15 Genetic Engineering

Big idea

Science as a Way of Knowing

Q: How and why do scientists manipulate DNA in living cells?

By cloning cells and modifying genes, scientists in Korea have developed cats that glow bright red in the dark. The cloned Turkish Angola on the left has a fluorescent protein in its skin cells. The protein gives off a red glow when exposed to ultraviolet light. The ordinary Turkish Angola on the right lacks the red fluorescent protein, so it appears green under ultraviolet light.

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INSIDE:

- Untamed Science Video
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CHAPTER MYSTERY

A CASE OF MISTAKEN IDENTITY

In the summer of 1998, an elderly Indiana woman was brutally assaulted. In the predawn darkness, she didn't get a look at her assailant's face.

At first light, police found a man only a few blocks from the victim's house. He was unconscious, his clothing was stained with blood, and there were scratches on his forearms. The man claimed that he had passed out following a drunken brawl. He couldn't remember what had happened afterward. The blood type of the stains on his clothing matched the victim's blood type. The police thought they had their man.

Hours later, the police knew they had the wrong suspect. They resumed their search for the real attacker, who was subsequently caught, tried, and convicted. As you read this chapter, look for clues to help you determine how the police knew they had the wrong suspect. Then, solve the mystery.

Never Stop Exploring Your World. Finding the solution to the case of mistaken identity is only the beginning. Take a video field trip with the ecogeeks of Untamed Science to see where the mystery leads.

Untamed Science™

15.1 Selective Breeding

Key Questions

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

Vocabulary

selective breeding
hybridization
inbreeding
biotechnology

Taking Notes

Outline Before you read this lesson, start an outline. Use the green headings in the lesson as first-level entries. Use the blue headings as second-level entries, leaving space after each entry. As you read, summarize the key ideas below your entries.

THINK ABOUT IT You've enjoyed popcorn at the movies, you've probably made it at home, and you've certainly seen it in stores. Where does it come from? Would you be surprised to learn that popcorn is one of the earliest examples of human efforts to select and improve living organisms for our benefit? Corn as we know it was domesticated at least 6000 years ago by Native Americans living in Mexico. A tiny kernel of popped corn found in a cave in New Mexico is more than 5000 years old!

Selective Breeding

What is selective breeding used for?

Visit a dog show, 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, like the ones in **Figure 15–1,** are so great that someone might think they are different species. They're not, of course, but where did these obvious differences come from?

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 better companions. We've done so by **selective breeding,** allowing only those animals with wanted characteristics to produce the next generation. **Humans use selective breeding, which takes advantage of naturally occurring genetic variation, to pass wanted traits on to the next generation of organisms.**

FIGURE 15–1 Dog Breeds There are more than 150 dog breeds, and many new breeds are still being developed.

For thousands of years, we've produced new varieties of cultivated plants and nearly all domestic animals—including horses, cats, and cows—by selectively breeding for particular traits. Long before Europeans came to the New World, Native Americans had selectively bred teosinte (tee oh SIN tee), a wild grass native to central Mexico, to produce corn, a far more productive and nutritious plant. **Figure 15–2** shows both plants. Corn is now one of the world's most important crops. There are two common methods of selective breeding—hybridization and inbreeding.

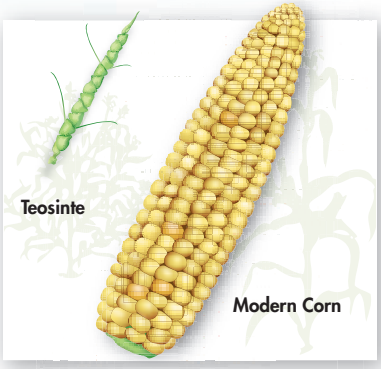


FIGURE 15–2 Corn From Teosinte Modern corn was selectively bred from teosinte at least 6000 years ago. During its domestication, corn lost the ability to survive in the wild but gained valuable agricultural traits. For example, the hard case around the kernel disappeared over time, leaving the rows of soft corn kernels we enjoy today. **Observe** ***What other differences can you see between the two plants?***

Hybridization American botanist Luther Burbank may have been the greatest selective breeder of all time. During his lifetime (1849–1926), he developed more than 800 varieties of plants. As one of his tools, Burbank used **hybridization,** crossing dissimilar individuals to bring together the best of both organisms. Hybrids—the individuals produced by such crosses—are often hardier than either of the parents. 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 had the traits farmers needed to increase food production. **Figure 15–3** shows a type of peach developed using Burbank's methods.

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.

In Your Notebook *Compare and contrast hybridization and inbreeding.*

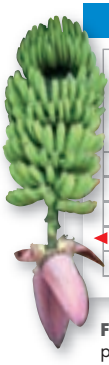
FIGURE 15–3 Selectively Bred Fruit Luther Burbank used hybridization—a form of selective breeding—to develop a variety of plants. These July Elberta peaches, *Prunus persica*, are among his most successful varieties.

Increasing Variation

How do people increase genetic variation?

Selective breeding would be nearly impossible without the wide variation found in natural populations of plants and animals. But sometimes breeders want 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.**

When scientists manipulate the genetic makeup of an organism, they are using biotechnology. **Biotechnology** is the application of a technological process, invention, or method to living organisms. Selective breeding is one form of biotechnology important in agriculture and medicine, but there are many others.



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

FIGURE 15–4 Ploidy Numbers Because polyploid plants are often larger than other plants, many farmers deliberately grow polyploid varieties of crops like those listed above. **Interpret Tables** ***Which plant has undergone the most dramatic changes in chromosome number?***

Bacterial Mutations Mutations—heritable changes in DNA—occur spontaneously, but breeders can increase the mutation rate of an organism by using radiation or chemicals. Many mutations are harmful to the organism. With luck and perseverance, however, breeders can often produce a few mutants—individuals with mutations—with useful characteristics that are 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.

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 15–4** lists several examples of polyploid plants.

15.1 Assessment

Review Key Concepts

1. a. Review Give an example of selective breeding.

b. Compare and Contrast Suppose you are a geneticist trying to develop a sunflower with red petals and a short stem. As you compare the sunflowers you have on hand, what genetic variations would you look for? What kinds of plants would you select for crossing?

2. a. Review What is the relationship between genetic variations and mutations?

b. Explain How can breeders introduce mutations?

c. Draw Conclusions How is selective breeding a form of biotechnology?

WRITE ABOUT SCIENCE

Explanation

3. Write a paragraph in which you suggest ways that plants could be genetically altered to improve the world's food supply. (*Hint*: The first sentence in your paragraph should express the paragraph's main idea.)

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15.2 Recombinant DNA

THINK ABOUT IT Suppose you have an electronic game you want to change. Knowing that the game depends on a coded program in a computer microchip, how would you set about rewriting the program? First you'd need a way to get the existing program out of the microchip. Then you'd have to read the program, make the changes you want, and put the modified code back into the microchip. What does this scenario have to do with genetic engineering? Just about everything.

Copying DNA

How do scientists copy the DNA of living organisms?

Until recently plant and animal breeders could only work with variations that already exist in nature. Even when breeders tried to add variation by introducing mutations, the changes they produced were unpredictable. Today genetic engineers can transfer certain genes at will from one organism to another, designing new living things to meet specific needs.

Recall from Chapter 14 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 according to size using gel electrophoresis or another similar technique. That's the easy part. The tough part comes next: How do you find a specific gene?

The problem is huge. If we were to cut DNA from a bacterium like *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 the DNA of 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.

Key Questions

- ***How do scientists copy the DNA of living organisms?***
- ***How is recombinant DNA used?***
- ***How can genes from one organism be inserted into another organism?***

Vocabulary

polymerase chain reaction
recombinant DNA
plasmid
genetic marker
transgenic
clone

Taking Notes

Preview Visuals Before you read, preview **Figure 15–7** and write down any questions you may have about the figure. As you read, find answers to your questions.

MYSTERY CLUE

How could restriction enzymes be used to analyze the DNA evidence found on the suspect?

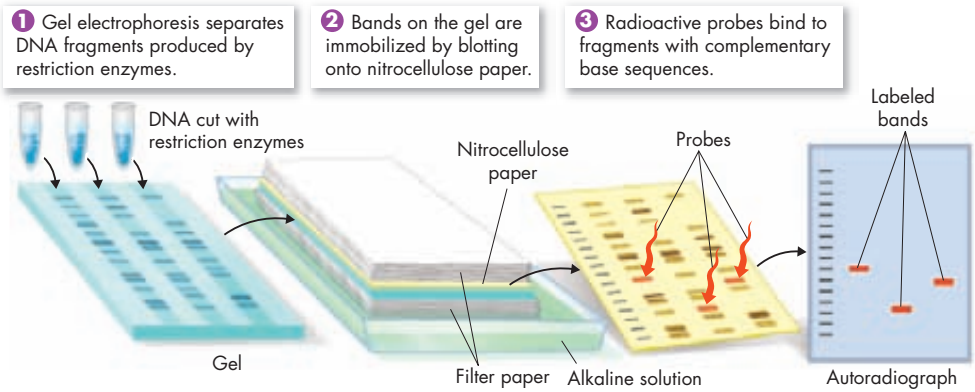
FIGURE 15–5 A Fluorescent Gene The Pacific Ocean jellyfish, *Aequoria victoria*, emits a bluish glow. A protein in the jellyfish absorbs the blue light and produces green fluorescence. This protein, called GFP, is now widely used in genetic engineering.

Finding Genes In 1987, Douglas Prasher, a biologist at Woods Hole Oceanographic Institute in Massachusetts, wanted to find a specific gene in a jellyfish. The gene he hoped to identify is the one that codes for a molecule called green fluorescent protein, or GFP. This natural protein, found in the jellyfish shown in **Figure 15–5,** absorbs energy from light and makes parts of the jellyfish glow. Prasher thought that GFP from the jellyfish could be used to report when a protein was being made in a cell. If he could somehow link GFP to a specific protein, it would be a bit like attaching a light bulb to that molecule.

To find the GFP gene, Prasher studied the amino acid sequence of part of the GFP protein. By comparing this sequence to a genetic code table, he was able to predict a probable mRNA base sequence that would have coded for this sequence of amino acids. Next, Prasher used a complementary base sequence to "attract" an mRNA that matched his prediction and would bind to that sequence by base pairing. After screening a genetic "library" with thousands of different mRNA sequences from the jellyfish, he found one that bound perfectly.

After Prasher located the mRNA that produced GFP, he set out to find the actual gene. Taking a gel in which restriction fragments from the jellyfish genome had been separated, he found that one of the fragments bound tightly to the mRNA. That fragment contained the actual gene for GFP, which is now widely used to label proteins in living cells. The method he used, shown in **Figure 15–6,** is called Southern blotting. 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.

FIGURE 15–6 Southern Blotting Southern blot analysis, named after its inventor Edwin Southern, is a research technique for finding specific DNA sequences, among dozens. A labeled piece of nucleic acid serves as a probe among the DNA fragments.



Polymerase Chain Reaction Once they find a gene, biologists often need to make many copies of it. A technique known as **polymerase chain reaction** (PCR) allows them to do exactly that. At one end of the original piece of DNA, a biologist adds a short piece of DNA that complements a portion of the sequence. At the other end, the biologist adds another short piece of complementary DNA. These short pieces are known as primers because they prepare, or prime, a place for DNA polymerase to start working.

As **Figure 15–7** suggests, the idea behind the use of PCR primers is surprisingly simple. **The first step in using the polymerase chain reaction method to copy a gene is to heat a piece of DNA, which separates its two strands. Then, as the DNA cools, primers bind to the single strands. Next, DNA polymerase starts copying the region between the primers. These copies can serve as templates to make still more copies.** In this way, just a few dozen cycles of replication can produce billions of copies of the DNA between the primers.

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 in the northwestern United States—a powerful example of the importance of biodiversity to biotechnology!

In Your Notebook *List the steps in the PCR method.*

Changing DNA

How is recombinant DNA used?

Just as they were beginning to learn how to read and analyze DNA sequences, scientists began wondering if it might be possible to change the DNA of a living cell. As many of them realized, this feat had already been accomplished decades earlier. Do you remember Griffith's experiments on bacterial transformation? During transformation, a cell takes in DNA from outside the cell, and that added DNA becomes a component of the cell's own genome. Today biologists understand that Griffith's extract of heat-killed bacteria contained DNA fragments. When he mixed those fragments with live bacteria, a few of them took up the DNA molecules, transforming them and changing their characteristics. Griffith, of course, could only do this with DNA extracted from other bacteria.

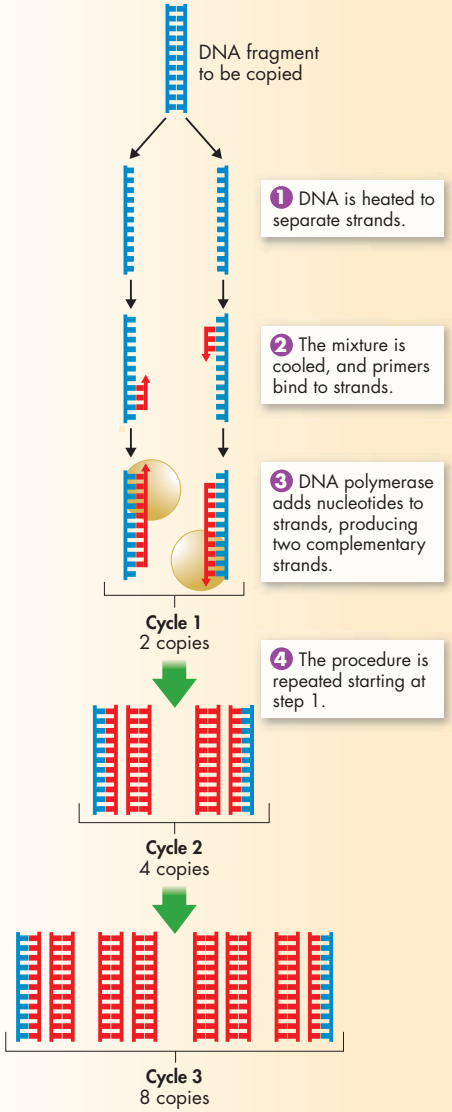


FIGURE 15–7 The PCR Method Polymerase chain reaction is used to make multiple copies of a gene. This method is particularly useful when only tiny amounts of DNA are available. **Calculate** ***How many copies of the DNA fragment will there be after six PCR cycles?***

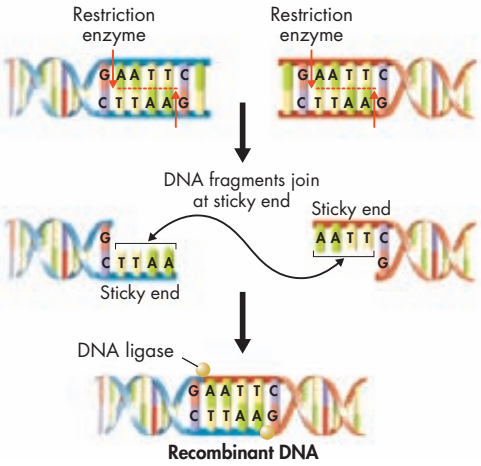


FIGURE 15–8 Joining DNA Pieces Together Recombinant DNA molecules are made up of DNA from different sources. Restriction enzymes cut DNA at specific sequences, producing "sticky ends," which are single-stranded overhangs of DNA. If two DNA molecules are cut with the same restriction enzyme, their sticky ends will bond to a fragment of DNA that has the complementary sequence of bases. An enzyme known as DNA ligase can then be used to join the two fragments.

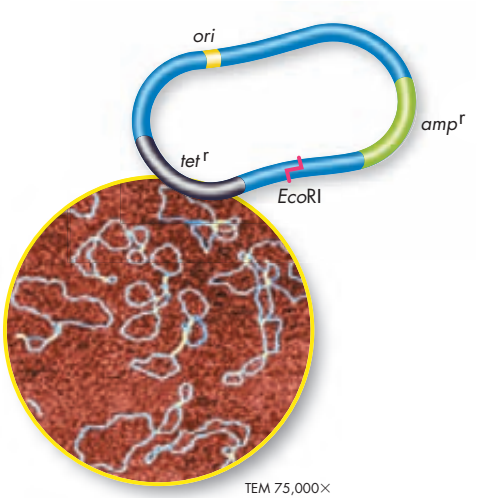


FIGURE 15–9 A Plasmid Map Plasmids used for genetic engineering typically contain a replication start signal, called the origin of replication (*ori*), and a restriction enzyme cutting site, such as *Eco*RI. They also contain genetic markers, like the antibiotic resistance genes *tet*^{r} and *amp*^{r} shown here.

Combining DNA Fragments With today's technologies, scientists can produce custom-built DNA molecules in the lab and then insert those molecules—along with the genes they carry—into living cells. The first step in this sort of genetic engineering is to build a DNA sequence with the gene or genes you'd like to insert into a cell. Machines known as DNA synthesizers can produce short pieces of DNA, up to several hundred bases in length. These synthetic sequences can then be joined to natural sequences using DNA ligase or other enzymes that splice DNA together. These same enzymes make it possible to take a gene from one organism and attach it to the DNA of another organism, as shown in **Figure 15–8.** The resulting molecules are called **recombinant DNA.** This technology relies on the fact that any pair of complementary sequences tends to bond, even if each sequence comes from a different organism.

Recombinant-DNA technology—joining together DNA from two or more sources—makes it possible to change the genetic composition of living organisms. By manipulating DNA in this way, scientists can investigate the structure and functions of genes.

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 large chromosomes, some bacteria contain small circular DNA molecules known as **plasmids.** Plasmids, like those shown in **Figure 15–9,** 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.

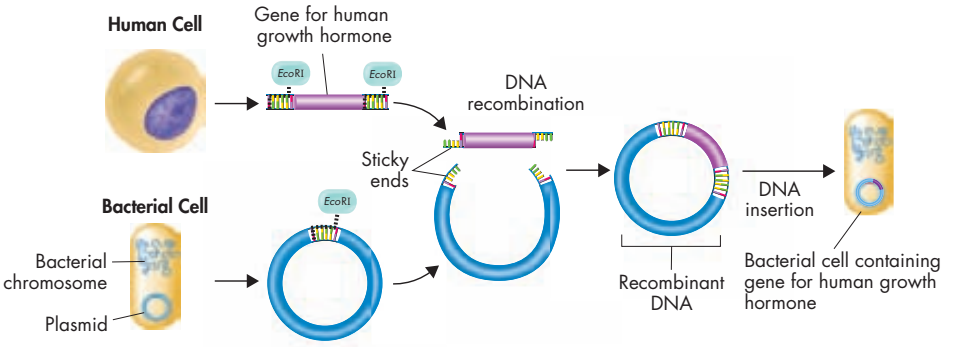


FIGURE 15–10 Plasmid DNA Transformation Scientists can insert a piece of DNA into a plasmid if both the plasmid and the target DNA have been cut by the same restriction enzymes to create sticky ends. With this method, bacteria can be used to produce human growth hormone. First, a human gene is inserted into bacterial DNA. Then, the new combination of genes is returned to a bacterial cell, which replicates the recombinant DNA over and over again. **Infer** ***Why might scientists want to copy the gene for human growth hormone?***

Figure 15–10 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, helping to ensure that if the DNA does get inside a bacterial cell, it will be replicated. In addition, the plasmid also has a genetic marker, such as a gene for antibiotic resistance. A **genetic marker** is a gene that makes it possible to distinguish bacteria that carry the plasmid from those that don't. Using genetic markers, researchers can mix recombinant plasmids with a culture of bacteria, add enough DNA to transform just one cell in a million, and still locate that one cell. After transformation, the culture is treated with an antibiotic. Only those rare cells that have been transformed survive, because only they carry the resistance gene.

In Your Notebook *Write a summary of the process of plasmid DNA transformation.*

Quick Lab
GUIDED INQUIRY

Inserting Genetic Markers

❶ Write a random DNA sequence on a long strip of paper to represent an organism's genome.

❷ Have your partner write a short DNA sequence on a short strip of paper to represent a marker gene.

❸ 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. **Apply Concepts** Which restriction enzyme did you use? Why?

2. **Use Models** What kind of molecule did you and your partner develop?

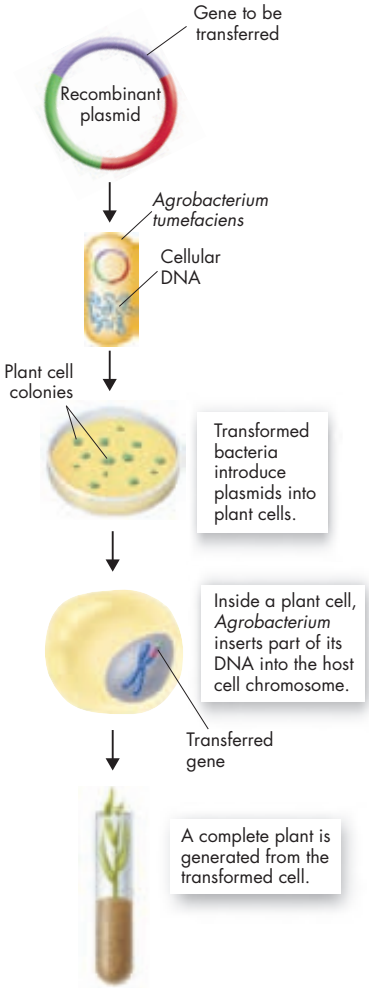


FIGURE 15–11 Transforming a Plant Cell *Agrobacterium* can be used to introduce bacterial DNA into a plant cell. The transformed cells can be cultured to produce adult plants.

Transgenic Organisms

How can genes from one organism be inserted into another organism?

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 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. By examining the traits of a genetically modified organism, it is possible to learn about the function of the transferred gene. This ability has contributed greatly to our understanding of gene regulation and expression.

Transgenic Plants Many plant cells can be transformed using *Agrobacterium.* In nature this bacterium inserts a small DNA plasmid that produces tumors in a plant's 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 15–11.**

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 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.

Recently it has become possible to eliminate particular genes by carefully engineering the DNA molecules that are used for transformation. The DNA molecules can be constructed with two ends that will sometimes recombine with specific sequences in the host chromosome. Once they do, the host gene normally found between those two sequences may be lost or specifically replaced with a new gene. This kind of gene replacement has made it possible to pinpoint the specific functions of genes in many organisms, including mice.

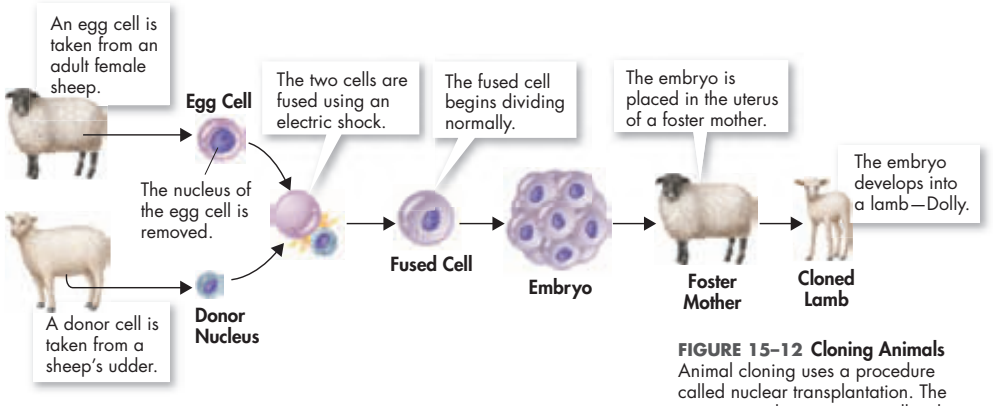


FIGURE 15–12 Cloning Animals Animal cloning uses a procedure called nuclear transplantation. The process combines an egg cell with a donor nucleus to produce an embryo. **Apply Concepts** ***Why won't the cloned lamb resemble its foster mother?***

Cloning A **clone** is a member of 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. Clones of animals were first produced in 1952 using amphibian tadpoles. In 1997, Scottish scientist Ian Wilmut stunned biologists by announcing that he had produced a sheep, called Dolly, by cloning.

Figure 15–12 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. The resulting diploid egg develops into an embryo, which is then implanted in the uterine wall of a foster mother, where it develops until birth. Cloned cows, pigs, mice, and even cats have since been produced using similar techniques.

15.2 Assessment

Review Key Concepts

1. a. Review Describe the process scientists use to copy DNA.

b. Infer Why would a scientist want to know the sequence of a DNA molecule?

2. a. Review How do scientists use recombinant DNA?

b. Use Analogies How is genetic engineering like computer programming?

3. a. Review What is a transgenic organism?

b. Compare and Contrast Compare the transformation of a plant cell with the transformation of an animal cell.

PRACTICE PROBLEM

4. Design an experiment to find a way to treat disorders caused by a single gene. State your hypothesis and list the steps you would follow. (*Hint*: Think about the uses of recombinant DNA.)

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15.3 Applications of Genetic Engineering

Key Questions

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

Vocabulary

gene therapy
DNA microarray
DNA fingerprinting
forensics

Taking Notes

Outline Make an outline of this lesson by using the green and blue headings. As you read, take notes on the different applications of genetic engineering.

THINK ABOUT IT Have you eaten any genetically modified food lately? Don't worry if you're not sure how to answer that question. In the United States and many other countries, this kind of food doesn't have to be labeled in grocery stores or markets. But if you've eaten corn, potatoes, or soy products in any of your meals this week, chances are close to 100 percent that you've eaten foods modified in some way by genetic engineering.

Agriculture and Industry

How can genetic engineering benefit agriculture and industry?

Everything we eat and much of what we wear come 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 could 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, like the soybeans in **Figure 15–13,** have become an important component of our food supply. In 2007, GM crops made up 92 percent of soybeans, 86 percent of cotton, and 80 percent of corn grown in the United States. One type of modification, which has already proved particularly useful to agriculture, uses bacterial genes that produce a protein known as Bt toxin. While this toxin is harmless to humans and most other animals, enzymes in the digestive systems of insects convert Bt to a form that kills the insects. Plants with the Bt gene, then, do not have to be sprayed with pesticides. In addition, they produce higher yields of crops.

Resistance to insects is just one useful characteristic being engineered into crops. Others include resistance to herbicides, which are chemicals that destroy weeds, and resistance to viral infections. 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.

FIGURE 15–13 GM Soybeans Genetically modified soybeans are a popular crop in the United States.

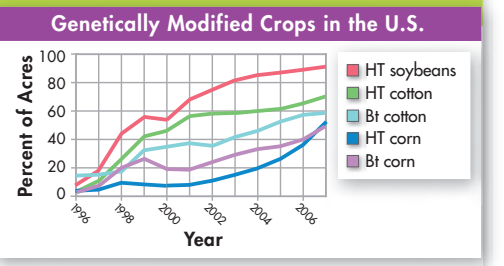
Analyzing Data

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 at the right summarizes the extent to which these crops were adopted between 1996 and 2007. The modified traits shown here include herbicide tolerance (HT) and insect resistance (Bt).

1. Analyze Data Which two crops were most widely and rapidly adopted?

2. Draw Conclusions Why do you think the levels of adoption fell at certain points over the period?



Source: U.S. Department of Agriculture Economic Research Service Data Sets

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.

4. Infer Why do you think an increasing number of farmers have chosen to grow crops with herbicide tolerance?

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 high levels of healthy omega-3 acids. Using growth-hormone genes, scientists have developed transgenic salmon that grow much more quickly than wild salmon. This effort makes it practical to grow these nutritious fish in captive aquaculture facilities that do not threaten wild populations.

When scientists in Canada combined spider genes into 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.

Researchers hope that cloning will enable them to make copies of transgenic animals, which would increase the food supply and could even help save endangered species. In 2008, the U.S. government approved the sale of meat and milk from cloned animals. Many farmers and ranchers hope that cloning technology will allow them to duplicate the best qualities of prize animals without the time and complications of traditional breeding.

In Your Notebook *Describe the ways in which GM organisms can benefit agriculture and industry.*

FIGURE 15–14 Antibacterial Goat Milk Scientists are working to combine a gene for lysozyme—an antibacterial protein found in human tears and breast milk—into the DNA of goats. Milk from these goats may help prevent infections in young children who drink it.
Apply Concepts ***What action do scientists hope the lysozyme gene will take in genetically modified goats?***

FIGURE 15–15 Vitamin-Rich Rice
Golden rice is a GM plant that contains increased amounts of provitamin A, or beta-carotene. Two genes engineered into the rice genome help the grains produce and accumulate beta-carotene. The intensity of the golden color indicates the concentration of beta-carotene in the edible part of the rice seed.

Health and Medicine

How can recombinant-DNA technology improve human health?

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 vaccination to save countless lives. **Today, recombinant-DNA technology is the source of some of the most important and exciting advances in the prevention and treatment of disease.**

Preventing Disease One interesting development in transgenic technology is golden rice, shown in **Figure 15–15.** This rice contains increased amounts of provitamin A, also known as beta-carotene—a nutrient that is essential for human health. Provitamin A deficiencies produce serious medical problems, including infant blindness. There is hope that provitamin A-rich golden rice will help prevent these problems. Other scientists are developing transgenic plants and animals that produce human antibodies to fight disease.

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.

Medical Research Transgenic animals are often used as test subjects in medical research. In particular they can simulate human diseases in which defective genes play a role. Scientists use models based on these simulations to follow the onset and progression of diseases and to construct tests of new drugs that may be useful for treatment. This approach has been used to develop models for disorders like Alzheimer's disease and arthritis.

Treating Disease 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 in genetically engineered bacteria include insulin to treat diabetes, blood-clotting factors for hemophiliacs, and potential cancer-fighting molecules such as interleukin-2 and interferon.

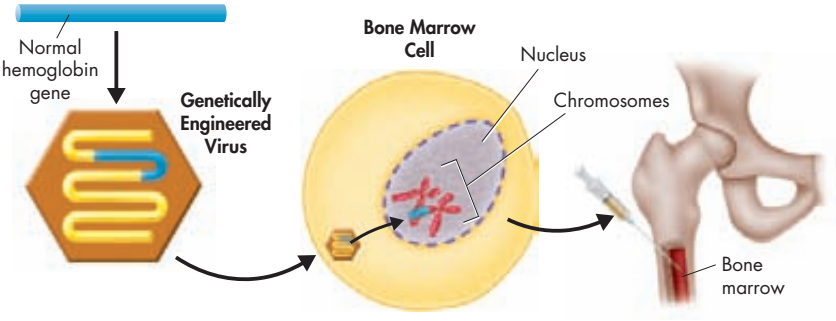


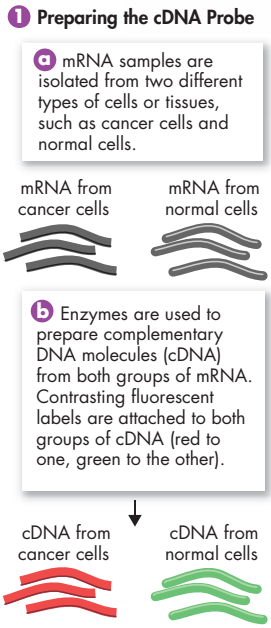
FIGURE 15–16 How Gene Therapy Can Be Used Gene therapy uses normal genes to add to or replace defective genes or to boost a normal function like immunity.
Interpret Visuals *How is the virus in this diagram being used?*

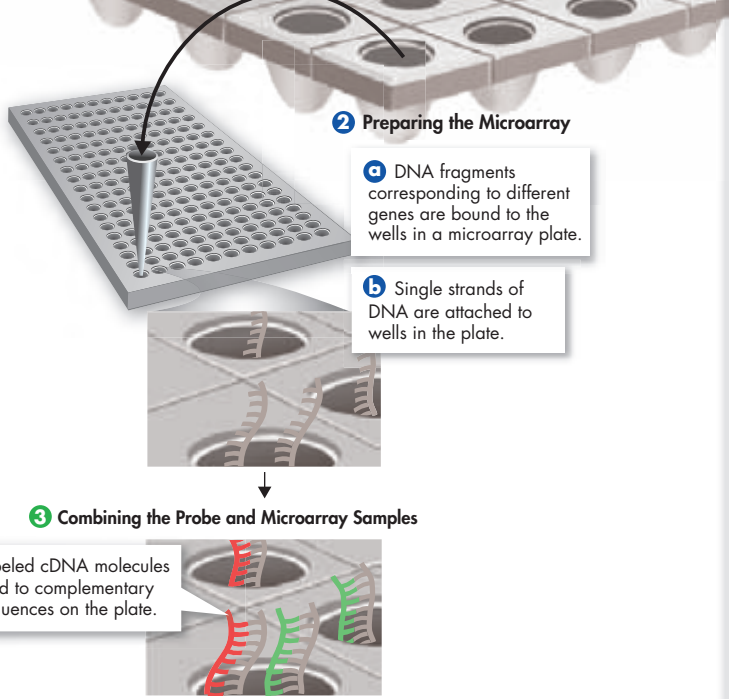
If an individual is suffering from a missing or defective gene, can we replace that gene with a healthy one and fix the problem? The experimental field of gene therapy is attempting to answer that question. **Gene therapy** is the process of changing a gene to treat a medical disease or disorder. In gene therapy, an absent or faulty gene is replaced by a normal, working gene. This process allows the body to make the protein or enzyme it needs, which eliminates the cause of the disorder.

The idea of using gene therapy to cure disease arose from the major advances in molecular biology made in the past 20 years, including the Human Genome Project. **Figure 15–16** shows one of the ways in which researchers have attempted to carry out gene therapy. To deliver the correct, or therapeutic, gene to the affected, or target, cells, researchers first engineer a virus that cannot reproduce or cause harmful effects. They place DNA containing the therapeutic gene into the modified virus, and then they infect the patient's cells with it. In theory the virus will insert the healthy gene into the target cell and correct the defect. The challenge, however, is to deliver a gene that works correctly over the long term. For all the promise it holds, in most cases gene therapy remains a high-risk experimental procedure. For gene therapy to become an accepted treatment, we need more reliable ways to insert working genes and to ensure that the DNA used in the therapy does no harm.

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 it. 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.

FIGURE 15–17 A Brave Volunteer Gene therapy can be risky. In 1999, 18-year-old Jesse Gelsinger volunteered for a gene therapy experiment designed to treat a genetic disorder of his liver. He suffered a massive reaction from the viruses used to carry genes into his liver cells, and he died a few days later. Jesse's case makes clear that experiments with gene therapy must be done with great caution.





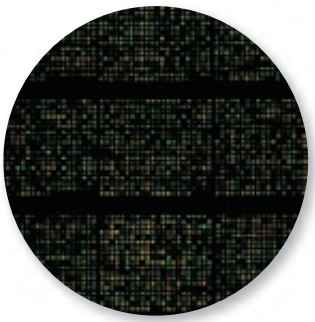


FIGURE 15–18 Analyzing Gene Activity DNA microarrays help researchers explore the underlying genetic causes of many human diseases.

Examining Active Genes Even though all of the cells in the human body contain identical 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. Different colored tags are used to label the source of DNA.

Suppose, for example, that you want to compare the genes abnormally 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. **Figure 15–18** shows how a DNA microarray is constructed and used.

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.

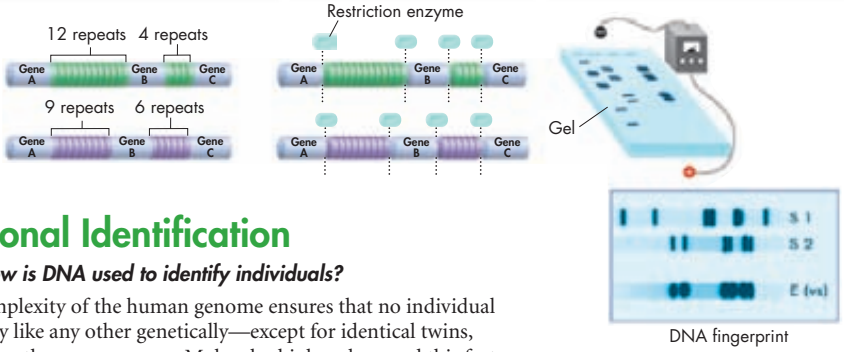


FIGURE 15–19 Identifying Individuals DNA fingerprinting can be used to determine a person's identity. It is especially useful in solving crimes. The diagram above shows how scientists match DNA evidence from a crime scene with two possible suspects. **Interpret Graphics** *Does the DNA fingerprint above match suspect 1 (S1) or suspect 2 (S2)? How can you tell?*

Personal Identification

How is DNA used to identify individuals?

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 15–19.** 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. DNA samples can be obtained from blood, sperm, or tissue—even from a hair strand if it has tissue at the root.

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. To date, DNA evidence has saved more than 110 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 precious 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.

In Your Notebook *Describe the process of DNA fingerprinting.*

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MYSTERY CLUE

What kind of evidence do you think investigators collected at the crime scene? What kinds of tests would they have run on this evidence? What would the tests have to show before the suspect was released?

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.

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 settle longstanding historical questions. One such question—did President Thomas Jefferson father the child of a slave?—may have been answered in 1998. DNA testing showed that descendants of the son of Sally Hemings, a slave on Jefferson's Virginia estate, carried his Y chromosome. This result suggests Jefferson was the child's father, although the Thomas Jefferson Foundation continues to challenge that conclusion.

15.3 Assessment

Review Key Concepts

1. a. Review Give two practical applications for transgenic plants and two for transgenic animals.

b. Infer What might happen if genetically modified fish were introduced into an aquaculture facility?

2. a. Review Name three uses for recombinant-DNA technology.

b. Apply Concepts Medicines in the body interact with the body's proteins. How might normal variations in your genes affect your response to different medicines?

3. a. Review List the steps in DNA fingerprinting.

b. Infer Why is DNA fingerprinting more accurate if the samples are cut with more than one restriction enzyme?

PRACTICE PROBLEM

4. Using restriction enzymes and gel electrophoresis, write the steps of a protocol in which you test for the allele of a gene that causes a genetic disorder.

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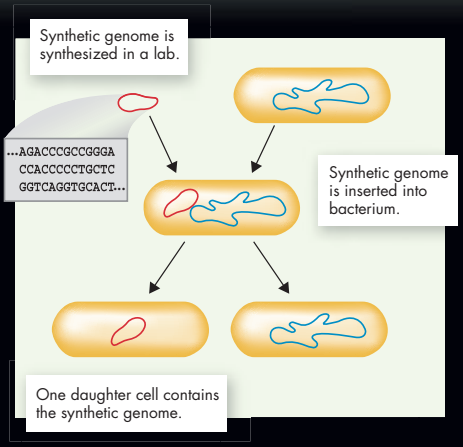
Technology & BIOLOGY

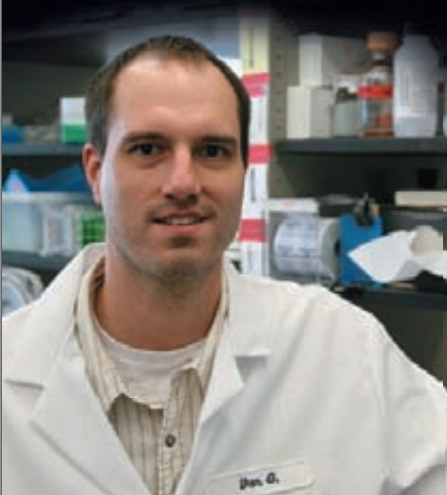
Artificial Life?

In 2008, scientists at the J. Craig Venter Institute in Rockville, Maryland, produced a synthetic genome with more than half a million DNA base pairs. It may not be long before artificial cells containing similar genomes can be grown in the laboratory. How? First a complete DNA molecule, containing the minimum set of the genetic information needed to keep a cell alive, is produced in the laboratory. Then, that molecule is inserted into a living cell to replace the cell's DNA. The result is a cell whose genome is entirely synthetic. Scientists hope this technique can help them design cells for specific purposes, like capturing solar energy or manufacturing biofuels.

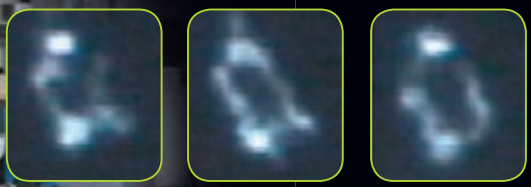


▲ **Synthesizing a Genome** One way to synthesize life is to replace a cell's genome with an artificial DNA molecule. As a result, cell division may produce a daughter cell containing only the human-made genome.

WRITING **What are the ethical issues in producing synthetic organisms? If you were a scientist working on the latest breakthroughs, how would you address those issues? Describe your ideas in an essay.**



◀ Daniel G. Gibson, a scientist at the J. Craig Venter Institute, and his team produced a completely synthetic genome of a bacterium, *Mycoplasma genitalium*.



▲ This series of photomicrographs of the synthetic genome was taken over approximately 0.6 second. The genome contains nearly 583,000 base pairs of DNA.

15.4 Ethics and Impacts of Biotechnology

Key Questions

- ***What privacy issues does biotechnology raise?***
- ***Are GM foods safe?***
- ***Should genetic modifications to humans and other organisms be closely regulated?***

Taking Notes

Two-Column Chart As you read, write down the opposing viewpoints on each ethical issue.

THINK ABOUT IT Years ago a science fiction movie titled *Gattaca* speculated about a future world in which genetics determines people's ability to get ahead in life. In the movie, schooling, job prospects, and legal rights are rigidly determined by an analysis of the individual's DNA on the day he or she is born. Are we moving closer to this kind of society?

Profits and Privacy

What privacy issues does biotechnology raise?

Private biotechnology and pharmaceutical companies do much of the research involving GM plants and animals. Their goal is largely to develop profitable new crops, drugs, tests, or other products. 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.

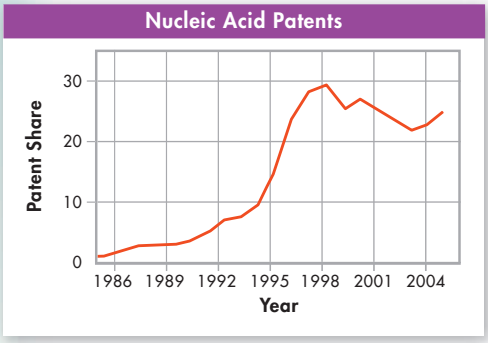


FIGURE 15–20 Patenting Nucleic Acids This graph shows the rise in the number of nucleic-acid patents between 1985 and 2005.

Patenting Life When you think about patents, you probably think about an inventor protecting a new machine or device. But molecules and DNA sequences can be patented, too. In fact, roughly one fifth of the known genes in the human genome are now patented commercially. Even laboratory techniques like PCR have been patented. When a scientist wants to run a PCR test, he or she must pay a fee for the license to use this process.

The ability to patent is meant to spur discovery and advancements in medicine and industry. After all, patent holders stand a good chance of reaping large financial rewards. Sometimes, though, patent holders demand high fees that block other scientists from exploring certain lines of research. That was the case in developing provitamin A-enriched golden rice, a GM plant described in Lesson 15.3. Even after the rice was developed, patent disputes kept it out of the hands of farmers for years.

Now consider the information held in your own genome. **Do you have exclusive rights to your DNA? Should you, like patent holders, be able to keep your genetic information confidential?** When it comes to your own DNA, how much privacy are you entitled to?

Genetic Ownership One of the most hallowed sites in the United States is the one shown in **Figure 15–21.** It is the Tomb of the Unknowns in Arlington National Cemetery, near Washington, D.C. Buried here are the remains of unidentified American soldiers who fought our nation's wars. 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.

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.

But what if the government wants to use an individual's DNA sample for another purpose, in a criminal investigation or a paternity suit? What if health-insurance providers manage their healthcare policies based on a genetic predisposition to disease? For example, suppose that, years after giving a DNA sample, an individual is barred from employment or rejected for health insurance because of a genetic defect detected in the sample. Would this be a fair and reasonable use of genetic information?

After considering this issue for years, United States Congress passed the Genetic Information Nondiscrimination Act, which became law in 2008. This act protects Americans against discrimination based on their genetic information. Physicians and ethicists hope this will lead to more effective use of personal genetic information, without fear of prejudice in obtaining health insurance or employment.

FIGURE 15–21 Unknown Identities The Tomb of the Unknowns in Arlington National Cemetery holds the remains of unknown American soldiers from World Wars I and II, the Korean War, and, until 1998, the Vietnam War. **Form an Opinion** ***Should DNA testing be used to identify the remaining soldiers buried here? Why or why not?***

Safety of Transgenics

Are GM foods safe?

Much controversy exists concerning foods that have had their DNA altered through genetic engineering. The majority of GM crops today are grown in the United States, although farmers around the world have begun to follow suit. Are the foods from GM crops the same as those prepared from traditionally bred crops?

Pros of 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 for everyone.

Insect-resistant GM plants need little, if any, insecticide to grow successfully, reducing the chance that chemical residues will enter the food supply and lessening damage to the environment. In addition, GM foods have been widely available for more than a decade. **Careful studies of such foods have provided no scientific support for concerns about their safety, and it does seem that foods made from GM plants are safe to eat.**

MYSTERY CLUE

What privacy considerations, if any, should investigators have taken into account when obtaining the DNA evidence?

Cons of 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 hazards these foods might present. **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 patents held on GM seeds by the companies that produce them may prove costly enough to force small farmers 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, current federal regulations treat GM foods and non-GM foods equally. As a result, GM foods are not required to undergo special safety testing before entering the market. No additional labeling is required to identify a product as genetically modified unless its ingredients are significantly different from its conventional counterpart. The possibility that meat from GM animals may soon enter the food supply has heightened concerns about labeling. As a result, some states have begun to consider legislation to require the labeling of GM foods, thereby providing consumers with an informed choice.

In Your Notebook *List the pros and cons of GM foods.*

Ethics of the New Biology

Should genetic modifications to humans and other organisms be closely regulated?

"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 15–22.** 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?**

Quick Lab GUIDED INQUIRY

Survey Biotechnology Opinions

1. Select three safety, legal, or ethical issues related to genetic engineering.
2. Design a survey to ask people their opinions on these issues.
3. Find 15 people to answer your survey.
4. Collect the surveys and tabulate the answers.

Analyze and Conclude

1. Analyze Data Did all respondents agree on any issue? If so, which one(s)?

2. Draw Conclusions If you had surveyed more people, do you think you would have found more or less agreement in the responses? Why or why not?

3. Evaluate How informed about biotechnology issues were the people you surveyed? If you were a politician or government official, how would you act on the results of your survey?

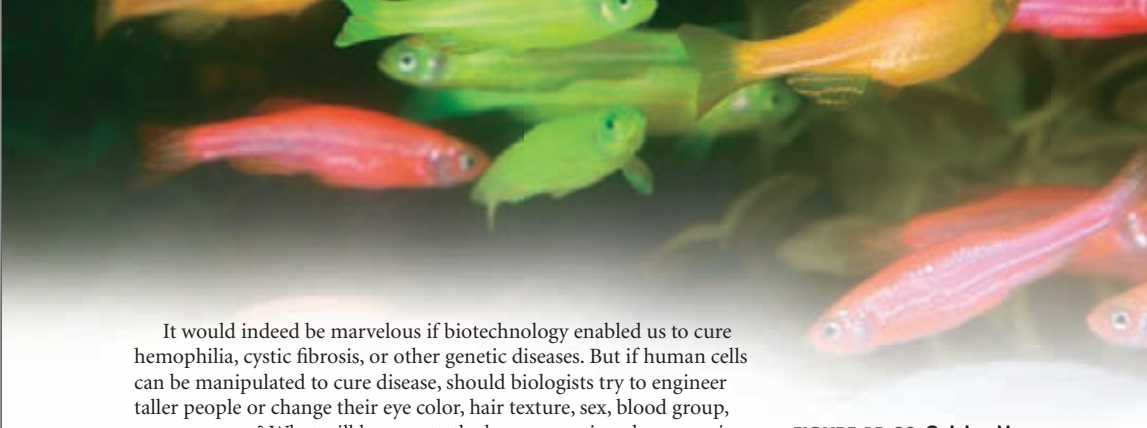


FIGURE 15–22 Gaining More Understanding These fluorescent zebra fish were originally bred to help scientists detect environmental pollutants. Today, studying fluorescent fish is helping us understand cancer and other diseases. The fish are also sold to the public at a profit.

It would indeed be marvelous if biotechnology enabled us to cure hemophilia, cystic fibrosis, or other genetic diseases. But if human cells can be manipulated to cure disease, should biologists try to engineer taller people or change their 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 with which society must come to grips.

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.

15.4 Assessment

Review Key Concepts

1. a. Review What is a patent?

b. Apply Concepts How could biotechnology affect your privacy?

2. a. Review What are genetically modified foods?

b. Form an Opinion Should a vegetarian be concerned about eating a GM plant that contains DNA from a pig gene? Support your answer with details from the text.

3. a. Review What are the main concerns about genetic engineering discussed in this lesson or elsewhere in the chapter?

b. Pose Questions Write three specific questions about the ethical, social, or legal implications of genetic engineering that do not appear in this lesson. For example, how does personal genetic information affect self-identity?

WRITE ABOUT SCIENCE

Persuasion

4. 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.

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Pre-Lab: Using DNA to Solve Crimes

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

Materials gel block, electrophoresis chamber, buffer solution, 250-mL beaker, metric ruler, DNA samples, micropipettes, 9-volt batteries, electric cords, staining tray, DNA stain, 100-mL graduated cylinder, clock or timer

Lab Manual Chapter 15 Lab

Skills Focus Measure, Compare and Contrast, Draw Conclusions

Connect to the Big Idea Scientists who worked on the Human Genome Project had to develop methods for sequencing and identifying genes. Those methods have since been used for many other applications. For example, genetically altered bacteria are used to produce large amounts of life-saving drugs. Another example is the use of DNA evidence to solve crimes. In this lab, you will prepare and compare DNA "fingerprints," or profiles.

Background Questions

a. Review What characteristic of the human genome makes DNA a powerful tool for solving crimes?

b. Review What do the segments of DNA that are used to make DNA profiles have in common?

c. Apply Concepts When forensic scientists want to determine whether two DNA samples come from the same person, they analyze more than one section of DNA. Why would the results be less reliable if the scientists compared only one section of DNA?

Pre-Lab Questions

Preview the procedure in the lab manual.

1. **Control Variables** Why must you use a new pipette to load each DNA sample?
2. **Relate Cause and Effect** Why will the DNA samples separate into bands as they move through the gel?
3. **Infer** Why is purple tracking dye added to the DNA samples?

BIOLOGY.com Search Chapter 15 GO

Visit Chapter 15 online to test yourself on chapter content and to find activities to help you learn.

Untamed Science Video Pigeon breeding helps the Untamed Science crew unravel the mysteries of genetic engineering.

Art in Motion View a short animation that brings bacterial transformation to life.

Art Review Review your understanding of DNA fingerprinting with this drag-and-drop activity.

Data Analysis Analyze nutrition and genetic data on nutrient deficiencies and crops genetically engineered to improve nutrition.

15 Study Guide

Big idea Science as a Way of Knowing

Genetic engineering allows scientists to manipulate the genomes of living things. Scientists can use bacteria to insert the DNA of one organism into another organism. Recombinant DNA has applications for agriculture, industry, medicine, and forensics. At the same time, there are ethical, legal, safety, and social issues surrounding the use of genetic engineering.

15.1 Selective Breeding

- Humans use selective breeding, which takes advantage of naturally occurring genetic variation, to pass wanted traits on to the next generation of organisms.
- Breeders can increase the genetic variation in a population by introducing mutations, which are the ultimate source of biological diversity.

selective breeding (418)
hybridization (419)
inbreeding (419)
biotechnology (419)

15.2 Recombinant DNA

- The first step in using the polymerase chain reaction method to copy a gene is to heat a piece of DNA, which separates its two strands. Then, as the DNA cools, primers bind to the single strands. Next, DNA polymerase starts copying the region between the primers. These copies can serve as templates to make still more copies.
- Recombinant-DNA technology—joining together DNA from two or more sources—makes it possible to change the genetic composition of living organisms.
- Transgenic organisms can be produced by the insertion of recombinant DNA into the genome of a host organism.

polymerase chain reaction (423)
recombinant DNA (424)
plasmid (424)
genetic marker (425)
transgenic (426)
clone (427)

15.3 Applications of Genetic Engineering

- Ideally, genetic modification could lead to better, less expensive, and more nutritious food as well as less-harmful manufacturing processes.
- Recombinant-DNA technology is advancing the prevention and treatment of disease.
- DNA fingerprinting analyzes sections of DNA that vary widely from one individual to another.

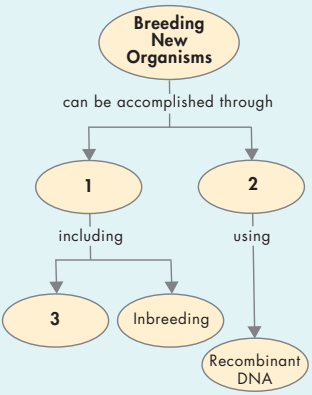
gene therapy (431)
DNA microarray (432)
DNA fingerprinting (433)
forensics (433)

15.4 Ethics and Impacts of Biotechnology

- Should you, like patent holders, be able to keep your genetic information confidential?
- Careful studies of GM foods have provided no scientific support for concerns about their safety.
- There are many concerns about unintended consequences that a shift to GM farming and ranching may have on agriculture.
- Just because we have the technology to modify an organism's characteristics, are we justified in doing so?

Think Visually

Complete the following concept map.



15 Assessment

15.1 Selective Breeding

Understand Key Concepts

1. Crossing dissimilar individuals to bring together their best characteristics is called
   a. domestication. **c.** hybridization.
   b. inbreeding. **d.** polyploidy.

2. Crossing individuals with similar characteristics so that those characteristics will appear in their offspring is called
   a. inbreeding. **c.** recombination.
   b. hybridization. **d.** polyploidy.

3. Taking advantage of naturally occurring variations in organisms to pass wanted traits on to future generations is called
   a. selective breeding. **c.** hybridization.
   b. inbreeding. **d.** mutation.

4. How do breeders produce genetic variations that are not found in nature?

5. What is polyploidy? When is this condition useful?

Think Critically

6. **Propose a Solution** 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 roses?

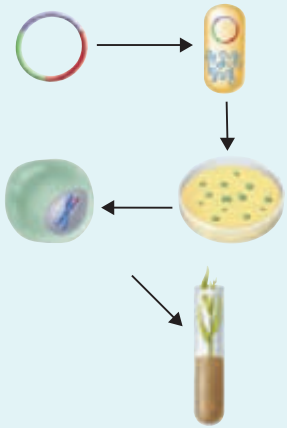
7. **Compare and Contrast** Hybridization and inbreeding are important methods used in selective breeding. How are the methods similar? How are they different?

15.2 Recombinant DNA

Understand Key Concepts

8. Organisms that contain genes from other organisms are called
   a. transgenic. **c.** donors.
   b. mutagenic. **d.** clones.

9. What process is shown below?
   a. cloning
   b. transformation
   c. hybridization
   d. polymerase chain reaction



10. 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.

11. Bacteria often contain small circular molecules of DNA known as
    a. clones. **c.** plasmids.
    b. chromosomes. **d.** hybrids.

12. A member of a population of genetically identical cells produced from a single cell is a
    a. clone. **c.** mutant.
    b. plasmid. **d.** sequence.

13. Describe what happens during a polymerase chain reaction.

14. Explain what genetic markers are and describe how scientists use them.

15. How does a transgenic plant differ from a hybrid plant?

Think Critically

16. **Apply Concepts** Describe one or more advantages of producing insulin and other proteins through genetic engineering.

17. **Apply Concepts** Bacteria and human beings are very different organisms. Why is it sometimes possible to combine their DNA and use a bacterium to make a human protein?

15.3 Applications of Genetic Engineering

Understand Key Concepts

18. 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

19. 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.

20. Physicians can screen for a genetic disorder using
- **a.** a DNA microarray.
- **b.** PCR.
- **c.** restriction enzyme analysis.
- **d.** DNA sequencing.

21. Describe how a DNA microarray might be used to distinguish normal cells from cancer cells.

22. Describe two important uses for DNA fingerprinting.

Think Critically

23. **Infer** If a human patient's bone marrow was removed, altered genetically, and reimplanted, would the change be passed on to the patient's children? Explain your answer.

solve the CHAPTER MYSTERY

A CASE OF MISTAKEN IDENTITY

The first suspect was lucky: Twenty years earlier, it would have been an open-and-shut case. But by 1998, DNA fingerprinting was widely available. After the police took the suspect into custody, forensic scientists tested the DNA in the bloodstains on his shirt. Within a few hours, they knew they had the wrong suspect. Before long, the police caught the real attacker, who was subsequently tried and convicted of the crime.

1. **Infer** How did the investigators determine that the person they took into custody was not guilty of this crime?

2. **Apply Concepts** Did the DNA evidence from the bloodstains come from the red blood cells, the white blood cells, or both? Explain your answer.

3. **Predict** What if the initial suspect was related to the victim? Would that have changed the result? Why or why not?

4. **Connect to the Big idea** What might have happened if this crime were committed before DNA fingerprinting was discovered? Describe the series of events that might have taken place after police took in the first suspect.

15.4 Ethics and Impacts of Biotechnology

Understand Key Concepts

24. 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.

25. Which of the following is most likely to be used in a court case to determine who the father of a particular child is?
- **a.** microarray analysis
- **b.** DNA fingerprinting
- **c.** gene therapy
- **d.** genetic engineering

26. Give an example of a disadvantage associated with patenting genes.

27. What is one argument used by critics of genetically modified foods?

Think Critically

28. Predict List three ways in which genetically engineered organisms might be used in the future.

29. Evaluate Your friend suggests that genetic engineering makes it possible for biologists to produce an organism with any combination of characteristics—an animal with the body of a frog and the wings of a bat, for example. Do you think this is a reasonable statement? Explain your answer.

Connecting Concepts

Use Science Graphics

Use the table below to answer question 30.

DNA Restriction Enzymes

Enzyme	Recognition Sequence
*Bgl*III	A↓G A T C T T C T A G↑A
*Eco*RI	G↓A A T T C C T T A A↑G
*Hind*III	A↓A G C T T T T C G A↑A

30. Apply Concepts Copy the following DNA sequence and write its complementary strand.

ATGAGATCTACGGAATTCTCAAGCTTGAATCG

Where will each restriction enzyme in the table cut the DNA strand?

Write About Science

31. Explanation Your local newspaper has published an editorial against using genetic modification. It asserts that GM is still too new, and traditional selective breeding can accomplish the same things as GM. Write a letter to the editor supporting or opposing this position.

32. Assess the Big idea Briefly describe the major steps involved in inserting a human gene into a bacterium.

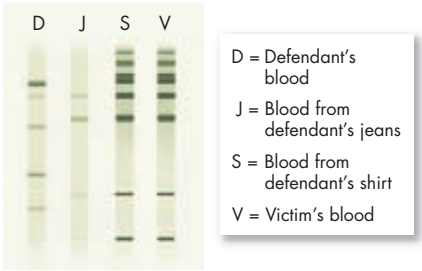
Analyzing Data

Questions 33–35 refer to the diagram, which shows the results of a criminal laboratory test.

33. Infer Briefly describe the biotechnological methods that would have been used to produce the results shown at the right.

34. Compare and Contrast How are the bands from the jeans and the shirt similar? How are they different?

35. Draw Conclusions Based on the results shown, what conclusions might a prosecutor present to a jury during a criminal trial?



Standardized Test Prep

Multiple Choice

1. Polyploidy may instantly produce new types of organisms that are larger and stronger than their diploid relatives in
A animals. **C** bacteria.
B plants. **D** fungi.

2. Which of the following characteristics does NOT apply to a plasmid?
A made of DNA
B found in bacterial cells
C has circular loops
D found in animal cells

3. To separate DNA fragments from one another, scientists use
A polymerase chain reaction.
B DNA microarrays.
C gel electrophoresis.
D restriction enzymes.

4. Restriction enzymes cut DNA molecules
A into individual nucleotides.
B at random locations.
C at short sequences specific to each type of enzyme.
D into equal-sized pieces.

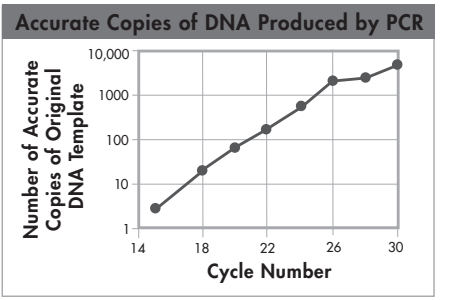
5. The expression of thousands of genes at one time can be followed using
A polymerase chain reaction.
B plasmid transformation.
C restriction enzymes.
D DNA microarrays.

6. Genetically engineered crop plants can benefit farmers by
A reducing the amount of land that is required to grow them.
B introducing chemicals into the environment.
C increasing an animal's resistance to antibiotics.
D changing the genomes of other crop plants.

7. Genetic markers allow scientists to
A clone animals.
B separate strands of DNA.
C synthesize antibiotics.
D identify transformed cells.

Questions 8–9

The graph below shows the number of accurate copies of DNA produced by polymerase chain reaction.



8. What can you conclude about cycles 18 through 26?
A PCR produced accurate copies of template DNA at an exponential rate.
B The amount of DNA produced by PCR doubled with each cycle.
C The DNA copies produced by PCR were not accurate copies of the original DNA template.
D The rate at which PCR produced accurate copies of template DNA fell in later cycles.

9. Based on the graph, which of the following might have happened between cycles 26 and 28?
A PCR stopped producing accurate copies of the template.
B The rate of reaction increased.
C All of the template DNA was used up.
D A mutation occurred.

Open-Ended Response

10. Why are bacteria able to make human proteins when a human gene is inserted in them with a plasmid?

If You Have Trouble With . . .

Question	1	2	3	4	5	6	7	8	9	10
See Lesson	15.1	15.2	15.2	15.2	15.3	15.4	15.2	15.2	15.2	15.3

Unit Project

Genetics Collage

Genetics is a fascinating field of study and is becoming increasingly important to society. A local genetics laboratory in your town wants to increase public awareness of the importance of genetics. To do so, it has decided to hold a scholarship competition. The scholarship will go to the student(s) who create the best educational collage related to topics in genetics.

Your Task Using magazine and newspaper clippings, Internet sources, and art materials to make a colorful collage. The images should relate to three central questions.

1) Why is DNA important to a cell?
2) Why is DNA important to you, as a human being?
3) Why is DNA important to society as a whole?

Be sure to

- communicate answers to the above questions in the images, words and phrases you choose.
- carefully design your collage so that it is clear and organized.

Reflection Questions

1. **Score your collage using the rubric below. What score did you give yourself?**
2. **What did you do well in this project?**
3. **What about your collage needs improvement?**
4. **What could a person who didn't know much about DNA learn from your collage?**

Assessment Rubric

Score	Scientific Content	Quality of Collage
4	Collage includes many important and thoughtful images related to the three central questions. Student demonstrates a deep understanding of genetics topics.	The collage is clear, organized, and creative.
3	Collage includes important images related to the three central questions. Student demonstrates an adequate understanding of genetics topics.	The collage is well designed and organized.
2	Collage is missing some important ideas and/or includes several insignificant ideas. Student demonstrates a limited level of understanding of genetics topics.	The collage could be better designed and organized.
1	Collage is missing several important ideas. Student demonstrates significant misunderstandings.	The collage is unclear and lacks a solid design.