_2 molecules. This approach has never been tested but seems practical.

Ebola Outbreak. In 2014–2015, an outbreak of Ebola virus in three densely populated countries of West Africa infected over 24,000 people, killing half of them. Described in Section 16.10 on page 360, never has an Ebola outbreak affected so many people in so many different places.

The Search for Life on Other Planets. For over 20 years, astronomers have been detecting planets orbiting distant stars. As described in Section 16.2 on page 347, over 10,000 have been identified. Might any of them be enough like Earth to hold life? On July 23, 2016, astronomers announced they have found a candidate planet, orbiting a star 1,400 light-years from Earth. Labeled Kepler 452b, it circles a star very much like our sun, taking only 20 days longer to get around than Earth does. Temperatures on Kepler 452b would be similar to lukewarm water—not unlike the tropics on Earth. Its mass seems to be about five times that of Earth, meaning there is a good chance it is rocky like Earth and not gaseous like Neptune.

The Double Helix Revisited. The history of how Watson and Crick discovered that the DNA molecule is a double helix is wrong in most texts, including past editions of this one. As now correctly described in Section 11.3 on pages 224–25, Rosalind Franklin did not discover how to obtain X-ray diffraction patterns of DNA or that the DNA molecule was a helix. Wilkins made that discovery and published that DNA was a helix a year before Franklin came to his lab as a postdoc to learn his X-ray techniques (his discovery that DNA was a helix was why Wilkins got 50% of the Nobel Prize, as is made clear in the Nobel citation).

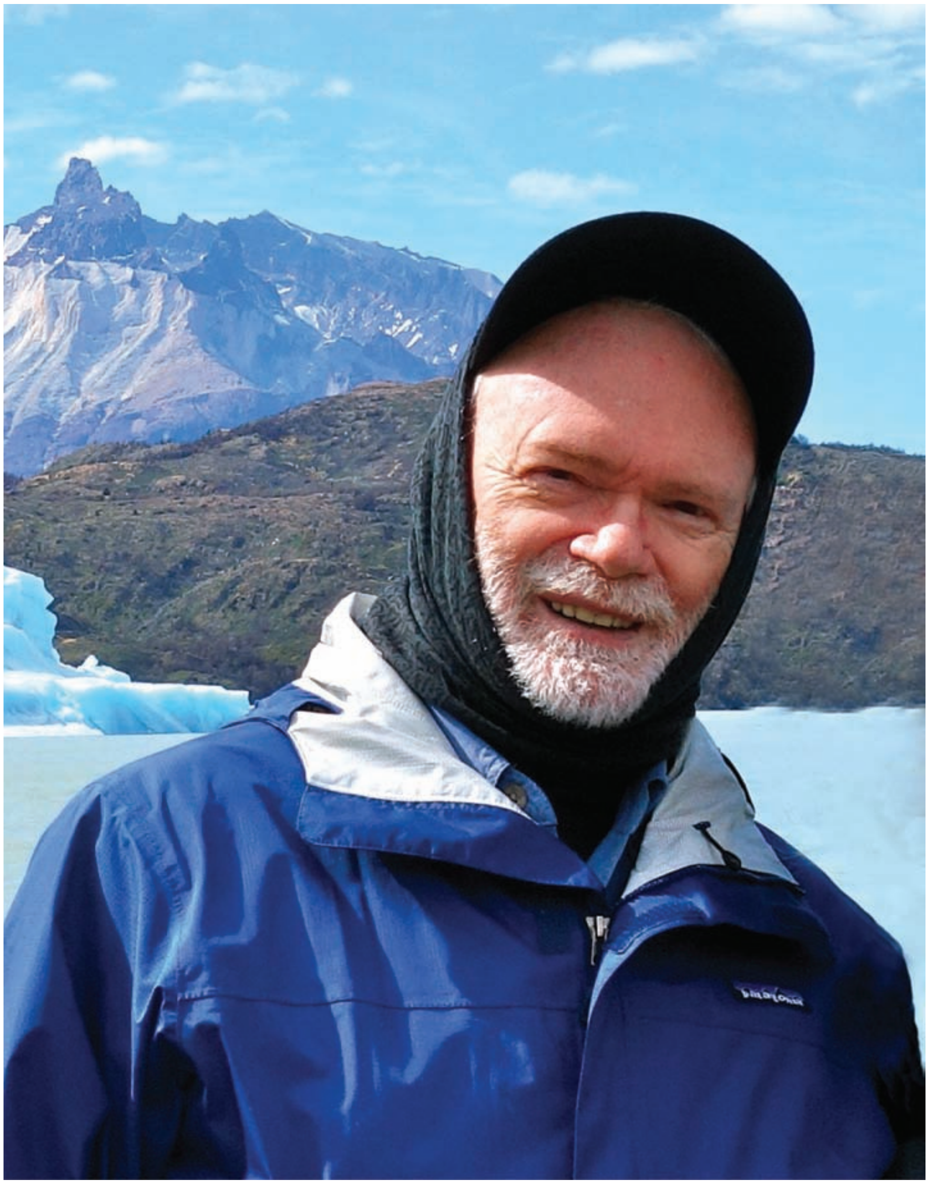
Zika Virus Threatens Pregnant Women. A sudden outbreak of microcephaly (incomplete head and brain development in newborns) in Brazil in 2016 was soon traced to mosquito-transmitted Zika virus. A common tropical virus, Zika (described in Section 16.10 on page 360) seems to have recently evolved into a deadly disease.

Meet the Denisovans. When DNA was recovered from an ancient fingerbone found in Siberia and the entire gemone sequenced, the sequence obtained by researchers was human but unlike either Neanderthal or modern humans—a new species of human. Now called the Denisovans (after the name of the cave where the fingerbone was found), this ancient species of human, described in Section 21.7 on page 478, has in the last few years been shown to have interbred with both Neanderthals and modern humans. As much as 8% of modern human DNA comes from Neanderthals and Denisovans. Your genome is a patchwork of genes of three different species.

Father's Age Impacts Gene Disorders. The last edition reported the sequencing of the entire genomes of a large number of individuals from Iceland. In Iceland, precise records have been kept for many generations of births and marriages, so it is possible to ascertain not only which mutations an individual possesses but also from which parent they were inherited and how old that parent was at the child's conception. As we recount in Section 11.5 on page 232, an unanticipated finding leaps out from the data: the great majority of the new mutations arise in fathers, and the older the father at conception, the greater the likelihood of mutation. Said simply, older fathers are much more likely to have children with gene disorders.

SmartBook® with Learning Resources. This edition of *The Living World* has improvements in pedagogy as well as updates in content. Students using SmartBook will now have the additional benefit of Learning Resources. This powerful educational aid was developed using LearnSmart "user data" to target content areas where students are most likely to struggle. For these content areas, Learning Resources provide videos, images, and brief explanations that summarize text content. Instead of reading the same passage repeatedly in an attempt to understand the material, a student can use these Learning Resources to visit difficult content areas stated another way—much as an instructor paraphrases the text to help explain a difficult concept during office hours. Whether in Reading or Practice mode, the Learning Resources are hidden behind an icon that the student can click on when needed to show the type of content available and the concept it covers. When finished viewing, the student is returned to the same point in SmartBook to continue their study.

About the Author



Courtesy George B. Johnson

Dr. George B. Johnson is a researcher, educator, and author. Born in 1942 in Virginia, he went to college in New Hampshire (Dartmouth), attended graduate school in California (Stanford), and is Professor Emeritus of Biology at Washington University in St. Louis, where he has taught freshman biology and genetics to undergraduates for over 35 years. Also Professor of Genetics at Washington University's School of Medicine, Dr. Johnson is a student of population genetics and evolution, authoring more than 50 scientific journal publications. His laboratory work is renowned for pioneering the study of previously undisclosed genetic variability. His field research has centered on alpine butterflies and flowers, much of it carried out in the Rocky Mountains of Colorado and Wyoming. Other ecosystems he has explored in recent years include Brazilian and Costa Rican rainforest, the Florida Everglades, the seacoast of Maine, coral reefs off Belize, the ice fields and mountains of Patagonia, and, delightfully, vineyards in Tuscany.

A prolific writer and educator, Dr. Johnson is the author of seven nationally recognized college texts for McGraw-Hill, including the hugely successful majors texts *Biology* (with botanist Peter Raven) and three nonmajors' texts: *Understanding Biology, Essentials of The Living World,* and this text, *The Living World*. He has also authored two widely used high school biology textbooks, *Holt Biology* and *Biology: Visualizing Life*. In the 30 years he has been authoring biology texts, over 3 million students have been taught from textbooks Dr. Johnson has written.

Dr. Johnson has been involved in innovative efforts to incorporate interactive learning and Internet experiences into our nation's classrooms. He has served on a National Research Council task force to improve high school biology teaching and as the founding director of The Living World, the education center at the St. Louis Zoo, where he was responsible for developing a broad range of innovative high-tech exhibits and an array of new educational programs.

St. Louis students may be familiar with Dr. Johnson as the author of a weekly science column, "On Science," appearing for many years in the *St. Louis Post-Dispatch*. Dedicated to educating the general public about today's science, Dr. Johnson continues to write columns regularly on current issues where science plays a key role, issues such as AIDS, the environment, cloning, genetic engineering, and evolution. The columns, focused on explaining "how" and "why," are intended to give readers the tools to think about these issues as citizens and voters. You may follow his columns on his blog site Biology-Writer.com and on Twitter @BiologyWriter.

Showing Students How Biology Is Relevant to Them

The author has written full-page boxed readings to help students make connections to the everyday world.

Author's Corner essays take a more personal view of how science relates to our everyday lives.

Author's *Corner*

The Author Works Out

No one seeing the ring of fat decorating my middle would take me for a runner. Only in my memory do I get up with the robins, lace up my running shoes, bounce out the front door, and run the streets around Washington University before going to work. Now my 5-K runs are 30-year-old memories. Any mention I make of my running in a race only evokes screams of laughter from my daughters and an arch look from my wife. Memory is cruelest when it is accurate.

I remember clearly the day I stopped running. It was a cool fall morning in 1978, and I was part of a mob running a 5-K (that's 5 kilometers for the uninitiated) race, winding around the hills near the university. I started to get flashes of pain in my legs below the knees—like shin splints but much worse. Imagine fire pouring on your bones. Did I stop running? No. Like a bonehead, I kept going, "working through the pain," and finished the race. I have never run a race since.

©Corbis RF

I had pulled a muscle in my thigh, which caused part of the pain. But that wasn't all. The pain in my lower legs wasn't shin splints and didn't go away. A trip to the doctor revealed multiple stress fractures in both legs. The X rays of my legs looked like tiny threads had been wrapped around the shaft of each bone, like the red stripe on a barber's pole. It was summer before I could walk without pain.

What went wrong? Isn't running supposed to be GOOD for you? Not if you run improperly. In my enthusiasm to be healthy, I ignored some simple rules and paid the price. The biology lesson I ignored had to do with how bones grow. The long bones of your legs are not made of stone, solid and permanent. They are dynamic structures, constantly being

it acts to spread any stress over many crystals, making bone resistant to fracture. As a result, bone is both strong and flexible.

When you subject a bone in your body to stress—say, by running—the bone grows so as to withstand the greater workload. How does the bone "know" just where to add more material? When stress deforms the collagen fibers of a leg bone, the interior of the collagen fibers becomes exposed, like opening your jacket and exposing your shirt. The fiber interior produces a minute electrical charge. Cells called fibroblasts are attracted to the electricity like bugs to night lights and secrete more collagen there. As a result, new collagen fibers are laid down on a bone along the lines of stress. Slowly, over months, calcium phosphate crystals convert the new collagen to new bone. In your legs, the new bone forms along the long stress lines that curve down along the shank of the bone.

Now go back 30 years and visualize me pounding happily down the concrete pavement each morning. I had only recently begun to run on the sidewalk and for an hour or more at a stretch. Every stride I took those mornings was a blow to my shinbones, a stress to which my bones no doubt began to respond by forming collagen along the spiral lines of stress. Had I run on a softer surface, the daily stress would have been far less severe. Had I gradually increased my running, new bone would have had time to form properly in response to the added stress. I gave my leg bones a lot of stress and no time to respond to it. I pushed them too hard, too fast, and they gave way.

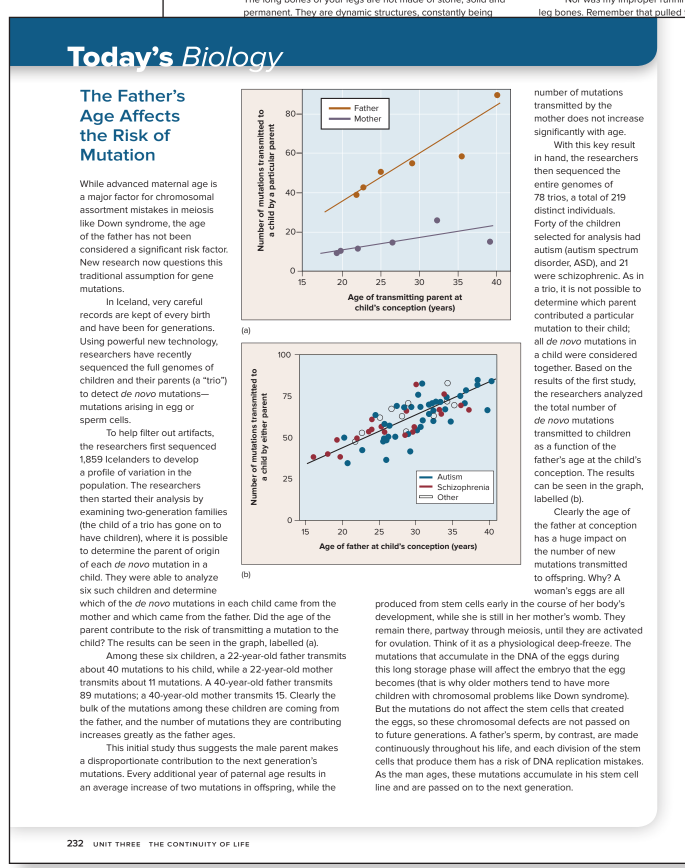
Nor was my improper running limited to overstressed leg bones. Remember that pulled thigh muscle? In my

ed up before I ran. I was
such details. Wiser now,
s a direct result of failing

uscle recently, listening
how she sets out early
stretching or warming
undled up warmly on the
elle pounding down the
Unless she uses more
t.

ODY AND HOW IT MOVES 503

Today's Biology closely examines important advances in science and medicine.



Today's *Biology*

The Father's Age Affects the Risk of Mutation

While advanced maternal age is a major factor for chromosomal assortment mistakes in meiosis like Down syndrome, the age of the father has not been considered a significant risk factor. New research now questions this traditional assumption for gene mutations.

In Iceland, very careful records are kept of every birth and have been for generations. Using powerful new technology, researchers have recently sequenced the full genomes of children and their parents (a "trio") to detect *de novo* mutations—mutations arising in egg or sperm cells.

To help filter out artifacts, the researchers first sequenced 1,859 Icelanders to develop a profile of variation in the population. The researchers then started their analysis by examining two-generation families (the child of a trio has gone on to have children), where it is possible to determine the parent of origin of each *de novo* mutation in a child. They were able to analyze six such children and determine which of the *de novo* mutations in each child came from the mother and which came from the father. Did the age of the parent contribute to the risk of transmitting a mutation to the child? The results can be seen in the graph, labelled (a).

Among these six children, a 22-year-old father transmits about 40 mutations to his child, while a 22-year-old mother transmits about 11 mutations. A 40-year-old father transmits 89 mutations; a 40-year-old mother transmits 15. Clearly the bulk of the mutations among these children are coming from the father, and the number of mutations they are contributing increases greatly as the father ages.

This initial study thus suggests the male parent makes a disproportionate contribution to the next generation's mutations. Every additional year of paternal age results in an average increase of two mutations in offspring, while the

(a)

(b)

number of mutations transmitted by the mother does not increase significantly with age.

With this key result in hand, the researchers then sequenced the entire genomes of 78 trios, a total of 219 distinct individuals. Forty of the children selected for analysis had autism (autism spectrum disorder, ASD), and 21 were schizophrenic. As in a trio, it is not possible to determine which parent contributed a particular mutation to their child; all *de novo* mutations in a child were considered together. Based on the results of the first study, the researchers analyzed the total number of *de novo* mutations transmitted to children as a function of the father's age at the child's conception. The results can be seen in the graph, labelled (b).

Clearly the age of the father at conception has a huge impact on the number of new mutations transmitted to offspring. Why? A woman's eggs are all produced from stem cells early in the course of her body's development, while she is still in her mother's womb. They remain there, partway through meiosis, until they are activated for ovulation. Think of it as a physiological deep-freeze. The mutations that accumulate in the DNA of the eggs during this long storage phase will affect the embryo that the egg becomes (that is why older mothers tend to have more children with chromosomal problems like Down syndrome). But the mutations do not affect the stem cells that created the eggs, so these chromosomal defects are not passed on to future generations. A father's sperm, by contrast, are made continuously throughout his life, and each division of the stem cells that produce them has a risk of DNA replication mistakes. As the man ages, these mutations accumulate in his stem cell line and are passed on to the next generation.

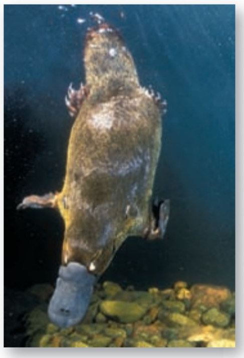
232 UNIT THREE THE CONTINUITY OF LIFE

Showing Students How Biology Is Relevant to Them

In **A Closer Look,** the author provides a more detailed examination of an interesting point from the chapter.

A Closer Look

How the Platypus Sees with Its Eyes Shut


©Dave Watts/Alamy

The duck-billed platypus (*Ornithorhynchus anatinus*) is abundant in freshwater streams of eastern Australia. These mammals have a unique mixture of traits—in 1799, British scientists were convinced that the platypus skin they received from Australia was a hoax. The platypus is covered in soft fur and has mammary glands, but in other ways it seems very reptilian. Females lay eggs as reptiles do, and like reptilian eggs, the yolk of the fertilized egg does not divide. In addition, the platypus has a tail not unlike that of a beaver, a bill not unlike that of a duck, and webbed feet!

It turns out that platypuses also have some very unique behaviors. Until recently, few scientists had studied the platypus in its natural habitat—it is elusive, spending its days in burrows it constructs on the banks of waterways. Also, a platypus is active mostly at night, diving in streams and lagoons to capture bottom-dwelling invertebrates such as shrimps and insect larvae. Interestingly, unlike whales and other marine mammals, a platypus cannot stay under water long. Its dives typically last a minute and a half. (Try holding your breath that long!)

When scientists began to study the platypus' diving behavior, they soon observed a curious fact: The eyes and ears of a platypus are located within a muscular groove, and when a platypus dives, the sides of these grooves close over tightly. Imagine pulling your eyebrows down to your cheeks: effectively blindfolded, you wouldn't be able to see a thing! To complete its isolation, the nostrils at the end of the snout also close. So how in the world does the animal find its prey?

For over a century biologists have known that the soft surface of the platypus bill is pierced by hundreds of tiny openings. In recent years Australian neuroscientists (scientists that study the brain and nervous system) have learned that these pores contain sensitive nerve endings. Nestled in an interior cavity, the nerves are protected from damage by the bill but are linked to the outside streamwater via the pore. The nerve endings act as sensory receptors, communicating to the brain information about the animal's surroundings. These pores in the platypus bill are its diving "eyes."

Platypuses have two types of sensory cells in these pores. Clustered in the front are so-called mechanoreceptors, which act like tiny pushrods. Anything pushing against them triggers a signal. Your ears work the same way, sound waves pushing against tiny mechanoreceptors within your ears. These pushrods evoke a response over a much larger area of the platypus brain than does stimulation from the eyes and ears—for the diving platypus, the bill is the primary sense organ. What responses do the pushrod receptors evoke? Touching the bill with a fine glass probe reveals the answer—a lightning-fast, snapping movement of its jaws. When the platypus contacts its prey, the pushrod receptors are stimulated, and the jaws rapidly snap and seize the prey.

But how does the platypus locate its prey at a distance, in murky water with its eyes shut? That is where the other sort of sensory receptor comes in. When a platypus feeds, it swims along steadily wagging its bill from side to side, two or three sweeps per second, until it detects and homes in on prey. How does the platypus detect the prey individual and orient itself to it? The platypus does not emit sounds like a bat, which rules out the possibility of sonar as an explanation. Instead, electroreceptors in its bill sense the tiny electrical currents generated by the muscle movements of its prey as the shrimp or insect larva moves to evade the approaching platypus!

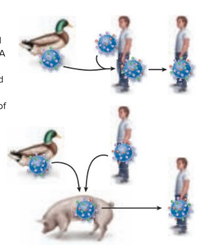
It is easy to demonstrate this, once you know what is going on. Just drop a small 1.5-volt battery into the stream. A platypus will immediately orient to it and attack it, from as far away as 30 centimeters. Some sharks and fishes have the same sort of sensory system. In muddy murky waters, sensing the muscle movements of a prey individual is far superior to trying to see its body or hear it move—which is why the platypus that you see in the photo above is hunting with its eyes shut.

CHAPTER 29 THE SENSES 629

Biology and Staying Healthy essays focus on issues affecting health.

Biology and Staying Healthy

Bird and Swine Flu



Recombination within humans
A person infected with a flu virus can become infected with another type of flu virus by direct contact with birds. The two viruses can undergo genetic recombination to produce a third type of virus, which can spread from human to human.

Recombination within pigs
Pigs can contract flu viruses from both birds and humans. The flu viruses can undergo genetic recombination in the pig to produce a new kind of flu virus, which can spread from pigs to humans.

The influenza virus has been one of the most lethal viruses in human history. Flu viruses are animal RNA viruses containing 11 genes. An individual flu virus resembles a sphere studded with spikes composed of two kinds of protein. Different strains of flu virus, called subtypes, differ in their protein spikes. One of these proteins, hemagglutinin (H), aids the virus in gaining access to the cell interior. The other, neuraminidase (N), helps the daughter virus break free of the host cell once virus replication has been completed. Flu viruses are currently classified into 13 distinct H subtypes and 9 distinct N subtypes, each of which requires a different vaccine to protect against infection. Thus, the virus that caused the Hong Kong flu epidemic of 1968 has type 3 H molecules and type 2 N molecules, and is called H3N2.

How New Flu Strains Arise

Worldwide epidemics of the flu in the last century have been caused by shifts in flu virus H-N combinations. The "killer flu" of 1918, H1N1, thought to have passed directly from birds to humans, killed between 40 and 100 million people worldwide. The Asian flu of 1957, H2N2, killed over 100,000 Americans, and the Hong Kong flu of 1968, H3N2, killed 70,000 Americans.

It is no accident that new strains of flu usually originate in the Far East. The most common hosts of influenza virus are ducks, chickens, and pigs, which in Asia often live in close proximity to each other and to humans. Pigs are subject to infection by both bird and human strains of the virus, and individual animals are often simultaneously infected with multiple strains. This creates conditions favoring genetic recombination between strains, as illustrated above, sometimes putting together novel combinations of H and N spikes unrecognizable by human immune defenses specific for the old configuration. The Hong Kong flu, for example, arose from recombination between H3N8 from ducks and H2N2 from humans. The new strain of influenza, in this case H3N2, then passed back to humans, creating an epidemic because the human population had never experienced that H-N combination before.

Conditions for a Pandemic

Not every new strain of influenza creates a worldwide flu epidemic. Three conditions are necessary: (1) The new strain must contain a novel combination of H and N spikes, so that the human population has no significant immunity from infection; (2) the new strain must be able to replicate in humans and cause death—many bird influenza viruses are harmless to people because they cannot multiply in human cells; (3) the new strain must be efficiently transmitted between humans. The H1N1 killer flu of 1918 spread in water droplets exhaled from infected individuals and subsequently inhaled into the lower respiratory tract of nearby people.

The new strain need not be deadly to every infected person in order to produce a pandemic—the H1N1 flu of 1918 had an overall mortality rate of only 2% and yet killed 40 million to 100 million people. Why did so many die? Because so much of the world's population was infected.

Bird Flu

A potentially deadly new strain of flu virus emerged in Hong Kong in 1997, H5N1. Like the 1918 pandemic strain, H5N1 passes to humans directly from infected birds, usually chickens or ducks, and for this reason has been dubbed "bird flu." Bird flu satisfies the first two conditions of a pandemic: H5N1 is a novel combination of H and N spikes for which humans have little immunity, and the resulting strain is particularly deadly, with a mortality of 59% (much higher than the 2% mortality of the 1918 H1N1 strain). Fortunately, the third condition for a pandemic is not yet met: The H5N1 strain of flu virus does not spread easily from person to person, and the number of human infections remains small.

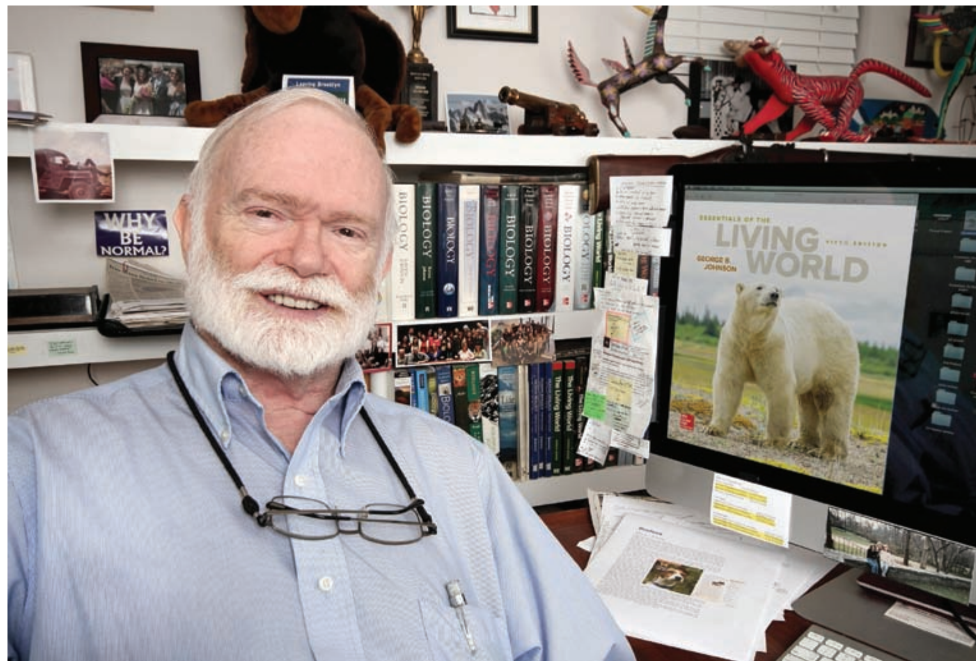
Swine Flu

A second potentially pandemic form of flu virus, H1N1, emerged in Mexico in 2009, passing to humans from infected pigs. It seems to have arisen by multiple genetic recombination events between humans, birds, and pigs. Like the 1918 H1N1 virus, this flu (dubbed "swine flu") passes easily from person to person, and within a year, it spread around the world. Also like the 1918 virus, swine flu infection triggers only mild symptoms in most people. A third dangerous strain, H7N9, emerged in China in 2013. Like H5N1, it is deadly but does not pass readily between people. Public health officials continue to watch these new flu strains carefully, for fear that a subsequent wave of infection may become more lethal.

CHAPTER 16 PROKARYOTES: THE FIRST SINGLE-CELLED CREATURES 357

Acknowledgements

Every author knows that he or she labors on the shoulders of many others; the text you see is the result of hard work by an army of "behind-the-scenes" editors, spelling and grammar checkers, photo researchers, and artists that perform their magic on our manuscript; and an even larger army of production managers and staff who then transform this manuscript into a bound book. I cannot thank them all enough.



Courtesy George B. Johnson

Executive Brand Manager Michelle Volger and Developmental Editor Anne Winch were my editorial team, with whom I worked every day. They provided valuable advice and support to a sometimes querulous and always anxious author. Managing Director Lynn Breithaupt has recently taken over all of McGraw-Hill's biology titles—no small job—and has aggressively backed my sometimes-clumsy attempts to improve this text, overseeing all the problems an overeager author inadvertently creates with humor and consistent support.

Program Manager Angie Fitzpatrick and Content Project Manager Vicki Krug spearheaded our production team, which worked miracles with the new Habitat publishing program that wove chapters together in new ways. The photo program was carried out by Content Licensing Specialists Lori Hancock and Photo Research Specialist Emily Tietz, who as always did a super job (just look at the cover image!). David Hash did a great job with the design and was unbelievably tolerant of the author's many "creative" changes. The book was produced by MPS Limited

My long-time, off-site developmental editor and right arm Megan Berdelman has over many years made a significant contribution to the quality of this book. For the first eight editions, she was one of two off-site editors I used to help me with the complex task of writing and revising *The Living World*. The other, Liz Sievers, was Megan's twin in importance to the book and in the sheer pleasure of working with her. Liz and Megan have gone on to work for *The Living World*'s publisher rather than its author, Liz in Dubuque and Megan in Oregon. I miss them a lot.

The marketing of *The Living World, 9e* has been planned and supervised by Marketing Development Manager Jenna Paleski, quick to address problems and eager to help the many able sales reps that present my books to instructors. It has been a lot of fun working with her—she even took the trouble to come to my "den" in Saint Louis for a few days to let me explain to her in detail how I developed the book, so that she could better present it to interested instructors. Marketing Manager Britney Ross is new to the team but has proved to be a quick study whose experience and enthusiasm have contributed to the success of this book. No author could wish for a better, more fiercely competitive marketing team.

No text goes through nine editions without the strong support of its editors, past and present. I would like to extend my special thanks to Pat Reidy, who got me over many rough bumps in early editions, and particularly to Michael Lange for his early and continued strong support of this project.

George Johnson

Mc Graw Hill Education connect®

Required=Results

©Getty Images/iStockphoto

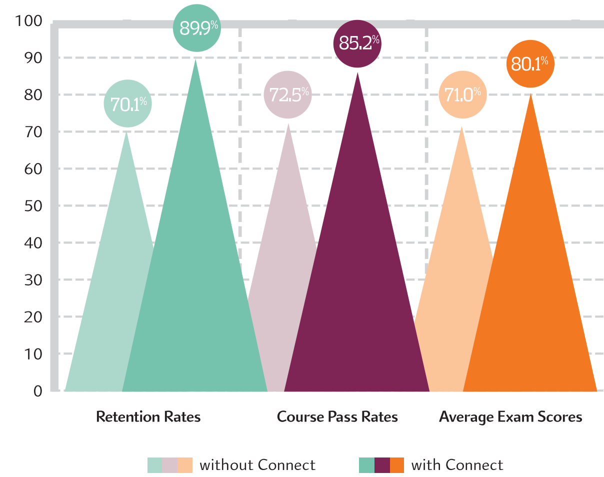
McGraw-Hill Connect® Learn Without Limits

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

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

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

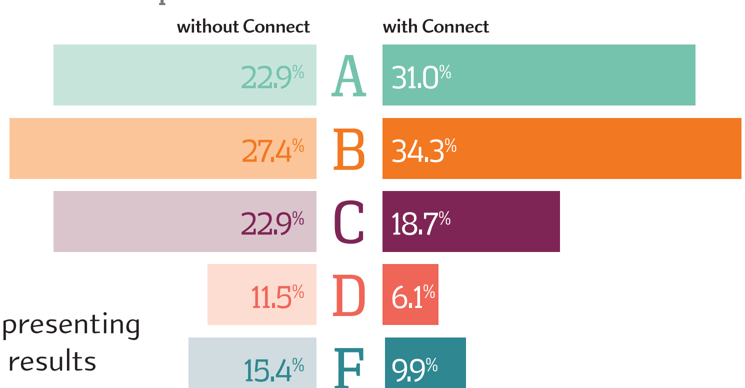
Connect's Impact on Retention Rates, Pass Rates, and Average Exam Scores



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

Analytics

Impact on Final Course Grade Distribution



Connect Insight®

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

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

Mobile

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

Adaptive

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

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

SmartBook®

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

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

www.mheducation.com

Contents

0

Studying Biology

Learning Objectives

Learning

0.1 How to Study

1. List the principal things you will need to do in order to study biology successfully.
2. Explain why it is important to recopy your lecture notes promptly.
3. Name two things you can do to slow down the forgetting process.
4. List three general means of rehearsal.
5. Describe three strategies to improve studying efficiency.

Author's Corner: Pulling an All-Nighter

0.2 Using Your Textbook

1. Describe how your text can be used to reinforce and clarify what you learn in lecture.
2. Review the assessment tools that the text provides to help you master the material.

0.3 Using Your Textbook's Internet Resources

1. Describe the five kinds of interactive questions encountered in *Connect*.
2. Describe how SmartBook tests how well you have learned.

Putting What You Learn to Work

0.4 Science Is a Way of Thinking

1. Analyze how biological scientists have come to a conclusion when confronted with problems of major public importance.

0.5 How to Read a Graph

1. Define independent variable, and explain why correlation of dependent variables does not prove causation.
2. Discriminate between arithmetic and logarithmic scales.
3. Explain how a regression line is drawn.
4. Contrast a line with a histogram.
5. List and discuss the four distinct steps scientists use to analyze a graph.

This thoughtful porcupine, nibbling his breakfast, is covered by 30,000 long quills. They are not for decoration, as any animal approaching the porcupine soon learns. The quills are sharp, and tiny barbs coat the tips—touch them, and they come off the porcupine and into you! Forest creatures, porcupines live a solitary life, their woodland habitat increasingly encroached by human progress. The porcupine's fate, and that of all other creatures of the living world, will depend critically on the steps we humans take to protect and preserve our world's climate and resources. Your study of biology will provide you with a key tool to help. You are about to leap into the study of molecules, cells, and intricate body processes, of evolution and ecology. Rich with new ideas unknown to many of you, biology is a science course full of promise. This short "Chapter Zero" is intended to provide you with the tools to make the leap more strongly and with greater confidence. Good luck.

0.1 How to Study

Learning Objective 0.1.1 List the principal things you will need to do in order to study biology successfully.

Some students will do well in this course, others poorly. One of the best predictors of how well you will do is how well you are prepared to learn. Entering an introductory science course like this one, do you know how to take lecture notes? Do you know how to use these notes effectively with your textbook? Can you read a graph? This edition of *The Living World* tackles this problem head-on by providing you with this "Chapter Zero" at the beginning of the text. It is intended to help you master these very basic but essential learning tools.

Taking Notes

Learning Objective 0.1.2 Explain why it is important to recopy your lecture notes promptly.

Listening to lectures and reading the text are only the first steps in learning enough to do well in a biology course. The key to mastering the mountain of information and concepts you are about to encounter is to take careful notes. Studying from poor-quality notes that are sparse, disorganized, and barely intelligible is not a productive way to approach preparing for an exam.

There are three simple ways to improve the quality of your notes:

1. **Take many notes.** Always attempt to take the most complete notes possible during class. If you miss class, take notes yourself from a tape of the lecture, if at all possible. It is the process of taking notes that promotes learning. Using someone else's notes is a poor substitute. When someone else takes the notes, that person tends to do most of the learning as well.
2. **Take paraphrased notes.** Develop a legible style of abbreviated note taking. Obviously, there are some things that cannot be easily paraphrased (referred to in a simpler way), but using abbreviations and paraphrasing will permit more comprehensive notes. Attempting to write complete organized sentences in note taking is frustrating and too time-consuming—people just talk too fast!
3. **Revise your notes.** As soon as possible after lecture, you should decipher and revise your notes. Nothing else in the learning process is more important, because this is where most of your learning will take place. By revising your notes, you meld the information together and put it into a context that is understandable to you. As you revise your notes, organize the material into major blocks of information with simple "heads" to identify each block. Add ideas from your reading of the text and note links to material in other lectures. Clarify terms and concepts that might be confusing with short notes and definitions. Thinking through the ideas of the lecture in this organized way will crystallize them for you, which is the key step in learning.

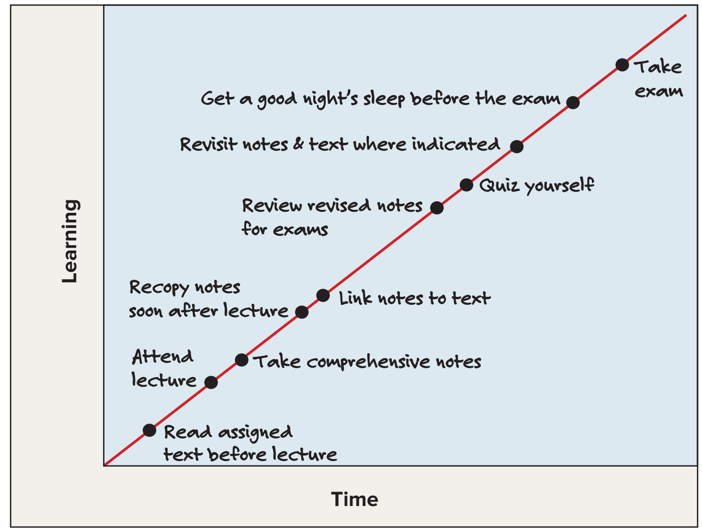


Figure 0.1 A learning timeline.

Remembering and Forgetting

Learning Objective 0.1.3 Name two things you can do to slow down the forgetting process.

Learning is the process of placing information in your memory. Just as in your computer, there are two sorts of memory. The first, *short-term memory,* is analogous to the RAM (random access memory) of a computer, holding information for only a short period of time. Just as in your computer, this memory is constantly being "written over" as new information comes in. The second kind of memory, *long-term memory,* consists of information that you have stored in your memory banks for future retrieval, like storing files on your computer's hard drive. In its simplest context, learning is the process of transferring information to your hard drive.

Forgetting is the loss of information stored in memory. Most of what we forget when taking exams is the natural consequence of short-term memories not being effectively transferred to long-term memory. Forgetting occurs very rapidly, dropping to below 50% retention within one hour after learning and leveling off at about 20% retention after 24 hours.

There are many things you can do to slow down the forgetting process (**figure 0.1**). Here are two important ones:

1. **Recopy your notes as soon as possible after lecture.** Remember, there is about a 50% memory loss in the first hours. Optimally, you should use your textbook as well while recopying your notes.

2. **Establish a purpose for reading.** When you sit down to study your textbook, have a definite goal to learn a particular concept. Each chapter begins with a preview of its key concepts—let them be your guides. Do not try to learn the entire contents of a chapter in one session; break it up into small, "easily digested" pieces.

Learning

Learning Objective 0.1.4 List three general means of rehearsal.

Learning may be viewed as the efficient transfer of information from your short-term memory to your long-term memory. This transfer is referred to as *rehearsal* by learning strategists. As its name implies, rehearsal always involves some form of repetition. There are three general means of rehearsal in the jargon of education called "critical thinking skills" (**figure 0.2**).

Repeating The most obvious form of rehearsal is repetition. To learn facts, the sequence of events in a process, or the names of a group of things, you write them down, say them aloud, and mentally repeat them over and over until you have "memorized" them. This often is a first step on the road to learning. Many students mistake this as the only step. It is not, as it involves only rote memory instead of understanding. If all you do in this course is memorize facts, you will not succeed.

Organizing It is important to organize the information you are attempting to learn because the process of sorting and ordering increases retention. For example, if you place a sequence of events in order, like the stages of mitosis, the entire sequence can be recalled if you can remember what gets the sequence started.

Connecting You will learn biology much more effectively if you relate what you are learning to the world around you. The many challenges of living in today's world are often related to the information presented in this course, and understanding these relationships will help you learn. In each chapter of this textbook, you will encounter full-page Connection essays that allow you to briefly explore a "real-world" topic related to what you are learning. One appears on page 5. Read these essays. You may not be tested on these essays, but reading them will provide you with another "hook" to help you learn the material on which you will be tested.

Studying to Learn

Learning Objective 0.1.5 Describe three strategies to improve studying efficiency.

If I have heard it once, I have heard it a thousand times, "Gee, Professor Johnson, I studied for 20 hours straight and I still got a D." By now, you should be getting the idea that just throwing time at the material does not necessarily ensure a favorable outcome.

Studying, said simply, is putting your learning skills to work. It should come as no surprise to you that how you set about doing this matters. Three simple strategies can make your study sessions more effective:

Figure 0.2 Learning requires work.
Learning is something you do, not something that happens to you.
©Image Source/Getty Images RF

1. **Study at intervals.** The length of time you spend studying and the spacing between study or reading sessions directly affect how much you learn. If you had 10 hours to spend studying, you would be better off if you broke it up into 10 one-hour sessions than spend it all in one or two sessions. There are two reasons for this:

   First, we know from formal cognition research (as well as from our everyday life experiences) that we remember "beginnings" and "endings" but tend to forget "middles." Thus, the learning process can benefit from many "beginnings" and "endings."

   Second, unless you are unusual, after 30 minutes or an hour, your ability to concentrate is diminished. Concentration is a critical component of studying to learn. Many short, topic-focused study sessions maximize your ability to concentrate effectively.
2. **Avoid distractions.** It makes a surprising amount of difference *where* you study. Why? Because effective studying requires concentration. For most of us, effective concentration requires a comfortable, quiet environment with no outside distractions like loud music or conversations.

It is for this reason that studying in front of a loudly playing television or stereo or at a table in a busy cafeteria is a recipe for failure. A quiet room, a desk in the library, outside on a sunny day—all these study locations are quiet, offering few distractions and allowing you to focus your concentration on what you are trying to learn. Keep your mobile phone off; texting while studying is as distracting as it is while driving and as much to be avoided.

3. **Reward yourself.** At the end of every study interval, schedule something fun, if only to get away from studying for a bit. This "carrot and stick" approach tends to make the next study interval more palatable.

Learning Is an Active Process

It is important to realize that learning biology is not something you can do passively. Many students think that simply possessing a lecture video or a set of class notes will get them through. In and of themselves, videos and notes are no more important than the Nautilus machine an athlete works out on. It is not the machine per se but what happens when you use it effectively that is of importance.

Common sense will have a great deal to do with your success in learning biology, as it does in most of life's endeavors. Your success in this biology course will depend on doing some simple, obvious things (**figure 0.3**):

- *Attend class.* Go to all the lectures and be on time.
- *Read the assigned readings before lecture.* If you have done so, you will hear things in lecture that will be familiar to you, a recognition that is a vital form of learning reinforcement. Later, you can go back to the text to check details.
- *Take comprehensive notes.* Recognizing and writing down lecture points is another form of recognition and reinforcement. Later, studying for an exam, you will have already forgotten lecture material you did not record, and so even if you study hard, you will miss exam questions on this material.
- *Revise your notes soon after lecture.* Actively interacting with your class notes while you still hold much of the lecture in short-term memory provides perhaps the most powerful form of reinforcement and will be a key to your success.

The process of revising your lecture notes can and should be a powerful learning tool. For the best results, don't simply transcribe more legibly what you scribbled down so rapidly in class. Instead, focus on how the lecture was organized, and use that framework to organize your revised notes. Most lectures are organized much like each chapter is in this textbook, with three or four main topics, each covered in a series of steps. To revise your class lecture notes most effectively, you should try to *outline* what was said in lecture: First write down the three or four main headings, and then under each heading, place the block of lecture material that addressed that topic.

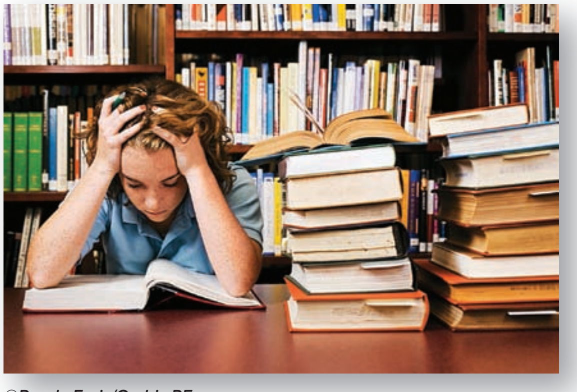
Perhaps more than you have realized, a lecture in a biology course is a network of ideas. Going through your class lecture notes and identifying the main topics is a powerful first step in sorting these ideas out in your mind. The second step, laying out the material devoted to each topic in a logical order (which is, hopefully, the order in which it was presented), will make clearer to you the ideas that link the material together—and this is, in the final analysis, much of what you are trying to learn.

Figure 0.3 Critical learning occurs in the classroom.
Learning occurs in at least four distinct stages: attending class; doing assigned textbook readings before lecture; listening and taking notes during lecture; and recopying notes shortly after lecture. If you are diligent in these steps, then studying lecture notes and text assignments before exams is much more effective. Skipping any of these stages makes successful learning far less likely.
©Corbis RF

As you proceed through this textbook, you will encounter a blizzard of terms and concepts. Biology is a field rich with ideas and the technical jargon needed to describe them. What you discover reading this textbook is intended to support the lectures that provide the core of your biology course. Integrating what you learn here with what you learn in lecture will provide you with the strongest possible tool for successfully mastering the basics of biology. The rest is just hard work.

Key Learning Outcome 0.1 Studying biology successfully is an active process. To do well, you should attend lectures, do assigned readings before lecture, take complete class notes, rewrite those notes soon after class, and study for exams in short, focused sessions.

Pulling an All-Nighter



©Randy Faris/Corbis RF

At some point in the next months, you will face that scary rite, the first exam in this course. As a university professor, I get to give the exams rather than take them, but I can remember with crystal clarity when the shoe was on the other foot. I didn't like exams a bit as a student—what student does? But in my case, I was often practically paralyzed with fear. What scared me about exams was the possibility of unanticipated questions. No matter how much I learned, there was always something I didn't know, some direction from which my teacher could lob a question that I had no chance of answering.

I lived and died by the all-nighter. Black coffee was my closest friend in final exam week, and sleep seemed a luxury I couldn't afford. My parents urged me to sleep more, but I was trying to cram enough in to meet any possible question and couldn't waste time sleeping.

Now I find I did it all wrong. In work published over the last few years, researchers at Harvard Medical School have demonstrated that our memory of newly learned information improves only after sleeping at least six hours. If I wanted to do well on final exams, I could not have chosen a poorer way to prepare. The gods must look after the ignorant, as I usually passed.

Learning is, in its most basic sense, a matter of forming memories. The Harvard researchers' experiments showed that a person trying to learn something does not improve his or her knowledge until after he or she has had more than six hours of sleep (preferably eight). It seems the brain needs time to file new information and skills away in the proper slots so they can be retrieved later. Without enough sleep to do all this filing, new information does not get properly encoded into the brain's memory circuits.

To sort out the role of sleep in learning, the Harvard Medical School researchers used Harvard undergrads as guinea pigs. The undergraduates were trained to look for particular visual targets on a computer screen and to push a button as soon as they were sure they had seen one. At first, responses were relatively sluggish: it typically took 400 milliseconds for a target to reach a student's conscious awareness. With an hour's training, however, many students were hitting the button correctly in 75 milliseconds.

How well had they learned? When they were retested from three to 12 hours later on the same day, there was no further improvement past a student's best time in the training session. If the researchers let a student get a little sleep, but less than six hours, then retested the next day, the student still showed no improvement. For students who slept more than six hours, the story was very different. Sleep greatly improved performance. Students who achieved 75 milliseconds in the training session would reliably perform the target identification in 62 milliseconds after a good night's sleep! After several nights of ample sleep, they often got even more proficient.

Why six or eight hours and not four or five? The sort of sleeping you do at the beginning of a night's sleep and the sort you do at the end are different, and both, it appears, are required for efficient learning.

The first two hours of sleeping are spent in deep sleep, what psychiatrists call slow wave sleep. During this time, certain brain chemicals become used up, which allows information that has been gathered during the day to flow out of the memory center of the brain, the hippocampus, and into the cortex, the outer covering of the brain, where long-term memories are stored. Like moving information in a computer from active memory to the hard drive, this process preserves experience for future reference. Without it, long-term learning cannot occur.

Over the next hours, the cortex sorts through the information it has received, distributing it to various locations and networks. Particular connections between nerve cells become strengthened as memories are preserved, a process that is thought to require the time-consuming manufacture of new proteins.

If you halt this process before it is complete, the day's memories do not get fully "transcribed," and you don't remember all that you would have, had you allowed the process to continue to completion. A few hours are just not enough time to get the job done. Four hours, the Harvard researchers estimate, is a minimum requirement.

The last two hours of a night's uninterrupted sleep are spent in rapid-eye-movement (rem) sleep. This is when dreams occur. The brain shuts down the connection to the hippocampus and runs through the data it has stored over the previous hours. This process is also important to learning, as it reinforces and strengthens the many connections between nerve cells that make up the new memory. Like a child repeating a refrain to memorize it, the brain goes over things until practice makes perfect.

That's why my college system of getting by on three or four hours of sleep during exam week and crashing for 12 hours on weekends didn't work. After a few days, all of the facts I had memorized during one of my "all-nighters" faded away. Of course, they did. I had never given them a chance to integrate properly into my memory circuits.

As I look back, I see now that how well I did on my exams probably had far less to do with how hard I studied than with how much I slept. It doesn't seem fair.

0.2 Using Your Textbook

A Textbook Is a Tool

Learning Objective 0.2.1 **Describe how your text can be used to reinforce and clarify what you learn in lecture.**

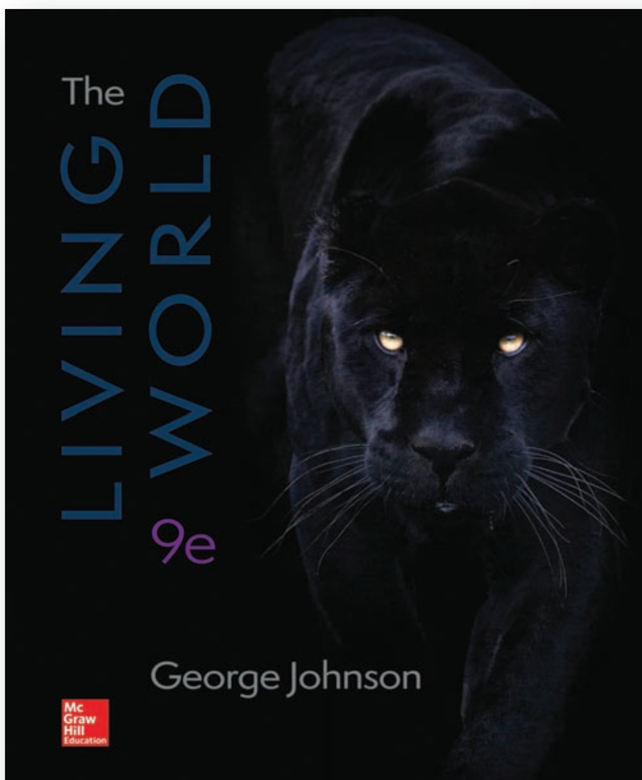
A student enrolled in an introductory biology course as you are almost never learns everything from the textbook. Your text is a tool to explain and amplify what you learn in lecture. No textbook is a substitute for attending lectures, taking notes, and studying them. Success in your biology course is like a stool with three legs: lectures, class notes, and text reading—all three are necessary. Used together, they will take you a long way toward success in the course.

When to Use Your Text While you can glance at your text at any time to refresh your memory, your use of your text should focus on providing support for the other two "legs" of course success: lectures and class notes.

Do the Assigned Reading. Many instructors assign reading from the text, reading that is supposed to be done before lecture. The timing here is very important: If you already have a general idea of what is being discussed in lecture, it is easier to follow the discussion and take better notes.

Link the Text to Your Lecture Notes. Few lectures cover exactly what is in the text, and much of what is in the text may not be covered in lecture. That said, much of what you will hear in lecture *is* covered in your text. This coverage provides you with a powerful tool to reinforce ideas and information you encounter in lecture. Text illustrations and detailed explanations can pound home an idea quickly grasped in lecture and answer any questions that might occur to you as you sort through the logic of an argument. Thus, it is absolutely essential that you follow along with your text as you recopy your lecture notes, keying your notes to the textbook as you go. Annotating your notes in this way will make them better learning tools as you study for exams later.

Review for Exams. It goes without saying that you should review your recopied lecture notes to prepare for an exam. But that is not enough. What is often missed in gearing up for an exam is the need to also review that part of the text that covers the same material. Reading the chapter again, one last time, helps place your lecture notes in perspective, so that it will be easier to remember key points when a topic explodes at you off the page of your exam.



©Sue Demetriou/Offset.com

How to Use Your Text The single most important way to use your text is to read it. As your biology course proceeds and you move through the text, read each assigned chapter all the way through at one sitting. This will give you valuable perspective. Then, guided by your lecture notes, go back through the chapter one topic at a time and focus on learning that one topic as you recopy your notes. As discussed earlier, building a bridge between text and lecture notes is a very powerful way to learn. Remember, your notes don't take the exam, and neither does the textbook; you do, and the learning that occurs as you integrate text pages and lecture notes in your mind will go a long way toward you taking it well.

Learning Tools at Your Disposal

Learning Objective 0.2.2 **Review the assessment tools that the text provides to help you master the material.**

Learning Objectives Every chapter begins by telling you precisely what each section of the chapter is attempting to teach you. Called "Learning Objectives," these items describe what you are intended to know after studying that section. Use them. They are a road map to success in the course.

Quiz Yourself When you have finished studying a chapter of your text, it will be very important for you to be able to assess how good a job you have done. Waiting until a class exam to find out if you have mastered the key points of a chapter is neither necessary nor wise. To give you some handle on how you are doing, questions appear at the end of every chapter linked directly to the learning objectives you have encountered as you studied the chapter.

At the end of each chapter, you will find a "Test Your Understanding" section. Most of the questions on this page are not difficult and are intended as a quick check to see if you have understood the key ideas and identified essential information.

One of the easiest mistakes to make in studying a chapter is to slide over its figures as if they were simply decoration. In fact, they often illustrate key ideas and processes. Many of the end-of-chapter questions will test your understanding of what the figures within the chapter are trying to teach you. While many of the questions are multiple choice, some are not and do not test your memory but rather your understanding. While you will find some questions easier than others, all of them will make you think.

Let the Illustrations Teach You. All introductory biology texts are rich with colorful photographs and diagrams. They are not there to decorate but to aid your comprehension of ideas and concepts. When the text refers you to a specific figure, look at it: the visual link will help you remember the idea much better than restricting yourself to cold words on a page.

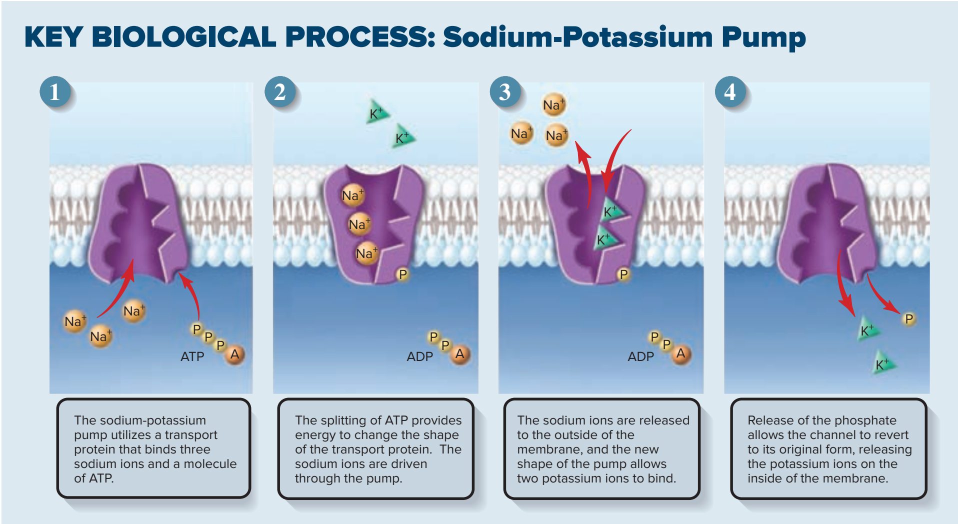
Three sorts of illustrations offer particularly strong reinforcement:

Key Biological Processes. While you will be asked to learn many technical terms in this course, learning the names of things is not your key goal. Your goal is to master a small set of concepts. A few dozen key biological processes explain how organisms work the way they do. When you have understood these processes, much of the heavy lifting in learning biology is done. Every time you encounter one of these key biological processes in the text, you will be provided with an illustration to help you better understand it. These illustrations break the process down into easily understood stages so that you can grasp how the overall process works without being lost in a forest of details (**figure 0.4*a***).

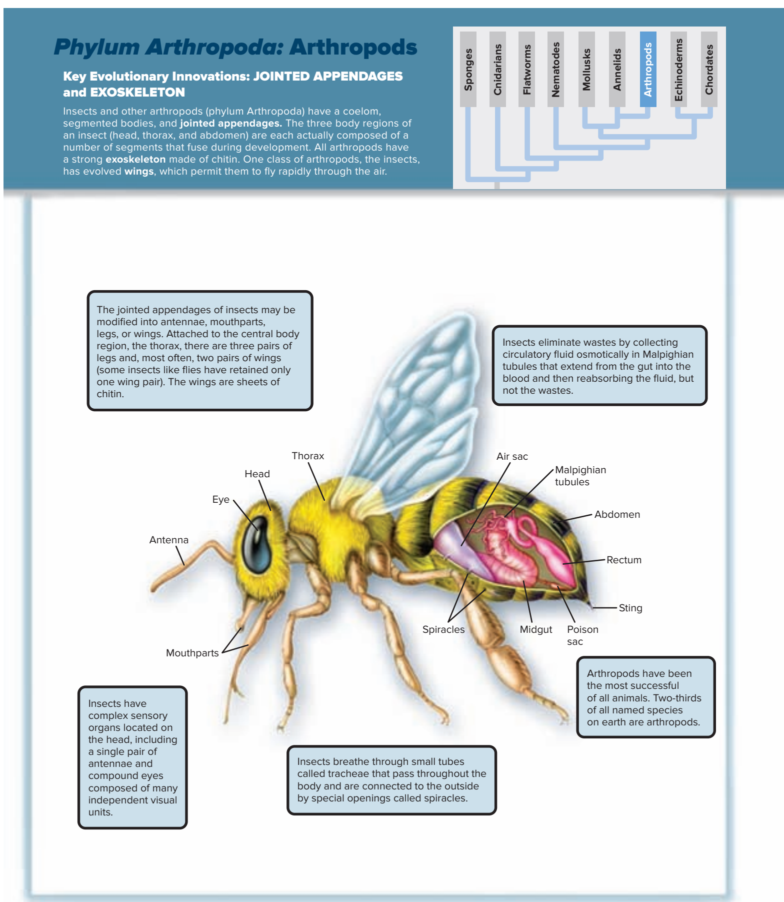
Bubble Links. Illustrations teach best when they are simple. Unfortunately, some of the structures and processes being illustrated just aren't simple. Every time you encounter a complex diagram in the text, it will be "predigested" for you, the individual components of the diagram each identified with a number in a colored circle, or bubble. This same number is also placed in the text narrative right where that component is discussed. These bubble links allow the text to step you through the illustration, explaining what is going on at each stage—the illustration is a feast you devour one bite at a time.

Phylum Facts. Not all of what you will learn are concepts. Sometimes you will need to soak up a lot of information, painting a picture with facts. Nowhere is this more true than when you study animal diversity. In chapter 19, you will encounter a train of animal phyla (a phylum is a major category of organisms) with which you must become familiar. In such a sea of information, what should you learn? Every time you encounter a phylum in chapter 19, you will be provided with a *Phylum Facts* illustration that selects the key bits of information about the body and lifestyle of that kind of animal (**figure 0.4*b***). If you learned and understood only the items highlighted there, you would have mastered much of what you need to know.

Key Learning Outcome 0.2 Your text is a tool to reinforce and clarify what you learn in lecture. Your use of it will only be effective if coordinated with your development of recopied lecture notes.



(a)



(b)

Figure 0.4 Visual learning tools.
(*a*) An example of a Key Biological Process illustration. (*b*) An example of a Phylum Facts illustration.

0.3 Using Your Textbook's Internet Resources

Connect

Learning Objective 0.3.1 Describe the five kinds of interactive questions encountered in *Connect.*

It probably came as no surprise to you that you were instructed in section 0.2 to read your text in order to learn the material on which you will be tested, using its illustrations to fortify your understanding. It thus came as something of a surprise to education researchers when they found that most successful students do exactly the opposite. Watching how college students actually use their textbooks, they repeatedly observed students going first to the illustrations, then to the captions beneath them, and only later to the words of the text, using the text to clarify their understanding of the illustrations! Said simply, successful students are often visual learners.

A visual learner is best tested with visual and interactive questions. If your class is utilizing an instructor-guided learning program called *Connect,* just such an approach is available to you. As a platform for tackling such interactive assessment of how you are doing, *Connect* provides you with a fully interactive *eBook* version of this text, with embedded animations and learning resources. For each class assignment, the instructor then assigns you a series of interactive questions, such as the one you see in **figure 0.5**. *Connect* grades each answer for you. If you have trouble with a question, the program connects that question to the learning objective in the *eBook* where the question is answered.

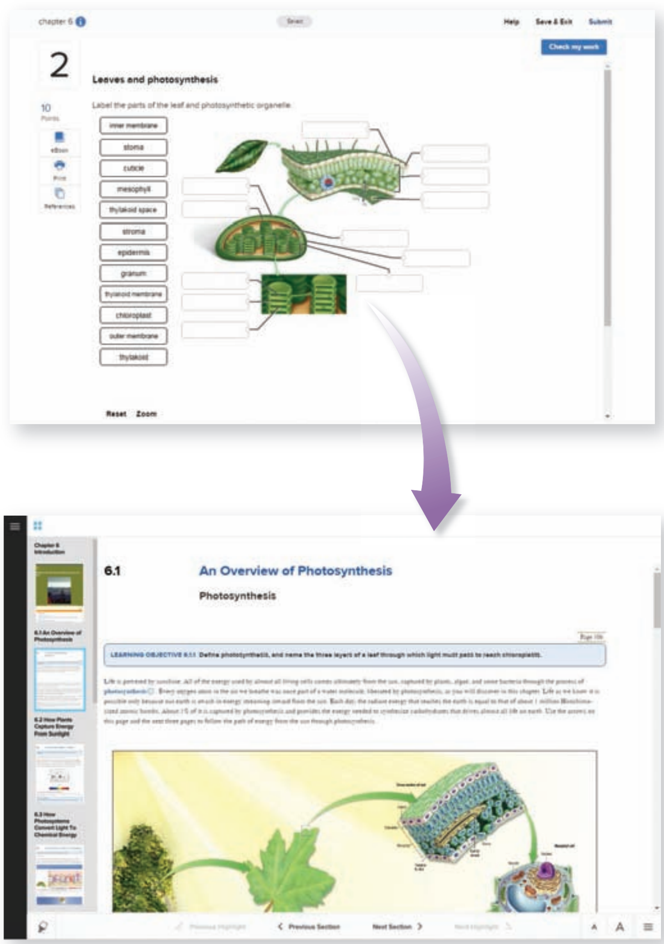


Figure 0.5 Using *Connect.*

Using a text-integrated assessment program called *Connect,* your instructor is able to provide you with a series of interactive questions that test your understanding of key concepts and information. (*a*) In the question about leaves and photosynthesis you see above, for example, your job is to correctly label the parts of a leaf and its chloroplasts. (*b*) By clicking on the "*eBook* and resources" button below the question, you can at any point review the learning objective in the *eBook* where this material is discussed.

How *Connect* Helps You to Learn. *Connect* is not simply a testing machine, used by the instructor to look over your shoulder and spy on how you are studying. Far from it. It is a powerful learning platform that you can use to help understand instructor-assigned material. By the time you have successfully navigated the series of questions assigned by your instructor, you will be well on the way to mastering the assignment. Also, you can search out the answer to any question that stumps you, using visual tools to guide the process.

Connect is no substitute for reading your text and linking it to your lecture notes. Make no mistake about it—your text and lecture notes are the only sure road to success in this course. The great utility of *Connect* is that it provides a way for you to check how you are doing. The visual and interactive questions you access through *Connect* are self-study questions fully integrated with the text. They provide you with a powerful—and fun—way to identify holes in your understanding of an assignment and the means to fill them in. Why wait until an exam to find out what you don't know? Your course grade will be far superior if you find and solve these problems before the exam. And should quizzes and exams be administered to you as unlinked *Connect* questions, it will be like meeting an old friend, a familiar face you have met many times before.

Kinds of *Connect* Questions. *Connect* presents you with five kinds of interactive questions: *Labeling questions,* such as **figure 0.5**, challenge you to drag terms to correctly label an illustration. *Composition questions* ask you to place words into a paragraph to correctly finish a sentence.

Sequence questions have you arrange a series of images or process steps into the proper order. *Classification questions* require you to place a set of terms or characteristics into their appropriate categories. Lastly, *Inquiry and Analysis* questions ask you to select the graph that best portrays the results expected when an experiment is modified in a particular way.

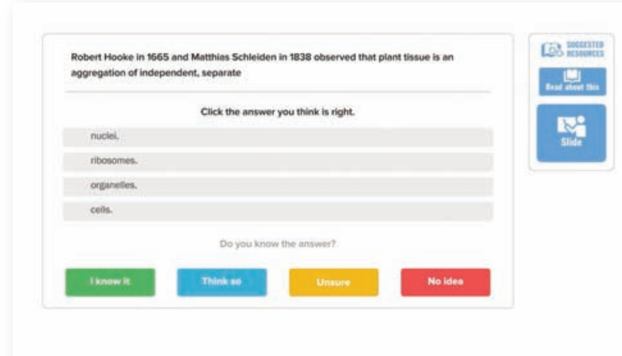
Adaptive Learning

Learning Objective 0.3.2 Describe how SmartBook tests how well you have learned.

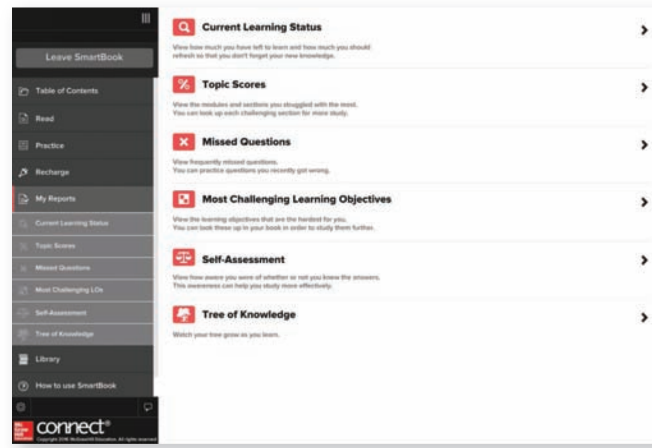
While *Connect* is a powerful learning tool that any student will profit from using, it is instructor-driven, typically with the same set of questions selected by the instructor for the entire class. Not all students come to a biology class, however, with the same level of preparation or remember equally well what they learned in high school. *SmartBook,* delivered through *Connect,* addresses this problem in a direct way, tailoring the learning path to each student individually.

SmartBook creates for you an adaptive and highly personalized reading experience by focusing your attention on the concepts you need to learn at that moment in time. As you begin the assigned chapter in *Read* phase, the most important topics to learn are highlighted yellow. *SmartBook* collects information while you read and puts together questions for you that are then presented in *Practice* phase. A glowing icon in the corner of the screen indicates when it's time to practice what you have learned so far. The questions that follow are directed specifically to you, to help improve performance and knowledge gaps identified by *SmartBook*. Once you have mastered the topics, those chapter highlights turn green, and *SmartBook* will highlight additional topics to read.

If you answer questions incorrectly, you are given the opportunity to return to the reading or to view available learning resources. You are then able to sort out the answer to the question you missed and resume quizzing to see if you mastered the point. At any point as you move along your own individual learning path through a chapter, you can call up a *SmartBook* report like the one you see in **figure 0.6** to see how you are doing. You can even look at the "Tree of Knowledge" to see your current learning status: what portions of the chapter's web of concepts you have mastered and which others still need attention. You and *SmartBook* constitute a one-person biology course, with *SmartBook* devising a learning path contoured to your own needs and speed of learning. As your own private instructor, *SmartBook* can see into what you are learning in surprising ways. Using its "self-assessment" feature, a *SmartBook* report will allow you to view how aware you were of whether or not you knew the answers. This awareness can help you study more effectively by identifying areas of a chapter where you are not doing so.



(a)



(b)

Figure 0.6 Using *SmartBook*.
SmartBook is an adaptive learning program that highlights content you need to learn, then quizzes you with a battery of questions like the one above on plasma membrane components (*a*). SmartBook issues reports like the one you see here that identify what you do not yet understand (*b*) and then continues to probe those areas until you do.

SmartBook can only help you if you use it. As you address the individual learning objectives of a chapter, let *SmartBook* focus your study of each learning objective on those aspects of it you have not yet mastered. Later, when you come back to a chapter to review for a test or exam, let *SmartBook* guide your review, making for you specialized quizzes to sharpen your memory of key points. Use *Recharge* phase to practice content that you are most likely to forget. In this way, you can proceed through the chapter until you have reached 100% mastery.

Key Learning Outcome 0.3 Visual and interactive questions available in *Connect* and *SmartBook's* adaptive reading experience can help you master the chapter content.