CHAPTER 16

Biotechnology

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These fish that glow in the dark were produced through genetic engineering.

HS-ETS1-1, HS-ETS1-2, HS-LS3-1

CASE STUDY

What will the future hold for genetically modified crops?

Throughout the twentieth century, scientists studied genes and genetic mechanisms. They investigated the genes of a huge variety of organisms, ranging from single-celled bacteria to multicellular plants and animals, including humans. All of these investigations support the same conclusion, which is that all living things use genes in very similar ways.

The similarity of genetic mechanisms led scientists to ask: Could a gene from one organism be transferred to another, and be made to function in its new home? The answer proved to be yes. In the 1970s, scientists began transferring genes between bacteria. Then in 1983, scientists announced the creation of the first transgenic plants. Genes from bacteria were successfully incorporated into plant genomes, and the plants were producing the bacterial proteins.

In the years after these experiments, scientists began developing genetically modified (GM) plants for use as farm crops. Some of the first GM plants received a gene from the bacterial species *Bacillus thuringiensis*. The gene directs the synthesis of a protein that is poisonous to certain insects, many of which are common farm pests. Potatoes, cotton, and corn were all modified with this gene. Many farmers were happy with the results. They did not need to spray their fields with pesticides because the crops made their own pesticides.

Scientists continue to develop new GM plants, and similar technology is now being applied to animals. Fast-growing GM salmon were approved for sale in 2015, and other GM animals may follow.

Many scientists and agricultural experts argue that GM plants and animals provide an effective, efficient way to feed Earth's growing human population. Many GM plants can resist insects without the need for chemical pesticides. Others are tolerant to herbicides, or weed-killing chemicals. Evidence shows that the food is likely to be safe and nutritious to eat, and is essentially the same as the food from the original crops.

However, many critics argue against GM crops. One of their arguments is that the crops may easily spread beyond farmers' fields and into the wild. If the GM plants breed with wild plants, the new genes could alter the plants—and natural ecosystems—in unforeseen ways. Their concern is that the combination of artificial and natural processes could generate a harmful plant, or even a toxic one.

How do scientists transfer genes from one organism into another? What are some of the other arguments in favor of and against the use of GM crops, as well as other genetic technologies? What ethical questions should we ask, and try to answer, about genetic technology?

Throughout this chapter, look for connections to the CASE STUDY to help you answer these questions.

LESSON 16.1

Changing the Living World

KEY QUESTIONS

- *What is selective breeding used for?*
- *How do people increase genetic variation?*

VOCABULARY

selective breeding
biotechnology
hybridization
inbreeding

READING TOOL

While you read the lesson, explain the two ways that scientists carry out selective breeding practices. Fill in the graphic organizer in your **Biology Foundations Workbook.**

Visit a dog park, and what do you see? Striking contrasts are everywhere—from a tiny Chihuahua to a massive Great Dane, from the short coat of a Labrador retriever to the curly fur of a poodle, from the long muzzle of a wolfhound to the pug nose of a bulldog. The differences among breeds of dogs are so great that someone might think they are different species. They're not, of course, but where did these obvious differences come from?

Selective Breeding

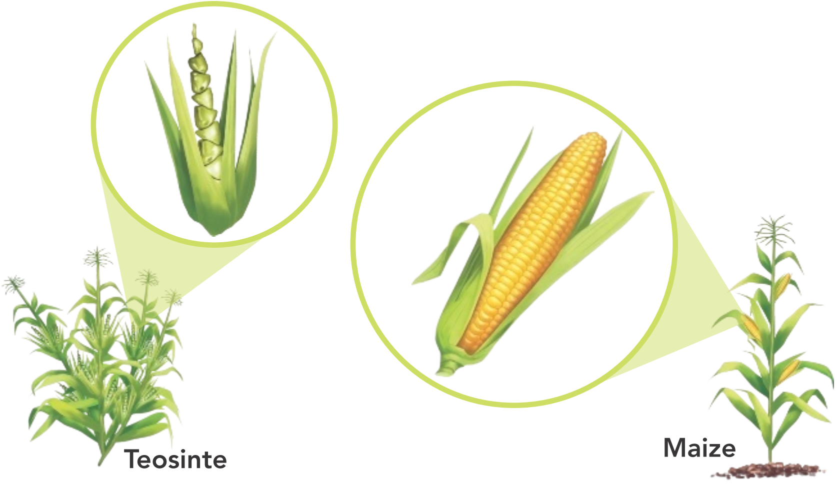
The answer is that we did it. Humans have kept and bred dogs for thousands of years, always looking to produce animals that are better hunters, better retrievers, or friendlier companions. We've done so by **selective breeding**, allowing only those animals with wanted characteristics to produce the next generation. ***Humans use selective breeding to take advantage of naturally occurring genetic variation to pass wanted traits on to the next generation of organisms.***

Selective breeding is just one example of **biotechnology**, the application of a technological process, invention, or method to living organisms. Although we tend to think of biotechnology as involving high-powered equipment in gleaming laboratories, humans have been practicing biotechnology for thousands of years as they bred domesticated plants and animals. A perfect example may be right in front of you in the form of the corn chips or popcorn we snack on.

When Europeans came to the New World, they discovered that Native Americans were cultivating corn, a productive and nutritious crop unknown to them. Where did this remarkable plant come from? The chromosomes of corn are remarkably similar to those of teosinte, a wild grass native to central Mexico. Corn can be crossed with teosinte, demonstrating that the two species are closely related.

VIDEO

Examine how the many breeds of dogs have originated from a common ancestor.



CASE STUDY

Figure 16-1

Teosinte to Modern Corn

During its domestication, corn (maize) lost the ability to survive in the wild but gained valuable agricultural traits. For example, the hard case around the kernel disappeared over time, leaving the rows of soft corn kernels we enjoy today.

Work by geneticist George Beadle and others showed that changes in just a few genes account for the differences between corn and teosinte, as shown in **Figure 16-1**. In a sense, corn is one of humankind's first great achievements in biotechnology. Nearly 10,000 years ago, Native Americans selectively bred teosinte to select for the traits controlled by those genes, producing what is now one of the world's most important crops.

Hybridization American botanist Luther Burbank (1849–1926) may have been the greatest selective breeder of all time. Burbank used **hybridization**, the crossing of dissimilar individuals to bring together the best of both organisms. Many of Burbank's hybrid crosses combined the disease resistance of one plant with the food-producing capacity of another. The result was a new line of plants that led to increased food production. **Figure 16-2** shows the Russet Burbank potato, the most widely grown potato in North America.

BUILD VOCABULARY

Related Words Recall that a *hybrid* is the offspring of parents with different traits. **Hybridization** is a method to produce offspring with the desired characteristics from both parents.

Inbreeding To maintain desirable characteristics in a line of organisms, breeders often use a technique known as inbreeding. **Inbreeding** is the continued breeding of individuals with similar characteristics. The many breeds of dogs—from beagles to poodles—are maintained using this practice. Inbreeding helps ensure that the characteristics that make each breed unique are preserved. Although inbreeding is useful in preserving certain traits, it can be risky. Most of the members of a breed are genetically similar, which increases the chance that a cross between two individuals will bring together two recessive alleles for a genetic defect.

READING CHECK Compare How do hybridization and inbreeding compare?

INTERACTIVITY

Figure 16-2

Burbank's Hybrids

Russet potatoes are just one of the 800 varieties of plants hybridized by Luther Burbank.

Increasing Variation

Selective breeding would be nearly impossible without the wide variation found in natural populations of plants and animals. But sometimes breeders want even more variation than exists in nature. ***Breeders can increase the genetic variation in a population by introducing mutations, which are the ultimate source of biological diversity.***

INTERACTIVITY

Explore different methods of selective breeding with animals and plants.

Bacterial Mutations Mutations—heritable changes in DNA—occur spontaneously, but breeders can increase the mutation rate of an organism by using radiation or chemicals. While many mutations are harmful, breeders can select for those mutations that produce useful characteristics not found in the original population. This technique has been particularly useful with bacteria. Because they are small, millions of bacteria can be treated with radiation or chemicals at the same time, which increases the chances of producing a useful mutant. This technique has allowed scientists to develop hundreds of useful bacterial strains. For instance, we have known for decades that certain strains of oil-digesting bacteria are effective for cleaning up oil spills. Today scientists are working to produce bacteria that can clean up radioactive substances and metal pollution in the environment.

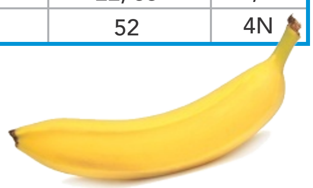
Figure 16-3

Ploidy Numbers

Because polyploid plants are often larger than other plants, many farmers deliberately grow polyploid varieties of crops like those listed.

Polyploid Crops

Plant	Probable Ancestral Haploid Number	Chromosome Number	Ploidy Level
Domestic oat	7	42	6N
Peanut	10	40	4N
Sugar cane	10	80	8N
Banana	11	22, 33	2N, 3N
Cotton	13	52	4N



Polyploid Plants Drugs that prevent the separation of chromosomes during meiosis are very useful in plant breeding. These drugs can produce cells that have many times the normal number of chromosomes. Plants grown from these cells are called polyploid because they have many sets of chromosomes. Polyploidy is usually fatal in animals. But, for reasons that are not clear, plants are much better at tolerating extra sets of chromosomes. Polyploidy can quickly produce new species of plants that are larger and stronger than their diploid relatives. A number of important crop plants, including bananas and many varieties of citrus fruits, have been produced in this way. **Figure 16-3** lists several examples of polyploid plants.

LESSON 16.1 Review

KEY QUESTIONS

1. Explain the process of selective breeding.
2. Why would breeders want to introduce mutations into a population?

CRITICAL THINKING

3. **Evaluate Claims** What evidence supports the claim that corn plants were bred from teosinte?
4. **Construct an Explanation** How do biotechnologies such as hybridization and the introduction of mutations increase genetic variation?
5. **Interpret Tables** Look at **Figure 16-3**. Which plant has undergone the most dramatic change in chromosome number?

The Process of Genetic Engineering

LESSON 16.2

Gel electrophoresis separates DNA fragments.

KEY QUESTIONS

- *How do scientists copy the DNA of living organisms?*
- *How is recombinant DNA used?*
- *How are transgenic organisms produced?*

HS-ETS1-1: Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.

VOCABULARY

polymerase chain reaction
recombinant DNA
plasmid
genetic marker
transgenic
clone

READING TOOL

Before you read, skim through the lesson and note the section headings. Fill in the graphic organizer in your **Biology Foundations Workbook** with those section headings.

For nearly all of human history, plant and animal breeders were limited in what they could do. They could only work with variations that already existed in nature, or were the result of mutations, which were risky and unpredictable. Today, however, all that has changed. Genetics is not just something we study. It is something we can engineer to change the characteristics of living organisms.

Analyzing DNA

You may recall from Chapter 15 that it is relatively easy to extract DNA from cells and tissues. The extracted DNA can be cut into fragments of manageable size using restriction enzymes. These restriction fragments can then be separated for study according to size, using gel electrophoresis or another similar technique. Finally, the base sequences of these fragments can be read, and then put back together to produce a complete genomic DNA sequence. Now the tough part: How do you find a specific gene in that DNA sequence?

The problem is huge. If we were to cut DNA from a bacterium such as *E. coli* into restriction fragments averaging 1000 base pairs in length, we would have 4000 restriction fragments. In the human genome, we would have 3 million restriction fragments. How do we find a single gene among millions of fragments? In some respects, it's the classic problem of finding a needle in a haystack—we have an enormous pile of hay and just one needle.

Actually, there is a way to find a needle in a haystack. We can toss the hay in front of a powerful magnet until something sticks. The hay won't stick, but a needle made of iron or steel will. Believe it or not, similar techniques can help scientists identify specific genes.

Figure 16-4

A Fluorescent Gene

The Pacific Ocean jellyfish, *Aequorea victoria*, emits a bluish glow. A protein in the jellyfish absorbs blue light from the sun and produces green fluorescence.

Finding a Gene

In 1987, biologist Douglas Prasher wanted to find the gene for the green fluorescent protein (GFP) found in some jellyfish, such as *Aequoria victoria*, shown in **Figure 16-4**. First Prasher predicted the mRNA base sequence that would code for some of the amino acids. Then he screened a genetic "library" with thousands of jellyfish mRNA sequences, until he found one that matched his predictions. Finally, using a gel in which DNA fragments from the jellyfish genome had been separated, he found one of the DNA fragments that matched the GFP mRNA. That fragment contained the actual gene for GFP.

The GFP sequence is now widely used to label proteins in living cells and organisms, like the glowing fish shown on the opening pages of this chapter. Today it is often quicker and less expensive for scientists to search for genes in computer databases where the complete genomes of many organisms are available.

Polymerase Chain Reaction

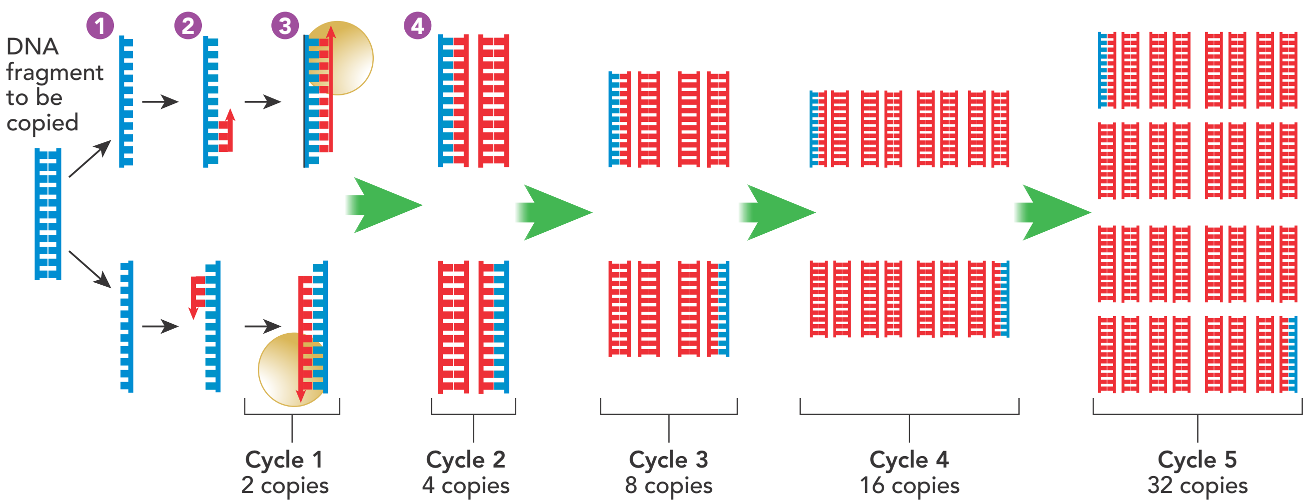
When a sample contains too little DNA to be analyzed easily, scientists use a technique known as **polymerase chain reaction** (PCR) to make multiple copies of specific DNA sequences. As shown in **Figure 16-5**, short pieces of single-stranded DNA known as primers, each about 20 or 30 bases in length, are added to the sample. The base sequences of these pieces are chosen to be complementary to sequences on either end of the region of DNA to be copied. The DNA sample is heated to separate its strands. Then, as the DNA cools, the primers bind to the single strands. Next, DNA polymerase copies or replicates the region between the primers. As the cycle of heating and cooling is repeated, these copies serve as templates to make still more copies. ***Using the PCR process, just a few dozen cycles of replication can produce billions of copies of the DNA between the primers in less than a day.***

Figure 16-5

The PCR Method

Polymerase chain reaction is used to make multiple copies of a gene. This method is particularly useful when only tiny amounts of DNA are available.

1. DNA is heated to separate strands.
2. The mixture is cooled, and primers bind to strands.
3. DNA polymerase adds nucleotides to strands, producing two complementary strands.
4. The procedure is repeated starting at step 1.



Where did Kary Mullis, the American scientist who invented PCR, find a DNA polymerase enzyme that could stand repeated cycles of heating and cooling? Mullis found it in bacteria from the hot springs of Yellowstone National Park—a powerful example of the importance of biodiversity to biotechnology!

READING CHECK **Identify** How does polymerase chain reaction make copies of a specific region of DNA?

Rewriting the Genome

Just as scientists were learning how to read and analyze DNA sequences, they began to wonder if it might be possible to change the DNA of a living cell. However, this feat had already been accomplished decades earlier. Do you remember Griffith's experiments on bacterial transformation? His extract of heat-killed bacteria contained DNA fragments. When he mixed those fragments with live bacteria, a few of the bacteria took up the DNA molecules, transforming the DNA and changing the bacteria's genomes. Griffith might have been the world's first genetic engineer.

Recombinant DNA Today, scientists can take DNA molecules from any source—either another organism or DNA custom-built in the lab—and insert them into living cells. Usually, these sequences are first joined to other DNA molecules using enzymes like DNA ligase to splice the molecules together. As **Figure 16-6** shows, the "sticky ends" left by restriction enzymes allow DNA fragments to combine. These combined molecules are known as **recombinant DNA**, since they are produced by recombining DNA from different sources. ***Recombinant-DNA technology makes it possible to change the genetic composition of living organisms.*** By manipulating DNA in this way, scientists can learn more about genome organization and function.

Plasmids and Genetic Markers Scientists working with recombinant DNA soon discovered that many of the DNA molecules they tried to insert into host cells simply vanished because the cells often did not copy, or replicate, the added DNA. Today scientists join recombinant DNA to another piece of DNA containing a replication "start" signal. This way, whenever the cell copies its own DNA, it copies the recombinant DNA too.

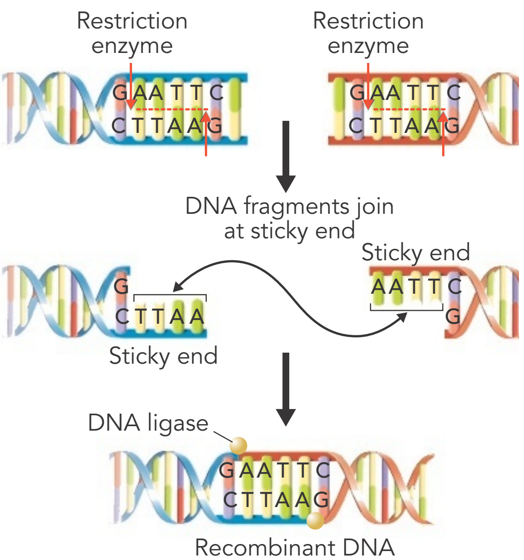
In addition to their own chromosomes, some bacteria contain small circular DNA molecules known as **plasmids**. Plasmids are widely used in recombinant DNA studies. Joining DNA to a plasmid, and then using the recombinant plasmid to transform bacteria, results in the replication of the newly added DNA along with the rest of the cell's genome.

Plasmids are also found in yeasts, which are single-celled eukaryotes that can be transformed with recombinant DNA as well. Biologists working with yeasts can construct artificial chromosomes containing centromeres, telomeres, and replication start sites. These artificial chromosomes greatly simplify the process of introducing recombinant DNA into the yeast genome.

Figure 16-6

Joining DNA Pieces Together

If DNA molecules from two sources are cut with the same restriction enzyme, their sticky ends will bond to a fragment of DNA that has the complementary sequence of bases.



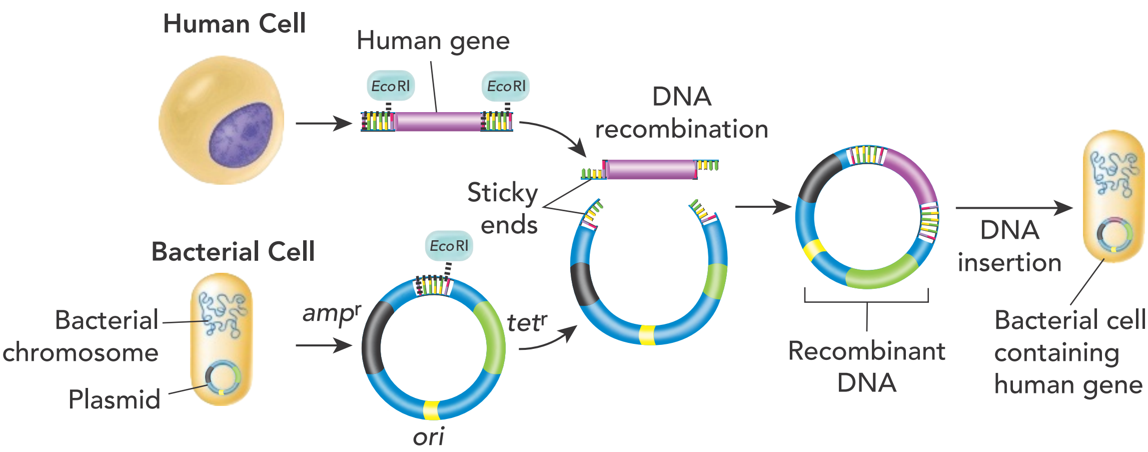


Figure 16-7

Plasmid DNA Transformation

Scientists can insert a piece of DNA into a plasmid if both the plasmid and the target DNA have been cut by the same restriction enzymes to create sticky ends. With this method, bacteria can be used to produce substances such as human growth hormone.

Figure 16-7 shows how bacteria can be transformed using recombinant plasmids. First, the DNA being used for transformation is joined to a plasmid. The plasmid DNA contains a signal for replication (*ori*) as well as genetic markers such as genes for antibiotic resistance (*ampr* and *tetr*). A **genetic marker** makes it possible to distinguish bacteria that carry the plasmid from those that don't. So, even if just a few cells in a million take up the recombinant plasmids, the markers make it possible to find those cells. After transformation, the culture is treated with the antibiotic. Only those rare cells that have been transformed survive, because only they carry the resistance gene.

READING CHECK Review How are plasmids used in genetic engineering?

READING TOOL

Before you read about how the CRISPR system is used to edit DNA, preview **Figure 16-8**. Write down any questions you have about the process and answer them as you read the text.

CRISPR and DNA Editing Although recombinant DNA technology has been useful, it is limited by the fact that it makes use of DNA from existing sources. Biologists have dreamed of a tool that could directly change the DNA base sequence of a gene in the way you might edit the words in an essay you are typing on your computer. Now, it seems, just such a tool is available. The technique is called CRISPR (clustered regularly interspersed short palindromic repeats), and its development began with a discovery made more than 20 years ago.

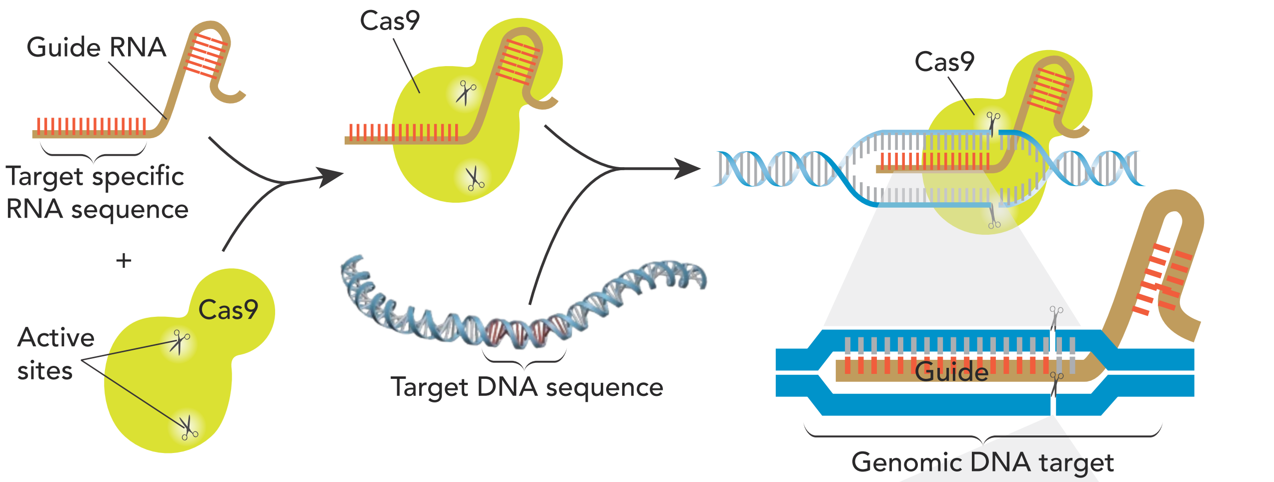
Quick Lab — Guided Inquiry

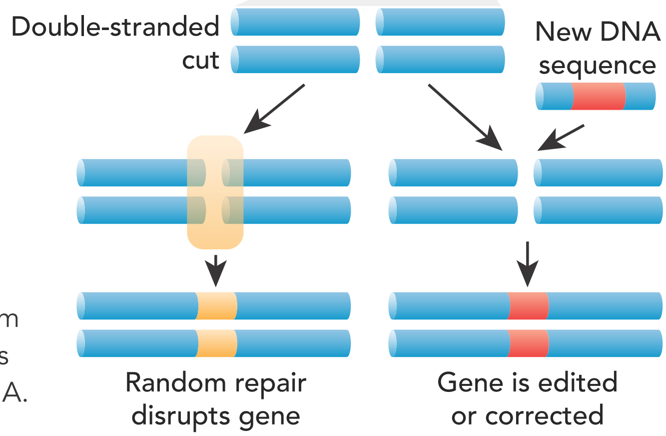
Inserting Genetic Markers

1. One partner should write a random DNA sequence on a long strip of paper to model an organism's genome.
2. The other partner should write a short DNA sequence on a short strip of paper to model a genetic marker.
3. Using the chart your teacher gives you, work with your partner to figure out how to insert the marker gene into the genome.

ANALYZE AND CONCLUDE

1. **Analyze** How did the structure of your DNA molecule change?
2. **Use Models** What kind of molecule did you and your partner model?
3. **Construct an Explanation** Suppose a cell contains the DNA sequence you modeled. Explain what will happen when the cell copies its own DNA.





Francisco Mojica, a biology graduate student, discovered that a fragment of bacterial DNA from a salt marsh in Spain contained short, repeated base sequences similar to those found in the DNA of certain bacterial viruses. Before long, it became clear that these DNA sequences were actually part of the defense mechanism against those viruses. If DNA from such a virus enters the cell, the bacterium uses these repeated base sequences to produce its own short RNA molecules that bind to the viral DNA. Guided by that RNA, an enzyme then cuts the viral DNA, making it useless. While it might seem that this discovery was of little practical benefit (unless you happen to be a bacterium!), scientists gradually realized that this system could be used to edit DNA.

ANIMATION

Figure 16-8

CRISPR Technology

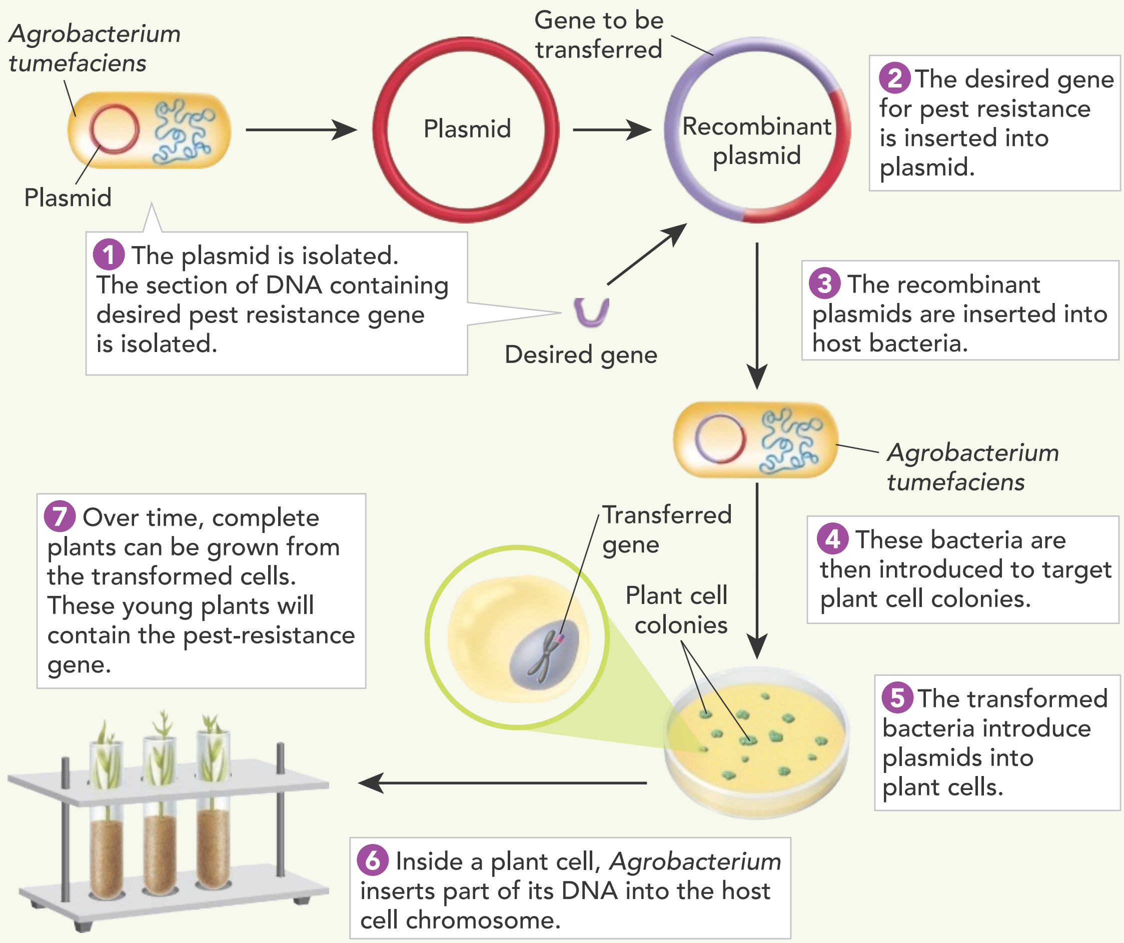
CRISPR allows scientists to change the base sequence of a gene without the insertion of DNA from another source.

Figure 16-8 shows how the CRISPR system is now used to edit DNA in a eukaryotic cell. A recombinant DNA molecule that contains two genes is constructed. One codes for an enzyme known as Cas9, and the other for a RNA molecule that will guide the Cas9 enzyme to a particular DNA sequence. The guide RNA enables the Cas9 enzyme to attach to DNA and cut both strands at an exact point. Enzymes in the cell then repair the broken ends by inserting random bases, which usually destroy the function of the gene. However, if a single strand of DNA with base sequences matching those at the break is also injected into the cell, the repair mechanism will use this DNA instead. In this way, scientists can rewrite the base sequence of nearly any gene in the cell.

More than a dozen laboratories around the world played a role in developing this technology, which is now widely used in research. CRISPR makes it possible to study gene function by inactivating specific genes. This technology also has the possibility of changing the DNA sequences of certain disease-causing genes, as well as re-engineering genes to perform new functions.

INTERACTIVITY

Practice genetic engineering by isolating particular genes and then transferring them into another organism.



CASE STUDY

Figure 16-9

Transgenic Organisms

Recombinant DNA is used to create transgenic plants.

BUILD VOCABULARY

Prefixes The prefix *trans-* means "changing thoroughly." A transgenic organism has been changed by the addition of genes from another species.

Transgenic Organisms and Cloning

The universal nature of the genetic code makes it possible to construct organisms that are **transgenic**, containing genes from other species. ***Transgenic organisms can be produced by the insertion of recombinant DNA into the genome of a host organism.*** Like bacterial plasmids, the DNA molecules used for the transformation of plant and animal cells contain genetic markers that help scientists identify which cells have been transformed. Transgenic technology was perfected using mice in the 1980s. Genetic engineers can now produce transgenic plants, animals, and microorganisms.

Transgenic Plants Many plant cells can be transformed using the bacterium *Agrobacterium*. In nature this bacterium inserts a small DNA plasmid that produces tumors in plant cells. Scientists can deactivate the plasmid's tumor-producing gene and replace it with a piece of recombinant DNA. The recombinant plasmid can then be used to infect and transform plant cells, as shown in **Figure 16-9**.

There are other ways to produce transgenic plants as well. When their cell walls are removed, plant cells in culture will sometimes take up DNA on their own. DNA can also be injected directly into some plant cells. If transformation is successful, the recombinant DNA is integrated into one of the plant cell's chromosomes.

Transgenic Animals Scientists can transform animal cells using some of the same techniques used for plant cells. The egg cells of many animals are large enough that DNA can be injected directly into the nucleus. Once the DNA is in the nucleus, enzymes that are normally responsible for DNA repair and recombination may help insert the foreign DNA into the chromosomes of the injected cell.

INTERACTIVITY

Review the process of genetic engineering.

Cloning A **clone** is a population of genetically identical cells produced from a single cell. The technique of cloning uses a single cell from an adult organism to grow an entirely new individual that is genetically identical to the organism from which the cell was taken.

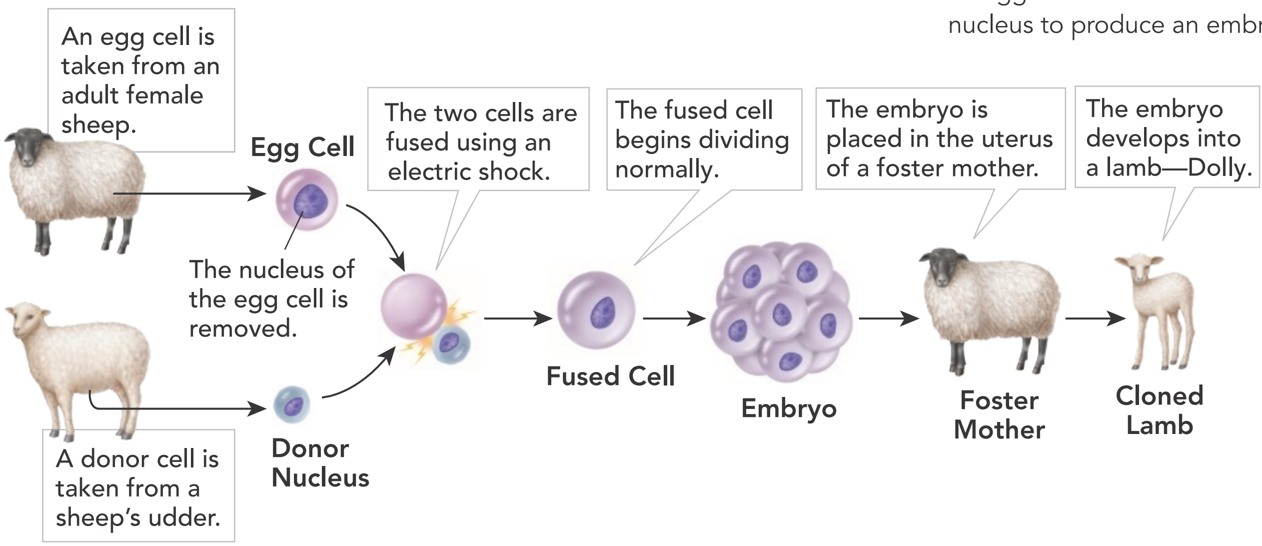
Cloned colonies of bacteria and other microorganisms are easy to grow, but this is not always true of multicellular organisms, especially animals. Nonetheless, in 1997 Scottish scientist Ian Wilmut announced that he had produced a sheep, called Dolly, by cloning.

Figure 16-10 shows the basic steps by which an animal can be cloned. First, the nucleus of an unfertilized egg cell is removed. Next, the egg cell is fused with a donor cell that contains a nucleus taken from an adult. That cell develops into an embryo, which is then implanted in the uterus of a foster mother, where it develops until birth. Farmers and ranchers have used these techniques to clone champion cows, pigs, and other animals to improve the breeding stock for their herds.

Figure 16-10

Cloning Animals

Animal cloning uses a procedure called nuclear transplantation. The process combines an egg cell with a donor nucleus to produce an embryo.



HS-ETS1-1

LESSON 16.2 Review

KEY QUESTIONS

1. Describe the process scientists use to make lots of copies of DNA sequences.
2. How are plasmids used to change the genetic composition of living organisms?
3. What is a transgenic organism?

CRITICAL THINKING

4. **Construct an Explanation** Why would a scientist want to determine the sequence of a DNA molecule?
5. **Compare and Contrast** Compare the transformation of a plant cell with the transformation of an animal cell.

LESSON 16.3 Applications of Biotechnology

KEY QUESTIONS

- *How can genetic engineering benefit agriculture and industry?*
- *How can biotechnology improve human health?*
- *How is DNA used to identify individuals?*

HS-ETS1-1: Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.
HS-LS3-1: Ask questions to clarify relationships about the role of DNA and chromosomes in coding the instructions for characteristic traits passed from parents to offspring.

VOCABULARY
gene therapy
DNA microarray
DNA fingerprinting
forensics

READING TOOL

As you read, identify the main ideas and supporting details under each main heading. Fill in the table in your **Biology Foundations Workbook.**

Have you eaten any genetically modified food lately? Don't worry if you're not sure. For many years, the labeling of these foods in grocery stores or markets has not been required. But if you eat corn, potatoes, or soy products, chances are close to 100 percent that you've eaten foods modified in some way by genetic engineering.

Agriculture and Industry

Everything we eat and much of what we wear comes from living organisms. Not surprisingly, then, researchers have used genetic engineering to try to improve the products we get from plants and animals. ***Ideally, genetic modification would lead to better, less expensive, and more nutritious food as well as less harmful manufacturing processes.***

GM Crops Since their introduction in 1996, genetically modified (GM) plants have become an important component of our food supply. In 2016, GM crops made up 94 percent of soybeans, 89 percent of cotton, and 89 percent of corn grown in the United States. Corn, for example, is often modified with bacterial genes that produce a protein known as Bt toxin. While it is harmless to humans and most other animals, enzymes in the digestive systems of insects convert the Bt protein to a form that kills the insects. Fields of Bt corn do not have to be sprayed with pesticides, and have been shown to produce higher crop yields.

Resistance to insects is just one useful characteristic being engineered into crops. Others include resistance to viral infections and herbicides, which are chemicals that kill weeds. Some transgenic plants may soon produce foods that are resistant to rot and spoilage. And engineers are currently developing GM plants that may produce plastics for the manufacturing industry.

GM Animals Transgenic animals are also becoming more important to our food supply. For example, about 30 percent of the milk in U.S. markets comes from cows that have been injected with hormones made by recombinant-DNA techniques to increase milk production. Pigs can be genetically modified to produce more lean meat or higher levels of healthy omega-3 acids. Using growth-hormone genes, scientists have developed transgenic salmon that grow much more quickly than wild salmon. These salmon are grown in captive aquaculture facilities to ensure that they do not outcompete wild populations.

When scientists in Canada combined spider genes with the cells of lactating goats, the goats began to manufacture silk along with their milk. By extracting polymer strands from the milk and weaving them into thread, we can create a light, tough, and flexible material that could be used in such applications as military uniforms, medical sutures, and tennis racket strings. Scientists are now using human genes to develop antibacterial goat milk.

READING CHECK **Summarize** What are some ways that genetic modification have improved farm crops and animals?

BUILD VOCABULARY

Academic Words When you modify something, you make small changes to it, often with the purpose of improving it. Modified is the past tense of modify. A genetically modified organism has had changes made to its genome.

Health and Medicine

Biotechnology, in its broadest sense, has always been part of medicine. Early physicians extracted substances from plants and animals to cure their patients. Twentieth-century medicine saw the use of vaccines to save countless lives. ***Today, biotechnology is the source of some of the most important and exciting advances in the prevention and treatment of disease.***

Genetic Testing If two prospective parents suspect they are carrying the alleles for a genetic disorder, such as cystic fibrosis (CF), how could they find out for sure? Because the CF allele has slightly different DNA sequences from its normal counterpart, genetic tests using labeled DNA probes can distinguish the presence of CF. Like many genetic tests, the CF test uses specific DNA sequences that detect the complementary base sequences found in the disease-causing alleles. Other genetic tests search for changes in cutting sites of restriction enzymes. Some use PCR to detect differences between the lengths of normal and abnormal alleles. Genetic tests are now available for diagnosing hundreds of disorders.

Medical Research Transgenic animals, such as the pig shown in **Figure 16-11**, are often used as model test subjects in medical research, simulating human genetic disorders. These animal models have been used to study the onset and progression of diseases and to conduct drug testing. Although they cannot completely simulate the responses of the human body, animal models are useful, and have been used to research human disorders, such as Alzheimer's disease and arthritis.

Figure 16-11
Transgenic Pig

This pig is greenish because it has jellyfish genes for fluorescent proteins. These jellyfish genes act as markers for genes being studied in medical research.

CASE STUDY

Figure 16-12

Vitamin-Rich Rice

Two genes engineered into the rice genome—a plant gene and a bacterial gene—help the grains produce and accumulate beta-carotene. The golden color indicates the concentration of beta-carotene in the edible part of the rice seed.

Preventing and Treating Disease

Bioengineering can prevent and treat human diseases in a variety of different ways, from making our food more nutritious to creating strains of mosquitoes that are incapable of transmitting particular pathogens.

Golden Rice One interesting development in transgenic technology is golden rice, shown in **Figure 16-12**. Traditional white rice does not contain provitamin A, also known as beta-carotene, which is essential for human health. Golden rice has been genetically modified to produce and accumulate beta-carotene. Provitamin A deficiencies lead to serious medical problems, including infant blindness. While there have been setbacks in bringing this new crop to the areas that could benefit from it, scientists continue to hope that provitamin A-rich golden rice will help prevent these problems.

Human Proteins When recombinant-DNA techniques were developed for bacteria, biologists realized almost immediately that the technology held the promise to do something that had never been done before—to make important proteins that could prolong and even save human lives. For example, human growth hormone, which is used to treat patients suffering from pituitary dwarfism, was once scarce. Human growth hormone is now widely available because it is mass-produced by recombinant bacteria. Other products now made with genetically engineered bacteria include insulin to treat diabetes, blood-clotting factors for hemophiliacs, and potential cancer-fighting molecules, such as interleukin-2 and interferon.

In the future, transgenic animals may provide us with an ample supply of our own proteins. Several laboratories have engineered transgenic sheep and pigs that produce human proteins in their milk, making it easy to collect and refine the proteins. Many of these proteins can be used in disease prevention.

INTERACTIVITY

Investigate the role of biotechnology in health and medicine and other fields.

Gene Therapy An even more ambitious goal of biotechnology would be to cure genetic disorders by fixing or replacing the alleles that cause them. The hope of many scientists is to make **gene therapy**, the changing of a gene to treat a disease or disorder, a routine part of medical treatment. As promising as this idea seems, there have been many problems in making it a reality. Researchers have carried out a number of experiments in which they inserted DNA containing a healthy, working gene into a modified virus. They then infected the cells of patient volunteers with the virus, hoping it would insert the healthy gene into the target cell and correct the defect. In some cases, there was modest success in reversing the effects of the disorder. But in other cases, the attempts failed and in 1999 one even took the life of a courageous young man who had volunteered for this experimental therapy. As a result, many potential plans for gene therapy were abandoned out of concern that they might actually harm, rather than help, patients.

Despite these setbacks, the development of CRISPR technology has caused many scientists to think of gene therapy once again. In 2013 a group of Chinese scientists did correct a genetic disorder in mice. The disorder was caused by a dominant allele that produced cataracts, small opaque regions that cloud the lens of the eye and interfere with vision. To knock out this dominant allele, they injected the mice with mRNA containing the Cas9 sequence and a guide RNA targeting the specific DNA sequence of the cataract allele. The guide RNA found the allele, and the Cas9 enzyme took care of the rest, inactivating the allele. When the mice developed, they were cataract free. This new approach to gene therapy is off to a promising start. It will be interesting to see what the future brings!

GM Mosquitoes Other techniques are targeting mosquitoes, which spread many diseases, including malaria and the Zika virus. In February 2016, Brazilian biologists released genetically modified mosquitoes. When these mosquitoes breed with wild mosquitoes, they pass on genes that prevent the mosquitoes from carrying the Zika virus. **Figure 16-13** shows a scientist releasing the genetically modified mosquitoes that were raised in the laboratory.

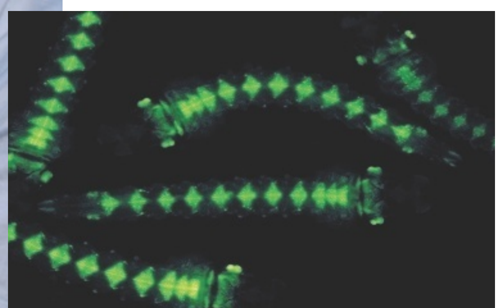


Figure 16-13

Preventing Disease

A scientist is releasing GM mosquitoes into a Brazilian neighborhood to help stop the spread of the Zika virus. The fluorescent mosquito larvae (inset) are part of a study to produce GM mosquitoes that cannot carry the protist that causes malaria.

Figure 16-14

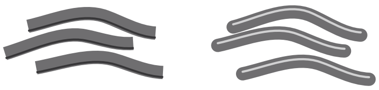
Analyzing Gene Activity

DNA microarrays help researchers explore the underlying genetic causes of many human diseases.

1 Preparing the cDNA Probe

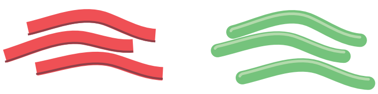
a mRNA samples are isolated from two different types of cells or tissues, such as cancer cells and normal cells.

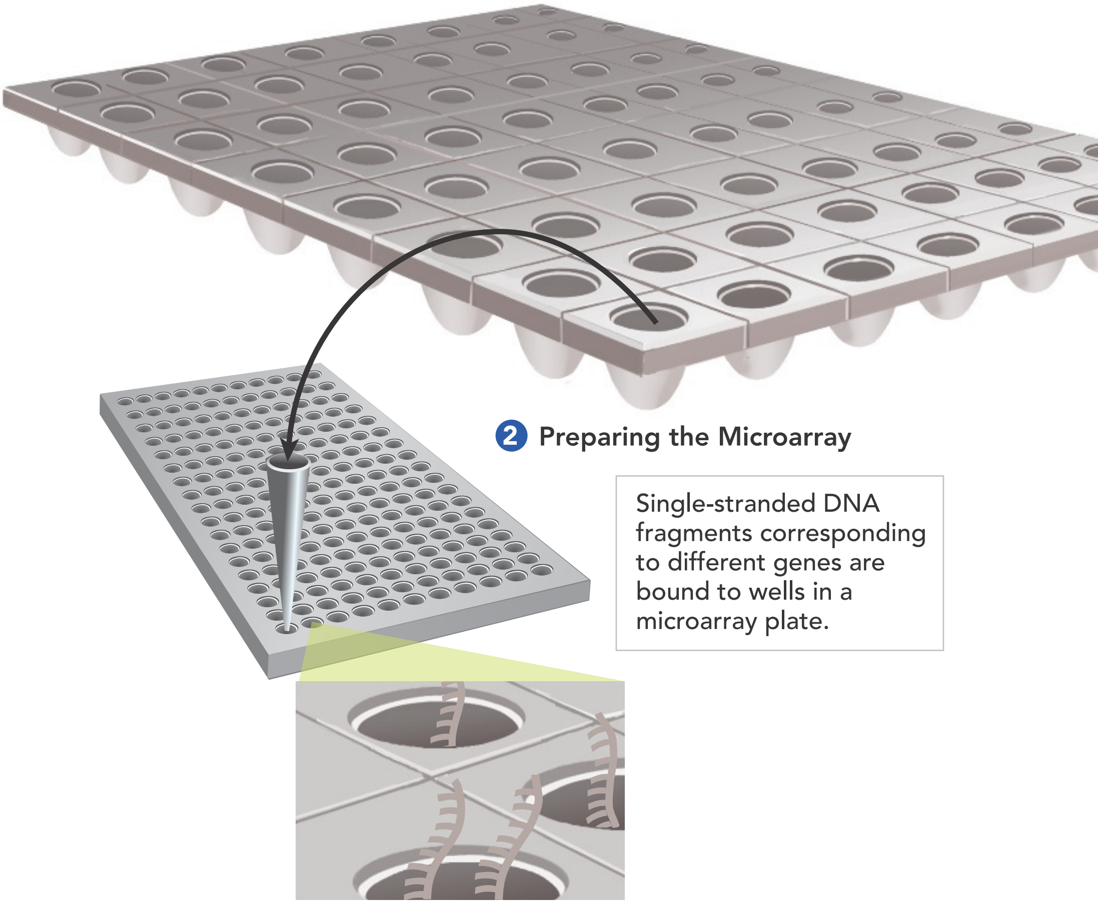
mRNA from cancer cells — mRNA from normal cells



b Enzymes are used to prepare complementary DNA molecules (cDNA) from both groups of mRNA. Contrasting fluorescent labels are attached to both groups of cDNA (red to one, green to the other).

cDNA from cancer cells — cDNA from normal cells

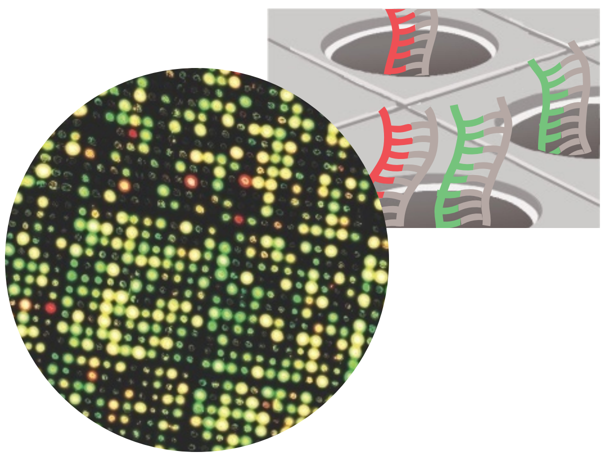




2 Preparing the Microarray

Single-stranded DNA fragments corresponding to different genes are bound to wells in a microarray plate.

3 Combining the Probe and Microarray Samples



a Color-labeled cDNA molecules from cancer and normal cells bind to complementary sequences on the plate.

b Red spots indicate higher levels of expression of that gene in cancer cells. Green spots indicate lower levels of gene expression. Yellow spots indicate equal gene expression in normal and cancerous cells.

Examining Active Genes Although each cell in a person contains the same genetic material, the same genes are not active in every cell. By studying which genes are active and which are inactive in different cells, scientists can understand how the cells function normally and what happens when genes don't work as they should. Today, scientists use **DNA microarray** technology to study hundreds or even thousands of genes at once to understand their activity levels. A DNA microarray is a glass slide or silicon chip to which spots of single-stranded DNA have been tightly attached. Typically each spot contains a different DNA fragment. **Figure 16-14** shows how a DNA microarray is constructed and used.

Suppose, for example, that you want to compare the genes expressed in cancer cells with genes in normal cells from the same tissue. After isolating mRNA from both types of cells, you would use an enzyme to copy the mRNA base sequence into single-stranded DNA labeled with fluorescent colors—red for the cancer cell and green for the normal cell. Next you would mix both samples of labeled DNA together and let them compete for binding to the complementary DNA sequences already in the microarray. If the cancer cell produces more of a particular form of mRNA, then more red-labeled molecules will bind at the spot for that gene, turning it red. Where the normal cell produces more mRNA for another gene, that spot will be green. Where there is no difference between the two cell types, the spot will be yellow because it contains both colors.

READING CHECK **List** What are five applications of genetic engineering in the field of health and medicine?

Personal Identification

The complexity of the human genome ensures that no individual is exactly like any other genetically—except for identical twins, who share the same genome. Molecular biology has used this fact to develop a powerful tool called **DNA fingerprinting** for use in identifying individuals. ***DNA fingerprinting analyzes sections of DNA that may have little or no function but that vary widely from one individual to another.*** This method is shown in **Figure 16-15**. First, restriction enzymes cut a small sample of human DNA. Next, gel electrophoresis separates the restriction fragments by size. Then a DNA probe detects the fragments that have highly variable regions, revealing a series of variously sized DNA bands. If enough combinations of enzymes and probes are used, the resulting pattern of bands can be distinguished statistically from that of any other individual in the world. By using PCR to amplify the sequences used for DNA fingerprinting, even the tiniest trace samples of blood, sperm, or hair can provide enough DNA to work with.

READING TOOL

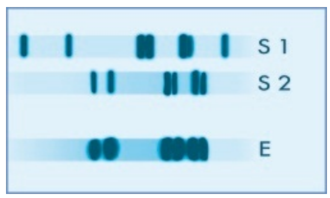
After reading the section Personal Identification, look closely at Figure 16-15. Which suspect was likely at the crime scene? Explain.

INTERACTIVITY

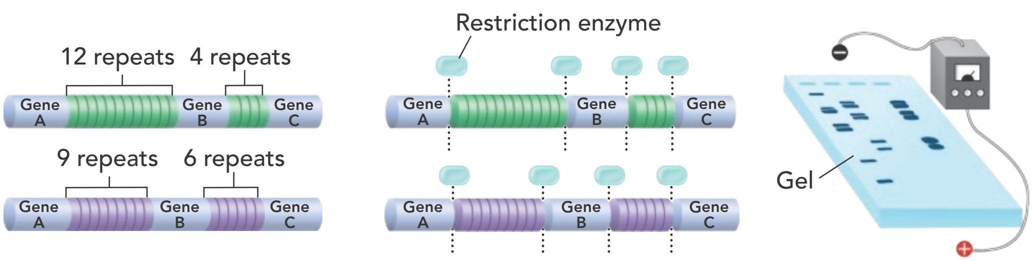
Figure 16-15

DNA Fingerprinting

DNA fingerprinting can be used to match a DNA sample to a particular person. It is especially useful in solving crimes. The diagram shows how scientists match DNA evidence from a crime scene with two possible suspects.



DNA fingerprint



1 Chromosomes contain many regions with repeated DNA sequences that do not code for proteins. These vary from person to person. Here, one sample has 12 repeats between genes A and B, while the second sample has 9 repeats between the same genes.

2 Restriction enzymes are used to cut the DNA into fragments containing genes and repeats. Note that the repeat fragments from these two samples are of different lengths.

3 The restriction fragments are separated according to size using gel electrophoresis. The DNA fragments containing repeats are then labeled using radioactive probes. This labeling produces a series of bands—the DNA fingerprint.

INTERACTIVITY

Practice using DNA fingerprinting to determine the genome of an individual from a crime scene.

Forensic Science DNA fingerprinting has been used in the United States since the late 1980s. Its precision and reliability have revolutionized **forensics**—the scientific study of crime scene evidence. DNA fingerprinting has helped solve crimes, convict criminals, and even overturn wrongful convictions. DNA evidence was first used to save an innocent person from execution in 1989. Since then, DNA evidence has saved more than 180 wrongfully convicted prisoners from death sentences. DNA forensics is used in wildlife conservation as well. African elephants are a highly vulnerable species. Poachers, who slaughter the animals mainly for their tusks, have reduced their population dramatically. To stop the ivory trade, African officials now use DNA fingerprinting to identify the herds from which black-market ivory has been taken.

Fallen Heroes Buried at the Tomb of the Unknowns, shown in **Figure 16-16**, are the remains of unidentified American soldiers who fought our nation's wars. Biotechnology offers hope that there will never be another unknown soldier. The U.S. military now requires all personnel to give a DNA sample when they begin their service. Those DNA samples are kept on file and used, if needed, to identify the remains of individuals who perish in the line of duty. In many ways, this practice is a comfort to military families, who can be assured that the remains of a loved one can be properly identified for burial.

Establishing Relationships In cases of disputed paternity, how does our justice system determine the rightful father of a child? DNA fingerprinting makes it easy to find alleles carried by the child that do not match those of the mother. Any such alleles must come from the child's biological father, and they will show up in his DNA fingerprint. The probability that those alleles will show up in a randomly picked male is less than 1 in 100,000. This means the likelihood that a given male is the child's father must be higher than 99.99 percent to confirm his paternity.

Figure 16-16

Unknown Identities

The Tomb of the Unknowns in Arlington National Cemetery, near Washington, D.C. holds the remains of unknown American soldiers from World Wars I and II, the Korean War, and, until 1998, the Vietnam War. The tomb also serves as a focal point for the honor and remembrance of those service members lost in combat whose bodies have never been recovered.

HS-LS3-1

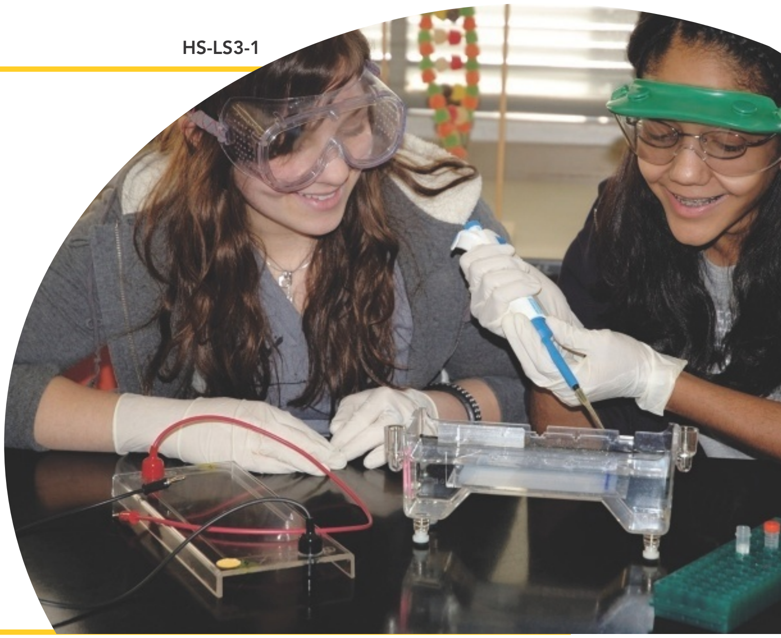
Forensics Lab Guided Inquiry

Using DNA to Solve Crimes

Problem How can DNA samples be used to connect a suspect to a crime scene?

In this lab, you will make and analyze four DNA profiles using gel electrophoresis. You will then compare the DNA profile collected from a crime scene with DNA profiles from three suspects.

You can find this lab in your digital course.



When genes are passed from parent to child, genetic recombination scrambles the molecular markers used for DNA fingerprinting, so ancestry can be difficult to trace. There are two ways to solve this problem. The Y chromosome never undergoes crossing-over, and only males carry it. Therefore, Y chromosomes pass directly from father to son with few changes. The same is true of the small DNA molecules found in mitochondria. These are passed, with very few changes, from mother to child in the cytoplasm of the egg cell.

Because mitochondrial DNA (mtDNA) is passed directly from mother to child, your mtDNA is the same as your mother's mtDNA, which is the same as her mother's mtDNA. This means that if two people have an exact match in their mtDNA, then there is a very good chance that they share a common maternal ancestor. Y-chromosome analysis has been used in the same way and has helped researchers to settle a longstanding historical question—did President Thomas Jefferson father the child of a slave? DNA testing showed that one of the modern descendants of Sally Hemings, a slave on Jefferson's Virginia estate, carried his Y chromosome. This result suggests that Jefferson was indeed the father of one of Hemings's sons.

HS-ETS1-1, HS-LS3-1

LESSON 16.3 Review

KEY QUESTIONS

1. Provide an example of a GM organism. What benefit does this organism provide that the non-GM organism could not provide?
2. In what ways can biotechnology prevent and treat diseases?
3. How is DNA fingerprinting useful?

CRITICAL THINKING

4. **Construct an Explanation** Medicines in the body interact with the body's proteins. Explain how normal variations in your genes may affect your response to different medicines.
5. **Ask Questions** You are researching different companies that analyze DNA to trace ancestry. What questions would you ask each company before you decide which company to use?

LESSON 16.4

Ethics and Impacts of Biotechnology

KEY QUESTIONS

- *What privacy issues does biotechnology raise?*
- *What are some of the pros and cons of transgenic organisms?*
- *What are some of the ethical issues around new biotechnology?*

HS-ETS1-1: Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.

READING TOOL

As you read, identify the opposing views on each ethical issue with biotechnology. Take notes in the two-column chart in your **Biology Foundations Workbook.**

We can already use biotechnology to analyze and change an organism's DNA. Should scientists be able to make any change they wish? And what should we make of a future world in which authorities might use genetics to decide a person's schooling, job prospects, and even his or her legal rights?

Profits and Privacy

Private biotechnology companies do much of the research involving GM plants and animals, hoping to make a profit. Like most inventors, they protect their discoveries and innovations with patents. A *patent* is a legal tool that gives an individual or company the exclusive right to profit from its innovations for a number of years.

Patenting Life Like new machines and devices, molecules and biotechnology procedures can be patented. But sometimes patent disputes have slowed research that might be beneficial. That was the case with provitamin A-enriched golden rice, a GM plant described in the last lesson. Even after the rice was developed, patent disputes kept it out of the hands of farmers for years. However, in 2013 the United States Supreme Court unanimously ruled that genes found in nature cannot be patented. Altered, or synthetic genes, however, can be patented, allowing companies to protect novel biotechnology products.

Genetic Privacy A great deal can be learned about a person from a sample of his or her DNA. ***DNA can reveal private information, including ethnic heritage, the chances of developing certain diseases, and evidence for criminal cases.*** As science advances, legal experts will debate ways to keep personal genetic information safe and confidential. No one wants to be denied a job or an education because of conclusions someone else might make about his or her intelligence or personality based on DNA.

Safety of Transgenic Organisms

There is a lot of controversy concerning foods that have had their DNA altered through genetic engineering. While nearly half of all GM crops today are grown in the United States, farmers around the world are now using GM technology. Are the foods from GM crops the same as those prepared from traditionally bred crops, and how will this new area of research affect the environment?

INTERACTIVITY

Explore the impacts and ethics of biotechnology.

BUILD VOCABULARY

Related Words *Insecticides* are chemicals that kill insects. *Pesticides* are chemicals that target a wide range of pests, including insects, weeds, fungi, rodents, and snails. An insecticide is a type of pesticide.

Arguments for GM Foods The companies producing seeds for GM crops would say that GM plants are actually better and safer than other crops. Farmers choose them because they produce higher yields, reducing the amount of land and energy that must be devoted to agriculture and lowering the cost of food and other plant-based products for everyone.

Insect-resistant GM plants need little, if any, insecticide to grow successfully. This reduces the chance that insecticide residues will enter the food supply and reduces damage to the environment. In addition, GM foods have been widely available for more than two decades. ***Careful studies of such foods have provided no scientific support for concerns about their safety, and the scientific community regards foods made from GM plants as safe to eat.***

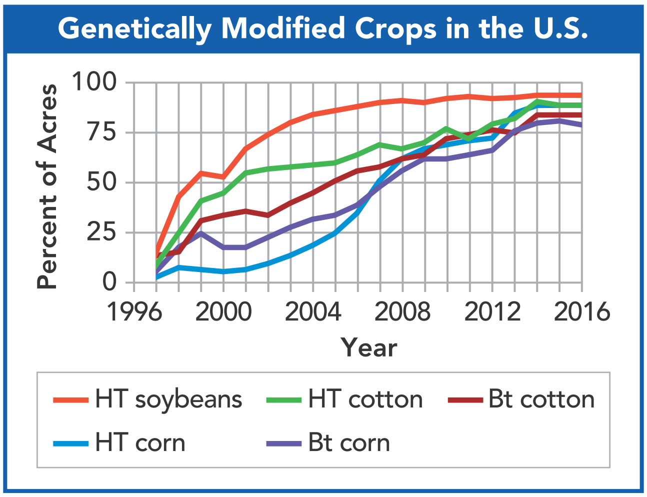
Arguments Against GM Foods Critics acknowledge some benefits of genetically modified foods, but they also point out that no long-term studies have been made of the potential hazards. Therefore, even if there is no current evidence that such products are harmful, they argue that adverse effects could appear in the future.

CASE STUDY Analyzing Data

Genetically Modified Crops in the United States

U.S. farmers have adopted GM crops widely since their introduction in 1996. Soybeans, cotton, and corn have been modified to tolerate herbicides and resist insect damage. The graph summarizes the extent to which these crops were adopted between 1996 and 2016. The modified traits shown here include herbicide tolerance (HT) and insect resistance (Bt).

1. **Analyze Graphs** Which two crops were most widely and rapidly adopted?
2. **Draw Conclusions** Why do you think the levels of adoption of GM crops fell at certain points over the period shown in the graph?
3. **Predict** What do you think will happen to HT soybeans and HT corn over the next few years? Why? Use the graph to support your prediction.



Data for each crop category include varieties with both HT and Bt (stacked) traits.
Sources: USDA, Economic Research Service using data from Fernandez-Cornejo and McBride (2002) for the years 1996–1999 and USDA, National Agriculture Statistics Service, *June Agriculture Survey* for years 2000–16.

VIDEO

Examine the ethics of biotechnology by looking at the benefits and drawbacks of the process.

CASE STUDY

Figure 16-17

Food Labeling

Many foods now include labeling that shows they were not produced using GM grains or other raw materials even though such labels are not yet required by law.

New efforts to develop genetically modified animal food products, such as salmon, pork, and beef, only add to this uncertainty, and have led critics to call for a complete ban on GM meats. ***Even if GM food itself presents no hazards, there are many serious concerns about the unintended consequences that a shift to GM farming and ranching may have on agriculture.*** Some worry that the insect resistance engineered into GM plants may threaten beneficial insects, killing them as well as crop pests. Others express concerns that use of plants resistant to chemical herbicides may lead to overuse of these weed-killing compounds.

Another concern is that the costly patents held on GM seeds by companies may raise the cost of seeds to the point that small farmers go out of business, especially in the developing world. It is not clear whether any of these concerns should block the wider use of these new biotechnologies, but it is certain that they will continue to prove controversial in the years ahead.

In the United States, many public interest groups have argued that GM foods should be labeled so that consumers know what they are eating. In 2016, the state of Vermont passed a law requiring such labeling, and other states considered similar laws. However, just a few months later, Congress overrode such state laws, and instructed the U.S. Department of Agriculture (USDA) to develop rules for GM food labeling that would apply across the country. At this point, the USDA has yet to finalize those rules. However, many food packages, like the one shown in **Figure 16-17**, are starting to include labeling that indicates that the food was not produced using GM materials.

READING CHECK **Summarize** In the United States, are manufacturer required to label products that contain genetically modified foods? Explain.

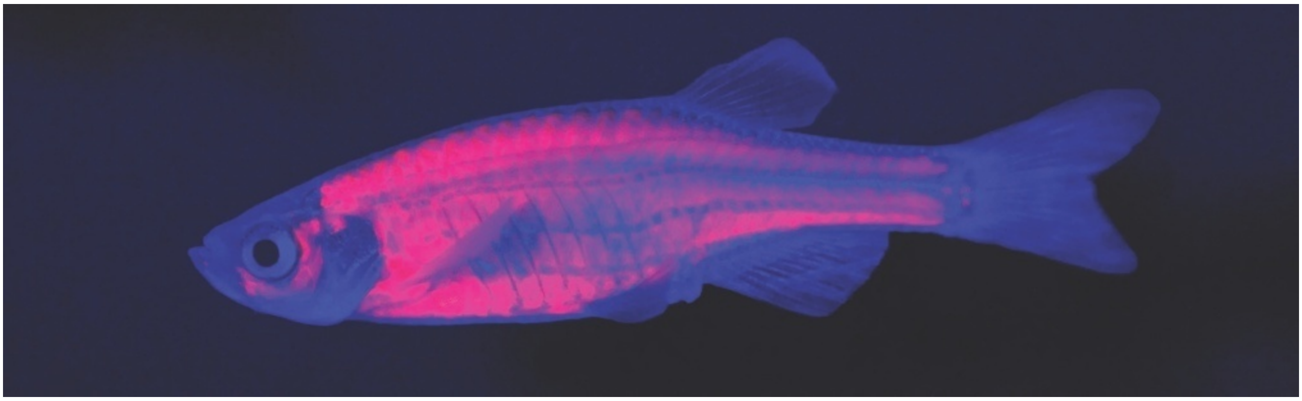
READING TOOL

Identify the effects of planting GM seeds for farmers.

Ethics of the New Biology

"Know yourself." The ancient Greeks carved this good advice in stone, and it has been guiding human behavior ever since. Biotechnology has given us the ability to know ourselves more and more. With this knowledge, however, comes responsibility. You've seen how easy it is to move genes from one organism to another. For example, the GFP gene can be extracted from a jellyfish and spliced onto genes coding for important cellular proteins. This ability has led to significant new discoveries about how cells function.

The same GFP technology was used to create the fluorescent zebra fish shown in **Figure 16-18**. These fish—along with fluorescent mice, tadpoles, rabbits, and even cats—have all contributed to our understanding of cells and proteins. But the ability to alter life forms for any purpose, scientific or nonscientific, raises important questions. ***Just because we have the technology to modify an organism's characteristics, are we justified in doing so?***



It would indeed be marvelous if new research in biotechnology enabled us to cure hemophilia, cystic fibrosis, or other genetic diseases. The technology now exists to eliminate mitochondrial diseases by transferring a zygote nucleus into the egg cytoplasm of a third person. But if human cells can be manipulated to cure disease, should biologists try to engineer taller people or change people's eye color, hair texture, sex, blood group, or appearance? What will happen to the human species when we gain the opportunity to design our bodies or those of our children? What will be the consequences if biologists develop the ability to clone human beings by making identical copies of their cells? These are questions that society must understand and deal with.

The goal of biology is to gain a better understanding of the nature of life. As our knowledge increases, however, so does our ability to manipulate the genetics of living things, including ourselves. In a democratic nation, all citizens—not just scientists—are responsible for ensuring that the tools science has given us are used wisely. This means that you should be prepared to help develop a thoughtful and ethical consensus of what should and should not be done with the human genome. To do anything less would be to lose control of two of our most precious gifts: our intellect and our humanity.

INTERACTIVITY

Figure 16-18

Solving Problems

Fluorescent zebra fish were originally bred to help scientists detect environmental pollutants. Today, studying fluorescent fish is helping us understand cancer and other diseases. Many of these fish are also sold to the public for their home aquariums.

HS-ETS1-1

LESSON 16.4 Review

KEY QUESTIONS

1. What private information can DNA reveal about a person?
2. What are some of the positive outcomes of GM agriculture?
3. What are the main concerns about genetic engineering discussed in this lesson or elsewhere in the chapter?

CRITICAL THINKING

4. **Defend Your Claim** Do you think GM food should be labeled? Cite evidence or logical reasoning to support your claim.
5. **Construct an Argument** Plants and animals have been genetically modified for a wide variety of purposes, including scientific research, improving food crops, improving human health, and commercial profit. Discuss the ethical arguments for and against these biotechnology techniques.
6. **CASE STUDY** Biologists may one day be able to use genetic engineering to alter a child's inherited traits. Under what circumstances, if any, should this ability be used? Write a persuasive paragraph expressing your opinion.

CASE STUDY WRAP-UP

What will the future hold for genetically modified crops?

The canola plants in this field look, grow, and function almost exactly the same as all other canola plants. The difference is a gene that enables them to resist chemicals used to control weeds.

HS-ETS1-1, CCSS.ELA-LITERACY.RST.9-10.1, CCSS.ELA-LITERACY.WHST.9-10.9

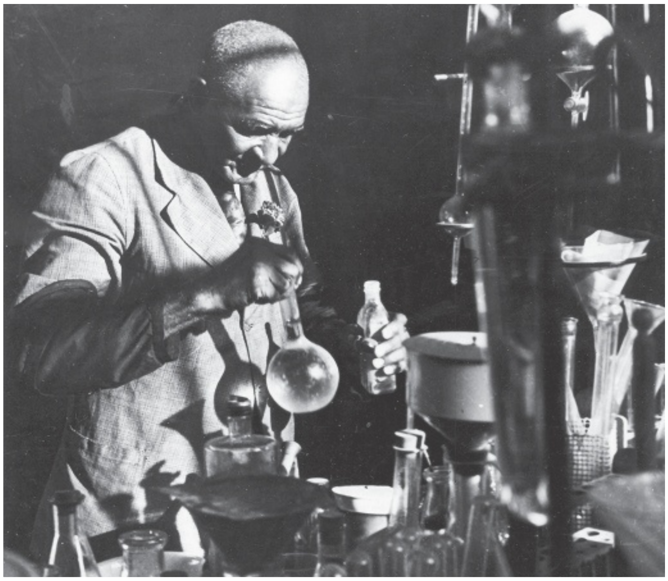
Make Your Case

Over the past 40 years, genetic technology has been changing the way we raise farm crops. These changes have brought many benefits to farmers and consumers alike. Yet critics of genetically modified (GM) foods have raised a variety of concerns. Research the arguments both in favor of and against this technology. Be sure to evaluate the sources you reference, and look for evidence that supports the arguments.

Construct an Argument

1. **Form an Opinion** What is your opinion about the use of GM crops in agriculture, as well as the development of new GM crops? Cite evidence from your research and use logical reasoning to construct an argument in support of your opinion.
2. **Conduct Peer Review** Work with a partner to discuss your arguments. Then evaluate your partner's argument. Verify the evidence that supports the argument, and evaluate the reasoning. If possible, suggest ways to strengthen either your partner's argument or your own.

A field of canola. Canola seeds (inset) change from green to brown as they mature.



Technology on the Case

Old Problem, New Solution

One hundred years ago, botanist George Washington Carver worked tirelessly to improve farming in the southeastern United States. Most farmers were growing cotton, which depleted the soil of nutrients. Carver encouraged farmers to alternate cotton with crops that restored nutrients to the soil, such as soybeans and peanuts. Carver also developed many new uses for peanuts to make them more valuable.

Today, huge volumes of fertilizer are spread on cotton and many other crops. The fertilizer supplies the nutrients and minerals that plants need. One of these nutrients is "fixed" nitrogen, which is the name for the nitrogen compounds that plants can use. Peanuts, and other legume plants, are able to supply their own fixed nitrogen because of certain bacteria that live on their roots.

Fertilizer is expensive to make and use, and it can pollute the environment. Genetic technology may offer an alternative. Scientists have identified three bacterial genes that produce the proteins involved in nitrogen fixation. Now their goal is to transfer those proteins into crop plants. If they succeed, then the modified crops would fix nitrogen from the atmosphere, just like bacteria do for legume plants. What would George Washington Carver think about that?

Careers on the Case

Work Toward a Solution

Scientists in several fields work together to invent, distribute, and manage GM farm crops. Yet ultimately the crops are in the hands of farmers. The economic and social demands of farming make science knowledge essential for farmers to succeed.

Farmer

The job of a farmer involves much more than merely planting seeds and then harvesting the crop. Farmers must now decide which crops to farm and if they want to raise GM crops. Many farmers and future farmers are now studying science at the college level. Their knowledge will help them run farms as effectively as possible.

VIDEO

Watch this video to learn about scientists who are working with genetically modified mosquitoes.

hhmi | BioInteractive

CHAPTER 16
STUDY GUIDE

Lesson Review

Go to your Biology Foundations Workbook for longer versions of these lesson summaries.

16.1 Changing the Living World

Biotechnology is the application of a technological process, invention, or method to living organisms. One example of biotechnology is selective breeding. Both hybridization and inbreeding are methods of selective breeding.

Sometimes breeders want even more variation than exists in nature and therefore introduce mutations into a population. Bacteria can be treated with radiation or chemicals to produce a useful mutant.

- selective breeding
- biotechnology
- hybridization
- inbreeding

16.2 The Process of Genetic Engineering

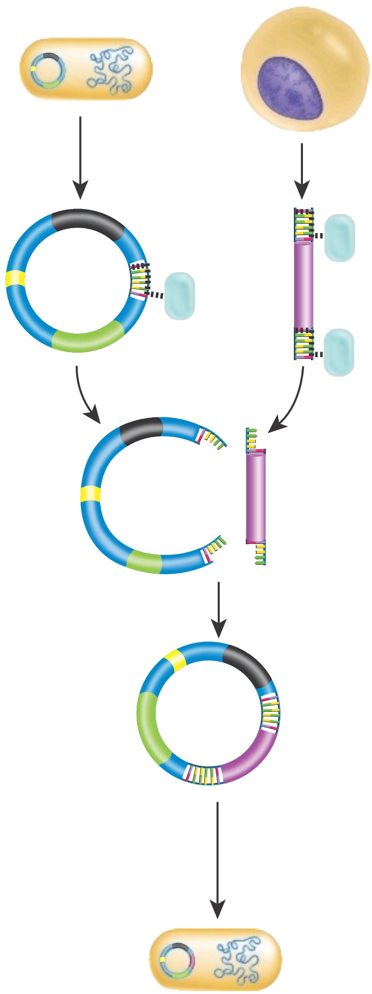
Scientists use computer databases to search for specific genes they wish to study. When a sample of DNA is too small to analyze, scientists use polymerase chain reaction (PCR) to produce billions of copies of DNA. Scientists can isolate genes and insert genes from one organism into another. Combined DNA from two or more organisms is called recombinant DNA.

Recombinant DNA can change the genetic composition of a living organism. Plasmids are small circular DNA molecules found in some bacteria and yeasts. Plasmids are used in recombinant DNA studies.

CRISPR technology allows scientists to edit DNA in a eukaryotic cell and makes it possible to study gene function by inactivating specific genes.

Transgenic organisms contain genes from other species. A clone is a population of genetically identical cells produced from a single cell. Cloning allows a single cell from an adult organism to grow an entirely new individual that is genetically identical to the organism from which the cell was taken.

- polymerase chain reaction
- recombinant DNA
- plasmid
- genetic marker
- transgenic
- clone



Interpret Diagrams Describe the process of inserting a gene for human growth hormone into a bacterial cell, as shown here.

16.3 Applications of Biotechnology

Genetic modification of plants and animals could lead to more nutritious food that is less expensive to grow or raise. Some GM plants make it possible for farmers to use less pesticides that can be harmful to the environment. Other GM plants can resist diseases that the natural varieties cannot. GM animals can produce human proteins in milk that can fight disease. Or they may be able to produce materials that are useful to industry.

Biotechnology has led to important advances in the prevention and treatment of diseases. Gene therapy, the changing of a gene to treat a disease or disorder, is a goal of biotechnology. DNA microarray technology allows scientists to study thousands of genes at once to understand their activity levels.

DNA fingerprinting analyzes sections of DNA that may have little or no function but that vary widely from one individual to another. DNA fingerprinting has applications in forensics, in identifying individuals, and in tracing ancestry.

- gene therapy
- DNA microarray
- DNA fingerprinting
- forensics

Construct an Explanation Explain how DNA microarray can help researchers determine differences between how cancer cells and normal cells function.

16.4 Ethics and Impacts of Biotechnology

Private biotechnology and pharmaceutical companies do much of the research involving GM plants and animals. They have often sought to protect their research by patenting discoveries. However, in 2013, the U.S. Supreme Court ruled that human genes cannot be patented.

There is much controversy surrounding foods that contain GM ingredients. Studies have provided no scientific support for concerns about their safety. However, there are serious concerns about the unintended consequences that farming and ranching with genetically modified organisms may have on agriculture.

The ability to alter life forms for any purpose raises important ethical questions. Just because something can be done doesn't mean it should be done. Should we manipulate human cells to engineer body design or appearance? How do we ensure that the tools of biotechnology are used wisely? A thoughtful and ethical consensus needs to be developed to preserve our intellect and our humanity.

Make Generalizations How do you evaluate the ethics of genetic technologies?

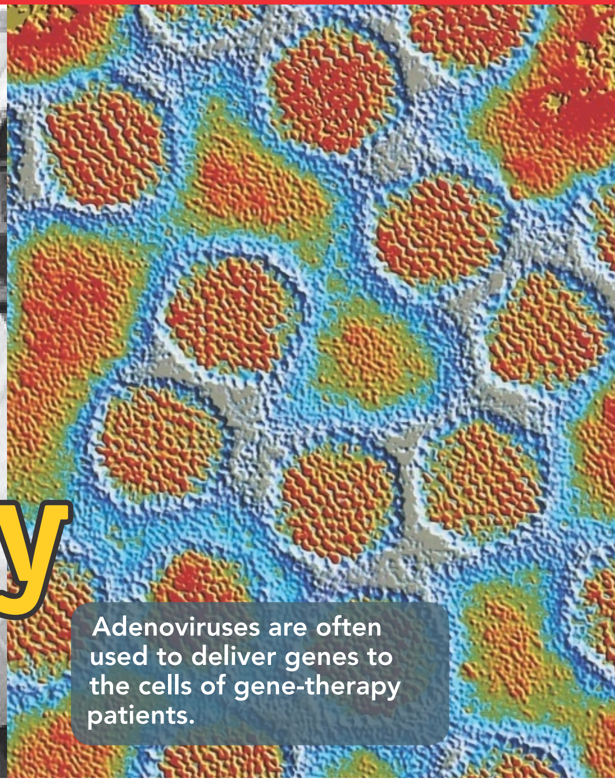
Organize Information

List the correct order of the lettered phrases to match the type of biotechnology with its application.

Type of Biotechnology	Used to ...
Selective breeding	a. transfer genes from one organism to another organism
Recombinant DNA	b. match a DNA sample to an individual
CRISPR	c. select for wanted characteristics from one generation to the next
DNA microarray	d. edit an organism's DNA
DNA fingerprinting	e. examine the activity level of a gene

Gene Therapy

1990
Dr. Kenneth Culver and Dr. Michael Blaese treated the first gene therapy patients.



Adenoviruses are often used to deliver genes to the cells of gene-therapy patients.

Evaluate a Solution

HS-ETS1-2, CCSS.ELA-LITERACY.RST.9-10.2, CCSS.ELA-LITERACY.WHST.9-10.2

STEM It all seemed so simple. To cure a disease caused by a defective gene, why not replace it with a healthy version of the same gene? In 1990, Dr. Kenneth Culver and Dr. Michael Blaese had done just that for a four-year-old girl with a genetic disorder called adenosine deaminase deficiency. Given such success, in 1999, researchers at the University of Pennsylvania thought they might be able to do something similar for eighteen-year-old Jessie Gelsinger.

Jessie suffered from ornithine transcarbamylase deficiency (OTCD), which prevents the liver from processing ammonia as it should. Although drugs had enabled Jessie to lead a fairly normal life, he volunteered to be a test subject for experimental gene therapy. His parents went along with his wishes, in the hope of helping children with potentially fatal versions of the same disease.

The treatment involved medical researchers inserting copies of the healthy gene into a virus. They expected that the virus would carry the replacement gene into Jessie's liver cells, curing him of OTCD. The virus had been carefully engineered for this purpose, and the researchers were confident that it would be harmless. But shortly after they injected this virus into the artery leading to Jessie's liver, something went terribly wrong.

Within days of the treatment, his immune system reacted against the virus so strongly that his liver and other organs underwent a complete shutdown. Five days later, this courageous volunteer was removed from life support, and died.

SCIENCE PROJECT

NEW Technology, NEW Challenges

1999
Jessie Gelsinger dies as a result of a gene therapy trial.

2017
Dr. Marina Cavazzana led a team that has developed a promising gene therapy treatment for sickle cell disease. The treatment uses the patient's stem cells.

You are a member of a journalism organization that has been assigned to write and produce a 10-minute feature broadcast about the history and future of gene therapy. Follow the steps to help you gather the information you will need to develop a script for your broadcast.

1. **Define the Problem** Jessie was the first reported patient to die during a gene therapy trial, and his death had an impact on the direction of the technology.
   - Research the gene therapy treatment that was given to Jessie Gelsinger. Prepare a description of the treatment and an explanation of what may have gone wrong.
   - Why did it seem as though gene therapy would be a promising treatment for people with disorders caused by a single gene?
   - Did the field of gene therapy head in a different direction after Jessie's death in 1999? Have there been any other tragedies or examples of success stories?

2. **Evaluate a Solution** How might CRISPR technology offer hope for the future of gene therapy? What problems might be solved by delivering replacement genes via CRISPR rather than using other types of vectors?

3. **Communicate Information** As a group, prepare a script for a 10-minute video to explain the information you gathered to a general audience. Decide how you will deliver the information. For example, one member of your group could be an interviewer and another member could be a scientist being interviewed. Consider any props you will need to explain gene therapy techniques and CRISPR to a general audience, such as images or models. Once your plan and script are complete, make your video to present to your teacher and class.

CHAPTER 16

ASSESSMENT

KEY QUESTIONS AND TERMS

16.1 Changing the Living World

1. Crossing dissimilar individuals to bring together their best characteristics is called
   a. domestication.
   b. inbreeding.
   c. hybridization.
   d. polyploidy.
2. Crossing individuals with similar characteristics so that those characteristics will appear in their offspring is called
   a. inbreeding.
   b. hybridization.
   c. recombination.
   d. polyploidy.
3. Taking advantage of naturally occurring variations in organisms to pass wanted traits on to future generations is called
   a. selective breeding.
   b. inbreeding.
   c. hybridization.
   d. mutation.
4. How do breeders produce genetic variations that are not found in nature?
5. What is polyploidy? When is this condition useful to researchers?

16.2 The Process of Genetic Engineering

HS-ETS1-1

6. Organisms that contain genes from other organisms are called
   a. transgenic.
   b. mutagenic.
   c. donors.
   d. clones.
7. When cell transformation is successful, the recombinant DNA
   a. undergoes mutation.
   b. is treated with antibiotics.
   c. becomes part of the transformed cell's genome.
   d. becomes a nucleus.
8. Bacteria often contain small circular molecules of DNA known as
   a. clones.
   b. chromosomes.
   c. plasmids.
   d. hybrids.
9. A member of a population of genetically identical cells produced from a single cell is a
   a. clone.
   b. plasmid.
   c. mutant.
   d. sequence.
10. Describe what happens during polymerase chain reaction.
11. Explain what genetic markers are and describe how scientists use them.
12. How does a transgenic plant differ from a hybrid plant?

16.3 Applications of Biotechnology

HS-ETS1-1, HS-LS3-1

13. Which of the following characteristics is often genetically engineered into crop plants?
    a. improved flavor
    b. resistance to herbicides
    c. shorter ripening times
    d. thicker stems
14. A substance that has been genetically engineered into transgenic rice has the potential to treat
    a. cancer.
    b. high blood pressure.
    c. vitamin A deficiency.
    d. malaria.
15. Which of the following techniques would scientists most likely use to understand the activity levels of hundreds of genes at once?
    a. a DNA microarray
    b. PCR
    c. restriction enzyme analysis
    d. DNA sequencing
16. Describe how a DNA microarray might be used to distinguish normal cells from cancer cells.
17. Describe two important uses for DNA fingerprinting.

16.4 Ethics and Impacts of Biotechnology

HS-ETS1-1

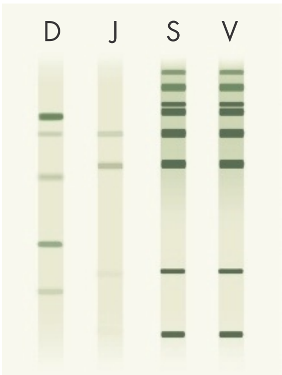
18. The right to profit from a new genetic technology is protected by
    a. getting a copyright for the method.
    b. discovering a new gene.
    c. obtaining a patent.
    d. publishing its description in a journal.
19. Give an example of a disadvantage associated with patenting genes.
20. What is one argument used by critics of genetically modified foods?

CRITICAL THINKING

HS-ETS1-1, HS-LS3-1

21. **Communicate Information** Suppose a plant breeder has a thornless rose bush with scentless pink flowers, a thorny rose bush with sweet-smelling yellow flowers, and a thorny rose bush with scentless purple flowers. How might this breeder develop a pure variety of thornless, sweet-smelling, purple flowers?
22. **Compare and Contrast** Hybridization and inbreeding are important methods used in selective breeding. Evaluate these methods to determine how they are similar and different.
23. **Design a Solution** *Salmonella* is a type of bacteria that may cause illness in humans. Some strains of *Salmonella* have been shown to cause tumors to shrink. Researchers think that when *Salmonella* enter tumor cells, they cause the tumor cells to create proteins that enable immune cells to connect to the tumor and kill them. How would you design a solution to use *Salmonella* as an agent for fighting tumor cells?
24. **Define the Problem** About 120,000 people in the United States are on a waiting list to receive an organ donation. Every day, about 22 people die due to a lack of available organs. One solution that may help alleviate this problem is xenotransplantation, or the removal of an organ or tissues from an organism of one species and the placing of it into the body of an organism of a different species. Pigs have been seen as suitable donor animals for humans for several reasons. However, organ rejection is a major obstacle to successful transplantation. Pig cells contain a sugar molecule called α-1,3-galactose that triggers the human immune response. Define the problem and identify a solution to solve this problem.
25. **Summarize** If a human patient's bone marrow were removed, altered genetically, and reimplanted, would the change be passed on to the patient's children? Defend your claim.
26. **Apply Concepts** Bacteria and humans are very different organisms. Why is it sometimes possible to combine their DNA and use a bacterium to make a human protein?
27. **Infer** Briefly describe the biotechnological methods that are used to match a DNA sample to a particular person.
28. **Compare and Contrast** For hundreds of years, farmers have used selective breeding to increase the usefulness of crop plants and livestock. How do these efforts compare with the use of genetic technology to produce GM crops and livestock?
29. **Construct an Explanation** How is mitochondrial DNA useful for identifying family relationships?

Questions 30–32 refer to the diagram, which shows the results of a criminal laboratory test.



D = Defendant's blood

J = Blood from defendant's jeans

S = Blood from defendant's shirt

V = Victim's blood

30. **Infer** Briefly describe the biotechnological methods that would have been used to produce these results.
31. **Compare and Contrast** How are the bands from the jeans and the shirt similar? How are they different?
32. **Draw Conclusions** Based on these results, what conclusions might a prosecutor present to a jury during a criminal trial?

ASSESSMENT

CROSSCUTTING CONCEPTS

33. Connect to Society You have a friend who claims that no one should eat GM crops. Construct an argument that connects the growing of golden rice to benefits for society. In fairness to your friend, consider alternatives to GM crops that might yield the same benefits. What might be some of the challenges in the implementation of these alternative solutions?

34. Connect to Technology Evaluate the production of insulin and other proteins through genetic engineering. Be sure to include advantages and disadvantages. Perform additional research as needed to answer this question.

35. Structure and Function How do the DNA sequences included in a plasmid help ensure that recombinant DNA molecules are reproduced when they are inserted into a host cell?

MATH CONNECTIONS

Analyze and Interpret Data

CCSS.MATH.CONTENT.HSS.IC.B.6

The table shows the impact of GM crop adoption on different aspects of farming. The data show the percentages of change in different factors when farmers switched from planting non-GM crops to GM crops. Use the table to answer questions 36 and 37.

Impact of GM Crops

Measurement	Percent Change
Crop yield	+21.6
Pesticide quantity	−36.9
Pesticide cost	−39.2
Total production cost	+3.3
Profit for the farm	+68.2

Data from: Wilhelm Klümper, Matin Qaim, November 3, 2014, doi.org/10.1371/journal.pone.0111629

36. Interpret Tables What were the effects of using GM crops in terms of yield?

37. Interpret Tables What were the effects of using GM crops in terms of farmer profit?

LANGUAGE ARTS CONNECTION

Write About Science

CCSS.ELA-LITERACY.WHST.9-10.1, CCSS.ELA-LITERACY.WHST.9-10.2

38. Write Arguments A friend blogs about genetically modified organisms. She asserts that GM is still too new, and traditional selective breeding can accomplish the same results as GM. Write a response to your friend's blog either supporting or opposing this position.

39. Write Technical Processes Describe the major steps involved in inserting a human gene into a bacterium.

Read About Science

CCSS.ELA-LITERACY.RST.9-10.1, CCSS.ELA-LITERACY.RST.9-10.4

40. Determine Meaning Many words and terms used in this chapter are based on the word *gene*. Examples include *genetic*, *transgenic*, and *genetically modified*. Look up the origins of the words *gene* and *genetics*. What is the original source of these words? Find as many variations as you can in the chapter. Determine their meanings and identify each word's part of speech.

41. Cite Textual Evidence Should a vegetarian be concerned about eating a GM plant that contains DNA from an animal gene? Support your answer with details from the text.

CHAPTER 16

END-OF-COURSE TEST PRACTICE

Questions 1-2
DNA fingerprinting is a technology that is used for many different purposes. The diagram below is an illustration of what DNA fingerprinting data may look like.

1. Police departments and other agencies are often tasked with investigating crimes. Which of the following describes a solution to a problem investigators face that DNA fingerprinting can help solve?
A. DNA fingerprinting can be used to treat criminals who have a genetic disease or disorder.
B. DNA fingerprinting can be used to identify persons who were wrongly convicted of a crime.
C. DNA fingerprinting can be used to identify which genes are active in persons who commit crimes.
D. DNA fingerprinting can allow persons who commit crimes to be used as animal models in medical research studies.
E. DNA fingerprinting allows investigators to identify suspects without evidence.

2. What do the dark bands in each sample represent?
A. chromosomes
B. active DNA fragments
C. clones
D. DNA fragments of different lengths
E. Cas9 enzymes

3. One of the challenges facing the world today is supplying enough food for the human population. Farming with genetically modified plants is a possible solution to this challenge. What is a concern with using GM plants?
A. GM plants produce higher yields, which may lead to an increase in the amount of wasted food.
B. Farming with GM plants that are resistant to chemical herbicides may lead to overuse of weed-killing compounds.
C. Farming with GM plants requires less land and energy, which may lead to lower food costs and an economic crisis for farmers.
D. GM plants require more insecticide use, which may increase the chance of chemical residues in the food supply.
E. Scientific studies on GM plants are not available, so the effects of GM plants are unknown.

4. A medical researcher hopes to cure a disease in mice by changing a gene. How can the researcher change the sequence of a gene?
A. CRISPR
B. cloning
C. gel electrophoresis
D. DNA fingerprinting
E. DNA sequencing

5. Farmer Jones noticed that some of his chickens grow much faster than the others. What can he use to increase the frequency of this trait in his chickens?
A. mutations
B. genetic engineering
C. DNA fingerprinting
D. selective breeding
E. gene therapy

ASSESSMENT

For additional assessment practice, go online to access your digital course.

If You Have Trouble With...					
Question	1	2	3	4	5
See Lesson	16.3	16.3	16.4	16.2	16.1
Performance Expectation	HS-ETS1-1	HS-ETS1-1	HS-ETS1-1	HS-ETS1-1	HS-ETS1-1