BIOLOGY

Concepts and Investigations

Mariëlle Hoefnagels

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The University of Oklahoma

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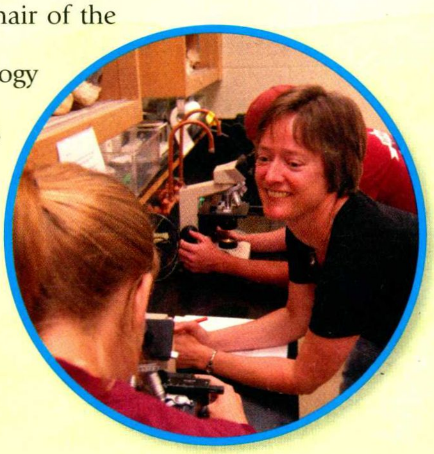
About the Author

Mariëlle Hoefnagels is an associate professor in the departments of Botany/Microbiology and Zoology at The University of Oklahoma where she teaches both traditional and online courses in introductory biology. She has received the University of Oklahoma General Education Teaching Award and the Longmire Prize, the Teaching Scholars Award from the College of Arts and Sciences. She has also been awarded honorary memberships in several student honor societies.

Dr. Hoefnagels received her B.S. in environmental science from the University of California at Riverside, her M.S. in soil science from North Carolina State University and her Ph.D. in plant pathology from Oregon State University in 1997. Her dissertation work focused on the use of bacterial biological control agents to reduce the spread of fungal pathogens on seeds. Her recent publications have focused on the creation of investigative teaching laboratories and methods for teaching experimental design in beginning and advanced biology classes. She frequently gives presentations on study skills and related topics to student groups across campus.

She has also served as Managing Editor and Chair of the Website Committee for the Association of Biology Laboratory Education and is a featured speaker at OU's annual freshman seminar for Women in Science and Engineering. Marielle is also a member of the National Association of Biology Teachers and the Mycological Society of America. Her hobbies include reading, traveling, gardening, and playing volleyball.



Dedication

To my students

MARIËLLE HOEFNAGELS

Preface: Thinking for Life

Investigating Life

Biology—the science of life—is central to our lives and our planet. On a typical morning, you use a toothbrush to scrub the bacteria off your teeth, decide what to wear based (in part) on your ability to regulate your body temperature, choose clothes made partly of natural fibers such as cotton or wool, and eat a breakfast composed of foods produced by other organisms. And that's all before leaving the house! True, you could have done these things even without opening this book. But learning about biology should help you to understand much more about your world.

Nutrition, cancer, HIV/AIDS, global climate change, water quality, endangered species, stem cells, the spread of drug-resistant bacteria, and countless other matters have their foundation in biology. This book offers concrete medical applications such as understanding how to stop the spread of disease, why you need to take the whole prescription of antibiotics, and why there are few drugs without side effects. At the other end of the spectrum, it's important to evaluate the arguments and issues surrounding global climate change.

Connecting these two ideas is the relationship between environmental quality and the virulence of disease-causing organisms. I hope that after reading this book you will be better able to understand and evaluate items in the news, make these types of connections yourself, become a more thoughtful voter, and, most importantly, develop a greater appreciation for the amazing, ever-changing world around you. I designed this book to convey the general concepts of biology and to connect them to your life.

Biological Concepts are the Result of Scientific Inquiry

Every biology textbook explores the process of science as a way of learning about the natural world, but this book is unique in that each chapter reinforces the importance of scientific inquiry with a section titled "Investigating Life." These capstone concepts each explain one study that sheds light on an evolutionary topic related to the chapter's content. In each case, the focus is on how scientists developed and tested a specific hypothesis. You will see that the scientific community consists of a global team of clever and creative professionals.

Often, the experiment profiled in an Investigating Life section reinforces the connections between multiple fields of biology. Genetics and natural selection weave together in a discussion of speciation in monkeyflowers, for example, and DNA sequence analysis is critical to a study of the evolution of the human brain.

Model Organisms: A related feature of this textbook reinforces these connections and the process of science. "Focus on Model Organisms" boxes appear in each chapter of Unit 4, The Diversity of Life. Each box highlights one or two species that have made extraordinary contributions to biology. For example, Chapter 18 has a box on the bacterium *Escherichia coli*, Chapter 21 profiles *Arabidopsis thaliana*, and Chapter 22 has boxes for the nematode *Caenorhabditis elegans* and the fruit fly, *Drosophila melanogaster*.

The Process of Evolution Unifies the Field of Biology

On a road trip across the Midwestern United States, I watched swallows swoop over the Mississippi River with split-second precision. Fireflies flashed above the grass soon after sundown, and woodpeckers expertly hammered tree bark with their stout bills. A male bullfrog's guttural croaking signaled his availability to female frogs in a small pond. How do these animals know exactly what to do, and where, and how, and when to do it? Oak, poplar, sassafras, and hickory trees thrive in the forests of the Midwest, with raspberries growing in the shaded understory. Purple coneflowers populate the meadows. Why do these particular plants occur in the Midwest, but redwood trees and banana trees are absent?

All around us, we can see that life seems perfectly suited to its habitat. Centuries of scientific research—from observations and detailed note taking to, now, probing the base pairs of the DNA double helix—tell the compelling story of how this came to be. When Charles Darwin wrote *On the Origin of Species* in the mid-1860s, he set into motion the science of evolutionary biology. But it didn't stop there. Generations of scientists have built on that foundation, and we now have a richly detailed understanding of the evolutionary processes that have brought life to this point.

A famous journal article is titled, "Nothing in biology makes sense except in light of evolution," a profound statement that is not to be taken lightly. Evolution permeates this book because it permeates our understanding of biology. Evolution is in an animal's selection of mates, in a farmer's choice to cultivate the crops that grow well in a particular region of the world, and in our tendency to eat sweets and fats (even though we know we shouldn't). In addition to the evolution and diversity units in this textbook, the Investigating Life sections and many other concepts will allow you to discover the evolutionary forces behind biology at every scale, from chemistry to ecology.

Thinking as a Scientist

This book is full of features that will help you learn to think scientifically. Each chapter begins with an attention-grabbing essay and a learning outline that previews the main concepts that you will encounter. Each main section finishes with a summary and a set of questions designed to help you assess your understanding of the concept before moving on. Moreover, the Investigating Life section that concludes each chapter includes data and a critical thinking question. The end-of-chapter Multiple Choice, Testing Your Knowledge, and Thinking As a Scientist questions reinforce basic content and conceptual understanding. Illustrated tables and strategically placed mini-glossaries will help you organize the information and understand the connections between details.

Scattered throughout the book are "Can *You* Relate?" boxes, brief readings that explain the biology behind phenomena that you may have noticed for yourself. For example, I discuss why some (but not all) artificial sweeteners are calorie-free, why leaves change color in the fall, and why purebred dogs often suffer from health problems.

"Burning Question" boxes are based on questions that my own students have asked me over more than 10 years of teaching introductory biology at the University of Oklahoma. On the first day of class, I always ask my students to write on an index card a burning question that they would like to have answered during the semester. Their questions range from the quirky ("Is it true that you can lick toads to get high?") to the medical ("My grandmother just died of cancer, so will I get cancer too?") to the environmental ("How does human-made pollution harm other life forms, and how does this hurt ecosystems as a whole?").

I answer each of the questions at some time during the semester. My students enjoy seeing their questions projected on the big screen, and I find it exciting to catch a glimpse of what they have on their minds. This textbook contains a selection of my students' Burning Questions, which represent an immediate connection between my own classes at The University of Oklahoma and other introductory biology students who use this book.

Biology is a Visual Science

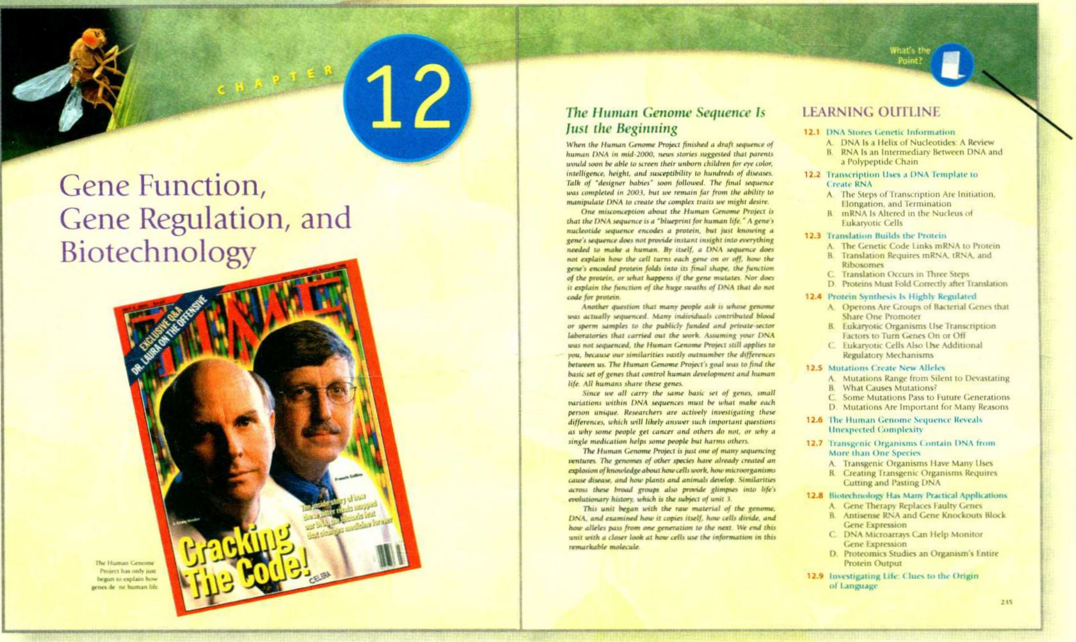
Biology is difficult to explain with words alone. This book features a new art program developed by a talented team of professional illustrators who considered my suggestions and improved on many of them. The illustrations are bright and colorful, often combining art and photos or micrographs into appealing and informative combinations. Repetition aids in learning, so the illustrators were careful to use consistent colors for membranes, DNA, proteins, cell organelles, molecules, atoms, and other structures that occur throughout the book. Numbered steps help you work through complex processes, and figure legends add additional explanation.

My Commitment to a Community of Educators and Students

Being a textbook author has made me a better teacher. In researching the topics in this book, I have developed a richer understanding of biological processes, and I have more examples to share with my students. At the same time, being an instructor makes me a better author. My students ask me questions that reveal which topics are the most difficult and confusing to them. I have devoted extra effort to developing new illustrations that offer extra help with these subjects. Sometimes, the solution is as simple as a small black-and-white context drawing that reminds students where a process occurs. In other cases, whole new illustrations were required. Throughout the book, I have tried to make sure that all the visual and textual information is accurate, complete, up-to-date, and explained at a level that a beginning student can understand.

Many of us who chose teaching as a profession are passionate about our subject, and we want our students to share our enthusiasm. I hope the text, art, and photos in this book will help bring biology to life for faculty and students alike. Therefore, this is a work in progress, and I welcome your suggestions on how to serve you better. I encourage you to write me at marielle_hoefnagels@mcgraw-hill.com with suggestions on how to improve this book and what you'd like to see in future editions. Perhaps one of your Burning Questions will become part of this story of life.

A Student's Guide
to Using This Textbook



Gene Function, Gene Regulation, and Biotechnology

The Human Genome Project has only just begun to explain how genes define human life.

The Human Genome Sequence Is Just the Beginning

When the Human Genome Project finished a draft sequence of human DNA in mid-2000, news stories suggested that parents would soon be able to screen their unborn children for eye color, intelligence, height, and susceptibility to hundreds of diseases. Talk of "designer babies" soon followed. The final sequence was completed in 2003, but we remain far from the ability to manipulate DNA to create the complex traits we might desire.

One misconception about the Human Genome Project is that the DNA sequence is a "blueprint for human life." A gene's nucleotide sequence encodes a protein, but just knowing a gene's sequence does not provide instant insight into everything needed to make a human. By itself, a DNA sequence does not explain how the cell turns each gene on or off, how the gene's encoded protein folds into its final shape, the function of the protein, or what happens if the gene mutates. Nor does it explain the function of the huge swaths of DNA that do not code for protein.

Another question that many people ask is whose genome was actually sequenced. Many individuals contributed blood or sperm samples to the publicly funded and private-sector laboratories that carried out the work. Assuming your DNA was not sequenced, the Human Genome Project still applies to you, because our similarities vastly outnumber the differences between us. The Human Genome Project's goal was to find the basic set of genes that control human development and human life. All humans share these genes.

Since we all carry the same basic set of genes, small variations within DNA sequences must be what make each person unique. Researchers are actively investigating these differences, which will likely answer such important questions as why some people get cancer and others do not, or why a single medication helps some people but harms others.

The Human Genome Project is just one of many sequencing ventures. The genomes of other species have already created an explosion of knowledge about how cells work, how microorganisms cause disease, and how plants and animals develop. Similarities across these broad groups also provide glimpses into life's evolutionary history, which is the subject of unit 3.

This unit began with the raw material of the genome, DNA, and examined how it copies itself, how cells divide, and how alleles pass from one generation to the next. We end this unit with a closer look at how cells use the information in this remarkable molecule.

LEARNING OUTLINE

12.1 DNA Stores Genetic Information
  A. DNA Is a Helix of Nucleotides: A Review
  B. RNA Is an Intermediary Between DNA and a Polypeptide Chain
12.2 Transcription Uses a DNA Template to Create RNA
  A. The Steps of Transcription Are Initiation, Elongation, and Termination
  B. mRNA Is Altered in the Nucleus of Eukaryotic Cells
12.3 Translation Builds the Protein
  A. The Genetic Code Links mRNA to Protein
  B. Translation Requires mRNA, tRNA, and Ribosomes
  C. Translation Occurs in Three Steps
  D. Proteins Must Fold Correctly after Translation
12.4 Protein Synthesis Is Highly Regulated
  A. Operons Are Groups of Bacterial Genes that Share One Promoter
  B. Eukaryotic Organisms Use Transcription Factors to Turn Genes On or Off
  C. Eukaryotic Cells Also Use Additional Regulatory Mechanisms
12.5 Mutations Create New Alleles
  A. Mutations Range from Silent to Devastating
  B. What Causes Mutations?
  C. Some Mutations Pass to Future Generations
  D. Mutations Are Important for Many Reasons
12.6 The Human Genome Sequence Reveals Unexpected Complexity
12.7 Transgenic Organisms Contain DNA from More than One Species
  A. Transgenic Organisms Have Many Uses
  B. Creating Transgenic Organisms Requires Cutting and Pasting DNA
12.8 Biotechnology Has Many Practical Applications
  A. Gene Therapy Replaces Faulty Genes
  B. Antisense RNA and Gene Knockouts Block Gene Expression
  C. DNA Microarrays Can Help Monitor Gene Expression
  D. Proteomics Studies an Organism's Entire Protein Output
12.9 Investigating Life: Clues to the Origin of Language

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Ask yourself, "What's the Point?"

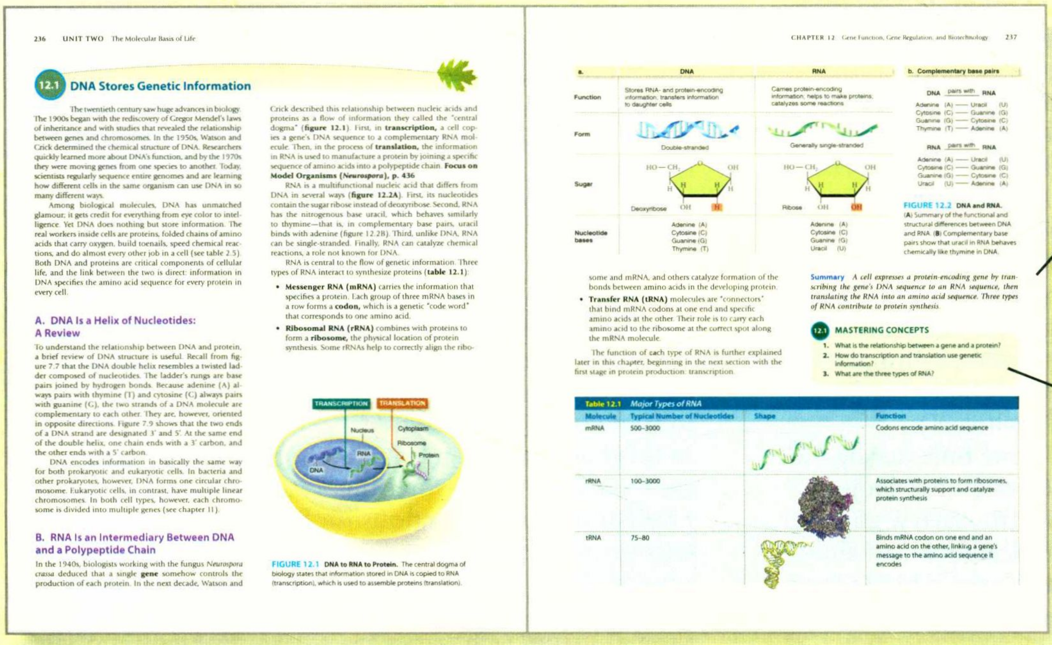
Try the digital learning aids available on the text's ARIS website.

Listen to the author briefly describe the key points of each chapter.

Check out the chapter Road Map.

The numbered concepts and detailed outline point the way.

The opening essay offers insights into why this chapter matters.



236 UNIT TWO The Molecular Basis of Life

12.1 **DNA Stores Genetic Information**

The twentieth century saw huge advances in biology. The 1900s began with the rediscovery of Gregor Mendel's laws of inheritance and with studies that revealed the relationship between genes and chromosomes. In the 1950s, Watson and Crick determined the chemical structure of DNA. Researchers quickly learned more about DNA's function, and by the 1970s they were moving genes from one species to another. Today, scientists regularly sequence entire genomes and are learning how different cells in the same organism can use DNA in so many different ways.

Among biological molecules, DNA has unmatched glamour; it gets credit for everything from eye color to intelligence. Yet DNA does nothing but store information. The real workers inside cells are proteins, folded chains of amino acids that carry oxygen, build toenails, speed chemical reactions, and do almost every other job in a cell (see table 2.5). Both DNA and proteins are critical components of cellular life, and the link between the two is direct: information in DNA specifies the amino acid sequence for every protein in every cell.

A. DNA Is a Helix of Nucleotides: A Review

To understand the relationship between DNA and protein, a brief review of DNA structure is useful. Recall from figure 7.7 that the DNA double helix resembles a twisted ladder composed of nucleotides. The ladder's rungs are base pairs joined by hydrogen bonds. Because adenine (A) always pairs with thymine (T) and cytosine (C) always pairs with guanine (G), the two strands of a DNA molecule are complementary to each other. They are, however, oriented in opposite directions. Figure 7.9 shows that the two ends of a DNA strand are designated 3' and 5'. At the same end of the double helix, one chain ends with a 3' carbon, and the other ends with a 5' carbon.

DNA encodes information in basically the same way for both prokaryotic and eukaryotic cells. In bacteria and other prokaryotes, however, DNA forms one circular chromosome. Eukaryotic cells, in contrast, have multiple linear chromosomes. In both cell types, however, each chromosome is divided into multiple genes (see chapter 11).

B. RNA Is an Intermediary Between DNA and a Polypeptide Chain

In the 1940s, biologists working with the fungus *Neurospora crassa* deduced that a single **gene** somehow controls the production of each protein. In the next decade, Watson and Crick described this relationship between nucleic acids and proteins as a flow of information they called the "central dogma" (**figure 12.1**). First, in **transcription,** a cell copies a gene's DNA sequence to a complementary RNA molecule. Then, in the process of **translation,** the information in RNA is used to manufacture a protein by joining a specific sequence of amino acids into a polypeptide chain. **Focus on Model Organisms (*Neurospora*), p. 436**

RNA is a multifunctional nucleic acid that differs from DNA in several ways (**figure 12.2A**). First, its nucleotides contain the sugar ribose instead of deoxyribose. Second, RNA has the nitrogenous base uracil, which behaves similarly to thymine—that is, in complementary base pairs, uracil binds with adenine (figure 12.2B). Third, unlike DNA, RNA can be single-stranded. Finally, RNA can catalyze chemical reactions, a role not known for DNA.

RNA is central to the flow of genetic information. Three types of RNA interact to synthesize proteins (**table 12.1**):

- **Messenger RNA (mRNA)** carries the information that specifies a protein. Each group of three mRNA bases in a row forms a **codon,** which is a genetic "code word" that corresponds to one amino acid.
- **Ribosomal RNA (rRNA)** combines with proteins to form a **ribosome,** the physical location of protein synthesis. Some rRNAs help to correctly align the ribosome and mRNA, and others catalyze formation of the bonds between amino acids in the developing protein.
- **Transfer RNA (tRNA)** molecules are "connectors" that bind mRNA codons at one end and specific amino acids at the other. Their role is to carry each amino acid to the ribosome at the correct spot along the mRNA molecule.

The function of each type of RNA is further explained later in this chapter, beginning in the next section with the first stage in protein production: transcription.

FIGURE 12.1 **DNA to RNA to Protein.** The central dogma of biology states that information stored in DNA is copied to RNA (transcription), which is used to assemble proteins (translation).

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a.	DNA	RNA
Function	Stores RNA- and protein-encoding information; transfers information to daughter cells	Carries protein-encoding information; helps to make proteins; catalyzes some reactions
Form	Double-stranded	Generally single-stranded
Sugar	Deoxyribose	Ribose
Nucleotide bases	Adenine (A) Cytosine (C) Guanine (G) Thymine (T)	Adenine (A) Cytosine (C) Guanine (G) Uracil (U)

b. Complementary base pairs

DNA $\overline{\text{pairs with}}$ RNA
Adenine (A) — Uracil (U)
Cytosine (C) — Guanine (G)
Guanine (G) — Cytosine (C)
Thymine (T) — Adenine (A)

RNA $\overline{\text{pairs with}}$ RNA
Adenine (A) — Uracil (U)
Cytosine (C) — Guanine (G)
Guanine (G) — Cytosine (C)
Uracil (U) — Adenine (A)

FIGURE 12.2 **DNA and RNA.** (**A**) Summary of the functional and structural differences between DNA and RNA. (**B**) Complementary base pairs show that uracil in RNA behaves chemically like thymine in DNA.

Summary *A cell expresses a protein-encoding gene by transcribing the gene's DNA sequence to an RNA sequence, then translating the RNA into an amino acid sequence. Three types of RNA contribute to protein synthesis.*

12.1 MASTERING CONCEPTS

1. What is the relationship between a gene and a protein?
2. How do transcription and translation use genetic information?
3. What are the three types of RNA?

Table 12.1 *Major Types of RNA*

Molecule	Typical Number of Nucleotides	Shape	Function
mRNA	500–3000		Codons encode amino acid sequence
rRNA	100–3000		Associates with proteins to form ribosomes, which structurally support and catalyze protein synthesis
tRNA	75–80		Binds mRNA codon on one end and an amino acid on the other, linking a gene's message to the amino acid sequence it encodes

Build your understanding one concept at a time.

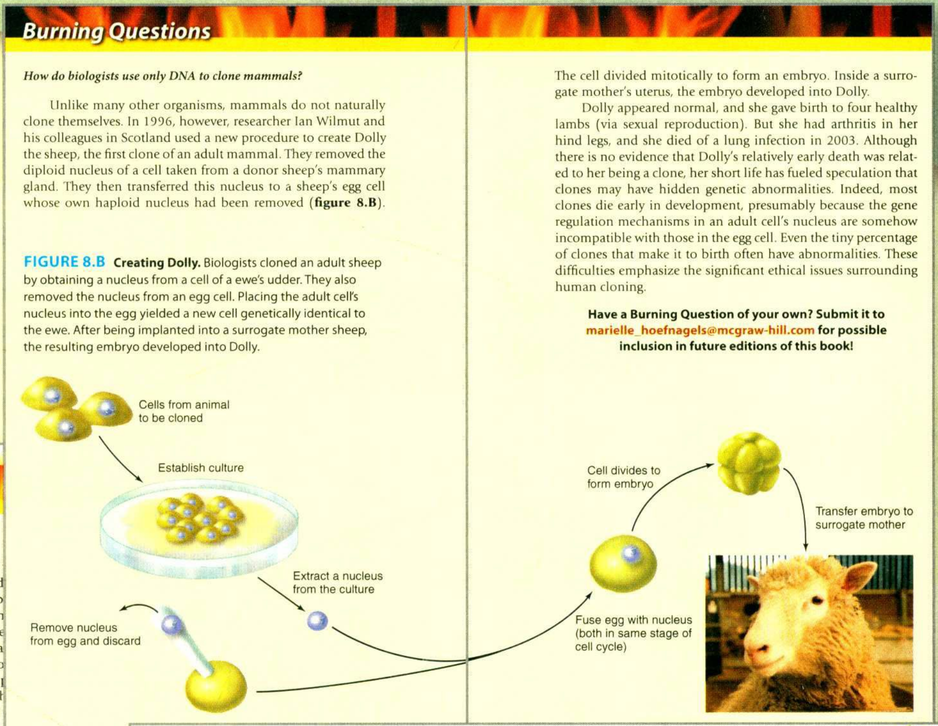
Focus on each concept's brief, summational statement.

Note key terms that appear in bold-faced, definitional sentences.

Take time to test your understanding after each concept.

Connect this material to your own life.

Burning Questions came from the author's own students.



Burning Questions

How do biologists use only DNA to clone mammals?

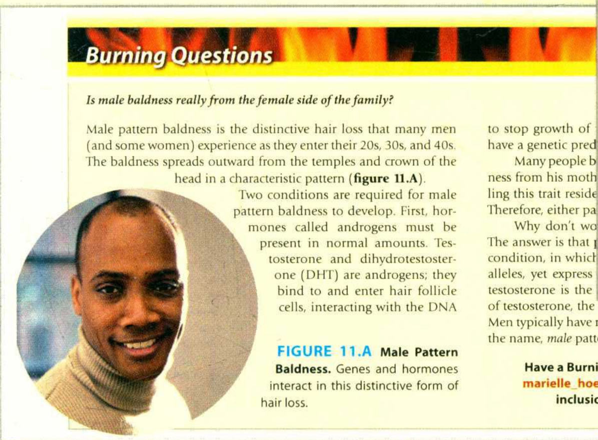
Unlike many other organisms, mammals do not naturally clone themselves. In 1996, however, researcher Ian Wilmut and his colleagues in Scotland used a new procedure to create Dolly the sheep, the first clone of an adult mammal. They removed the diploid nucleus of a cell taken from a donor sheep's mammary gland. They then transferred this nucleus to a sheep's egg cell whose own haploid nucleus had been removed (**figure 8.B**).

FIGURE 8.B **Creating Dolly.** Biologists cloned an adult sheep by obtaining a nucleus from a cell of a ewe's udder. They also removed the nucleus from an egg cell. Placing the adult cell's nucleus into the egg yielded a new cell genetically identical to the ewe. After being implanted into a surrogate mother sheep, the resulting embryo developed into Dolly.

The cell divided mitotically to form an embryo. Inside a surrogate mother's uterus, the embryo developed into Dolly.

Dolly appeared normal, and she gave birth to four healthy lambs (via sexual reproduction). But she had arthritis in her hind legs, and she died of a lung infection in 2003. Although there is no evidence that Dolly's relatively early death was related to her being a clone, her short life has fueled speculation that clones may have hidden genetic abnormalities. Indeed, most clones die early in development, presumably because the gene regulation mechanisms in an adult cell's nucleus are somehow incompatible with those in the egg cell. Even the tiny percentage of clones that make it to birth often have abnormalities. These difficulties emphasize the significant ethical issues surrounding human cloning.

Have a Burning Question of your own? Submit it to marielle_hoefnagels@mcgraw-hill.com for possible inclusion in future editions of this book!



Burning Questions

Is male baldness really from the female side of the family?

Male pattern baldness is the distinctive hair loss that many men (and some women) experience as they enter their 20s, 30s, and 40s. The baldness spreads outward from the temples and crown of the head in a characteristic pattern (**figure 11.A**).

Two conditions are required for male pattern baldness to develop. First, hormones called androgens must be present in normal amounts. Testosterone and dihydrotestosterone (DHT) are androgens; they bind to and enter hair follicle cells, interacting with the DNA

FIGURE 11.A **Male Pattern Baldness.** Genes and hormones interact in this distinctive form of hair loss.

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have a genetic pred
Many people b
ness from his moth
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Therefore, either pa
Why don't wo
The answer is that
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testosterone is the
of testosterone, the stronger the influence
Men typically have more of this sex hormo
the name, *male* pattern baldness.

Have a Burning Question of your
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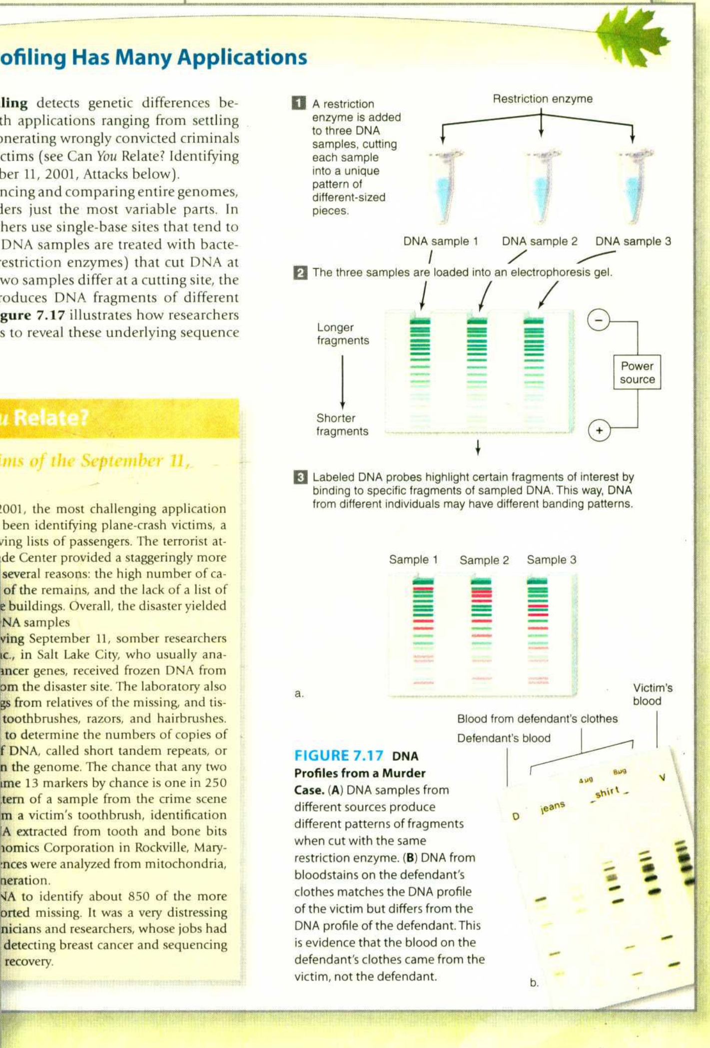
inclusion in future editions



7.6 DNA Profiling Has Many Applications

DNA profiling detects genetic differences between individuals, with applications ranging from settling paternity claims to exonerating wrongly convicted criminals to identifying crime victims (see Can *You* Relate? Identifying Victims of the September 11, 2001, Attacks below).

Rather than sequencing and comparing entire genomes, DNA profiling considers just the most variable parts. In one approach, researchers use single-base sites that tend to vary in a population. DNA samples are treated with bacterial enzymes (called restriction enzymes) that cut DNA at specific sequences. If two samples differ at a cutting site, the restriction enzyme produces DNA fragments of different sizes and numbers. **Figure 7.17** illustrates how researchers use gel electrophoresis to reveal these underlying sequence differences.

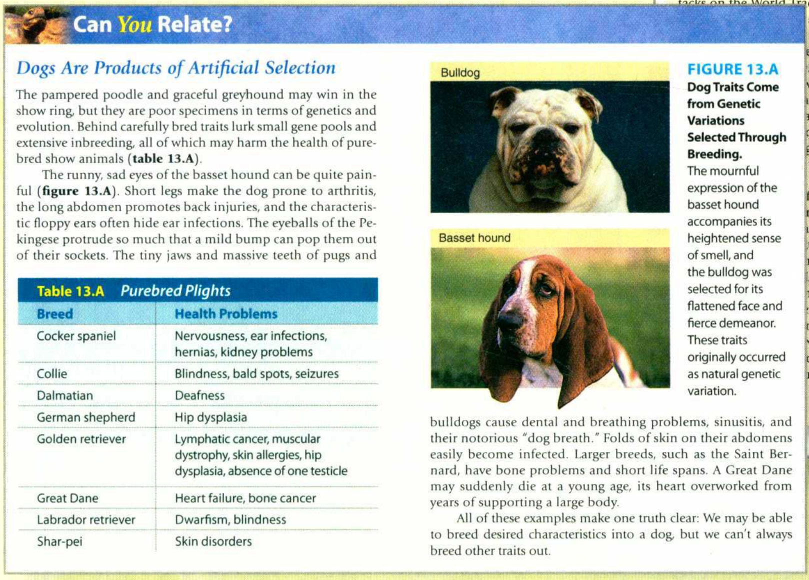
Can *You* Relate?

Identifying Victims of the September 11, 2001, Attacks

Until September 11, 2001, the most challenging application of DNA profiling had been identifying plane-crash victims, a grim task eased by having lists of passengers. The terrorist attacks on the World Trade Center provided a staggeringly more
several reasons: the high number of ca-
of the remains, and the lack of a list of
e buildings. Overall, the disaster yielded
NA samples
ving September 11, somber researchers
ıc., in Salt Lake City, who usually ana-
ancer genes, received frozen DNA from
om the disaster site. The laboratory also
gs from relatives of the missing, and tis-
toothbrushes, razors, and hairbrushes.
to determine the numbers of copies of
f DNA, called short tandem repeats, or
n the genome. The chance that any two
ame 13 markers by chance is one in 250
tern of a sample from the crime scene
m a victim's toothbrush, identification
A extracted from tooth and bone bits
nomics Corporation in Rockville, Mary-
nces were analyzed from mitochondria,
neration.
NA to identify about 850 of the more
orted missing. It was a very distressing
nicians and researchers, whose jobs had
detecting breast cancer and sequencing
recovery.

FIGURE 7.17 **DNA Profiles from a Murder Case.** (**A**) DNA samples from different sources produce different patterns of fragments when cut with the same restriction enzyme. (**B**) DNA from bloodstains on the defendant's clothes matches the DNA profile of the victim but differs from the DNA profile of the defendant. This is evidence that the blood on the defendant's clothes came from the victim, not the defendant.

Can You Relate to the biology behind news items and your own experiences?



Can *You* Relate?

Dogs Are Products of Artificial Selection

The pampered poodle and graceful greyhound may win in the show ring, but they are poor specimens in terms of genetics and evolution. Behind carefully bred traits lurk small gene pools and extensive inbreeding, all of which may harm the health of purebred show animals (**table 13.A**).

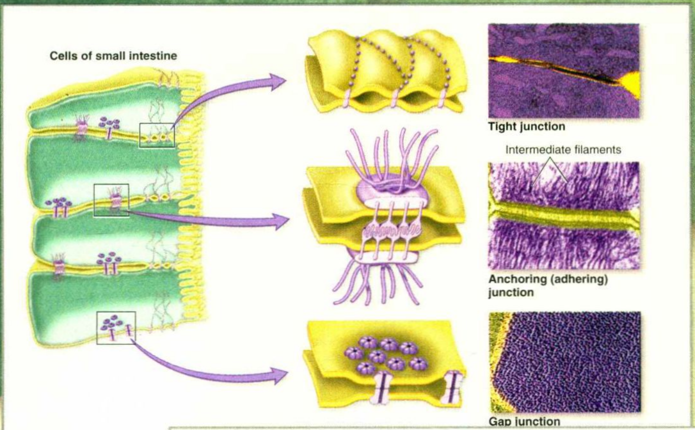
The runny, sad eyes of the basset hound can be quite painful (**figure 13.A**). Short legs make the dog prone to arthritis, the long abdomen promotes back injuries, and the characteristic floppy ears often hide ear infections. The eyeballs of the Pekingese protrude so much that a mild bump can pop them out of their sockets. The tiny jaws and massive teeth of pugs and bulldogs cause dental and breathing problems, sinusitis, and their notorious "dog breath." Folds of skin on their abdomens easily become infected. Larger breeds, such as the Saint Bernard, have bone problems and short life spans. A Great Dane may suddenly die at a young age, its heart overworked from years of supporting a large body.

All of these examples make one truth clear: We may be able to breed desired characteristics into a dog, but we can't always breed other traits out.

Table 13.A *Purebred Plights*

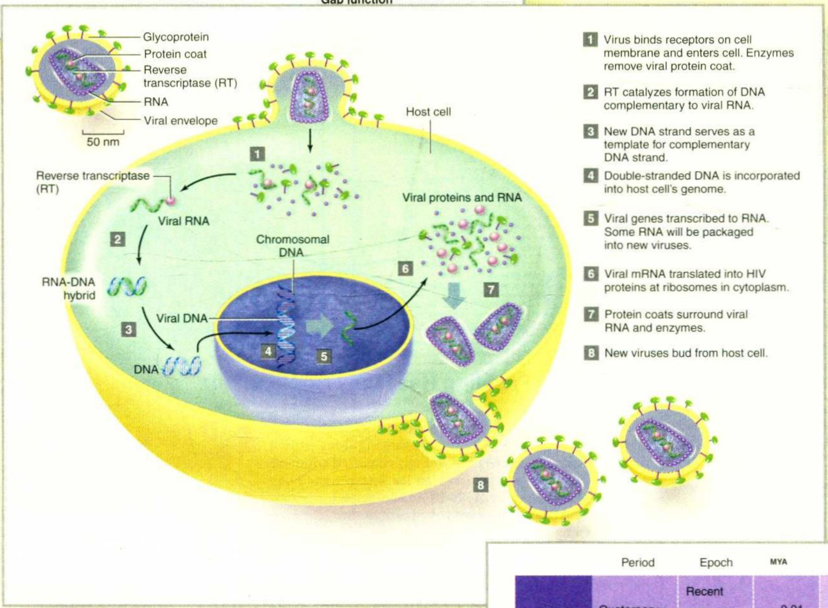
Breed	Health Problems
Cocker spaniel	Nervousness, ear infections, hernias, kidney problems
Collie	Blindness, bald spots, seizures
Dalmatian	Deafness
German shepherd	Hip dysplasia
Golden retriever	Lymphatic cancer, muscular dystrophy, skin allergies, hip dysplasia, absence of one testicle
Great Dane	Heart failure, bone cancer
Labrador retriever	Dwarfism, blindness
Shar-pei	Skin disorders

FIGURE 13.A **Dog Traits Come from Genetic Variations Selected Through Breeding.** The mournful expression of the basset hound accompanies its heightened sense of smell, and the bulldog was selected for its flattened face and fierce demeanor. These traits originally occurred as natural genetic variation.



Become an art expert—use your visual learning skills.

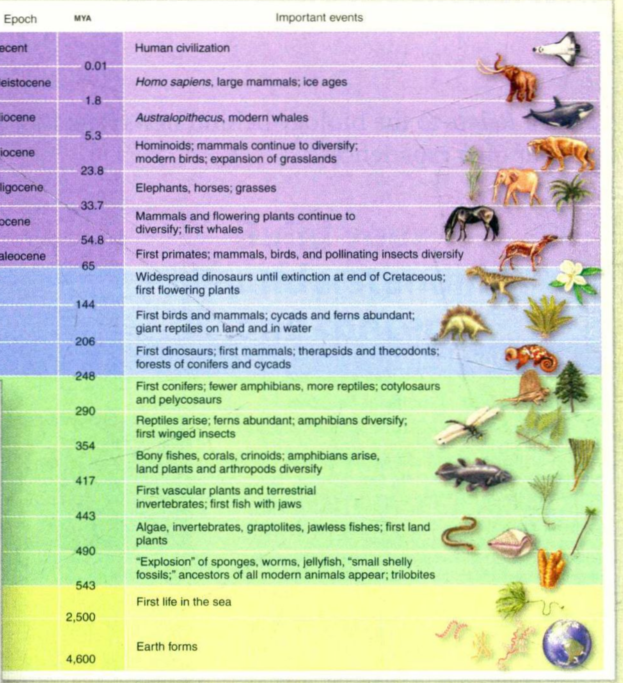
Combination Figures link art and photos to provide both perspectives.



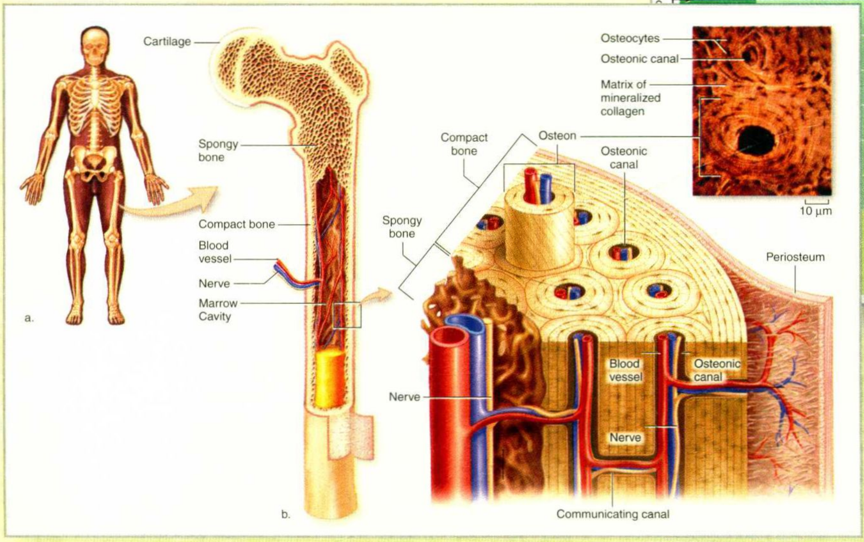
1. Virus binds receptors on cell membrane and enters cell. Enzymes remove viral protein coat.
2. RT catalyzes formation of DNA complementary to viral RNA.
3. New DNA strand serves as a template for complementary DNA strand.
4. Double-stranded DNA is incorporated into host cell's genome.
5. Viral genes transcribed to RNA. Some RNA will be packaged into new viruses.
6. Viral mRNA translated into HIV proteins at ribosomes in cytoplasm.
7. Protein coats surround viral RNA and enzymes.
8. New viruses bud from host cell.

Step-by-Step Figures present concepts in easy-to-follow steps.

Illustrated Tables help organize information and connect details.



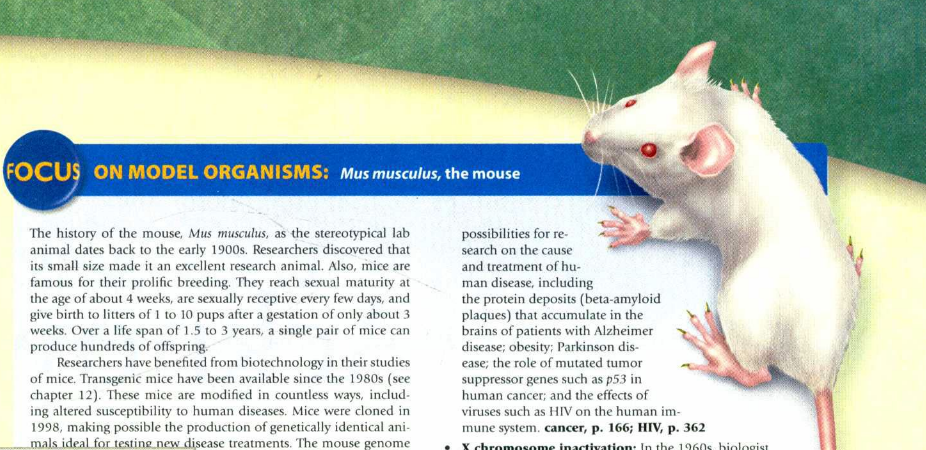
	Period	Epoch	MYA	Important events
Cenozoic era	Quaternary	Recent	0.01	Human civilization
		Pleistocene	1.8	*Homo sapiens*, large mammals; ice ages
	Tertiary	Pliocene	5.3	*Australopithecus*, modern whales
		Miocene	23.8	Hominoids; mammals continue to diversify; modern birds; expansion of grasslands
		Oligocene	33.7	Elephants, horses; grasses
		Eocene	54.8	Mammals and flowering plants continue to diversify; first whales
		Paleocene	65	First primates; mammals, birds, and pollinating insects diversify
Mesozoic era	Cretaceous		144	Widespread dinosaurs until extinction at end of Cretaceous; first flowering plants
	Jurassic		206	First birds and mammals; cycads and ferns abundant; giant reptiles on land and in water
	Triassic		248	First dinosaurs; first mammals; therapsids and thecodonts; forests of conifers and cycads
			290	First conifers; fewer amphibians, more reptiles; cotylosaurs and pelycosaurs
			354	Reptiles arise; ferns abundant; amphibians diversify; first winged insects
			417	Bony fishes, corals, crinoids; amphibians arise, land plants and arthropods diversify
			443	First vascular plants and terrestrial invertebrates; first fish with jaws
			490	Algae, invertebrates, graptolites, jawless fishes; first land plants
			543	"Explosion" of sponges, worms, jellyfish, "small shelly fossils;" ancestors of all modern animals appear; trilobites
			2,500	First life in the sea
			4,600	Earth forms



Macro-to-Micro Figures provide context and perspective.

Become an investigator!

Study how science works in each chapter and in the Model Organisms feature.



FOCUS ON MODEL ORGANISMS: *Mus musculus*, the mouse

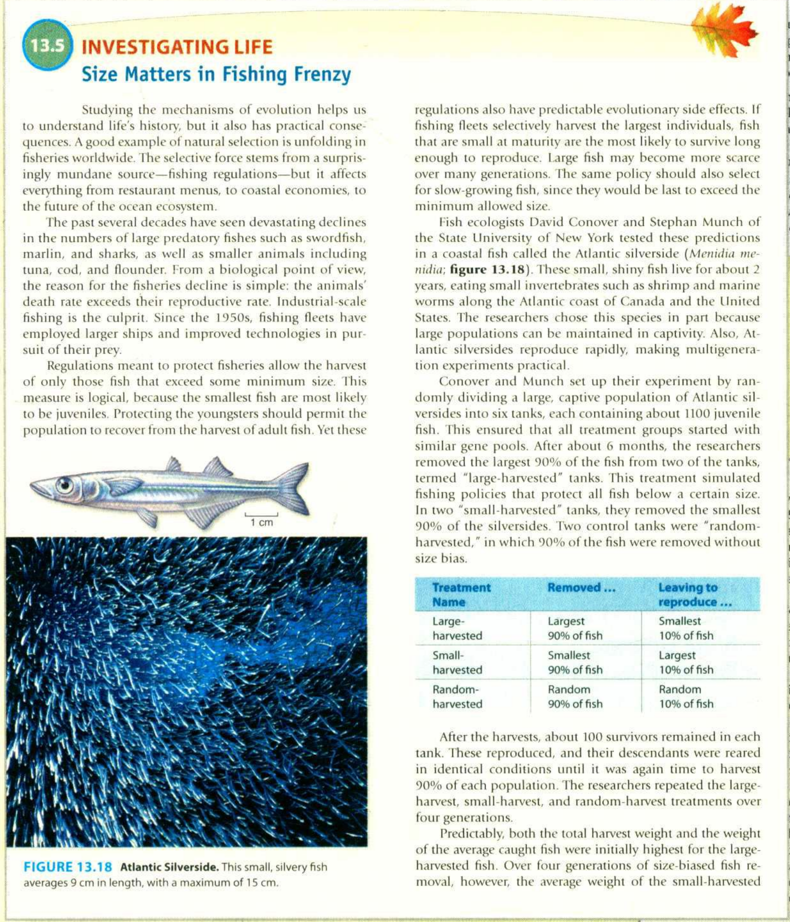
The history of the mouse, *Mus musculus*, as the stereotypical lab animal dates back to the early 1900s. Researchers discovered that its small size made it an excellent research animal. Also, mice are famous for their prolific breeding. They reach sexual maturity at the age of about 4 weeks, are sexually receptive every few days, and give birth to litters of 1 to 10 pups after a gestation of only about 3 weeks. Over a life span of 1.5 to 3 years, a single pair of mice can produce hundreds of offspring.

Researchers have benefited from biotechnology in their studies of mice. Transgenic mice have been available since the 1980s (see chapter 12). These mice are modified in countless ways, including altered susceptibility to human diseases. Mice were cloned in 1998, making possible the production of genetically identical animals ideal for testing new disease treatments. The mouse genome
2002, revealing about 30,000 genes
mes. Not surprisingly, more than 99%
parts in the human genome. This sim-
e of the following ways in which *Mus*
iological research:

e 1930s, the discovery that mice
ll but their very close relatives led
ajor histocompatibility complex
biologists have discovered an array
ne function (see chapter 36).
ave been used to study human dis-
en researchers discovered that mice
er. Vaccines were subsequently tested
of transgenic mice has opened new

possibilities for research on the cause and treatment of human disease, including the protein deposits (beta-amyloid plaques) that accumulate in the brains of patients with Alzheimer disease; obesity; Parkinson disease; the role of mutated tumor suppressor genes such as *p53* in human cancer; and the effects of viruses such as HIV on the human immune system. **cancer, p. 166; HIV, p. 362**

- **X chromosome inactivation:** In the 1960s, biologist Mary Lyon proposed that in female mammals, one of the two X chromosomes is inactivated early in embryonic development. This phenomenon, often illustrated using calico cats, was first proved in mice with mottled coats. **X inactivation, p. 226**
- **Stem cells:** These undifferentiated cells, which can be derived from embryos or adults, can specialize into many other cell types. Mouse stem cell research has shown great promise in treating spinal cord injuries and many other ailments. **stem cells, p. 158**



13.5 INVESTIGATING LIFE

Size Matters in Fishing Frenzy

Studying the mechanisms of evolution helps us to understand life's history, but it also has practical consequences. A good example of natural selection is unfolding in fisheries worldwide. The selective force stems from a surprisingly mundane source—fishing regulations—but it affects everything from restaurant menus, to coastal economies, to the future of the ocean ecosystem.

The past several decades have seen devastating declines in the numbers of large predatory fishes such as swordfish, marlin, and sharks, as well as smaller animals including tuna, cod, and flounder. From a biological point of view, the reason for the fisheries decline is simple: the animals' death rate exceeds their reproductive rate. Industrial-scale fishing is the culprit. Since the 1950s, fishing fleets have employed larger ships and improved technologies in pursuit of their prey.

Regulations meant to protect fisheries allow the harvest of only those fish that exceed some minimum size. This measure is logical, because the smallest fish are most likely to be juveniles. Protecting the youngsters should permit the population to recover from the harvest of adult fish. Yet these regulations also have predictable evolutionary side effects. If fishing fleets selectively harvest the largest individuals, fish that are small at maturity are the most likely to survive long enough to reproduce. Large fish may become more scarce over many generations. The same policy should also select for slow-growing fish, since they would be last to exceed the minimum allowed size.

Fish ecologists David Conover and Stephan Munch of the State University of New York tested these predictions in a coastal fish called the Atlantic silverside (*Menidia menidia*; **figure 13.18**). These small, shiny fish live for about 2 years, eating small invertebrates such as shrimp and marine worms along the Atlantic coast of Canada and the United States. The researchers chose this species in part because large populations can be maintained in captivity. Also, Atlantic silversides reproduce rapidly, making multigeneration experiments practical.

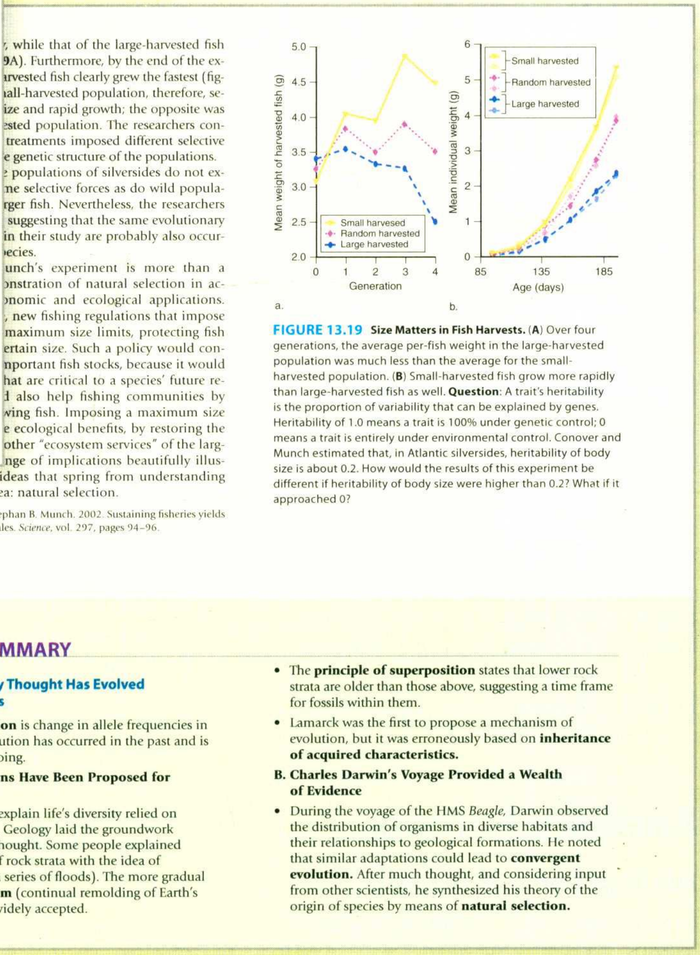
Conover and Munch set up their experiment by randomly dividing a large, captive population of Atlantic silversides into six tanks, each containing about 1100 juvenile fish. This ensured that all treatment groups started with similar gene pools. After about 6 months, the researchers removed the largest 90% of the fish from two of the tanks, termed "large-harvested" tanks. This treatment simulated fishing policies that protect all fish below a certain size. In two "small-harvested" tanks, they removed the smallest 90% of the silversides. Two control tanks were "random-harvested," in which 90% of the fish were removed without size bias.

Treatment Name	Removed ...	Leaving to reproduce ...
Large-harvested	Largest 90% of fish	Smallest 10% of fish
Small-harvested	Smallest 90% of fish	Largest 10% of fish
Random-harvested	Random 90% of fish	Random 10% of fish

After the harvests, about 100 survivors remained in each tank. These reproduced, and their descendants were reared in identical conditions until it was again time to harvest 90% of each population. The researchers repeated the large-harvest, small-harvest, and random-harvest treatments over four generations.

Predictably, both the total harvest weight and the weight of the average caught fish were initially highest for the large-harvested fish. Over four generations of size-biased fish removal, however, the average weight of the small-harvested

FIGURE 13.18 Atlantic Silverside. This small, silvery fish averages 9 cm in length, with a maximum of 15 cm.



, while that of the large-harvested fish
9A). Furthermore, by the end of the ex-
rvested fish clearly grew the fastest (fig-
all-harvested population, therefore, se-
ize and rapid growth; the opposite was
ested population. The researchers con-
treatments imposed different selective
e genetic structure of the populations.
populations of silversides do not ex-
ne selective forces as do wild popula-
rger fish. Nevertheless, the researchers
suggesting that the same evolutionary
in their study are probably also occur-
ecies.

unch's experiment is more than a
onstration of natural selection in ac-
onomic and ecological applications.
, new fishing regulations that impose
maximum size limits, protecting fish
ertain size. Such a policy would con-
nportant fish stocks, because it would
hat are critical to a species' future re-
d also help fishing communities by
wing fish. Imposing a maximum size
e ecological benefits, by restoring the
other "ecosystem services" of the larg-
nge of implications beautifully illus-
trates the powerful ideas that spring from understanding one fundamental idea: natural selection.

Conover, David O. and Stephan B. Munch. 2002. Sustaining fisheries yields over evolutionary time scales. *Science*, vol. 297, pages 94–96.

FIGURE 13.19 Size Matters in Fish Harvests. (**A**) Over four generations, the average per-fish weight in the large-harvested population was much less than the average for the small-harvested population. (**B**) Small-harvested fish grow more rapidly than large-harvested fish as well. **Question:** A trait's heritability is the proportion of variability that can be explained by genes. Heritability of 1.0 means a trait is 100% under genetic control; 0 means a trait is entirely under environmental control. Conover and Munch estimated that, in Atlantic silversides, heritability of body size is about 0.2. How would the results of this experiment be different if heritability of body size were higher than 0.2? What if it approached 0?

CHAPTER SUMMARY

13.1 Evolutionary Thought Has Evolved for Centuries

- Biological **evolution** is change in allele frequencies in populations. Evolution has occurred in the past and is constant and ongoing.

A. Many Explanations Have Been Proposed for Life's Diversity

- Early attempts to explain life's diversity relied on belief in a creator. Geology laid the groundwork for evolutionary thought. Some people explained the distribution of rock strata with the idea of **catastrophism** (a series of floods). The more gradual **uniformitarianism** (continual remolding of Earth's surface) became widely accepted.
- The **principle of superposition** states that lower rock strata are older than those above, suggesting a time frame for fossils within them.
- Lamarck was the first to propose a mechanism of evolution, but it was erroneously based on **inheritance of acquired characteristics.**

B. Charles Darwin's Voyage Provided a Wealth of Evidence

- During the voyage of the HMS *Beagle*, Darwin observed the distribution of organisms in diverse habitats and their relationships to geological formations. He noted that similar adaptations could lead to **convergent evolution.** After much thought, and considering input from other scientists, he synthesized his theory of the origin of species by means of **natural selection.**

Read and analyze the data in each chapter's capstone Investigating Life section.

Use chapter study tools to check your understanding and prepare for the test.

Acknowledgments

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Brief Contents

UNIT 1 *The Cellular Basis of Life*

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UNIT 3 *The Evolution of Life*

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