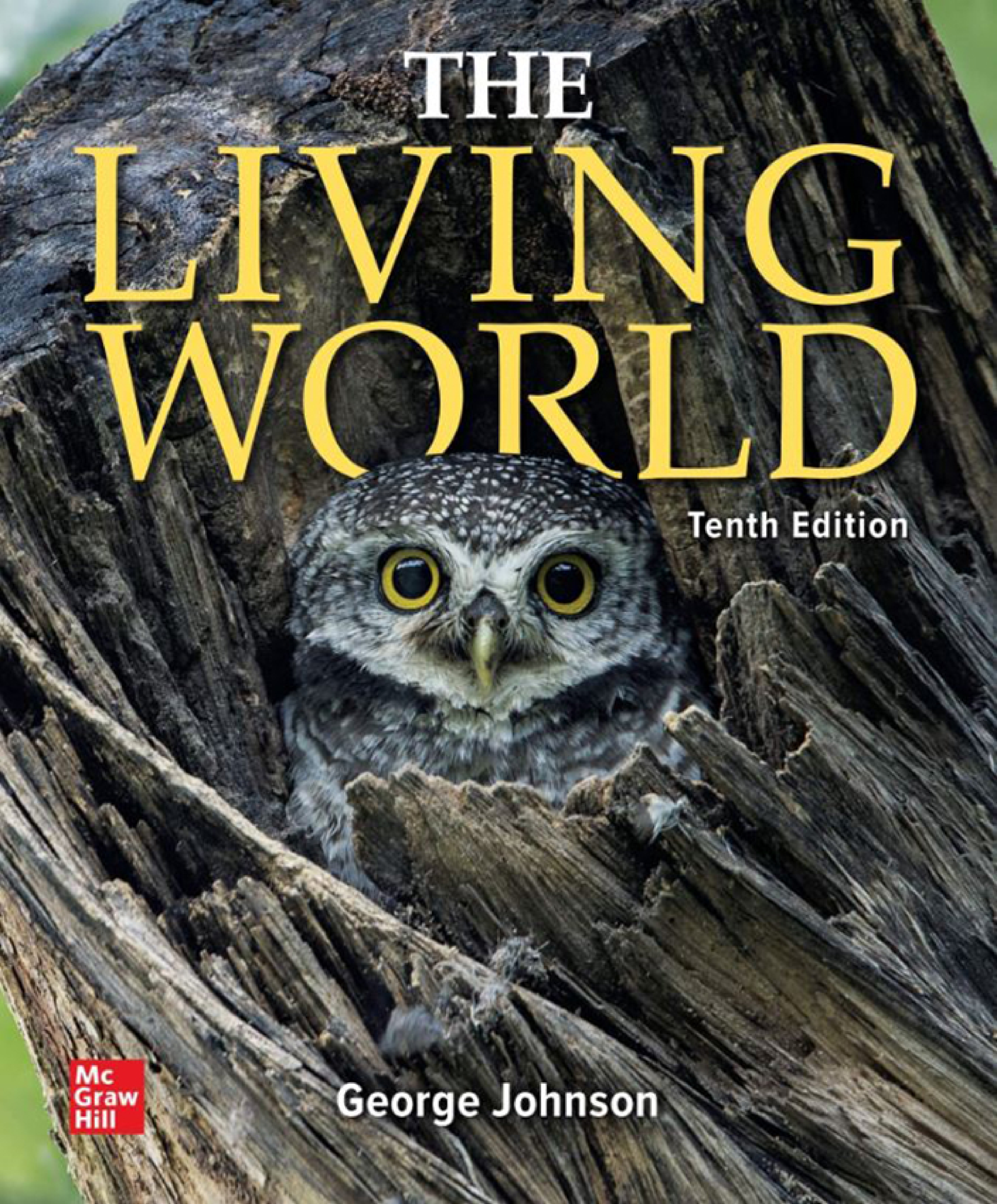

THE LIVING WORLD

Tenth Edition

George Johnson

McGraw Hill

TENTH EDITION

The Living World

George B. Johnson

Washington University
St. Louis, Missouri

Mc Graw Hill

THE LIVING WORLD, TENTH EDITION

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Brief Contents

Preface

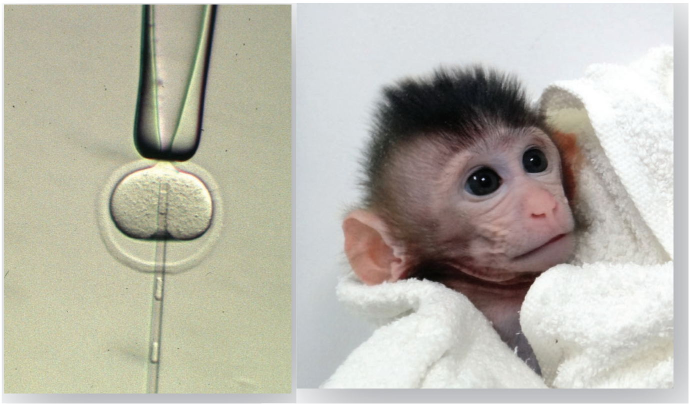
Teaching Science as a Process

We are all of us scientists. We live in a world where science impacts our lives daily. Atomic bombs are the product of science, and so are antibiotics and cancer treatments. This year, human babies had their genes edited, and climate change was debated in the halls of Congress. What are we to make of the science that is forming the world in which we will live our lives? How do we know what to fear and what to seek? The first step is to understand how science is done. How does a scientist "know" something? Understanding how to evaluate a scientific claim has become a necessary tool for every educated citizen.

Analyzing Important Experiments Biology is at its core a detective story. Over many years, scientists have performed experiments to solve mysteries. Faced with a question, they have, like Sherlock Holmes, devised ways to test alternative possibilities. And it doesn't stop there. Learning the answer to one question has led scientists to other questions, addressed by other experiments. Every major concept taught to students taking a biology course is the result of a chain of experiments. In this text, you will analyze many of the most important experiments that have taught us what we know. By seeing how scientists conducted the experiments, you can see how scientists think and how ideas are tested.

Take, for example, the scientific question faced by a biologist named Peter Agre. Scientists had learned that plasma membranes, the skin of cells, are double layers of an oily substance called lipid. Water cannot pass through oil, so how can water enter cells? On page 76, you can follow the experiments Agre used to solve this mystery, experiments that won him the Nobel Prize. Often, a chain of experiments underlie our understanding. In chapter 11, you will follow a chain of experiments by Griffith, Avery, Hershey and Chase, Wilkins, and Meselson and Stahl that led to an ever-clearer understanding of DNA as the hereditary material. In *The Living World,* you will take a detailed look at over 60 experiments that have formed the conceptual framework of modern biology.

Inquiry and Analysis One of the most important things you will take away from this course is the ability to judge scientific claims you will encounter as a citizen long after college is over. Studying past experiments that have taught us what we know about biology is one step in this direction. Another way of learning this important skill is to actually do the analysis yourself. Every chapter of this text ends with an *Inquiry & Analysis* feature, a full-page presentation of an actual scientific investigation that requires you to formulate an experiment, analyze the data, and reach conclusions. The best way to learn how science is done is to do it.



(a) Handout/Getty Images; (b) Courtesy Yongchang Chen, PhD

Linking Biology to Everyday Life

Biology isn't all dry stuff, complex chemical pathways to memorize, and strange-sounding terms to learn. Biology affects you personally, in your own everyday life. As you proceed through *The Living World,* you will encounter a variety of features linking a chapter's contents to your everyday world.

Relevancy Readings Throughout *The Living World* are full-page features devoted to how today's biology affects you:

Answering Your Questions About A lot of today's biology affects you directly, raising a variety of interesting questions concerning matters like vaping and e-cigarettes, energy drinks, medical marijuana, LGBTQ matters and the science behind sexual orientation, the opioid crisis, and gene editing of human babies.

Biology and Staying Healthy Many aspects of biology will impact your own health, and are worth a closer look. They include what you eat—diets like the currently popular Paleo diet, and chemicals like the bisphenol A found in the clear plastic lining of canned foods. Protecting your genes from DNA-attacking chemicals in cigarettes and DNA-damaging UV radiation in tanning booths will be very important to your healthy future.

Today's Biology Many of today's advances in biology are affecting society in important and interesting ways. They allow you to trace your family history with DNA, eat test-tube hamburgers, meet babies with three parents, and look for life on other planets.

A Closer Look Sometimes it's fun to take a closer look. *A Day In the Life of Your Body,* for example, lets you see how often you heart beats and how much blood it pumps, how often your lungs inhale and how much air moves in and out, how fast your hair and fingernails grow, and other fascinating events. *A Sense of Where You Are* teaches you how LeBron James is able to sink a jump shot without looking at the basket.

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Relevancy Modules Comprehensive *Relevancy Modules* correspond to each unit of *The Living World*. These modules demonstrate the connections between biological content and topics that are of interest to society as a whole. Each module consists of an overview of basic scientific concepts, and then a closer look at the application of these concepts to the topic. Assessment questions specific to the module are also available.

These modules are available as a supplementary e-book to this text within *Connect,* and may be assigned by your instructor for use in the classroom. Examples of topics covered include cancer biology, fermentation science, weed evolution, antibiotic resistance, mega crops, the biology of weight gain, and climate change. New topics are planned for launch each year to keep this resource current.

Relevancy Videos: BioNOW Like the *Inquiry & Analysis* feature at the end of each chapter of *The Living World, BioNOW* videos narrated and produced by educator Jason Carlson provide a relevant, applied approach that allows students to feel they can actually do and learn biology themselves. While tying directly to the content of your course, the series of videos helps you relate your daily life to the biology you are learning.

Each video provides an engaging and entertaining story about applying the science of biology to a real situation or problem. Attention is given to using tools and techniques that the average person would have access to, so you can see science has something you yourself can do and understand.

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New to This Edition

Editing Your Genes

The most exciting advances since this text's last edition have involved the widespread application of a new, easy-to-use tool called CRISPR that allows researchers to edit genes. As described in chapter 13 on pages 280–28, CRISPR is being used to treat human diseases on many fronts, including developing a potential cure for AIDS, facilitating organ transplants from pigs(!), correcting disease-causing mutations such as cystic fibrosis and sickle-cell disease, and genetically modifying a patient's own blood cells to fight leukemia.

CRISPR-Edited Human Babies

The invention of gene editing with CRISPR has led quickly to an ethical nightmare. As recounted in chapter 13 on page 284, a Chinese researcher in November of 2018 announced he had used CRISPR to edit the genomes of human babies! Do you see the problem? In the CRISPR applications described in the preceding paragraph, DNA was edited in the somatic (body) tissues of adults, changes that could not be passed on to future generations. As described on page 284, the Chinese researcher edited the DNA of a single-cell embryo. This alters all the tissues that derive from it, germ-line as well as somatic—the changes he created with CRISPR will be passed on in the germ line to future human generations.

Metazoan Tree of Life

The classification of animals has until recently been based on close examination of their bodies, animals with similar traits being grouped together. Traits shared by many kinds of animals—like having body segments—have been judged fundamental. With the advent of DNA sequencing, genomes can now be compared directly, which has led to the more detailed understanding of the animal family tree presented in chapter 19.

The Opioid Crisis

Opioids have been used as painkillers since 1806, when a German chemist isolated the active chemical ingredient of opium, calling it morphine. In an attempt to lessen addiction, morphine was chemically modified in 1898, but the modified form, heroin, proved even more addictive. In 1924, a substitute opioid was invented called oxycodone. Marketed as less addictive than heroin, it became widely used in the 1950s. By 2010, a continuous-release form called OxyContin reached over $3 billion in annual sales. Tragically, pharmaceutical marketing had downplayed the danger of their new painkiller: as detailed in chapter 28 on page 612, these next-generation opioids are actually quite addictive. And addicts often seek more powerful forms like fentanyl, increasing the danger of fatal overdoses. The Center for Disease Control reports that 47,600 Americans died of opioid overdoses in 2017, almost triple the number of fatal overdoses 10 years earlier. On the day you read this, a hundred more will die.

A Sense of Where You Are

How is a basketball superstar like LeBron James able to sink a jump shot without looking at the basket? Seeking an answer to this question, explored in chapter 28 on page 618, has led to two recent Nobel Prizes and a lot of rat races through mazes. Researchers were able to show that your brain keeps a "map" of where you are in three dimensions and constantly updates it as you move through space.

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Human Sexual Orientation

Adult sexual behavior is determined by the activation, early in development, of fetal genes located on the Y chromosome that lead to secretion of the hormone testosterone. This testosterone acts on the brain of the fetus in a way that determines that individual's future sexual behavior. Depending upon its action, the sexual orientation of the individual will be to persons of the opposite gender (heterosexual or "straight"), to the same gender (homosexual), or to both genders (bisexual). Non-heterosexual individuals commonly refer to themselves as LGBTQ (lesbian, gay, bisexual, transgender, queer). The CDC estimates the number of these individuals as 5% of the total U.S. population—some 13 million LGBTQ individuals. As discussed in chapter 31 on page 662, their sexual orientation was determined before birth, and is not subject to later change.

Role of Volcanoes in Mass Extinctions

A large asteroid slammed into earth 66 million years ago, the same time dinosaurs went extinct. Recent excavations have revealed a site in North Dakota with clear evidence of the impact: a jumbled mess of fossils, including fish that had choked to death on glassy particles raining down from the fireball. Did the dinosaurs die on this day? Perhaps. Perhaps not. Other mass extinctions are not correlated with similar impacts, while almost all *are* correlated with huge volcanic eruptions, as described in chapter 20 on page 450. Perhaps 66 million years ago the asteroid impact triggered these volcanic eruptions, too, like setting off a bear trap with a nudge.

Vaping

Fearing the lung cancer caused by chemicals in tobacco, people are no longer smoking as much. While 40% of Americans smoked in 1965, only 16% did in 2017. The commercial answer to this lost market? Sell the addictive nicotine to consumers without the tobacco! As described in chapter 24 on page 539, e-cigarettes release nicotine as a vapor (hence, the term *vaping*). An e-cigarette called a juul (pronounced "jewel") vaporizes a liquid that is 5% nicotine, a powerful amount. Juul users quickly become addicted to nicotine, just as cigarette smokers did, and a lot of teens are smoking juuls—nearly 21% of high school students vaped in 2018. Serious efforts are under way to regulate e-cigarette sales, driven by reports from the CDC that, over the course of 2018, the number of high school students using tobacco products increased by 38% in a single year, almost entirely through e-cigarette smoking.

Global Warming Revisited

Perhaps the greatest challenge we face in the future is the rise in global temperature resulting from increases in the CO_2 content of earth's atmosphere. While the world's scientists are almost universal in blaming the increase on the burning of fossil fuels, there is considerable discussion among the general public about the reality of the problem and the need for action. Taking a closer look in chapter 38 on pages 822–823, we address an array of questions about what is happening now, what scientists predict will happen soon, and what can be done.

About the Author


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 rain forests, 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, such as AIDS, the global warming, gene editing, 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 BiologyWriter.com.

Acknowledgments

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, plus an even larger army of production managers and staff who then transform this manuscript into a bound book. I cannot thank them all enough.

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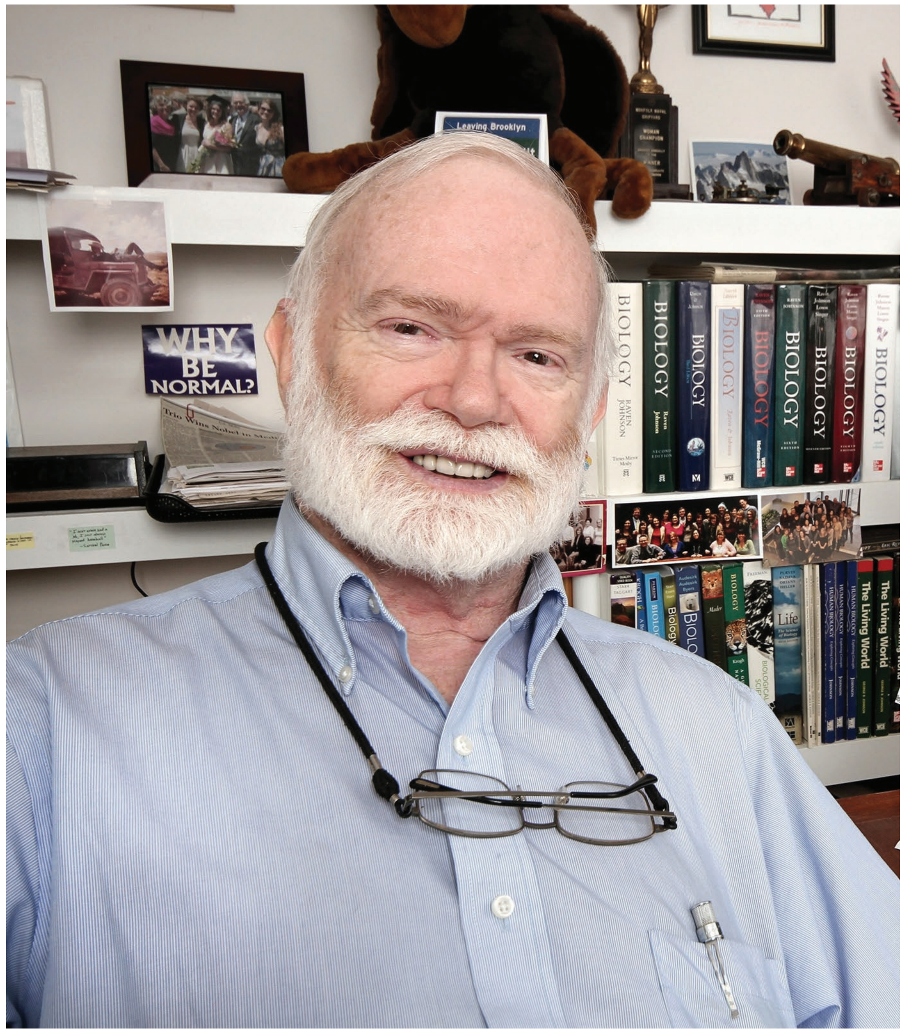
Senior Content Project Manager Vicki Krug spearheaded our production team. The photo program was carried out by Content Licensing Specialist Abbey Jones. David Hash did a great job with the design and was unbelievably tolerant of the author's many "creative" changes. The book was produced by MPS Limited.

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.



Courtesy George B. Johnson

The marketing of *The Living World, 10e* has been planned and supervised by Marketing Development Manager Beth Theisen, who was 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 St. Louis for a few days to let me explain to her in detail how I developed the book, so 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 ten 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

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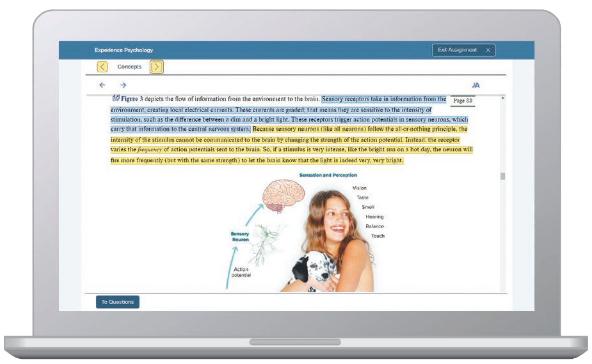

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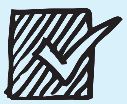

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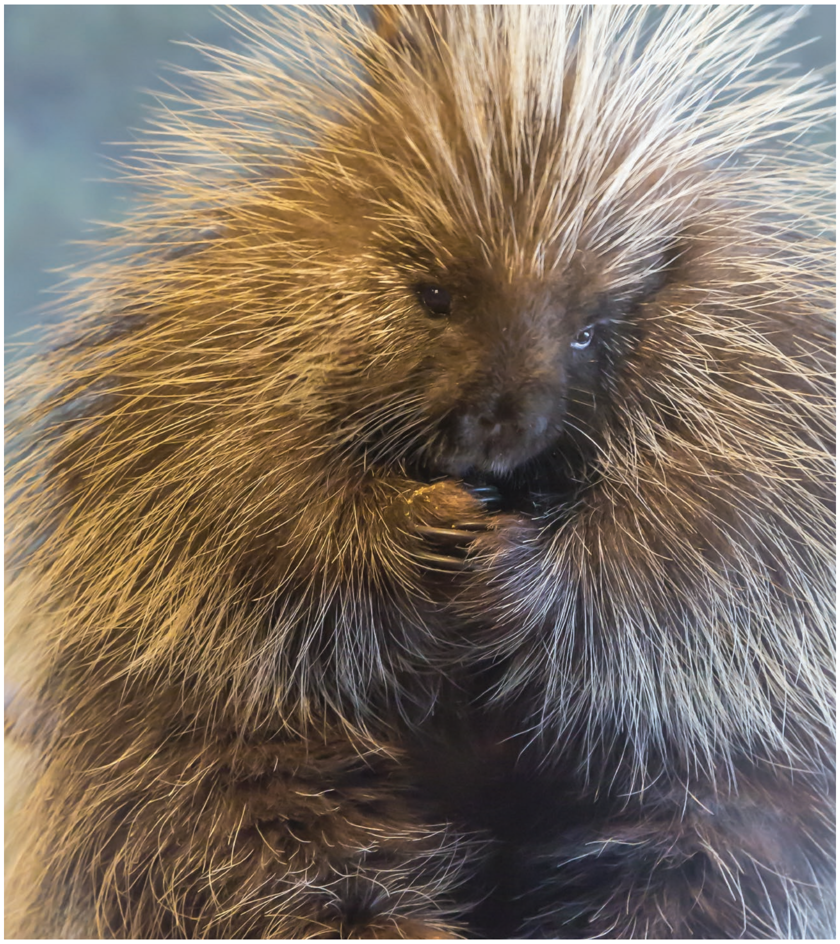
Studying Biology

0

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.



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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.

A Closer Look: 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. Identify the assessment tools that the text provides to help you master the material.

Putting What You Learn to Work

0.3 Science Is a Way of Thinking

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

0.4 How to Read a Graph

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

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.

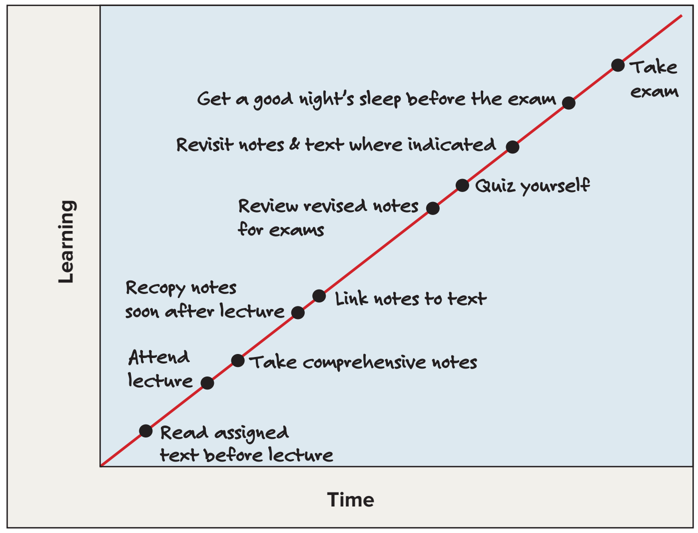


Figure 0.1 A learning timeline.

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, because 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

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.

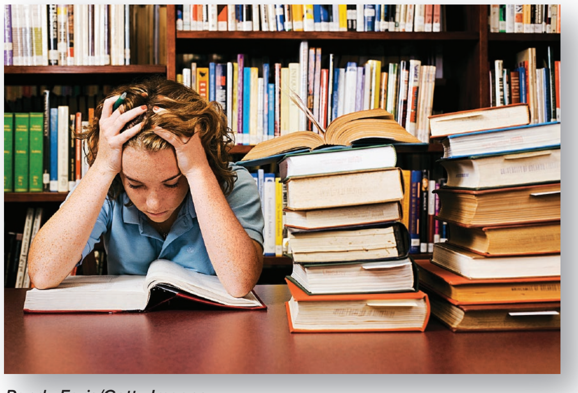
Figure 0.3 Critical learning occurs in the classroom.
Learning occurs in at least four distinct stages: attending class; doing assigned textbook readings before lecture; listening and taking notes during lecture; and recopying notes shortly after lecture. If you are diligent in these steps, then studying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

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.

A Closer Look

Pulling an All-Nighter



Randy Faris/Getty Images

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 3 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, because 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 3 or 4 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.

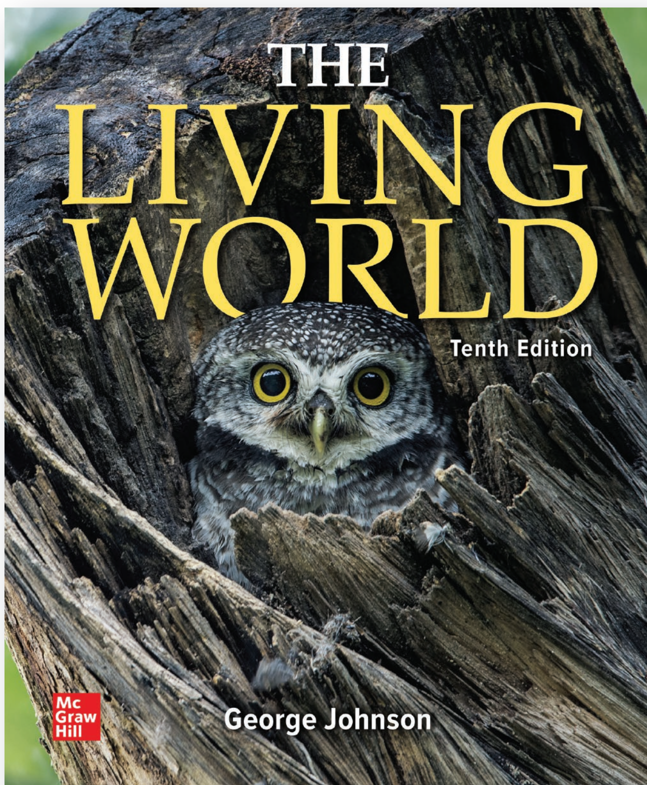
0.2 Using Your Textbook

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.



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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.

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 Identify 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.

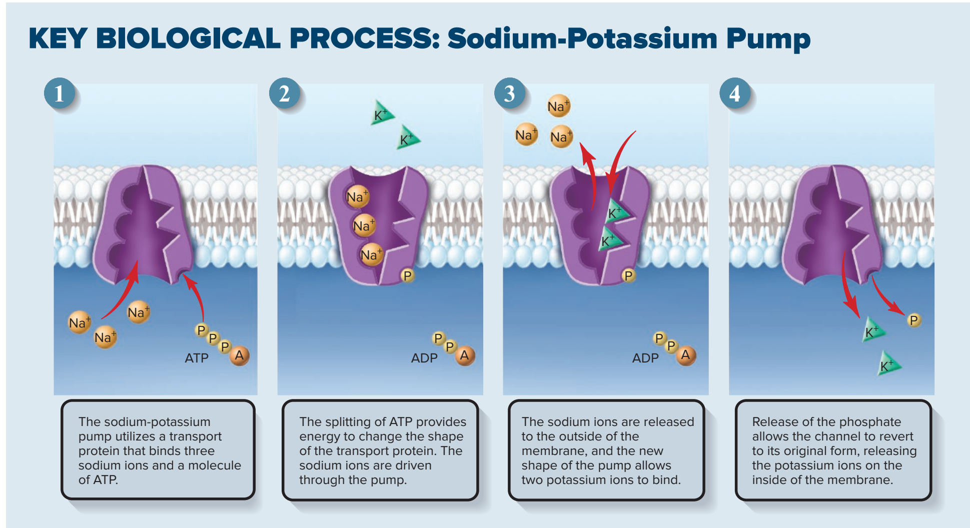
Three sorts of illustrations offer particularly strong reinforcement:

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 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.



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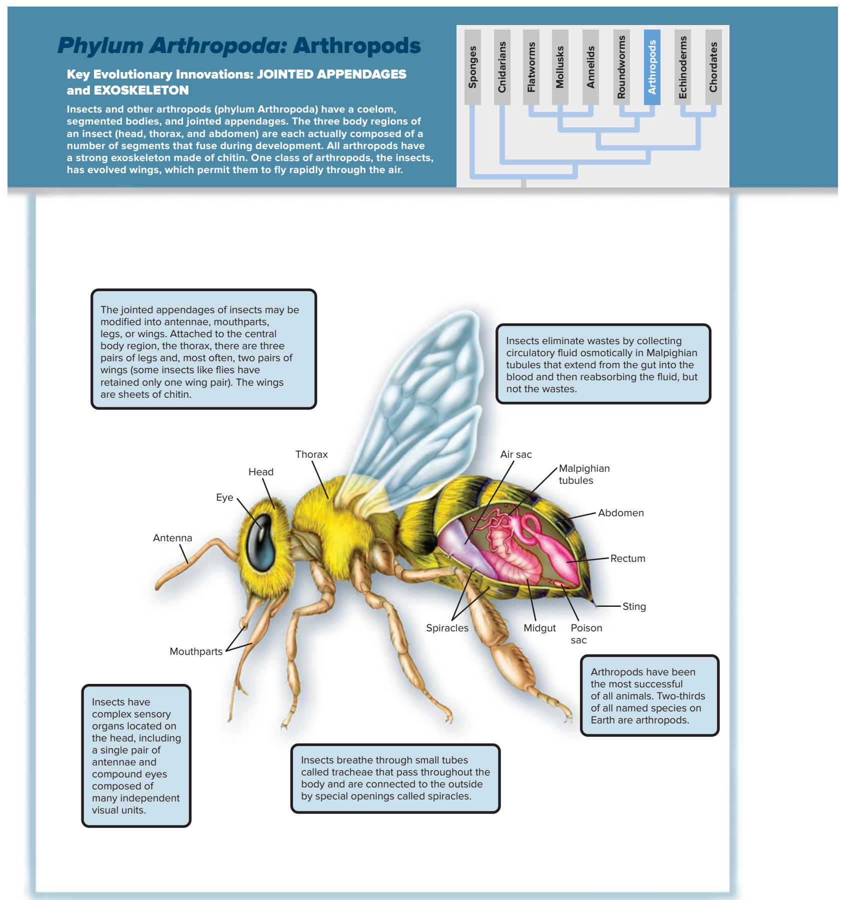

(b)

Figure 0.4 Visual learning tools.

(*a*) An example of a Key Biological Process illustration. (*b*) An example of a Phylum Facts illustration.

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Putting What You Learn to Work

0.3 Science Is a Way of Thinking

One of the most important things you can learn in a biology course is how to evaluate scientific claims. Long after this class is completed, you will be making decisions that involve biology, and they will be better, more informed decisions if you have acquired the skill to evaluate scientific claims for yourself. Because it is printed in the newspaper or cited on a website doesn't make a scientific claim valid. **Figure 0.5** illustrates the sorts of biology topics you encounter today in the news—and this is just a small sample. They are, all of them, important issues that will affect your own life. How do you reach informed opinions about them?

You do it by asking the question, "How do we know this?" Science is a way of thinking that demands to see the evidence, that challenges the validity of every claim. If you can learn to do this, to apply this skill in the future to personal decisions about biology as it impacts your life, you will have taken from this course a valuable lesson.

Figure 0.5 Biology in the news.

(corn): Ingram Publishing/SuperStock; (duck): Robert Burton/USFWS; (cells): Steve Gschmeissner/Science Source; (sunbather): Kristy-Anne Glubish/Design Pics; (Darwin): Shutterstock/Everett Historical; (runner): Matthew Stockman/Getty Images

How Do We Know What We Know?

Learning Objective 0.3.1 Analyze how biological scientists have come to a conclusion when confronted with problems of major public importance.

A useful way to learn how scientists think, how they constantly check and question what they know, is to look at real cases. What follows are four instances where biologists have come to a conclusion. These conclusions will be taught in this textbook, reflecting the world about us as best as science can determine. All four of these cases will be treated at length in later chapters; here they serve only to introduce the process of scientific questioning.

Does Cigarette Smoking Cause Lung Cancer? The American Cancer Society estimates that 600,920 Americans died of cancer in 2017. Fully one in four of the students using this textbook can be expected to die of it. Twenty-seven percent of these cancer victims die of lung cancer, by far the leading cause of cancer death.

As you might imagine, something that kills so many of us has been the subject of much research. The first step biologists took was to ask a simple question: "Who gets lung cancer?" The answer came back loud and clear: Fully 80% of those who die from lung cancer are cigarette smokers. Delving into this more closely, researchers looked to see if the incidence of lung cancer (that is, how many people contract it per 100,000 people) can be predicted by how many cigarettes a person smokes each day. As you can see in the graph in **figure 0.6** (which is shown again in chapter 14), it can. The more cigarettes smoked, the higher the occurrence of lung cancer. Based on this study and lots of others like it, examined in more detail in sections 11.5 and 24.6, biologists concluded that smoking cigarettes causes lung cancer.

Figure 0.6 Does smoking cause lung cancer?

Photo: UK Stock Images Ltd./Alamy

Does Carbon Dioxide Cause Global Warming? Our world is getting warmer. Looking for the cause, atmospheric scientists soon began to suspect what might at first seem an unlikely culprit: carbon dioxide (CO_2), a gas that is a minor component (0.03%) of the air we breathe. As you will learn in this course, burning coal and other fossil fuels releases CO_2 into the atmosphere. Problems arise because CO_2 traps heat. As the modern world industrializes, more and more CO_2 is released. Does this lead to a hotter earth? To find out, researchers looked to see if the rise in global temperature reflected a rise in the atmosphere's CO_2. As you can see in the graph in **figure 0.7** (which is shown again in section 38.3), it does. After these and other careful studies we will explore in detail in chapter 38, scientists concluded that rising CO_2 levels are indeed the cause of global warming.

Does Obesity Lead to Type 2 Diabetes? The United States is in the midst of an obesity epidemic. From 1999 to 2017, the percentage of Americans who are obese has almost tripled, from 13% to 39.6%. Coincidentally, the number of Americans suffering from type 2 diabetes (a disorder in which the body loses its ability to regulate glucose levels in the blood, often leading to blindness and amputation of limbs) has more than tripled over the same 20-year period, from 7 million to more than 23 million (that's one in every 14 Americans!).

What is going on here? When researchers compared obesity levels with type 2 diabetes levels, they found a marked correlation, clearly visible in the graph in **figure 0.8** (which is shown again in section 30.4). Investigating more closely, the researchers found that an estimated 80% of people who develop type 2 diabetes are obese. Detailed investigations described in section 30.4 have now confirmed the relationship that these early studies hinted at: Overeating triggers changes in the body that lead to type 2 diabetes.

What Causes the Ozone Hole? Thirty-five years ago, atmospheric scientists first reported a loss of UV-absorbing ozone (O_3) gas high in the atmosphere over Antarctica. Trying to understand the reason for this "ozone hole," researchers began to suspect chlorofluorocarbons, or CFCs. CFCs are supposedly inert chemicals that are widely used as heat exchangers in air conditioners. However, further studies, detailed in sections 1.7 and 38.4, indicated that CFCs are not inert after all: In the intense cold temperatures high over Antarctica, they cause O_3 to be converted to O_2. Scientists concluded that CFCs were indeed causing the ozone hole over Antarctica. As you can see in the graph in **figure 0.9**, the size of the ozone hole soon stopped expanding after CFC production was restricted.

Looking at the Evidence

One thing these four cases have in common is that, in each, scientists reached their conclusion not by applying established rules but rather by looking in detail at what was going on and then testing possible explanations. In short, they gathered and analyzed data. If you are going to think independently about scientific issues in the future, then you will need to learn how to analyze and understand what the data are telling you. In each case above, the data are presented in the form of a graph. Said simply, you will need to learn to read a graph.

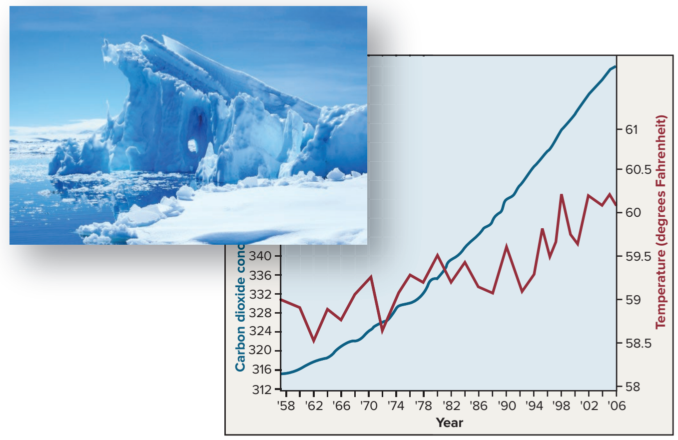

Figure 0.7 **Does carbon dioxide cause global warming?**
Photo: Kelly Cheng/Getty Images

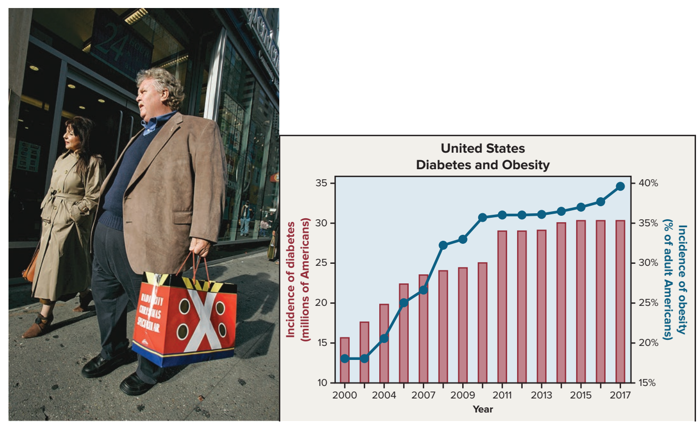

Figure 0.8 **Does obesity lead to type 2 diabetes?**
Photo: ©Lars A. Niki

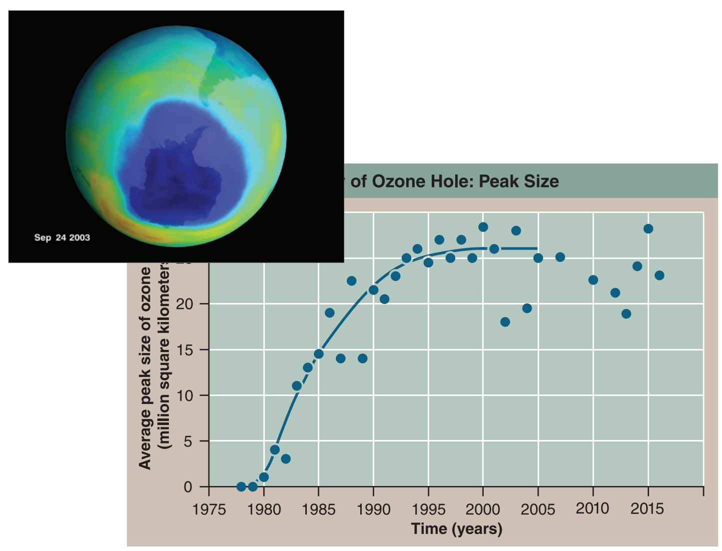

Figure 0.9 **What causes the ozone hole?**
Photo: SVS/TOMS/NASA

Key Learning Outcome 0.3 Scientists investigate by gathering data and analyzing it to form possible explanations they can test.

0.4 How to Read a Graph

Variables and Graphs

Learning Objective 0.4.1 Define *independent variable,* and explain why correlation of dependent variables does not prove causation.

In section 0.3, you encountered four graphs illustrating what happened to variables, such as global temperature, size of the ozone hole, incidence of obesity, and incidence of lung cancer, when other variables changed. A **variable,** as its name implies, is something that can change. Variables are the tools of science, and you will encounter many different kinds as you proceed through this text. Many of the variables biologists study are examined in graphs like you saw in the previous section. A **graph** shows what happens to one variable when another one changes.

There are two types of variables. The first kind, an **independent variable,** is one that a researcher deliberately changes—for example, the concentration of a chemical in a solution, or the number of cigarettes smoked per day. The second kind, a **dependent variable,** is what happens in response to the changes in the independent variable—for example, the intensity of a solution's color or the incidence of lung cancer. Importantly, the change in a dependent variable that is measured in an experiment is not predetermined by the investigator.

In science, all graphs are presented in a consistent way. The independent variable is always presented and labeled across the bottom, called the *x axis.* The dependent variable is always presented and labeled along the side (usually the left side), called the *y axis* (**figure 0.10**).

Some research involves examining correlations between sets of variables, rather than the deliberate manipulation of a variable. For example, a researcher who measures both diabetes and obesity levels (as described in section 0.3) is actually comparing two dependent variables. While such a comparison can reveal correlations and so suggest potential relationships, *correlation does not prove causation*. What is happening to one variable may actually have nothing to do with what happens to the other variable. Only by manipulating a variable (making it an independent variable) can you test for causality. Just because people who are obese tend to also have diabetes does not establish that obesity *causes* diabetes. Other experiments are needed to determine causation.

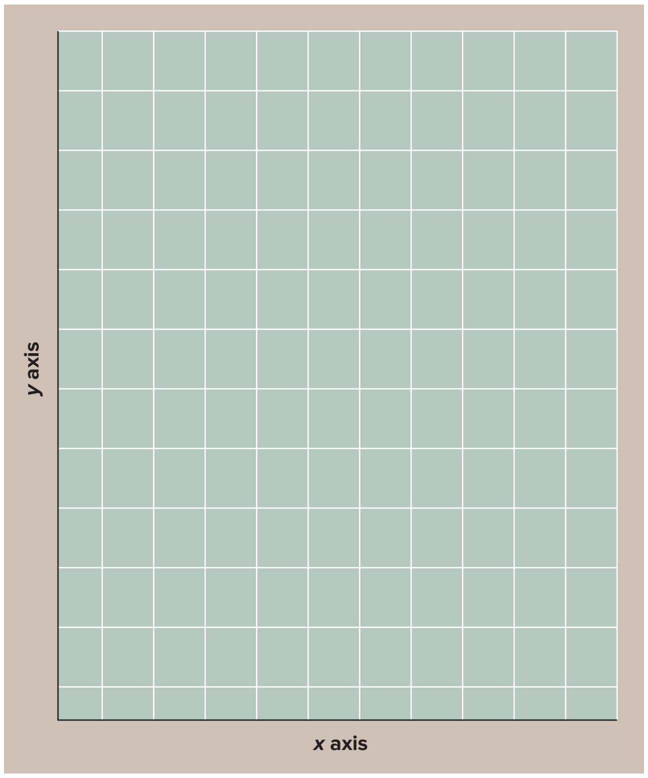

Figure 0.10 The two axes of a graph.
The independent variable is almost always presented along the *x* axis, and the dependent variable shown along the *y* axis.

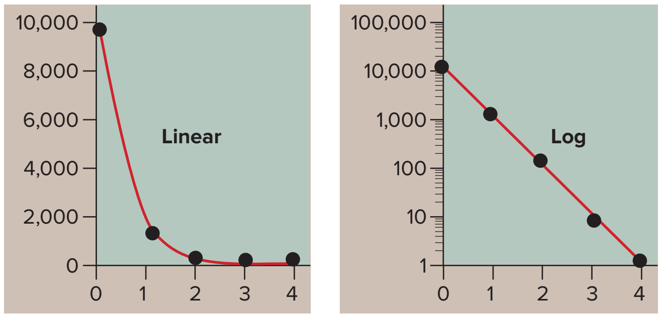

Figure 0.11 Linear and log scale: two ways of presenting the same data.

Using the Appropriate Scale and Units

Learning Objective 0.4.2 Differentiate between arithmetic and logarithmic scales.

A key aspect of presenting data in a graph is the selection of proper scale. Data presented in a table can utilize many scales, from seconds to centuries, with no problems. A graph, however, typically has a single scale on the *x* axis and a single scale on the *y* axis, which might consist of microscopic units (for example, nanometers, microliters, micrograms) or macroscopic units (for example, feet, inches, liters, days, milligrams). In each instance, a scale must be chosen that fits what is being measured. Changes in centimeters would not be obvious in a graph scaled in kilometers. Also, if a variable changes a great deal over the course of the experiment, it is often useful to use an expanding scale. A **log** or **logarithmic scale** is a series of numbers plotted as powers of 10 (1, 10, 100, 1,000, ...), rather than in the linear progression seen on most graphs (2,000, 4,000, 6,000, ...). Consider the two graphs in **figure 0.11**, where the *y* axis is plotted on a linear scale on the left and on a log scale on the right. You can see that the log scale more clearly displays changes in the dependent variable (the *y* axis) for the upper values of the independent variable (the *x* axis, values 2, 3, and 4). Notice that the interval *between* each *y* axis number is not linear either: the interval between each number is itself subdivided on a log scale. Thus, 50 (the fourth tick mark between 10 and 100) is plotted much closer to 100 than to 10.

Individual graphs use different units of measurement, each chosen to best display the experimental data. By international convention, scientific data are presented in **metric units,** a system of units expressed as powers of 10. For example, weight is expressed in units called *grams*. Ten grams make up a decagram, and 1,000 grams is a kilogram. Smaller weights are expressed as a portion of a gram—for example, a centigram is a hundredth of a gram, and a milligram is a thousandth of a gram. The units of measurement employed in a graph are by convention indicated in parentheses next to the independent variable label on the *x* axis and the dependent variable label on the *y* axis.

Drawing a Line

Learning Objective 0.4.3 Explain how a regression line is drawn.

Most of the graphs that you will find in this text are **line graphs,** which are graphs composed of data points and one or more lines. Line graphs are typically used to present *continuous data;* that is, data that are discrete samples of a continuous process. An example might be data measuring how quickly the ozone hole develops over Antarctica in August and September of each year. You could in principle measure the area of the ozone hole every day, but to make the project more manageable in time and resources, you might actually take a measurement only once a week. Measurements reveal that the ozone hole increases in area rapidly for about six weeks before shrinking, yielding six data points during its expansion. These six data points are like individual frames from a movie—frozen moments in time. The six data points might indicate a very consistent pattern, or they might not.

Consider the hypothetical data in the graphs of **figure 0.12**. The data points on the left graph are changing in a very consistent way, with little variation from what a straight line (drawn in red) would predict. The graph in the middle shows more experimental variation, but a straight line still does a good job of revealing the overall pattern of how the data are changing. Such a straight "best-fit line" is called a **regression line** and is calculated by estimating the distance of each point to possible lines, adding the values, and selecting the line with the lowest sum. The data points in the graph on the right are randomly distributed and show no overall pattern, indicating that there is no relationship between the dependent and the independent variables.

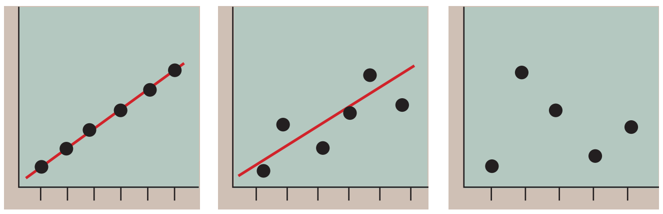

Figure 0.12 Line graphs: hypothetical growth in size of the ozone hole.

Other Graphical Presentations of Data

Learning Objective 0.4.4 Differentiate between a line and a histogram.

Sometimes the independent variable for a data set is not continuous but rather represents discrete sets of data. A line graph, with its assumption of continuity, cannot accurately represent the variation occurring in discrete sets of data, where the data sets are being compared with one another. In these cases, the preferred presentation is that of a **histogram,** a kind of bar graph. For example, if you were surveying the heights of pine trees in a park, you might group their heights (the independent variable) into discrete "categories" such as 0 to 5 meters tall, 5 to 10 meters, and so on. These categories are placed on the *x* axis. You would then count the number of trees in each category and present that dependent variable on the *y* axis, as shown in **figure 0.13**.

Some data represent proportions of a whole data set; for example, the different types of trees in the park as a percentage of all the trees. This type of data is often presented in a **pie chart** (**figure 0.14**).

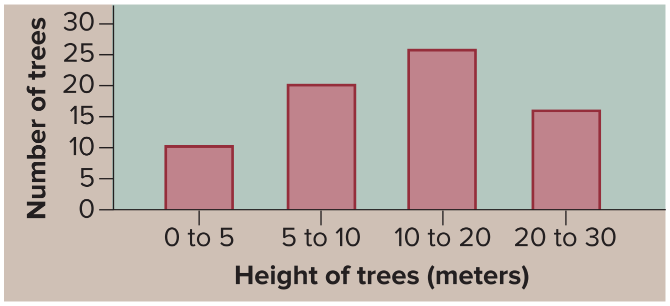

Figure 0.13 Histogram: the frequency of tall trees.

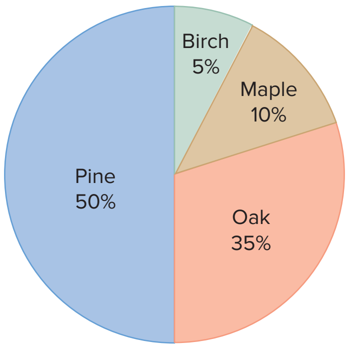

Figure 0.14 Pie chart: the composition of a forest.