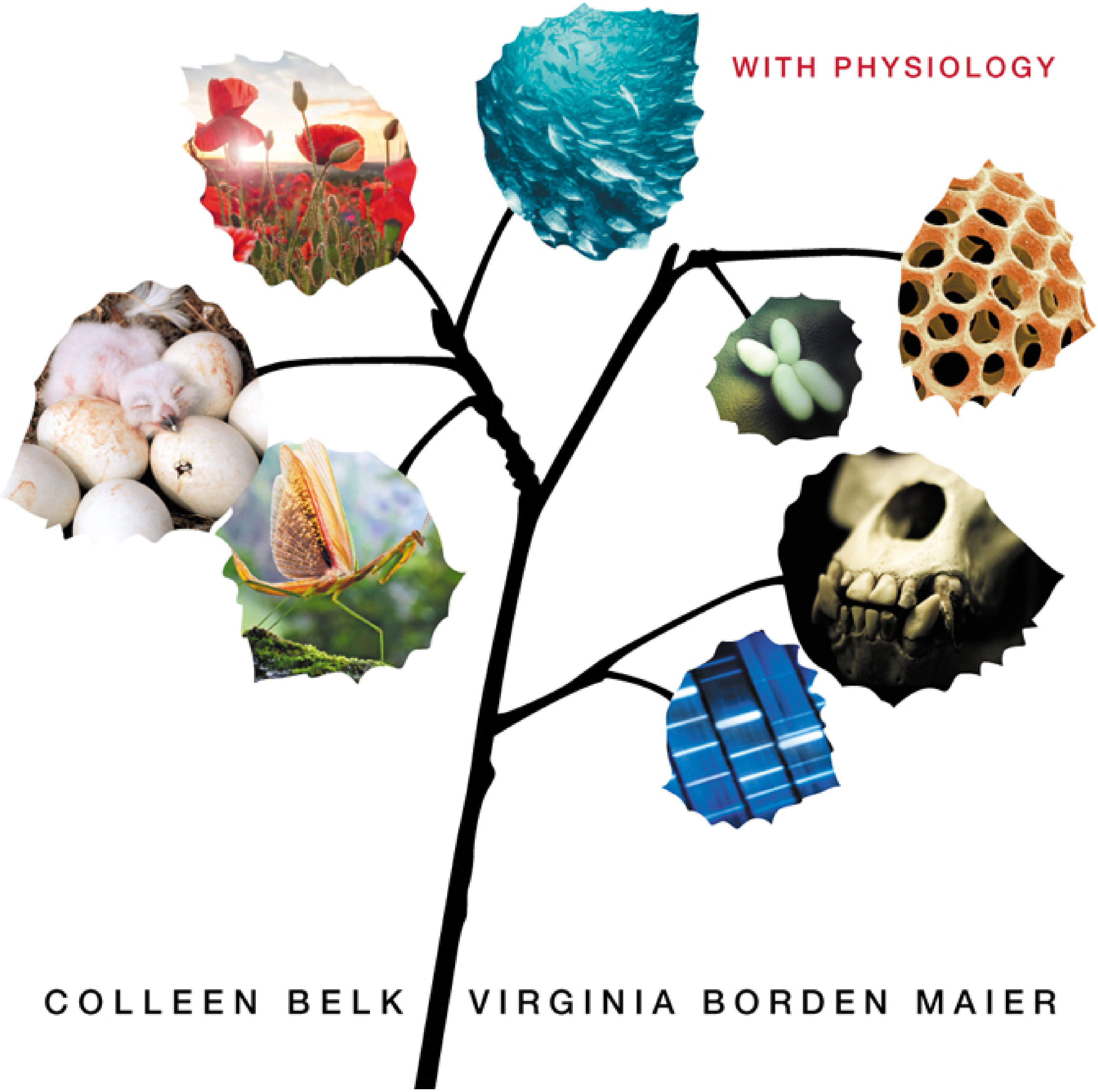
# BIOLOGY

FIFTH EDITION

## SCIENCE FOR LIFE

WITH PHYSIOLOGY



COLLEEN BELK / VIRGINIA BORDEN MAIER

# Biology

## Science for Life

**WITH PHYSIOLOGY**

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**Colleen Belk**
University of Minnesota–Duluth

**Virginia Borden Maier**
St. John Fisher College



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# About the Authors


**Colleen Belk** and **Virginia Borden Maier** collaborated on teaching biology to non-majors for over a decade at the University of Minnesota–Duluth. This collaboration has continued for an additional decade through Virginia's move to St. John Fisher College in Rochester, New York, and has been enhanced by their differing but complementary areas of expertise. In addition to the non-majors course, Colleen Belk teaches general biology for majors, genetics, cell biology, and molecular biology courses. Virginia Borden Maier teaches general biology for majors, evolutionary biology, zoology, plant biology, ecology, and conservation biology courses.

After several somewhat painful attempts at teaching the breadth of biology to non-majors in a single semester, the two authors came to the conclusion that they needed to find a better way. They realized that their students were more engaged when they understood how biology directly affected their lives. Colleen and Virginia began to structure their lectures around stories they knew would interest students. When they began letting the story drive the science, they immediately noticed a difference in student engagement and willingness to work harder at learning biology. Not only has this approach increased student understanding, but it has also increased the authors' enjoyment in teaching the course—presenting students with fascinating stories infused with biological concepts is simply a lot more fun.

# Preface

## To the Student

Is it acceptable to clone humans? When does human life begin? What should be done about our warming planet? Who owns living organisms? What are our responsibilities toward endangered species? Having taught this course for nearly 40 combined years, we understand that no amount of knowledge alone will provide satisfactory answers to these questions. Addressing them requires the development of a scientific literacy that surpasses the rote memorization of facts. To make decisions that are individually, socially, and ecologically responsible, you must not only understand some fundamental principles of biology but also be able to use this knowledge as a tool to help you analyze ethical and moral issues involving biology. This is the aim of this textbook.

To help you understand biology and apply your knowledge to an ever-expanding suite of issues, we have structured each chapter of *Biology: Science for Life* around a compelling story in which biology plays an integral role. Through the story you not only will learn the relevant biological principles but also will see how science can be used to help answer complex questions. As you learn to apply the strategies modeled by the text, you will also be developing your critical thinking skills.

Even though you may not be planning to be a practicing biologist, well-developed critical thinking skills will enable you to make better decisions about issues that affect your own life and form well-reasoned, fact-based opinions about personal, social, and ecological issues.

## To the Instructor

You are probably all too aware that teaching non-majors students is very different from teaching biology majors. You know that most of these students will never take another formal science course; therefore, your course may be the last chance for these students to appreciate how biology is woven throughout the fabric of their lives and to develop a deep understanding of the process of science. You recognize the importance of engaging non-majors because you know that these students will one day be voting on issues of scientific importance, holding positions of power in the community, serving on juries, and making health care decisions for themselves and their families. This text is designed to help you reach your goals.

By now, most non-majors biology instructors are aware that this book differs from other books in that we use a compelling storyline woven throughout the entire chapter to garner student interest. Once we draw students in, we keep them engaged by returning to the storyline again and again until the end of the chapter, when students should be able to form their own data-driven opinions about each topic. Storylines are skillfully crafted to allow the same depth and breadth of coverage as any non-majors biology text.

Our experience has taught us that students will not remember as many facts as we hope they will, but they can and do remember how to apply the scientific method to novel questions involving biology, and they can retain a strong appreciation for how science differs from other methods of understanding the world. To ensure our students leave our course with the ability to critically evaluate information they may come across, this text focuses heavily on process of science, providing opportunities for students to practice applying the scientific method and analyze data at every opportunity.

### New to the Fifth Edition

The positive feedback obtained in previous editions assured us that presenting science alongside a story works for students and instructors alike. In the fifth edition, we have added two new features and several reorganized chapters. We also updated storylines and continued to improve popular features from previous editions as well as our supplements.

### New Features: Working with Data and Sounds Right, But Is It?

In this edition, we have added new **Working with Data** questions to select figures within each chapter. Students are asked questions that guide them in how to carefully and critically analyze and interpret data in graphical, tabular, or written form. Each chapter contains at least one of these critical data analysis questions. In Chapter 6, for example, students are asked to evaluate a graph showing the cancer risks associated with smoking.

A new end-of-chapter feature, **Sounds Right, But Is It?**, addresses common misconceptions we know that our own students often have. In Chapter 4, for example, the misconception deals with whether use of laxatives can cause permanent weight loss. To help students identify and discard such misconceptions, the description of the misconception is followed by guided inquiry questions, which lead students through a careful analysis of the reliability of the misconception, using the biological concepts from the chapter covered.

## Updated Physiology Coverage and New Chapter

Content in physiology chapters has been significantly reorganized to address concerns from instructors that too much material was covered in too few chapters; what was once covered in two chapters is now spread over three. **Chapter 17** now focuses only on tissues and organs, while the new **Chapter 18** uses a discussion of the biology of the digestive and urinary systems as a way to help students understand the biological and safety consequences of binge drinking.

## Revised Unit One Coverage

Because we have found that our students need more practice analyzing pseudoscientific information they come across, we are using **Chapter 2** of the book to build on Chapter 1's introduction to the scientific method. There, students will use their newly acquired skills to learn about life and evolution in analyzing whether zombies as they are portrayed in popular culture are "alive" and whether humans are evolutionarily progressing to become higher beings. They will learn basic biochemistry while determining whether the Bermuda Triangle is a site of massive ship and plane disappearances, whether ingesting sugar causes hyperactivity, and whether tryptophan in turkey does make people tired.

## Updated Storylines

Our chapter on cellular respiration and body weight (**Chapter 4**) incorporates new meta-data showing that being underweight is less healthy than being overweight and the health consequences of being overweight start at higher weights than once thought. Our chapter on global warming and photosynthesis (**Chapter 5**) is updated to reflect the continued global changes resulting from this process. The cell division chapter (**Chapter 6**) helps students understand the biology of differently acquired cancers using the examples of the very public battles fought by celebrities like Angelina Jolie. The protein synthesis chapter (**Chapter 9**) has been updated to reflect current developments in pet and human cloning as well as so-called genetic pharming practices.

Our review of biological diversity (**Chapter 13**) now examines the question of humanity's supposed superiority over other species. The skeletal, endocrine, and muscular system coverage (**Chapter 21**) revolves around the 2014 inclusion of women's ski jumping as an Olympic sport for the first time, and the chapter on the nervous system has been revised to focus on the phenomenon of students sharing non-prescribed ADD meds with each other (**Chapter 23**).

## Improved Pedagogy

With the previous editions, we focused on improving flexibility for instructors via **A Closer Look** chapter subsections; these are now streamlined and better identified within the text. Our popular **Roots to Remember** feature that helps students build their scientific vocabulary is now integrated into the chapter itself; students can find definitions for these terms as they occur. Features that help students assess their understanding within the chapter—**Stop and Stretch** and **Visualize This** questions—have been expanded and updated in nearly every chapter. Many **Savvy Reader** essays, found in every chapter and meant to develop students as better consumers of popular media, have been updated as well.

# Supplements and Media

For the fifth edition, we've undertaken a significant revision and updating of the complete supplements package. Judi Roux EdD, a talented college instructor with years of classroom experience in non-majors biology and colleague of Colleen Belk at the University of Minnesota, Duluth, has undertaken authoring these innovative new items. We think you will find that the supplements she developed are brimming with ideas for how to reach this particular population of students. In addition to a completely revamped Instructor's Manual (for use in traditional lectures as well as flipped classrooms) and a test bank, we also provide slides, animation, and videos to enrich instruction efforts. Available online, the *Biology: Science for Life with Physiology* resources are easy to navigate and support a variety of learning and teaching styles. Judi Roux authored not only the Instructor Guide, MasteringBiology Quiz and Test Items, but the PowerPoint lectures as well.

New features in MasteringBiology include interactive concept maps and Working with Data exercises for each chapter. And our **Learning Outcomes** continue to provide support to students and instructors by organizing the chapter summary and tagging questions and activities within MasteringBiology and other ancillary material.

We believe you will find that the design and format of this text and its supplements will help you meet the challenge of helping students both succeed in your course and develop science skills—for life.

We look forward to learning about your experience with *Biology: Science for Life with Physiology*, *Fifth Edition.*

# Compelling Stories Highlight the Relevance of Biology to Everyday Life

**Each chapter weaves a compelling story based on a current issue or hot topic that presents, explains, and demystifies biological concepts, examples, and applications.**

CHAPTER **18** | **Binge Drinking**

A student is turning 21.



## UPDATED!

**Six thoroughly revised storylines** have been added to the Fifth Edition to highlight the relevance of biology concepts to everyday life, along with one entirely new storyline:

- **Chapter 2:** Science Fiction, Bad Science, and Pseudoscience
- **Chapter 4:** Body Weight and Health
- **Chapter 13:** The Greatest Species on Earth?
- **NEW CHAPTER! Chapter 18:** Binge Drinking*
- **Chapter 19:** Clearing the Air*
- **Chapter 21:** Human Sex Differences*
- **Chapter 23:** Study Drugs*

* Chapters 17–25 are included in the expanded version of the text that includes coverage of animal and plant anatomy and physiology.

MasteringBiology®

**NEW! Storyline PPTs** help instructors incorporate the stories into their lectures with videos and pre-made lectures.

# The Digestive and Urinary Systems

It's Saturday night and Malik is hosting a surprise party to celebrate the 21st birthday of his friend Lin. Lin is several years younger than Malik. She lived with Malik's family, sharing a room with his younger sister, for 2 years when she was a high school exchange student. Now an international student attending college in the United States, Lin has had almost no experience with alcohol. Malik knows that Lin is eagerly anticipating this birthday and that she is planning to drink at least a little alcohol. Because he feels as protective of Lin as he does his little sister, Malik wants to help Lin learn how to enjoy the benefits of alcohol consumption while limiting the negative consequences that can also occur.

**Malik is worried about his friend Lin.**

**He does not want her alcohol consumption to place her at risk of overdose ...**

Some of Malik's concerns about negative consequences are based on situations he has witnessed and others on information he came across while writing a paper on alcohol abuse for a health class he took last semester.

A student who lived on Malik's dorm floor freshman year broke his ankle when he tripped while running from the police to avoid an underage consumption ticket. His chemistry lab partner broke her nose when she was riding with an intoxicated driver whose car hit a tree on a snow-covered road. While working on the paper for his health class, he came across a government website that indicated over 30,000 students required medical treatment for alcohol poisoning last year and he does not want this to happen to Lin. He also worries about the high rate of sexual assault on college campuses. He does not want Lin to become one of the 20% of female students who will be sexually assaulted while in college.

Malik wants to develop a plan for convincing Lin, a pre-med biology major, that drinking too much is bad for her body, an argument he thinks she may find credible. Because he has heard that eating food before drinking might help absorb some of the alcohol and that alcohol consumption causes dehydration, he plans to focus his efforts on the digestive and urinary systems.

**... or jeopardize her safety.**

NEW!

**Chapter 18*** covers the digestive and urinary systems, which were previously part of the chapters on the cardiovascular and respiratory systems. This new chapter presents this material in a more manageable format for instructors and students.

and alcohol is broken down and absorbed across the intestinal wall and into the bloodstream. When alcohol relaxes muscles involved with peristalsis, food spends more time in the digestive tract than normal and this increased exposure to digestive enzymes can cause diarrhea.

Malik has heard that it is good to eat a large meal before drinking. This is because the presence of food in the stomach causes the pyloric sphincter to remain closed. Since the stomach does not absorb alcohol as readily as the small intestine, preventing the alcohol from reaching the small intestine can slow the rate at which it reaches the blood stream. Therefore, Malik plans to take Lin out to eat before the birthday party.

Many of the digestive enzymes used in the small intestine are produced by an organ called the **pancreas.** Secretions from the pancreas neutralize stomach

wastes including urea and various ions. During urine **excretion,** urine leaves the kidneys and flows to the bladder.

Alcohol is a diuretic, which means that it promotes the formation of urine and increases the volume of urine that is released from the bladder, a process called **micturation.** Coupling the increased volume of urine produced with the deadening of awareness of the need to urinate that goes with intoxication can result in a very full bladder. Even though micturition is typically under conscious control, an intoxicated person that passes out before emptying the bladder may end up urinating on himself. In this case, the body overrides the conscious control of micturition to prevent a potentially lethal bladder rupture.

Alcohol is a depressant, slowing down brain function and altering perceptions, reflexes and balance, and causing slurred speech. In an attempt to prevent the depressant effects of intoxication, some of Malik's friends mix alcohol with energy drinks. Malik will recommend to Lin that she does not do this because Lin should develop an awareness of when to stop drinking. This is harder to do if the depressant effects of intoxication are, in part, masked by the stimulant effects of the energy drink.

In addition to managing wastes, the urinary system also plays an important role in regulating blood volume, acidity, and salt balance. The kidneys regulate

**The story is revisited** throughout the chapter. In these examples, the story narrative provides an opportunity for students to learn about the digestive system as they follow a student's experience with binge drinking.

# Learn and Practice Science and Literacy Skills

**Building upon the popular features of previous editions, the Fifth Edition of *Biology: Science for Life* helps students develop scientific thinking skills for a lifetime of critically evaluating scientific—and pseudoscientific—information.**

NEW!

**Sounds Right, But Is It?** activities are located at the end of each chapter and challenge students to answer a series of questions that address common biology-related misconceptions.

## SOUNDS RIGHT BUT IS IT?

A couple with two boys is considering having another child. While they are grateful to be fertile and to have had two healthy boys, they do think it would be fun to have a girl. In investigating their odds, they came across some data on sibships, or groups of siblings with the same parents. The study they saw showed that three-fourths of sibships of three contain members of both genders versus containing all boys or all girls. The couple now believes that their next child will very likely be a girl.

**If a couple has two boys, the odds are higher than normal that their next child will be a girl.**

Sounds right, but it isn't.

1. The probabilities of independent events, that is, events not affected by previous events, are multiplied to determine their combined probability. For example, when you flip a coin twice, the outcome of the second flip is independent of the outcome of the first flip. Therefore, the likelihood of flipping heads twice is one-half times one-half or one-fourth. What is the likelihood of flipping heads three times in a row?
2. Each fertilization of an egg by a sperm is an independent event. What is the probability that a couple will have three boys in a row?
3. The total probabilities of related independent events equal one. This means that the probability that a couple with three kids will have some outcome aside from three boys is seven-eighths. Describe, in terms of gender, what those sibships could contain.
4. While it is true that in sibships with three children seven-eighths would have at least one girl, how is looking at all the possible sibships that could be produced when there are three children different than the scenario outlined above?
5. Consider your answers to questions 1–4 and explain why the original statement bolded above sounds right, but isn't.

**Sounds Right, But Is It?** misconceptions include:

- "If a product is clinically proven to do what it advertises, that means it will work for you." —Chapter 1
- "The use of tanning beds is not only safe, it improves health." —Chapter 6
- "If a couple has two boys, the odds are higher than normal that their next child will be a girl." —Chapter 8
- "The human eye is too complex to have evolved by chance from nothing." —Chapter 11
- "There is always a chance that a brain-dead person will make a full recovery." —Chapter 17*
- "The number of vaccinations given to modern children is too much for the average immune system to handle." —Chapter 20*

…and more!

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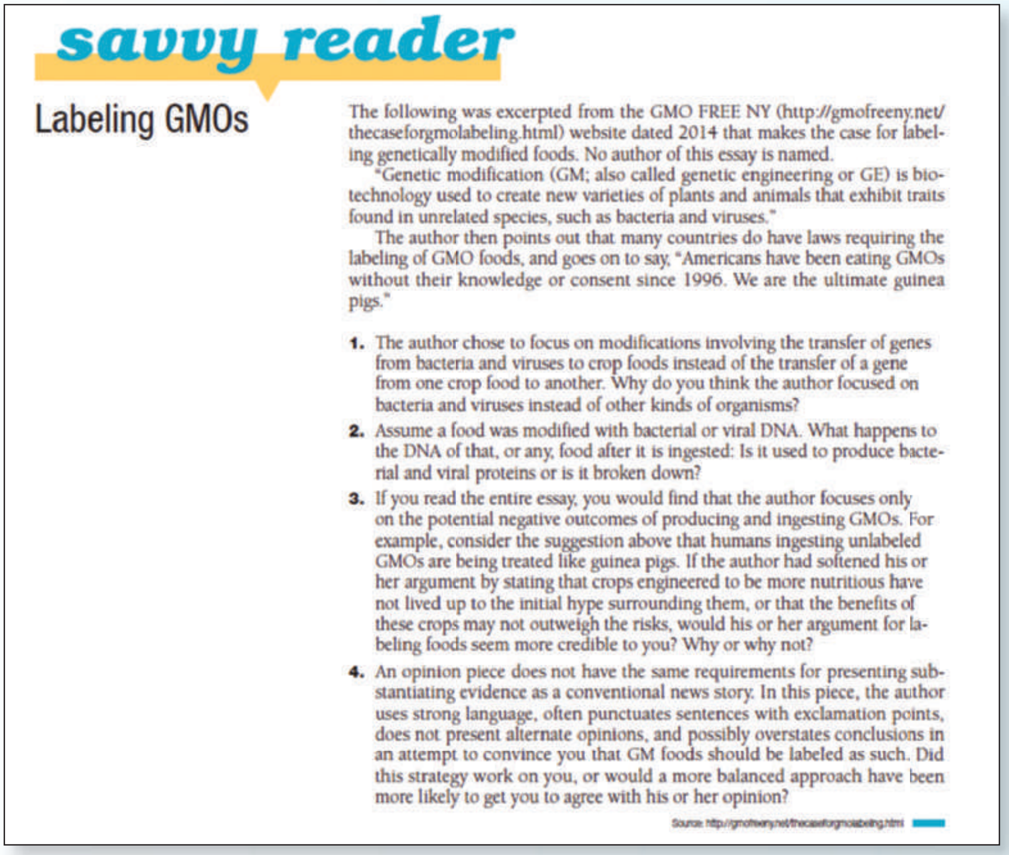
**NEW! Sounds Right, But Is It?** questions in the text are also available for in-class activities using Learning Catalytics.

* Chapters 17–25 are included in the expanded version of the text that includes coverage of animal and plant anatomy and physiology.

**Savvy Reader** activities in each chapter investigate a short excerpt from a variety of current news sources relating to discussions in the main chapter narrative. Critical thinking questions help students evaluate scientific information and data presented in the media.



## savvy reader

### Labeling GMOs

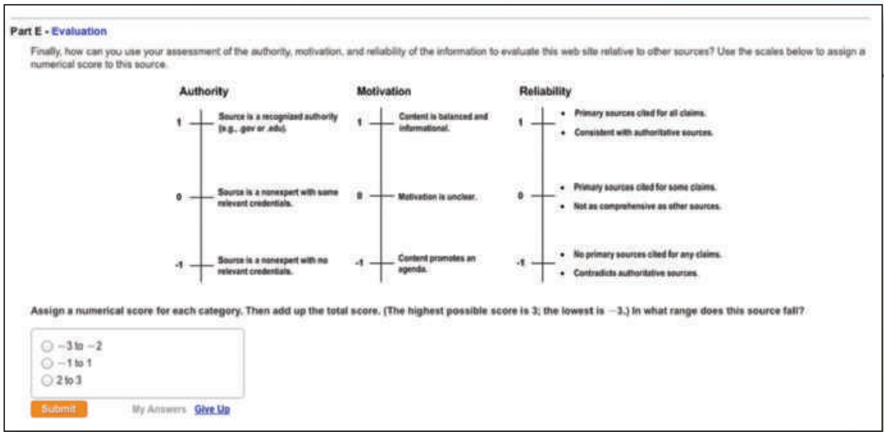
The following was excerpted from the GMO FREE NY (http://gmofreeny.net/thecaseforgmolabeling.html) website dated 2014 that makes the case for labeling genetically modified foods. No author of this essay is named.

"Genetic modification (GM; also called genetic engineering or GE) is biotechnology used to create new varieties of plants and animals that exhibit traits found in unrelated species, such as bacteria and viruses."

The author then points out that many countries do have laws requiring the labeling of GMO foods, and goes on to say, "Americans have been eating GMOs without their knowledge or consent since 1996. We are the ultimate guinea pigs."

1. The author chose to focus on modifications involving the transfer of genes from bacteria and viruses to crop foods instead of the transfer of a gene from one crop food to another. Why do you think the author focused on bacteria and viruses instead of other kinds of organisms?
2. Assume a food was modified with bacterial or viral DNA. What happens to the DNA of that, or any, food after it is ingested: Is it used to produce bacterial and viral proteins or is it broken down?
3. If you read the entire essay, you would find that the author focuses only on the potential negative outcomes of producing and ingesting GMOs. For example, consider the suggestion above that humans ingesting unlabeled GMOs are being treated like guinea pigs. If the author had softened his or her argument by stating that crops engineered to be more nutritious have not lived up to the initial hype surrounding them, or that the benefits of these crops may not outweigh the risks, would his or her argument for labeling foods seem more credible to you? Why or why not?
4. An opinion piece does not have the same requirements for presenting substantiating evidence as a conventional news story. In this piece, the author uses strong language, often punctuates sentences with exclamation points, does not present alternate opinions, and possibly overstates conclusions in an attempt to convince you that GM foods should be labeled as such. Did this strategy work on you, or would a more balanced approach have been more likely to get you to agree with his or her opinion?

Source: http://gmofreeny.net/thecaseforgmolabeling.html



Part E - Evaluation

Finally, how can you use your assessment of the authority, motivation, and reliability of the information to evaluate this web site relative to other sources? Use the scales below to assign a numerical score to this source.

| Score | Authority | Motivation | Reliability |
|---|---|---|---|
| 1 | Source is a recognized authority (e.g., .gov or .edu). | Content is balanced and informational. | • Primary sources cited for all claims. • Consistent with authoritative sources. |
| 0 | Source is a nonexpert with some relevant credentials. | Motivation is unclear. | • Primary sources cited for some claims. • Not as comprehensive as other sources. |
| -1 | Source is a nonexpert with no relevant credentials. | Content promotes an agenda. | • No primary sources cited for any claims. • Contradicts authoritative sources. |

Assign a numerical score for each category. Then add up the total score. (The highest possible score is 3; the lowest is −3.) In what range does this source fall?

- ○ −3 to −2
- ○ −1 to 1
- ○ 2 to 3

Submit   My Answers   Give Up

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**NEW! Savvy Reader: Evaluating Sources** activities ask students to examine a website, article, or video with a critical eye on the sources and methods used to convey information.

# Engage with Data and Visual Information

**The hallmark illustration style of previous editions has been enhanced in the Fifth Edition with new pedagogy to help students interpret data and other visual information.**

### Working with Data ▼

**Is the cancer risk associated with smoking and drinking additive or multiplicative? Explain your answer.**


**FIGURE 6.2 Alcohol and tobacco are synergists.** Smoking cigarettes while drinking is an unhealthy practice.

### Working with Data ▶

**The line looks relatively flat from 8000 B.C.E. to 1500 B.C.E., though the population doubled four times in that period. Was the population growing exponentially at this time?**

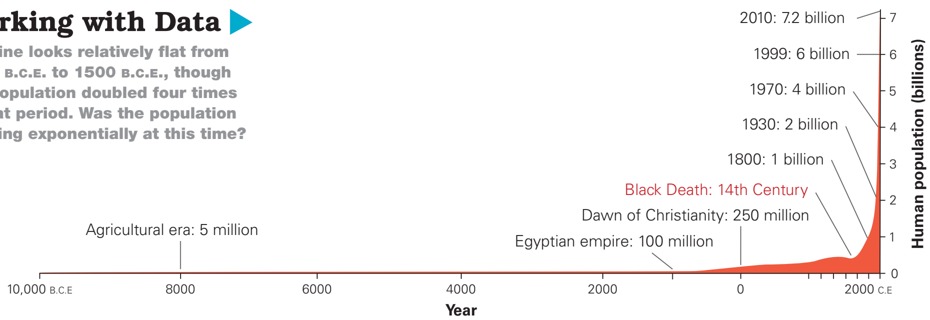



**FIGURE 14.3 Exponential growth.** The number of people on Earth grew relatively slowly until the eighteenth century. The rapid growth since then has occurred in proportion to the total, causing a J-shaped curve.

## NEW!

**Working with Data** questions have been added to the figure legends of selected graphs, tables, or figures, and challenge students to closely interpret the data.

## MasteringBiology®

**NEW! Working with Data** assignments are available for each chapter and ask students to analyze and apply their knowledge of biology to a graph or a set of data.

## Visualize This ▶

**Evaporation occurs when molecules at the surface of a liquid "escape" into a gaseous phase. Where would most of these escaped molecules appear on this figure and why?**

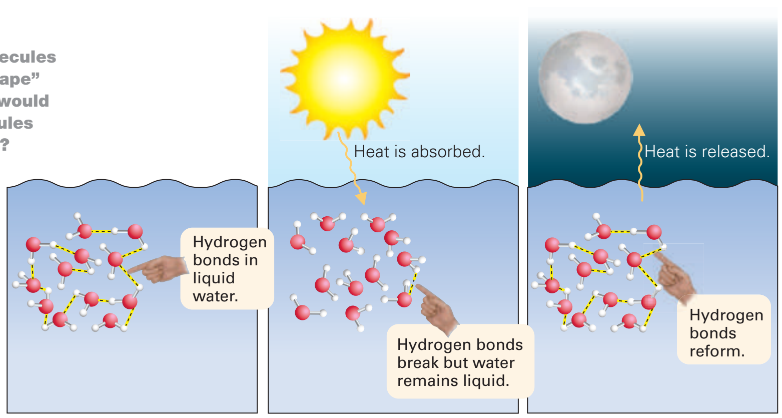



**FIGURE 5.3 Hydrogen bonding in water.** Hydrogen bonds break as they absorb heat and reform as water releases heat.

## Visualize This ▼

**Based only on structures shown in this figure, can you guess which parts of the virus are most likely to help it attach to a cell?**

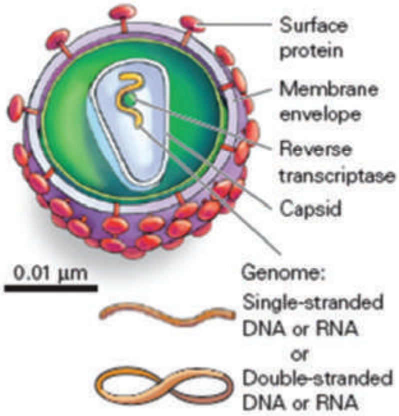
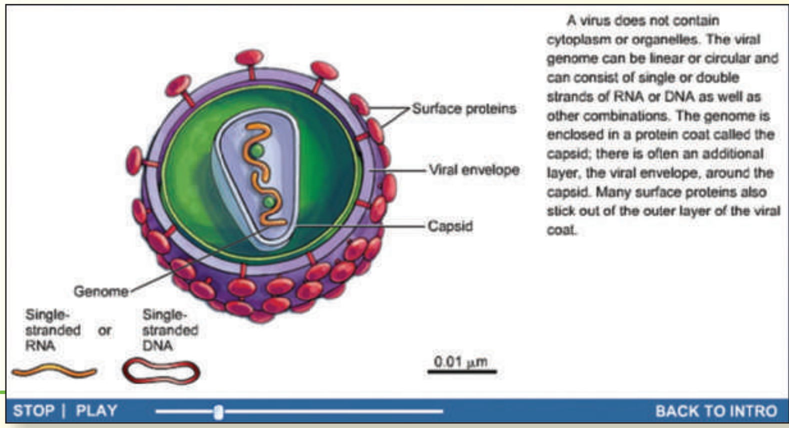



**FIGURE 20.4 Viral structure.** Viruses are composed of genetic material surrounded by a protein coat. Some viruses, including the one shown, are also surrounded by an envelope.

# EXPANDED!

**Visualize This** questions within selected figure legends encourage students to look more closely at figures to more fully understand their content.

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**Narrated Animations** of selected figures from the text can be assigned in MasteringBiology as activities with assessment questions that include answer-specific feedback and hints.

# Tools to Learn and Visualize Key Concepts

**Colleen Belk and Virginia Borden Maier incorporate many classroom-tested teaching techniques into the Fifth Edition prose and illustrations, making it easier for students to learn and remember unfamiliar biology concepts.**

### The Process of Evolution

Generally, the word *evolution* means "change," and the process of evolution reflects this definition as it applies to populations of organisms. A **biological population** is a group of individuals of the same species that is somewhat independent of other groups, often isolated from them by geography. **Biological evolution**, then, is a change in the characteristics of a biological population that occurs over the course of generations. The changes in populations that are considered evolutionary are those that are passed from parent to offspring via genes.

**evol-** means to unroll.

NEW!

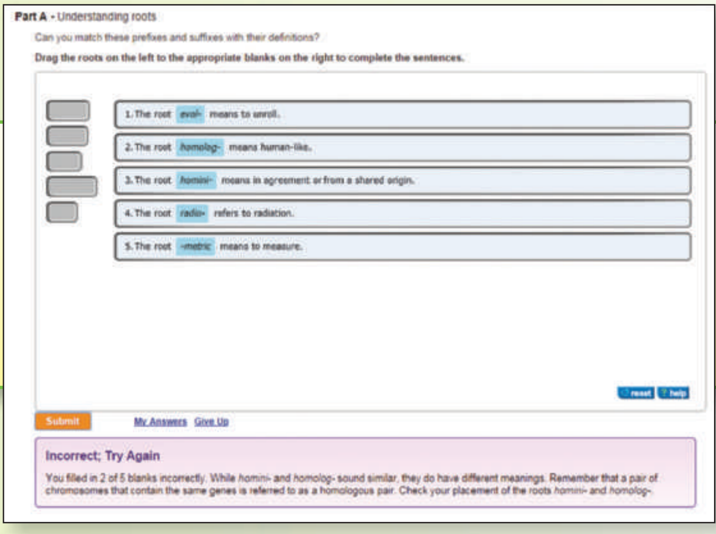
**Roots to Remember** references have been added in context within chapter discussions to help students learn the language of biology using word roots.

A **Roots to Remember summary** is also provided at the end of each chapter for quick reference.

### Roots to Remember

**These roots come from Greek or Latin and will help you decode the meaning of words:**

| | |
|---|---|
| **evol-** | means to unroll. Chapter term: *evolution* |
| **homini-** | means human-like. Chapter terms: *hominid, hominin* |
| **homolog-** | indicates similar or shared origin; from a word meaning "in agreement." Chapter terms: *homologous, homology* |
| **macro-** | means large scale. Chapter term: *macroevolution* |
| **-metric** | means to measure. Chapter term: *radiometric* |
| **micro-** | means extremely small. Chapter term: *microevolution* |
| **radio-** | is the combining form of radiation. Chapter term: *radiometric* |

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**Roots to Remember** coaching activities provide a fun, interactive way to learn word roots.

only one amino acid (phe, the three-letter abbreviation for phenylalanine).

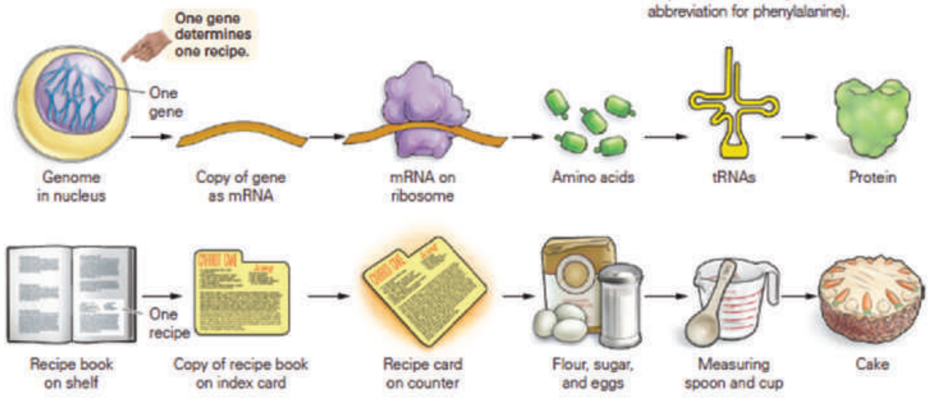



**FIGURE 9.6 Protein synthesis and cake baking.** A recipe book on a shelf resembles the genome in the nucleus of a cell. Copying one recipe onto an index card is similar to copying the gene to produce mRNA. The recipe card is placed on the kitchen counter, and the mRNA is placed on the ribosome. The ingredients for a cake are flour, sugar, butter, milk, and eggs. The ingredients to make a protein are various amino acids. The ingredients are measured in measuring spoons and cups (tRNAs) that are dedicated to one specific ingredient. The measuring spoons and cups bring the ingredients to the kitchen counter. The ingredients (amino acids) are always added according to the instructions specified by the original recipe (gene).

**Unique Visual Analogies** compare abstract science with familiar objects and experiences to help students grasp complex biology concepts.

**Illustrated Tables** organize information in one place and provide easy visual references to compare and contrast.

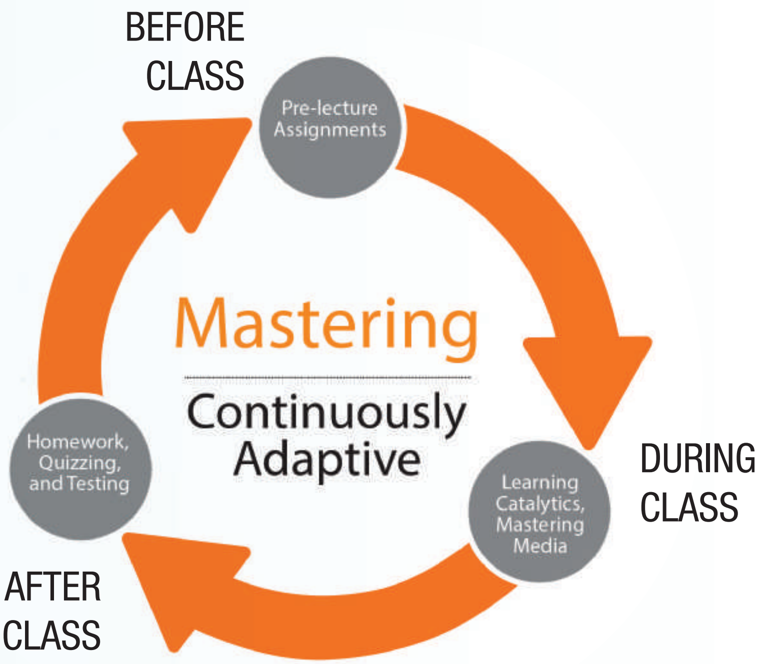
**TABLE 7.2 To what extent is IQ heritable?** A summary of various estimates of IQ heritability, their shortcomings, and the problems with using them to understand the role of genes in determining an individual's potential intelligence.

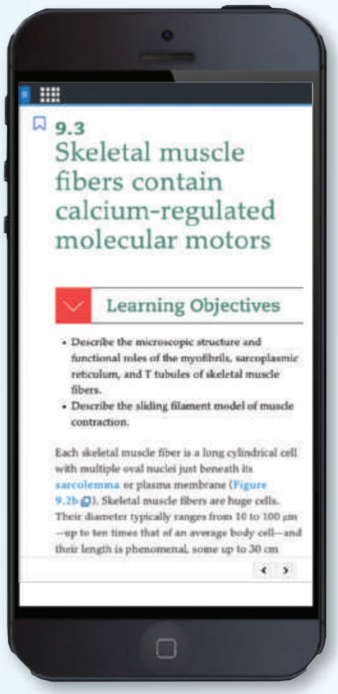
| Method of Measurement | Estimated Percentage of Phenotype Determined by Genes | Warnings When Interpreting This Result | Warnings That Apply to All Measurements of Heritability |
| --- | --- | --- | --- |
| Correlation between parents' IQ and children's IQ in a population | 42% | When parents and children live together, a correlation can't rule out environmental influence. | • Heritability values are specific to the populations for which they were measured. • High heritability for a trait does not mean that the trait will not respond to a change in the environment. • Heritability is a measure of a population, not an individual. |
| Natural experiment comparing IQ in pairs of identical twins versus nonidentical twins | 52% | Because identical twins are treated as more alike than nonidentical twins the heritability value could be an overestimate. | |
| Natural experiment comparing IQ of identical twins raised apart versus nonidentical twins raised apart | 72% | Small sample size may skew results. | |

# Support For Your Students Anytime, Anywhere

**MasteringBiology®**

**is an online homework, tutorial, and assessment program that helps you quickly master biology concepts and skills. Self-paced tutorials provide immediate wrong-answer feedback and hints to help keep you on track to succeed in the course.**

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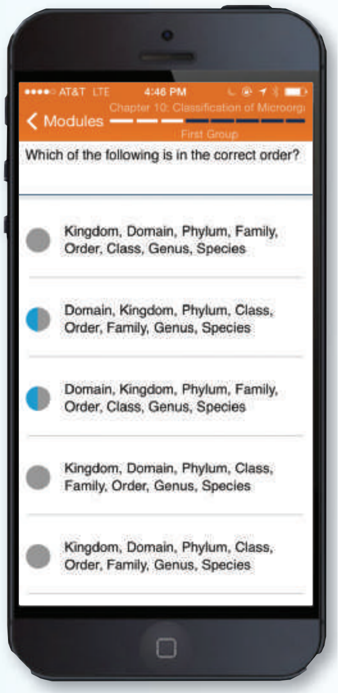



Dynamic Study Modules

## BEFORE CLASS

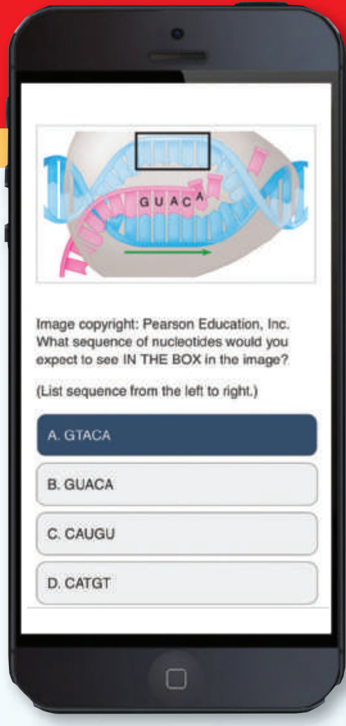
### NEW!

**eText 2.0** Allow your students to access their text anytime, anywhere.

- Now available on Smartphones and Tablets.
- Seamlessly integrated digital and media resources.
- Fully accessible (screen-reader ready).
- Configurable reading settings, including resizable type and night reading mode.
- Instructor and student note-taking, highlighting, bookmarking and search.

### NEW!

**Dynamic Study Modules** help students acquire, retain, and recall information faster and more efficiently than ever before. These convenient practice questions and detailed review explanations can be accessed using a smartphone, tablet, or computer.




## DURING CLASS

### NEW!

**Learning Catalytics** is an assessment and classroom activity system that works with any web-enabled device and facilitates collaboration with your classmates. Your MasteringBiology subscription with eText includes access to Learning Catalytics.

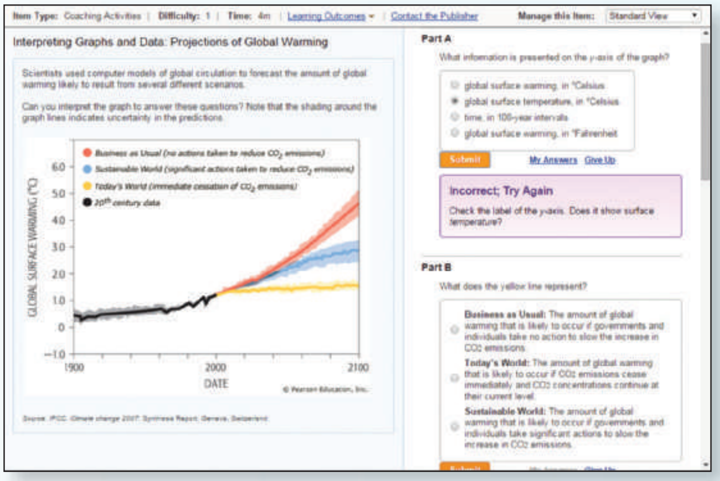
### NEW!

**Everyday Biology Videos** briefly explore interesting and relevant biology topics that relate to concepts in the course. These 20 videos, produced by the BBC, can be shown in class or assigned as homework in MasteringBiology.

## AFTER CLASS

**A wide range of question types and activities** are available for homework assignments, including the following **NEW** assignment options for the Fifth Edition:

- **Interactive Storyline Activities** tie the storyline of the chapter to key science concepts.
- **Working with Data questions** require you to analyze and apply your knowledge of biology to a graph or set of data.
- **Savvy Reader Evaluating Media activities** challenge you to evaluate various information from websites, articles, and videos.



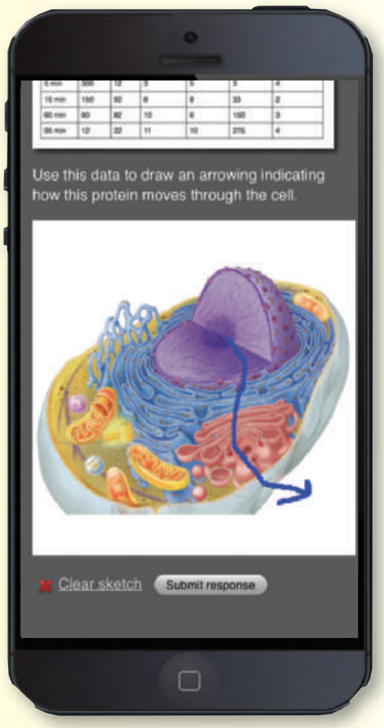
# New Resources for Flipped Classrooms and More

**New resources save valuable time both during course prep and during class.**

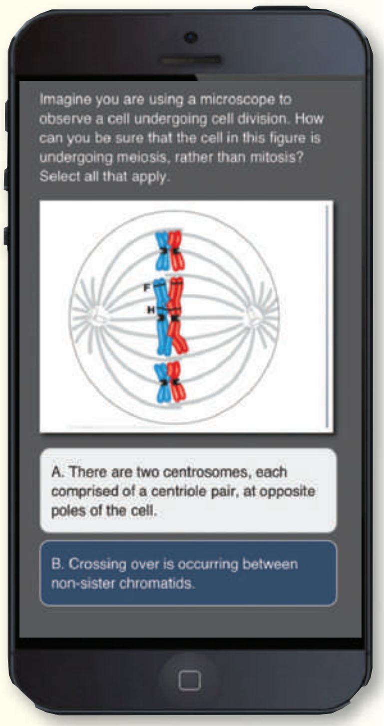
## NEW!

**Learning Catalytics** is a "bring your own device" assessment and classroom activity system that expands the possibilities for student engagement. Using Learning Catalytics, instructors can deliver a wide range of auto-gradable or open-ended questions that test content knowledge and build critical thinking skills. Eighteen different answer types provide great flexibility, including:

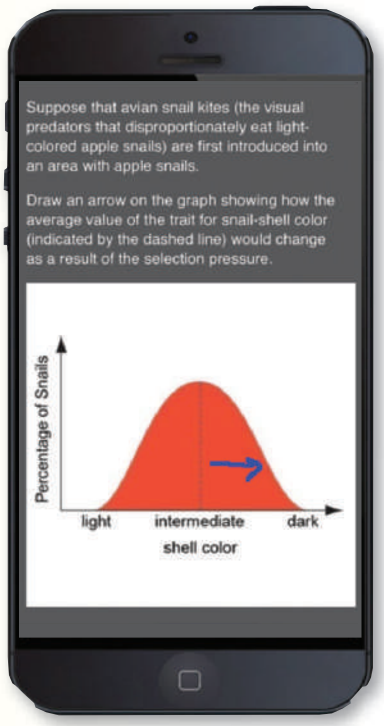
### SKETCH/DIRECTION




### MANY CHOICE




### REGION

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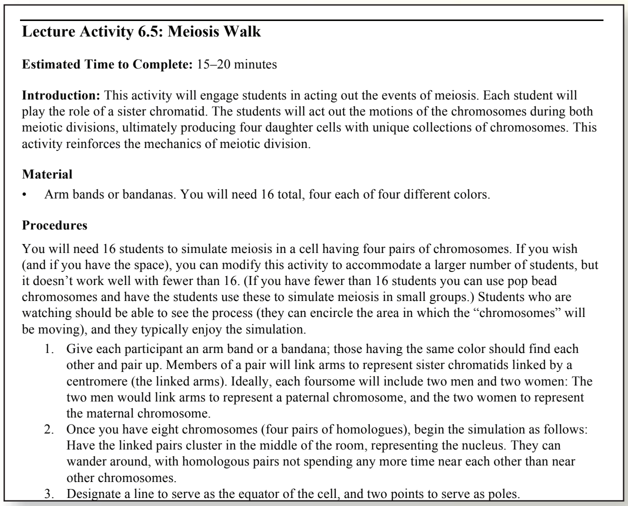
MasteringBiology users may select from Pearson's library of Learning Catalytics questions, including two **NEW** types of questions developed from the **Stop and Stretch** and **Sounds Right, But Is It?** questions in the Fifth Edition of *Biology: Science for Life.*

NEW!

**“Flipped Classroom” Instructor’s Manual** includes many activities that have been tested by Colleen Belk, Virginia Borden Maier, and their colleagues in their own classes. Each text chapter is supplemented with a selection of in-class activities, suggestions for student “pre-work” outside of class, media references, and more. In addition, teaching tip videos by the authors are available in MasteringBiology.



**Lecture Activity 6.5: Meiosis Walk**

**Estimated Time to Complete:** 15–20 minutes

**Introduction:** This activity will engage students in acting out the events of meiosis. Each student will play the role of a sister chromatid. The students will act out the motions of the chromosomes during both meiotic divisions, ultimately producing four daughter cells with unique collections of chromosomes. This activity reinforces the mechanics of meiotic division.

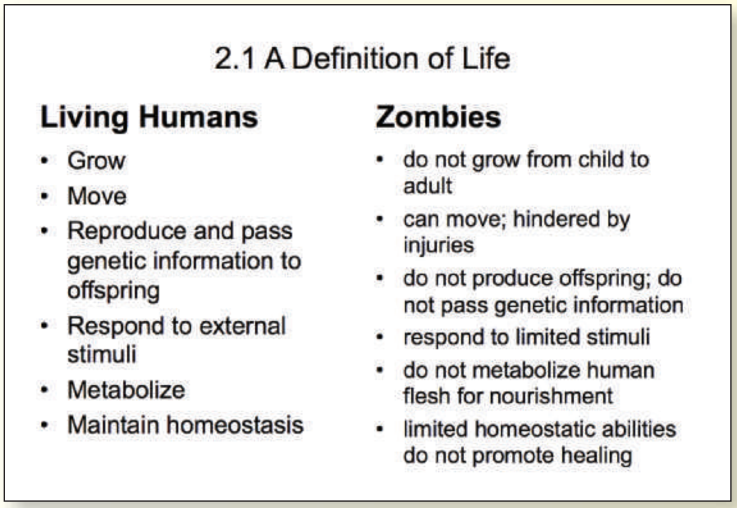
**Material**

- Arm bands or bandanas. You will need 16 total, four each of four different colors.

**Procedures**

You will need 16 students to simulate meiosis in a cell having four pairs of chromosomes. If you wish (and if you have the space), you can modify this activity to accommodate a larger number of students, but it doesn’t work well with fewer than 16. (If you have fewer than 16 students you can use pop bead chromosomes and have the students use these to simulate meiosis in small groups.) Students who are watching should be able to see the process (they can encircle the area in which the “chromosomes” will be moving), and they typically enjoy the simulation.

1. Give each participant an arm band or a bandana; those having the same color should find each other and pair up. Members of a pair will link arms to represent sister chromatids linked by a centromere (the linked arms). Ideally, each foursome will include two men and two women: The two men would link arms to represent a paternal chromosome, and the two women to represent the maternal chromosome.
2. Once you have eight chromosomes (four pairs of homologues), begin the simulation as follows: Have the linked pairs cluster in the middle of the room, representing the nucleus. They can wander around, with homologous pairs not spending any more time near each other than near other chromosomes.
3. Designate a line to serve as the equator of the cell, and two points to serve as poles.




NEW!

**Storyline PPTs** for instructors allow easy integration of the stories into lecture. The PPT presentations include integrated story examples and video launcher segments to engage students.

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These valuable resources are available to adopting instructors and can be downloaded from the Instructor Resources area of MasteringBiology.

# Acknowledgments

## Reviewers

Each chapter of this book was thoroughly reviewed several times as it moved through the development process. Reviewers were chosen on the basis of their demonstrated talent and dedication in the classroom. Many of these reviewers are already trying various approaches to actively engage students in lectures and to raise the scientific literacy and critical thinking skills among their students. Their passion for teaching and commitment to their students were evident throughout this process. These devoted individuals scrupulously checked each chapter for scientific accuracy, readability, and coverage level.

All of these reviewers provided thoughtful, insightful feedback, which improved the text significantly. Their efforts reflect their deep commitment to teaching nonmajors and improving the scientific literacy of all students. We are very thankful for their contributions.

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## The Book Team

We feel blessed to be able to work with Star MacKenzie, our editor for the last three editions, and our new development editor Leata Holloway. Both of these women are insightful, funny, kind, and generous with their time. Their commitment to producing an excellent book that meets the needs of students and instructors is unrivaled in the industry.

This book is dedicated to our families, friends, and colleagues who have supported us over the years. Having loving families, great friends, and a supportive work environment has enabled us to make this heartfelt contribution to non-majors biology education.

COLLEEN BELK AND
VIRGINIA BORDEN MAIER

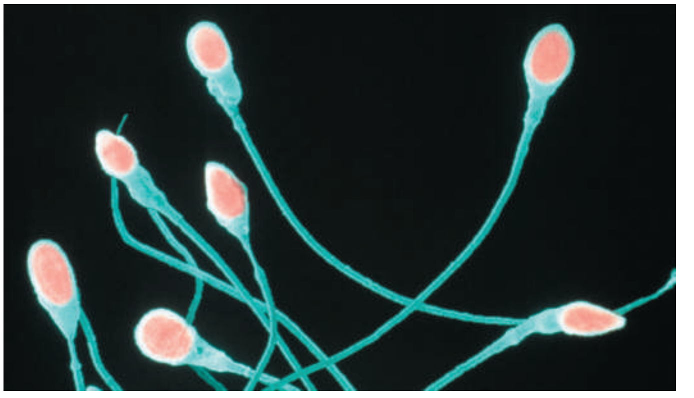
*"Because science, told as a story, can intrigue and inform the non-scientific minds among us, it has the potential to bridge the two cultures into which civilization is split—the sciences and the humanities. For educators, stories are an exciting way to draw young minds into the scientific culture."*

—E.O. WILSON

# Brief Contents

# Contents





UNIT FIVE
# Animal Structure and Function



CHAPTER 1

# Can Science Cure the Common Cold?

**Another cold! What can I do?**

# Introduction to the Scientific Method

We have all been there—you just recover from one bad head cold and on a morning soon after you notice that scratchy feeling in your throat that signals a new one is about to begin. It is always at the worst time, too, when you have an important exam coming up, a term paper due, and a packed social calendar. Why are you sick yet again? What can you do about it?

If you ask your friends and relatives, you will hear the usual advice on how to prevent and treat colds: Take massive doses of vitamin C. Suck on zinc lozenges. Drink plenty of echinacea tea. Meditate. Get more rest. Exercise vigorously every day. Put that hat on when you go outside! You are left with an overwhelming list of options, often contradictory and some contrary to common sense.

**Take massive doses of vitamin C?**

**Drink echinacea tea?**

If you keep up with health news, you may be even more confused. One website reports that a popular over-the-counter cold treatment is effective, while a local TV news story details the risks of using this remedy and highlights its ineffectiveness. How do you decide what to do?

Faced with this bewildering situation, most people follow the advice that makes the most sense to them, and if they find they still feel terrible, they try another remedy. Testing ideas and discarding ones that don't work is a kind of "everyday science." This technique has its limitations—for example, even if you feel better after trying a new cold treatment, you can't know if your recovery occurred because the treatment was effective or because the cold was ending anyway.

What professional scientists do is a more refined version of this everyday science—using strategies that help eliminate other possible explanations for a result. And while some fields of science may use unintelligible words or complicated and expensive equipment, the basic process for testing ideas is simple and universal to all areas of science. An understanding of this process can help you evaluate information about many issues that may concern and intrigue you—from health issues, to global warming, to the origin of life and the universe—with more confidence. In this chapter, we introduce you to the powerful process scientists use by asking the question we've considered here: Is there a cure for the common cold?

**How would a scientist determine which advice is best?**

## 1.1 The Process of Science

The term *science* can refer to a body of knowledge—for example, the science of **biology** is the study of living organisms. You may believe that science requires near-perfect recall of specific sets of facts about the world. In reality, this goal is impossible and unnecessary—we do have reference books, after all. The real action in science is not memorizing what is already known but using the process of science to discover something new and unknown.

**bio-** means life.

**-ology** means the study of or branch of knowledge about.

This process—making observations of the world, proposing ideas about how something works, testing those ideas, and discarding (or modifying) our ideas in response to the test results—is the essence of the **scientific method.** The scientific method allows us to solve problems and answer questions efficiently and effectively. Can we use the scientific method to solve the complicated problem of preventing and treating colds?

### The Nature of Hypotheses

The statements our friends and family make about which actions will help us remain healthy (for example, the advice to wear a hat) are in some part based on the advice giver's understanding of how our bodies resist colds. Ideas about "how things work" are called **hypotheses.** Or, more formally, a hypothesis is a proposed explanation for one or more observations.

Hypotheses in biology come from knowledge about how the body and other biological systems work, experiences in similar situations, our understanding of other scientific research, and logical reasoning; they are also shaped by our creative mind (**FIGURE 1.1**). When your mom tells you to dress warmly to avoid colds, she is basing her advice on the following hypothesis: Becoming chilled makes you more susceptible to illness.

**hypo-** means under, below, or basis.

The hallmark of science is that hypotheses are subject to rigorous testing. Therefore, scientific hypotheses must be **testable—**it must be possible to evaluate a hypothesis through observations of the measurable universe. Not all hypotheses are testable. For instance, the statement that "colds are generated by disturbances in psychic energy" is not a scientific hypothesis because psychic energy has not been demonstrated to exist and thus cannot be measured in a test.

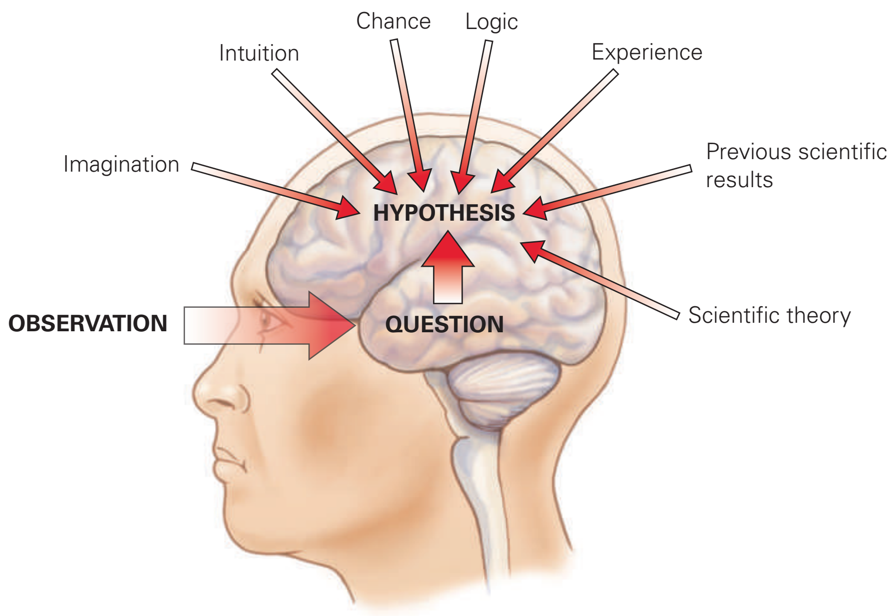



**FIGURE 1.1 Hypothesis generation.** All of us generate hypotheses. Many different factors, both logical and creative, influence the development of a hypothesis. Scientific hypotheses are both testable and falsifiable.

**Visualize This**

**Most colleges require students who are science majors to take courses in the humanities and social sciences, just as they require students in these majors to take science courses. What skills do scientists gain from humanities and social sciences that can help them be better scientists?**

In addition, hypotheses that require the intervention of a supernatural force cannot be tested scientifically. If something is **supernatural,** it is not constrained by any laws of nature, and its behavior cannot be predicted using our current understanding of the natural world. A scientific hypothesis must also be **falsifiable;** that is, an observation or set of observations could potentially prove it false. The hypothesis that exposure to cold temperatures increases your susceptibility to colds is falsifiable; we can imagine an observation that would cause us to reject this hypothesis (for instance, the observation that people exposed to cold temperatures do not catch more colds than people protected from chills). Of course, not all hypotheses are proved false, but it is essential in science that incorrect ideas be discarded, which can occur only if it is *possible* to prove those ideas false. Lack of falsifiability is another reason supernatural hypotheses cannot be scientific. Because a supernatural force can cause any possible result, hypotheses that rely on supernatural forces cannot be falsified.

Finally, statements that are value judgments, such as, "It is wrong to cheat on an exam," are not scientific because different people have different ideas about right and wrong. It is impossible to falsify these types of statements. To find answers to questions of morality, ethics, or justice, we turn to other methods of gaining understanding—such as philosophy and religion.

## Scientific Theories

Most hypotheses fit into a larger picture of scientific understanding. We can see this relationship when examining how research upended a commonly held belief about diet and health—that chronic stomach and intestinal inflammation is caused by eating too much spicy food. This belief directed the standard medical practice for ulcer treatment for decades. Patients with ulcers were prescribed drugs that reduced stomach acid levels and advised to avoid eating acidic or highly spiced foods. These treatments were rarely successful, and ulcers were considered chronic problems.

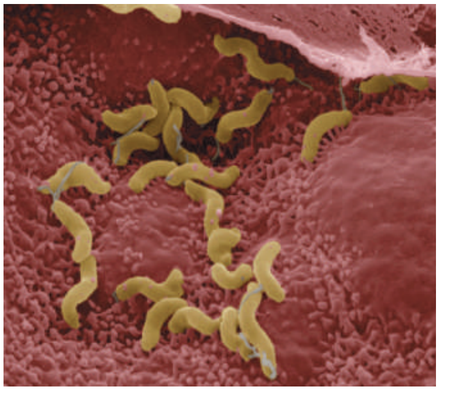
In 1982, Australian scientists Robin Warren and Barry Marshall discovered that the bacterium *Helicobacter pylori* was present in nearly all samples of ulcer tissue that they examined (**FIGURE 1.2**). From this observation, Warren and Marshall reasoned that *H. pylori* infection—invasion of the stomach wall by the bacteria—was the cause of most ulcers. Barry Marshall even tested this hypothesis on himself by consuming live *H. pylori*. He subsequently suffered from acute stomach pain.

Warren and Marshall's colleagues were at first unconvinced that ulcers could have such a simple cause. Today, the hypothesis that *H. pylori* infection is responsible for most ulcers is accepted as fact. Why is this the case? First, no reasonable alternative hypotheses about the causes of ulcers (for instance, consumption of spicy foods) has been consistently supported by hypothesis tests; and second, the hypothesis has not been rejected—that is, there have been no carefully designed experiments that show that *H. pylori* removal fails to cure most ulcers.

The third reason that the relationship between *H. pylori* and ulcers is considered fact is that it conforms to a well-accepted scientific principle, namely, the germ theory of disease. A **scientific theory** is an explanation for a set of related observations that is based on well-supported hypotheses from several different, independent lines of research. The basic premise of germ theory is that microorganisms (that is, organisms too small to be seen with the naked eye) are the cause of some or all human diseases.

The biologist Louis Pasteur first observed that bacteria cause milk to become sour. From this observation, he reasoned that these same types of organisms could injure humans. Later, Robert Koch demonstrated a link between anthrax bacteria and a specific set of fatal symptoms in mice, providing additional evidence for the theory. Germ theory is further supported by the observation that

(a)



(b)

**FIGURE 1.2 A scientific breakthrough.** (a) *Helicobacter pylori* on stomach lining (image from electron microscope). (b) Robin Warren and Barry Marshall won the 2005 Nobel Prize in Medicine for their discovery of the link between *H. pylori* and ulcers.

antibiotic treatment that targets particular microorganisms can cure certain illnesses—as is the case with bacteria-caused ulcers.

In everyday speech, the word *theory* is synonymous with untested ideas based on little information. In contrast, scientists use the term when referring to well-supported ideas of how the natural world works. The supporting foundation of all scientific theories is multiple hypothesis tests.

**If you ask your friends and relatives, you will hear the usual advice on how to prevent and treat colds.**

## The Logic of Hypothesis Tests

One common hypothesis about cold prevention is that taking vitamin C supplements keeps you healthy. This hypothesis is very appealing, especially given the following generally accepted facts:

1. Fruits and vegetables contain a lot of vitamin C.
2. People with diets rich in fruits and vegetables are generally healthier than people who skimp on these food items.
3. Vitamin C is known to be an anti-inflammatory agent, reducing throat and nose irritation.

With these facts in mind, we can state the following testable and falsifiable hypothesis: Consuming vitamin C decreases the risk of catching a cold. This hypothesis makes sense given the statements just listed and the experiences of the many people who insist that vitamin C keeps them healthy.

The process used to construct this hypothesis is called **inductive reasoning**—combining a series of specific observations (here, statements 1–3) to discern a general principle. Inductive reasoning is an essential tool for understanding the world. However, a word of caution is in order: Just because the inductive reasoning that led to a hypothesis seems to make sense does not mean that the hypothesis is necessarily true. The example that follows demonstrates this point.

**induc-** means to rely on reason to derive principles (also, to cause to happen).

Consider the ancient hypothesis that the sun revolves around Earth. This hypothesis was induced based on the observations that the sun rose in the east every morning, traveled across the sky, and set in the west every night. For almost all of history, this hypothesis was considered to be a "fact" by nearly all of Western society. It wasn't until the early seventeenth century that this hypothesis was overturned—as the result of Galileo Galilei's observations of Venus. His observations proved false the hypothesis that the sun revolved around Earth. Galileo's work helped to confirm the more modern hypothesis, proposed by Nicolaus Copernicus, that Earth revolves around the sun.

So, even though the hypothesis about vitamin C is sensible, it needs to be tested to see if it can be proved false. Hypothesis testing is based on **deductive reasoning** or deduction. Deduction involves using a general principle to predict an expected observation. This **prediction** concerns the outcome of an action, test, or investigation. In other words, the prediction is the result we expect from a hypothesis test.

**deduc-** means to reason out, working from facts.

Deductive reasoning takes the form of "if/then" statements. That is, if our idea is correct, then we expect to observe a specific outcome from a hypothesis test. A prediction based on the vitamin C hypothesis could be: *If* vitamin C decreases the risk of catching a cold, *then* people who take vitamin C supplements with their regular diets will experience fewer colds than will people who do not take supplements.

**STOP & STRETCH** Consider the following scenario: Your coworker, Homer, is a notorious doughnut lover who has a nose for free food. You walk into the break room one morning to discover a box from the doughnut shop that is already completely empty. According to this information, what most likely happened to the doughnuts? Is this inductive or deductive reasoning?

Deductive reasoning, with its resulting predictions, is a powerful method for testing hypotheses. However, the structure of such a statement means that hypotheses can be clearly rejected if untrue but impossible to prove if true. This shortcoming is illustrated using the if/then statement concerning vitamin C and colds (**FIGURE 1.3**).

Consider the possible outcomes of a comparison between people who supplement with vitamin C and those who do not. People who take vitamin C supplements may suffer through more colds than people who do not; they may have the same number of colds as the people who do not supplement; or supplementers may in fact experience fewer colds. What does each of these results tell us about the hypothesis?

If, in a well-designed test, people who take vitamin C have more colds or the same number of colds as those who do not supplement, then the hypothesis that vitamin C provides protection against colds can be clearly rejected. But what if people who supplement with vitamin C do experience fewer colds? If this is the case, then we can only say that the hypothesis has been supported and not disproven.

Why is it impossible to say from this possible experimental result that the hypothesis that vitamin C prevents colds is true? Because there are **alternative hypotheses** that explain why people with different vitamin-taking habits vary in their cold susceptibility. In other words, demonstrating the truth of the *then* portion of a deductive statement does not prove that the *if* portion is true.

**STOP & STRETCH** Consider this if/then statement: If your coworker Homer ate all the doughnuts, then there won't be any doughnuts left in the box that was placed in the break room 30 minutes ago. Imagine you find that the doughnuts are all gone—did you just prove that Homer ate them? Why or why not?

Consider the alternative hypothesis that frequent exercise reduces susceptibility to catching a cold. And suppose that people who take vitamin C supplements are more likely to engage in regular exercise. If both of these hypotheses are true, then the prediction that vitamin C supplementers experience fewer colds than people who do not supplement would be true but not because the original hypothesis (vitamin C reduces the risk of colds) is true. Instead, people who take vitamin C supplements experience fewer colds because they are also more likely to exercise, and it is exercise that reduces cold susceptibility.

A hypothesis that seems to be true because it has not been rejected by an initial test may be rejected later because of a different test. This is what happened to the hypothesis that vitamin C consumption reduces susceptibility to colds. The argument for the power of vitamin C was popularized in 1970 by Nobel Prize–winning chemist Linus Pauling. Pauling based his assertion—that large doses of vitamin C reduce the incidence of colds by as much as 45%—on the results of a few studies that had been published between the 1930s and 1970s. However, repeated, careful tests of this hypothesis have since failed to support it. In many of the studies Pauling cited, it appears that alternative hypotheses explain the difference in cold incidence between vitamin C supplementers and nonsupplementers. Today, most health scientists agree that the hypothesis that vitamin C prevents colds has been convincingly falsified.

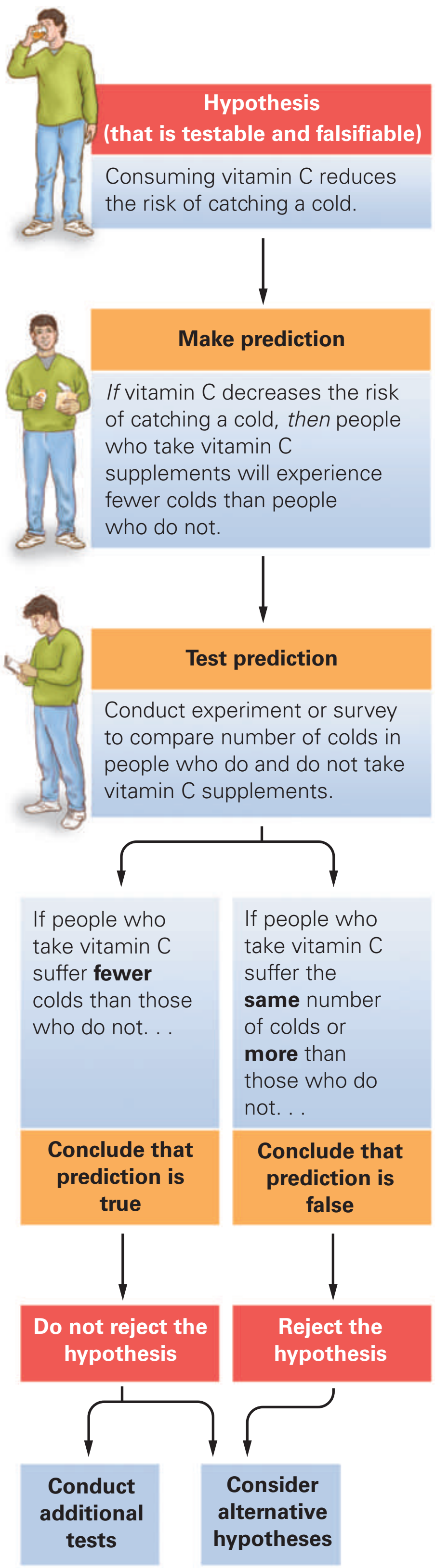



**FIGURE 1.3 The scientific method.** Tests of hypotheses follow a logical path. This flowchart illustrates the process of deduction as practiced by scientists.

## Visualize This ▶

**According to this flowchart, scientists should consider alternative hypotheses even if their hypothesis is supported by their research. Explain why this is the case.**

The example of the vitamin C hypothesis also highlights a challenge of communicating scientific information. You can see why the belief that vitamin C prevents colds is so widespread. If you don't know that scientific knowledge relies on rejecting incorrect ideas, a book by a Nobel Prize–winning scientist may seem like the last word on the benefits of vitamin C. It took many years of careful research to show that this "last word" was, in fact, wrong.

## 1.2 Hypothesis Testing

The previous discussion may seem discouraging: How can scientists determine the truth of any hypothesis when there is always a chance that the hypothesis could be falsified? Even if one of the hypotheses about cold prevention is supported, does the difficulty of eliminating alternative hypotheses mean that we will never know which approach is truly best? The answer is yes—and no.

Hypotheses cannot be proven absolutely true; it is always possible that the true cause of a phenomenon may be found in a hypothesis that has not yet been tested. However, in a practical sense, a hypothesis can be proven beyond a reasonable doubt. That is, when one hypothesis has not been disproven through repeated testing and all reasonable alternative hypotheses have been eliminated, scientists accept that the well-supported hypothesis is, in a practical sense, true. *Truth* in science can therefore be defined as *what we know and understand based on all currently available information*. But scientists always leave open the possibility that what seems true now may someday be proven false.

An effective way to test many hypotheses is through rigorous scientific experiments. Experimentation has enabled scientists to prove beyond a reasonable doubt that the common cold is caused by a virus. A virus is a microscopic entity with a simple structure—it typically contains a short strand of genetic material and a few proteins encased in a relatively tough protein shell and sometimes surrounded by a membrane. A virus must infect a cell to reproduce. Of the over 200 types of viruses that are known to cause the common cold, most infect the cells in our noses and throats. The sneezing, coughing, congestion, and sore throat of a cold appear to result from the body's protective response—established by our immune system—to a viral invasion (**FIGURE 1.4**).

As you may know, if we survive a viral infection, we are unlikely to experience a recurrence of the disease the virus causes. For example, it is extremely rare to suffer from chicken pox twice because one exposure to the chicken pox virus (through either infection or vaccination) usually provides lifelong immunity to future infection. The huge variety of cold viruses makes immunity to the common cold—and the development of a vaccine to prevent it—very improbable. Scientists thus focus their experimental research about common colds on methods of prevention and treatment.

### The Experimental Method

**Experiments** are sets of actions or observations designed to test specific hypotheses. Generally, an experiment allows a scientist to control the conditions that may affect the subject of study. Manipulating the environment allows a scientist to eliminate some alternative hypotheses that may explain the result.

Experimentation in science is analogous to what a mechanic does when diagnosing a car problem. There are many reasons why a car engine might not start. If a mechanic begins by tinkering with numerous parts to apply all possible fixes before restarting the car, she will not know what exactly caused the problem (and will have an unhappy customer who is charged for unnecessary parts and labor). Instead, a mechanic begins by testing the battery for

## Visualize This

**Find two points in this process where intervention by drugs or other treatment could disrupt either the virus or the immune response and therefore lead to fewer cold symptoms.**

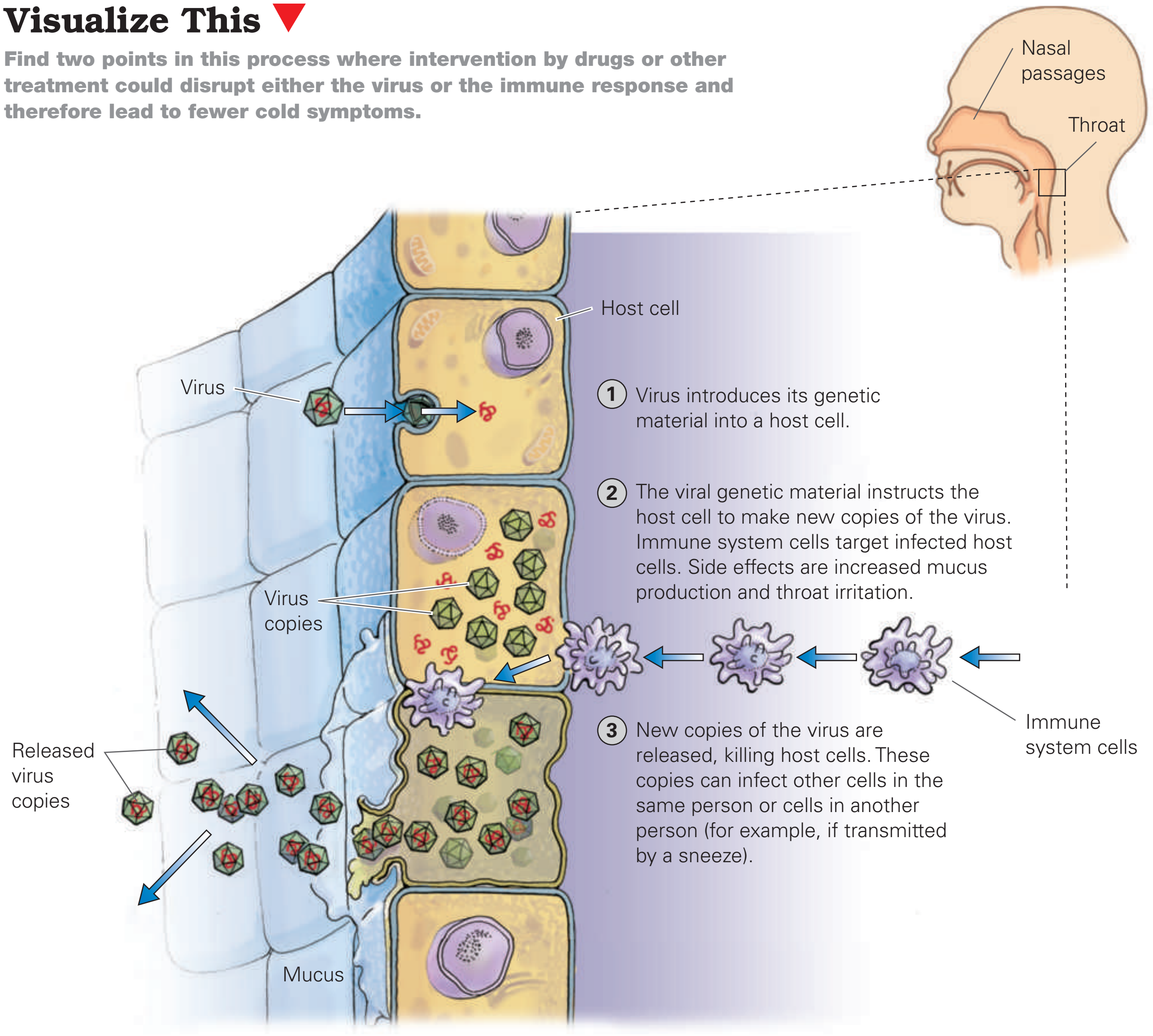



**FIGURE 1.4 A cold-causing virus.** A rhinovirus causes illness by invading nose and throat cells and using them as "factories" to make virus copies. Cold symptoms result from immune system attempts to eliminate the virus.

power; if the battery is charged, then she checks the starter motor; if the car still doesn't start, she looks over the fuel pump; and she continues in this manner until identifying the problem. Likewise, a scientist systematically attempts to eliminate hypotheses that do not explain a particular phenomenon.

Not all scientific hypotheses can be tested through experimentation. For instance, hypotheses about how life on Earth originated or the cause of dinosaur extinction are usually not testable in this way. These hypotheses are instead tested using careful observation of the natural world. For instance, the examination of fossils and other geological evidence allows scientists to test hypotheses regarding the extinction of the dinosaurs (**FIGURE 1.5**).

**FIGURE 1.5 Testing hypotheses through observation.** The fossil record provides a source of data to test hypotheses about evolutionary history.