SECTION 1

Human Inheritance

DISCOVER

How Tall Is Tall?

1. Choose a partner. Measure each other's height to the nearest 5 centimeters. Record your measurements on the chalkboard.
2. Create a bar graph showing the number of students at each height. Plot the heights on the horizontal axis and the number of students on the vertical axis.

ACTIVITY

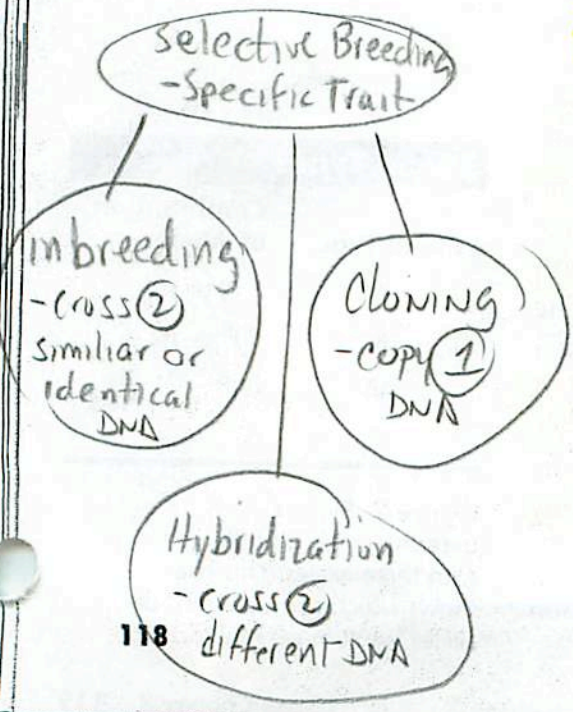
Think It Over

Inferring If Gregor Mendel had graphed the heights of his pea plants, the graph would have had two bars—one for tall stems and one for short stems. Do you think height in humans is controlled by a single gene, as it is in peas? Explain your answer.

GUIDE FOR READING

- Why do some human traits show a large variety of phenotypes?
- Why are some sex-linked traits more common in males than in females?
- How do geneticists use pedigrees?

Reading Tip Before you read, rewrite the headings in this section as *how*, *why*, or *what* questions. As you read, write answers to the questions.



Have you ever heard someone say "He's the spitting image of his dad" or "She has her mother's eyes"? Children often resemble their parents. The reason for this is that alleles for eye color, hair color, and thousands of other traits are passed from parents to their children. People inherit some alleles from their mother and some from their father. This is why most people look a little like their mother and a little like their father.

Traits Controlled by Single Genes

In Chapter 3, you learned that many traits in peas and other organisms are controlled by a single gene with two alleles. Often one allele is dominant, while the other is recessive. Many human traits are also controlled by a single gene with one dominant allele and one recessive allele. As with tall and short pea plants, these human traits have two distinctly different phenotypes, or physical appearances.

For example, a widow's peak is a hairline that comes to a point in the middle of the forehead. The allele for a widow's peak is dominant over the allele for a straight hairline. The Punnett square in Figure 1 illustrates a cross between two parents who are heterozygous for a widow's peak. Trace the possible combinations of alleles that a child may inherit. Notice that each child has a 3 in 4, or 75 percent, probability of having a widow's peak. There is only a 1 in 4, or 25 percent, probability that a child will have a straight hairline. Recall from Chapter 3 that when Mendel crossed peas that were heterozygous for a trait, he obtained similar percentages in the offspring.

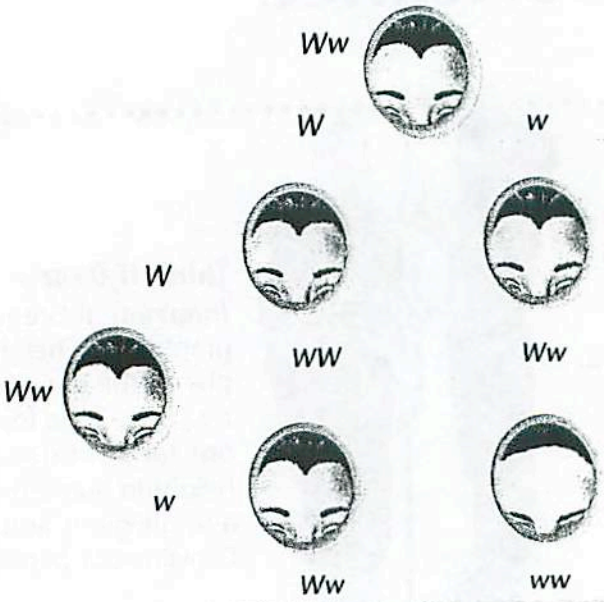


Figure 1 This Punnett square shows a cross between two parents with widow's peaks. *Interpreting Diagrams What are the possible genotypes of the offspring? What percent of the offspring will have each genotype?*

Do you have dimples when you smile? If so, then you have the dominant allele for this trait. Like having a widow's peak, having smile dimples is controlled by a single gene. People who have two recessive alleles do not have smile dimples.

Multiple Alleles

Some human traits are controlled by a single gene that has more than two alleles. Such a gene is said to have **multiple alleles**—three or more forms of a gene that code for a single trait. You can think of multiple alleles as being like flavors of pudding. Pudding usually comes in more flavors than just chocolate and vanilla!

Even though a gene may have multiple alleles, a person can carry only two of those alleles. This is because chromosomes exist in pairs. Each chromosome in a pair carries only one allele for each gene.

One human trait that is controlled by a gene with multiple alleles is blood type. There are four main blood types—A, B, AB, and O. Three alleles control the inheritance of blood types. The allele for blood type A and the allele for blood type B are codominant. The codominant alleles are written as capital letters with superscripts—I^A for blood type A and I^B for blood type B. The allele for blood type O—written *i*—is recessive. Recall that when two codominant alleles are inherited, neither allele is masked. A person who inherits an I^A allele from one parent and an I^B allele from the other parent will have type AB blood. Figure 2 shows the allele combinations that result in each blood type. Notice that only people who inherit two *i* alleles have type O blood.

Checkpoint *If a gene has multiple alleles, why can a person only have two of the alleles for the gene?*

Blood Types

Blood Type	Combination of Alleles
A	I^AI^A or I^Ai
B	I^BI^B or I^Bi
AB	I^AI^B
O	*ii*

Figure 2 Blood type is determined by a single gene with three alleles. This chart shows which combinations of alleles result in each blood type.

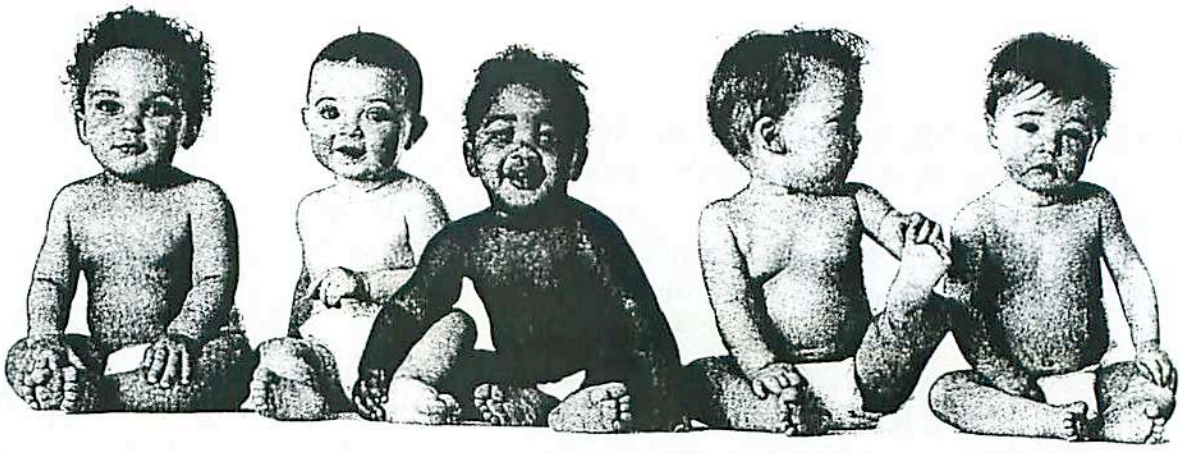


Figure 3 Skin color in humans is determined by three or more genes. Different combinations of alleles at each of the genes result in a wide range of possible skin colors.

TRY THIS

ACTIVITY

One inherited trait is eye dominance—the tendency to use one eye more than the other. Here's how you can test yourself for this trait.

1. Hold your hand out in front of you at arm's length. Point your finger at an object across the room.
2. Close your right eye. With only your left eye open, observe how far your finger appears to move.
3. Repeat Step 2 with the right eye open. With which eye did your finger seem to remain closer to the object? That eye is dominant.

Designing Experiments Is eye dominance related to hand dominance—whether a person is right-handed or left-handed? Design an experiment to find out. Obtain your teacher's permission before carrying out your experiment.

Traits Controlled by Many Genes

If you did the Discover activity, you observed that height in humans has more than two distinct phenotypes. In fact, there is an enormous variety of phenotypes for height. What causes this wide range of phenotypes? **Some human traits show a large number of phenotypes because the traits are controlled by many genes. The genes act together as a group to produce a single trait.** At least four genes control height in humans, so there are many possible combinations of genes and alleles.

Like height, skin color is determined by many genes. Human skin color ranges from almost white to nearly black, with many shades in between. Skin color is controlled by at least three genes. Each gene, in turn, has at least two possible alleles. Various combinations of alleles at each of the genes determine the amount of pigment that a person's skin cells produce. Thus, a wide variety of skin colors is possible.

The Effect of Environment

The effects of genes are often altered by the environment—the organism's surroundings. For example, people's diets can affect their height. A diet lacking in protein, minerals, and vitamins can prevent a person from growing to his or her potential maximum height. Since the late 1800s, the average height of adults in the United States has increased by almost 10 centimeters. During that time, American diets have become more healthful. Other environmental factors, such as medical care and living conditions, have also improved since the late 1800s.

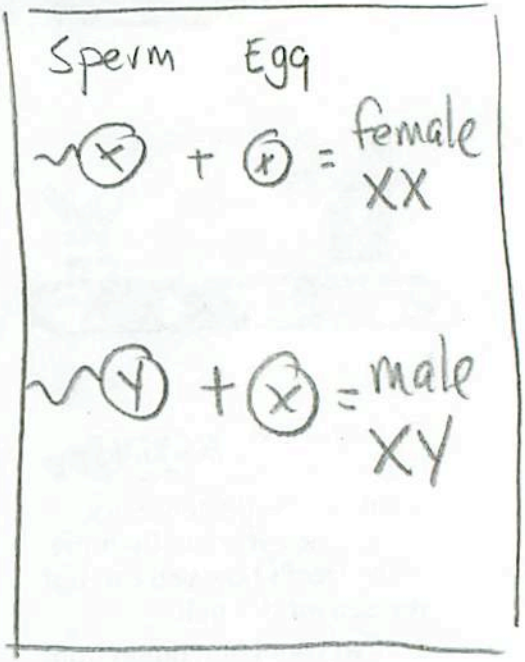
☑ *Checkpoint* *How can environmental factors affect a person's height?*

"Congratulations, Mr. and Mrs. Gonzales. It's a baby girl!" What factors determine whether a baby is a boy or a girl? As with other traits, the sex of a baby is determined by genes on chromosomes. Among the 23 pairs of chromosomes in each body cell is a single pair of chromosomes called the sex chromosomes. The sex chromosomes determine whether a person is male or female.

The sex chromosomes are the only pair of chromosomes that do not always match. If you are female, your two sex chromosomes match. The two chromosomes are called X chromosomes. If you are male, your sex chromosomes do not match. One of your sex chromosomes is an X chromosome. The other chromosome is a Y chromosome. The Y chromosome is much smaller than the X chromosome.

What happens to the sex chromosomes when egg and sperm cells form? As you know, each egg and sperm cell has only one chromosome from each pair. Since both of a female's sex chromosomes are X chromosomes, all eggs carry one X chromosome. Males, however, have two different sex chromosomes. This means that half of a male's sperm cells carry an X chromosome, while half carry a Y chromosome.

When a sperm cell with an X chromosome fertilizes an egg, the egg has two X chromosomes. The fertilized egg will develop into a girl. When a sperm with a Y chromosome fertilizes an egg, the egg has one X chromosome and one Y chromosome. The fertilized egg will develop into a boy. Thus it is the sperm that determines the sex of the child, as you can see in Figure 4.



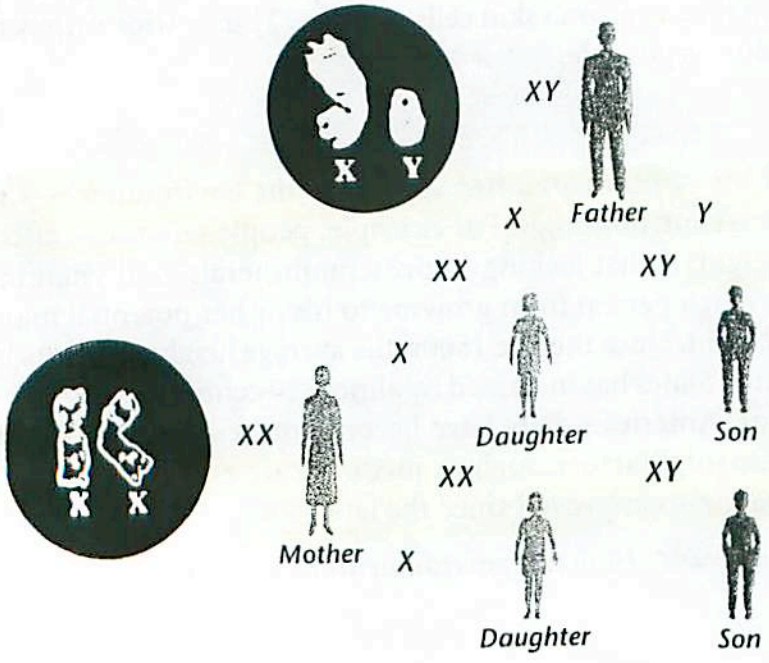


Figure 4 As this Punnett square shows, there is a 50 percent probability that a child will be a girl and a 50 percent probability that a child will be a boy. *Interpreting Diagrams What sex will the child be if a sperm with a Y chromosome fertilizes an egg?*

TRY THIS

Girl or Boy?

ACTIVITY

You can model how the sex of an offspring is determined.

1. Label one paper bag "female." Label another paper bag "male."
2. Place two red marbles in the bag labeled "female." The red marbles represent X chromosomes.
3. Place one red marble and one white marble in the bag labeled "male." The white marble represents a Y chromosome.
4. Without looking, pick one marble from each bag. Two red marbles represent a female offspring. One red marble and one white marble represent a male offspring. Record the sex of the "offspring."
5. Put the marbles back in the correct bags. Repeat Step 4 nine more times.

Making Models How many males were produced? How many females? How close were your results to the expected probabilities for male and female offspring?

Sex-Linked Genes

Some human traits occur more often in one sex than the other. The genes for these traits are often carried on the sex chromosomes. Genes on the X and Y chromosomes are often called **sex-linked genes** because their alleles are passed from parent to child on a sex chromosome. Traits controlled by sex-linked genes are called sex-linked traits.

Like other genes, sex-linked genes can have dominant and recessive alleles. Recall that females have two X chromosomes, whereas males have one X chromosome and one Y chromosome. In females, a dominant allele on one X chromosome will mask a recessive allele on the other X chromosome. The situation is not the same in males, however. In males, there is no matching allele on the Y chromosome to mask, or hide, the allele on the X chromosome. As a result, any allele on the X chromosome—even a recessive allele—will produce the trait in a male who inherits it. **Because males have only one X chromosome, males are more likely than females to have a sex-linked trait that is controlled by a recessive allele.**

One example of a sex-linked trait that is controlled by a recessive allele is red-green colorblindness. A person with red-green colorblindness cannot distinguish between red and green.

Many more males than females have red-green colorblindness. You can understand why this is the case by examining the Punnett square in Figure 6. Both parents in this example have normal color vision. Notice, however, that the mother is a carrier of colorblindness. A **carrier** is a person who has one recessive allele for a trait and one dominant allele. Although a carrier does not have the trait, the carrier can pass the recessive allele on to his or her offspring. In the case of sex-linked traits, only females can be carriers.

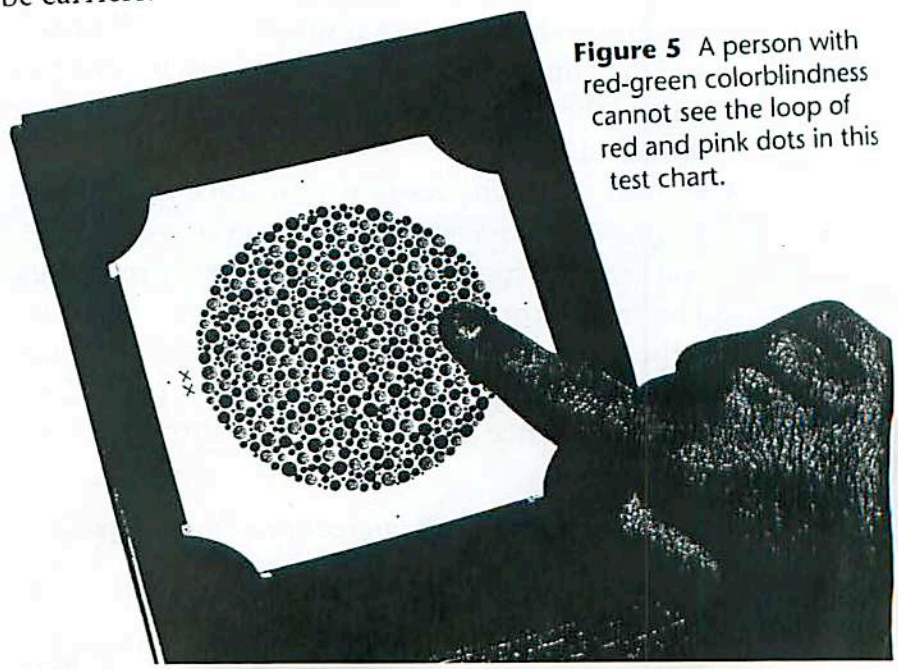


Figure 5 A person with red-green colorblindness cannot see the loop of red and pink dots in this test chart.

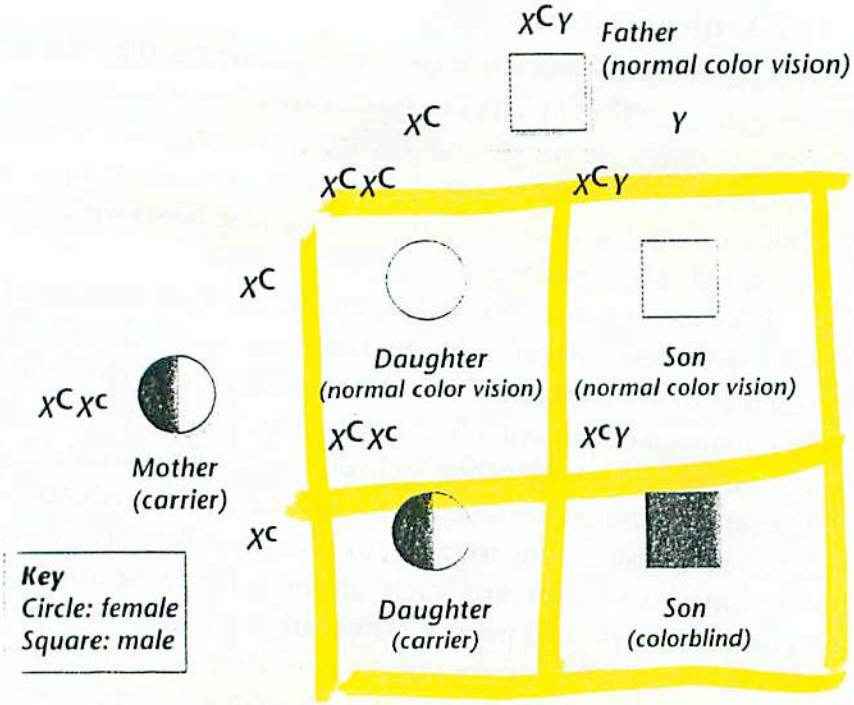


Figure 6 Red-green colorblindness is a sex-linked trait. A girl who receives only one recessive allele (written X^c) for red-green colorblindness will not have the trait. However, a boy who receives one recessive allele will be colorblind. *Applying Concepts What allele combination would a daughter need to inherit to be colorblind?*

As you can see in Figure 6, there is a 25 percent probability that this couple will have a colorblind child. Notice that none of the couple's daughters will be colorblind. On the other hand, the sons have a 50 percent probability of being colorblind. For a female to be colorblind, she must inherit two recessive alleles for colorblindness, one from each parent. A male needs to inherit only one recessive allele. This is because there is no gene for color vision on the Y chromosome. Thus, there is no allele that could mask the recessive allele on the X chromosome.

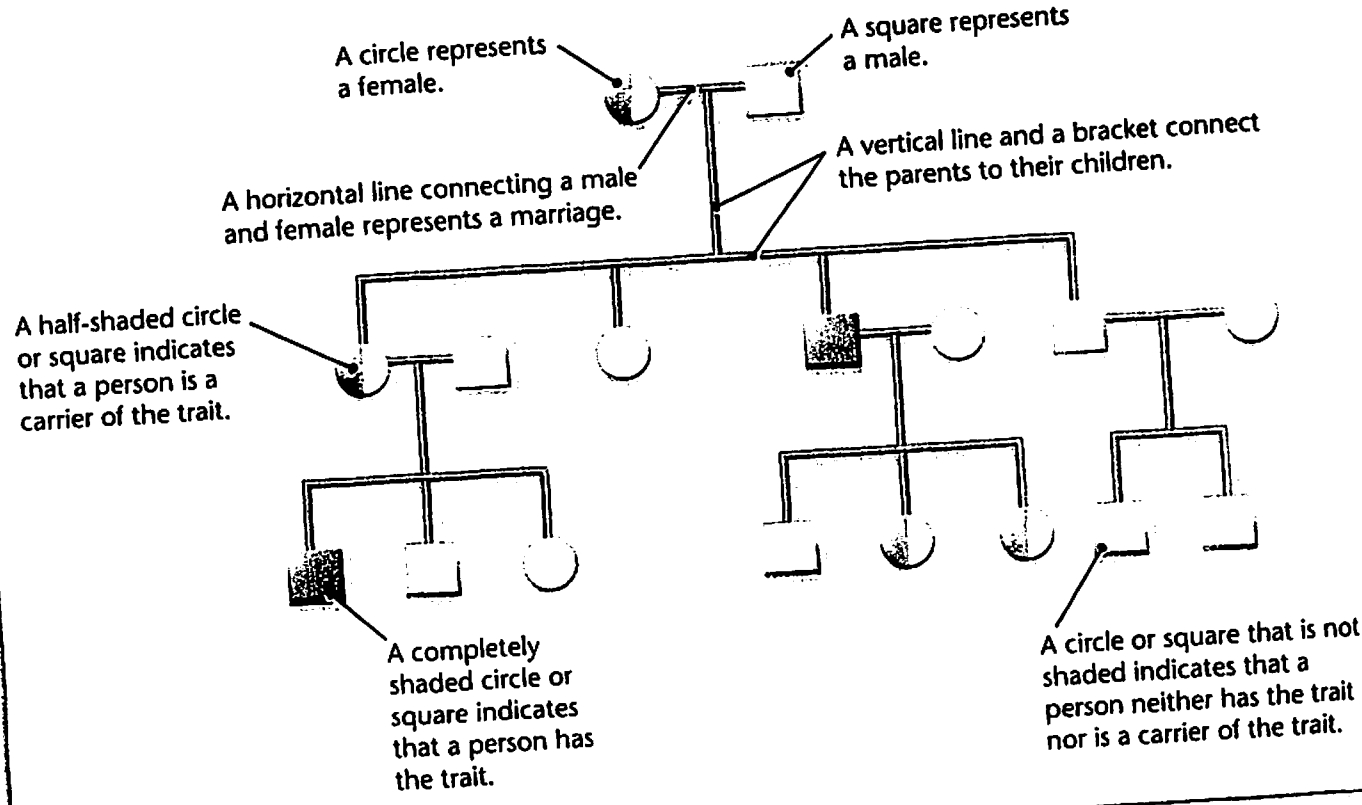
Imagine that you are a geneticist interested in studying inheritance patterns in humans. What would you do? You can't set up crosses with people as Mendel did with peas. Instead, you would need to trace the inheritance of traits through many generations in a number of families.

One tool that geneticists use to trace the inheritance of traits in humans is a pedigree. A **pedigree** is a chart or "family tree" that tracks which members of a family have a particular trait. The trait recorded in a pedigree can be an ordinary trait such as the widow's peak, or it could be a sex-linked trait such as colorblindness. In *Exploring a Pedigree* on page 124, you can trace the inheritance of colorblindness through three generations of a family.

Checkpoint How is a pedigree like a "family tree"?

EXPLORING *a Pedigree*

This pedigree traces the occurrence of colorblindness in three generations of a family. Colorblindness is a sex-linked trait that is controlled by a recessive allele. Notice that specific symbols are used in pedigrees to communicate genetic information.



Section 1 Review

1. Why do human traits such as height and skin color have many different phenotypes?
2. Explain why red-green colorblindness is more common in males than in females.
3. What is a pedigree? How are pedigrees used?
4. **Thinking Critically Predicting** Could two people with widow's peaks have a child with a straight hairline? Could two people with straight hairlines have a child with a widow's peak? Explain.

CHAPTER PROJECT

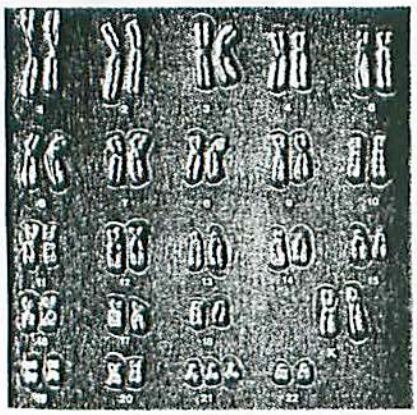
Check Your Progress

By now, you should be creating your pedigree for the first trait you chose. Start with one couple, and show two generations of offspring. The couple should have five children. It is up to you to decide how many children each of those children has. Use Punnett squares to make sure that your imaginary family's inheritance pattern follows the laws of genetics.

SECTION 2

Human Genetic Disorders

DISCOVER ..... **ACTIVITY**



How Many Chromosomes?

The photo at the left shows the chromosomes from a cell of a person with Down syndrome, a genetic disorder. The chromosomes have been sorted into pairs.

1. Count the number of chromosomes in the photo.
2. How does the number of chromosomes compare to the usual number of chromosomes in human cells?

Inferring How do you think a cell could have ended up with this number of chromosomes? (*Hint:* Think about the events that occur during meiosis.)

The air inside the stadium was hot and still. The crowd cheered loudly as eight runners approached the starting blocks. The runners shook out their arms and legs to loosen up their muscles and calm their jitters. When the starter raised the gun, all eyes focused on the runners. At the crack of the starter's gun, the runners leaped into motion and sprinted down the track.

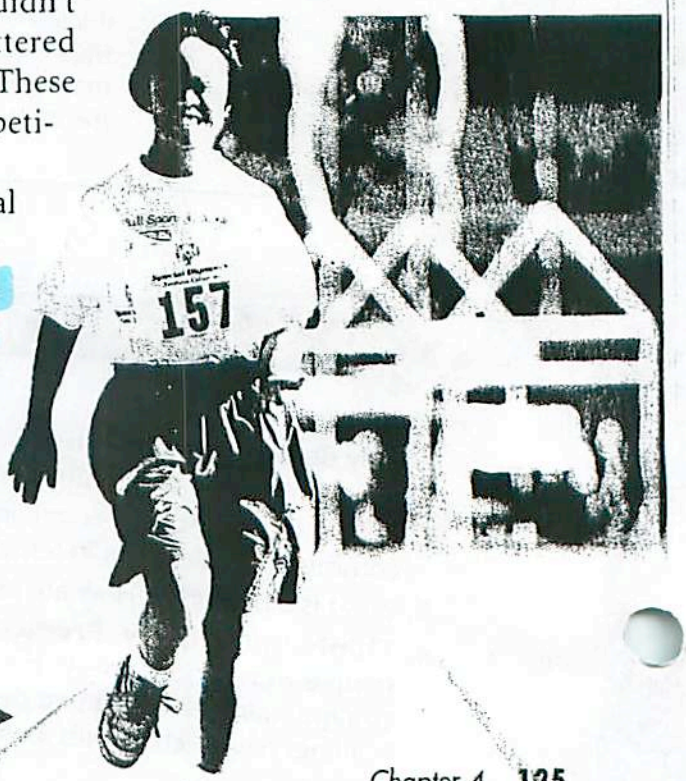
Seconds later, the race was over. The runners, bursting with pride, hugged each other and their coaches. It didn't matter where each of the runners placed. All that mattered was that they had finished the race and done their best. These athletes were running in the Special Olympics, a competition for people with disabilities.

Many of the athletes who compete in the Special Olympics have disabilities that result from genetic disorders. A **genetic disorder** is an abnormal condition that a person inherits through genes or chromosomes. **Genetic disorders are caused by mutations, or changes in a person's DNA.** In some cases, a mutation occurs when sex cells form during meiosis. In other cases, a mutation that is already present in a parent's cells is passed on to the offspring. In this section, you will learn about some common genetic disorders.

GUIDE FOR READING

- What causes genetic disorders?
- How are genetic disorders diagnosed?

Reading Tip As you read, make a list of different types of genetic disorders. Write a sentence about each disorder.



A runner at the Special Olympics ▶

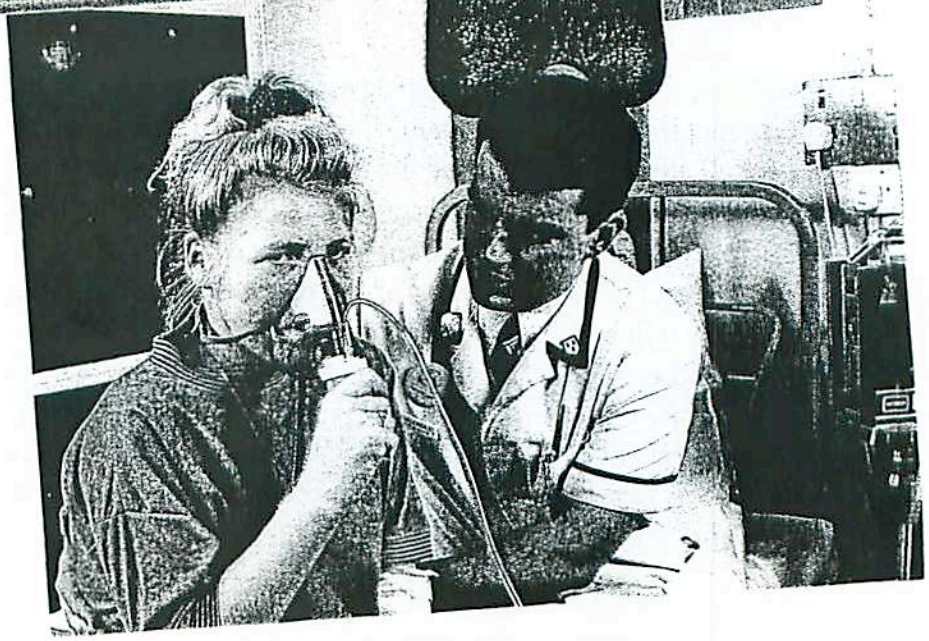


Figure 7 Cystic fibrosis is a genetic disorder that causes thick mucus to build up in a person's lungs and intestines. This patient is inhaling a fine mist that will help loosen the mucus in her lungs.

Cystic Fibrosis

Cystic fibrosis is a genetic disorder in which the body produces abnormally thick mucus in the lungs and intestines. The thick mucus fills the lungs, making it hard for the affected person to breathe. Bacteria that grow in the mucus can cause infections and, eventually, lung damage. In the intestines, the mucus makes it difficult for digestion to occur.

The mutation that leads to cystic fibrosis is carried on a recessive allele. The cystic fibrosis allele is most common among people whose ancestors are from Northern Europe. Every day in this country, four babies are born with cystic fibrosis.

Currently there is no cure for cystic fibrosis. Medical treatments include drugs to prevent infections and physical therapy to break up mucus in the lungs. Recent advances in scientists' understanding of the disease may lead to better treatments and longer lifespans for people with cystic fibrosis.

☑ ***Checkpoint*** *What are some symptoms of cystic fibrosis?*

Figure 8 Normally, red blood cells are shaped like round disks (top). In a person with sickle-cell disease, red blood cells can become sickle-shaped (bottom). *Relating Cause and Effect What combination of alleles leads to sickle-cell disease?*

Sickle-Cell Disease

Sickle-cell disease is a genetic disorder that affects the blood. Th
mutation that causes the disorder affects the production of a
important protein called hemoglobin. Hemoglobin is the pr
tein in red blood cells that carries oxygen. People with sickle-c
disease produce an abnormal form of hemoglobin. When oxyg
concentrations are low, their red blood cells have an unusu
sickle shape, as you can see in Figure 8.

Sickle-shaped red blood cells cannot carry as much oxygen
normal-shaped cells. Because of their shape, the cells becom
stuck in narrow blood vessels, blocking them. People with sick
cell disease suffer from lack of oxygen in the blood and expe
ence pain and weakness.

The allele for the sickle-cell trait is most common in people of African ancestry. About 9 percent of African Americans carry the sickle-cell allele. The allele for the sickle-cell trait is codominant with the normal allele. A person with two sickle-cell alleles will have the disease. A person with one sickle-cell allele will produce both normal hemoglobin and abnormal hemoglobin. This person usually will not have symptoms of the disease.

Currently, there is no cure for sickle-cell disease. People with sickle-cell disease are given drugs to relieve their painful symptoms and to prevent blockages in blood vessels. As with cystic fibrosis, scientists are hopeful that new, successful treatments will soon be found.

Hemophilia is a genetic disorder in which a person's blood clots very slowly or not at all. People with the disorder do not produce one of the proteins needed for normal blood clotting. A person with hemophilia can bleed to death from a minor cut or scrape. The danger of internal bleeding from small bumps and bruises is also very high.

Hemophilia is an example of a disorder that is caused by a recessive allele on the X chromosome. Because hemophilia is a sex-linked disorder, it occurs more frequently in males than in females.

INTEGRATING People with hemophilia must get regular doses of the missing clotting protein. In general, people with hemophilia can lead normal lives. However, they are advised to avoid contact sports and other activities that could cause internal injuries.

Figure 9 Empress Alexandra of Russia (center row, left) passed the allele for hemophilia to her son Alexis (front).

Studies CONNECTION

Hemophilia has affected European history. Queen Victoria of England had a son and three grandsons with hemophilia. Victoria, at least two of her daughters, and four of her granddaughters were carriers of the disease.

As Victoria's descendants passed the hemophilia allele to their offspring, hemophilia spread through the royal families of Europe. For example, Empress Alexandra, Queen Victoria's granddaughter, married the Russian Czar Nicholas II in 1894. Alexandra, a carrier of hemophilia, passed the disease to her son Alexis, who was heir to the throne.

A monk named Rasputin convinced Alexandra that he could cure Alexis. As a result of his control over Alexandra, Rasputin was able to control the Czar as well. The people's anger at Rasputin's influence may have played a part in the Russian Revolution of 1917, in which the Czar was overthrown.

In Your Journal

Imagine that you are Empress Alexandra. Write a diary entry expressing your feelings and unanswered questions about Alexis's condition.

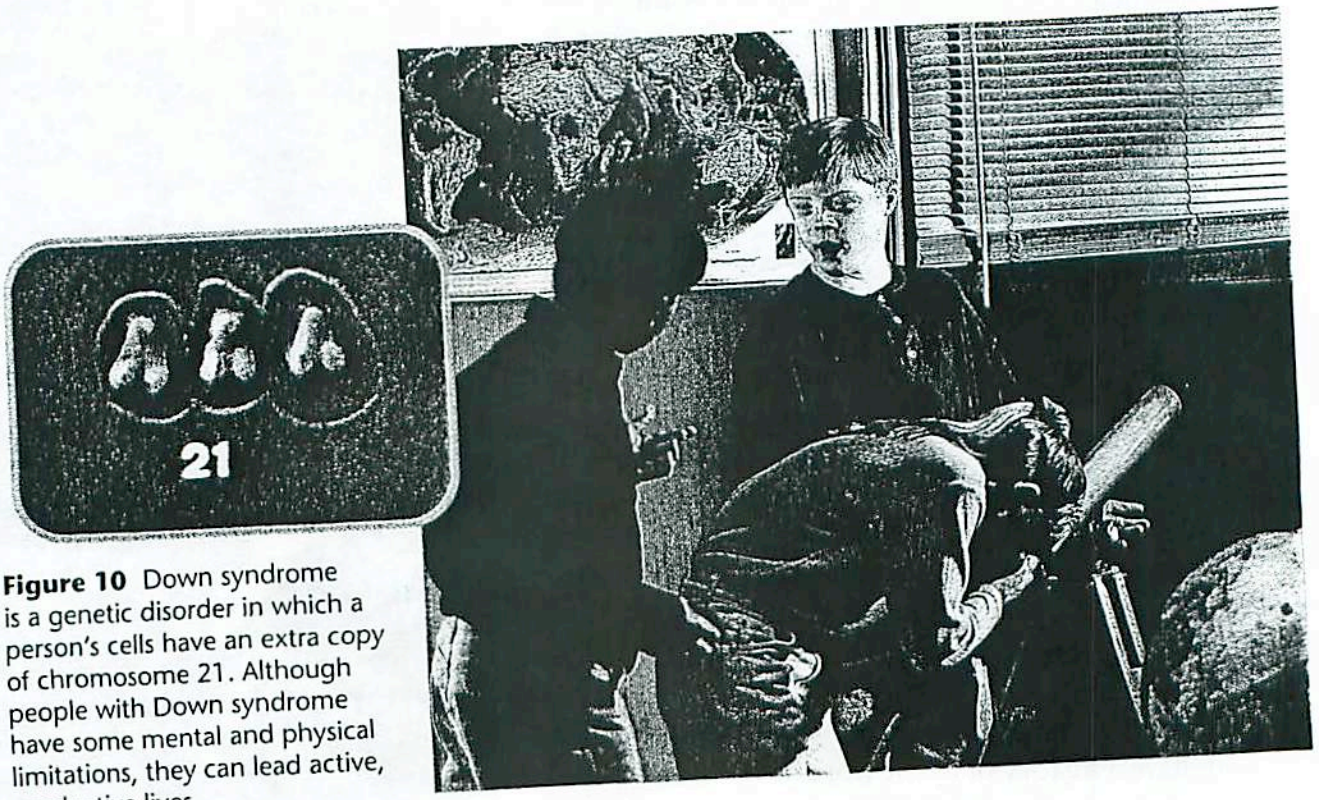


Figure 10 Down syndrome is a genetic disorder in which a person's cells have an extra copy of chromosome 21. Although people with Down syndrome have some mental and physical limitations, they can lead active, productive lives.

Down Syndrome

Some genetic disorders are the result of too many or too few chromosomes. In one such disorder, called Down syndrome, a person's cells have an extra copy of chromosome 21. The extra chromosome is the result of an error during meiosis. Recall that in meiosis, cells divide and chromosomes separate to produce sex cells with half the normal chromosome number. Down syndrome most often occurs when chromosomes fail to separate properly during meiosis.

People with Down syndrome have a distinctive physical appearance, and have some degree of mental retardation. Heart defects are also common, but can be treated. Despite their limitations, many people with Down syndrome lead full, active lives.

Diagnosing Genetic Disorders

Integrating Technology

Years ago, doctors had only Punnett squares and pedigrees to help them predict whether a child might have a genetic disorder. **Today doctors use tools such as amniocentesis and karyotypes to help detect genetic disorders.**

Before a baby is born, doctors can use a procedure called **amniocentesis** (am nee oh sen TEE sis) to determine whether the baby will have some genetic disorders. During amniocentesis, a doctor uses a very long needle to remove a small amount of the fluid that surrounds the developing baby. The fluid contains cells from the baby.

The doctor then examines the chromosomes from the cells. To do this, the doctor creates a karyotype. A **karyotype** (KA ree uh typ) is a picture of all the chromosomes in a cell. The chromosomes in a karyotype are arranged in pairs. A karyotype can reveal whether a developing baby has the correct number of chromosomes in its cells and whether it is a boy or a girl. If you did the Discover activity, you saw a karyotype from a girl with Down syndrome.

A couple that has a family history or concern about a genetic disorder may turn to a genetic counselor for advice. Genetic counselors help couples understand their chances of having a child with a particular genetic disorder. Genetic counselors use tools such as karyotypes, pedigree charts, and Punnett squares to help them in their work.

Suppose, for example, that a husband and wife both have a history of cystic fibrosis in their families. If they are considering having children, they might seek the advice of a genetic counselor. The genetic counselor might order a test to determine whether they are carriers of the allele for cystic fibrosis. The genetic counselor would then apply the same principles of probability that you learned about in Chapter 3 to calculate the couple's chances of having a child with cystic fibrosis.

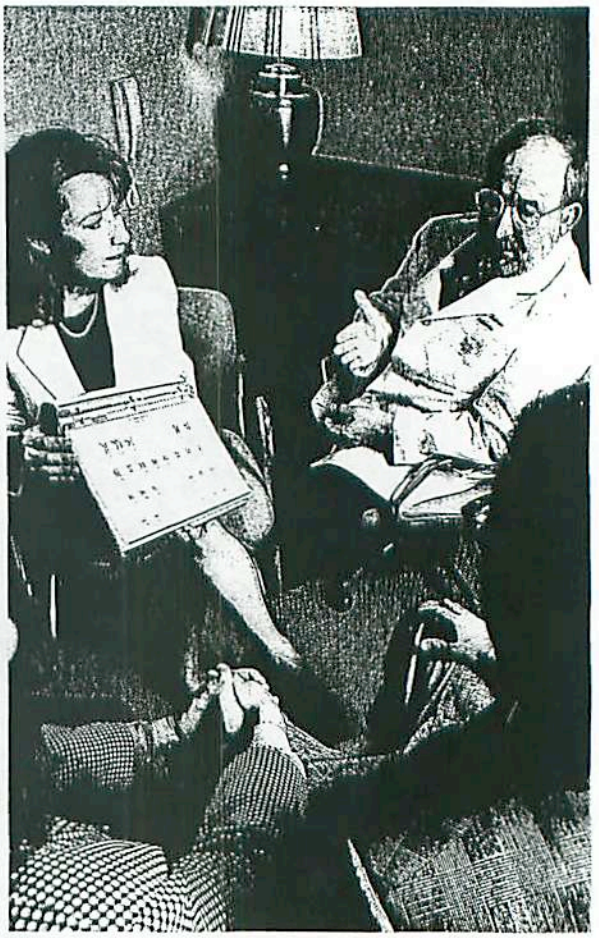


Figure 11 Couples may meet with a genetic counselor and their doctor in order to understand their chances of having a child with a genetic disorder.

Section 2 Review

1. Explain how genetic disorders occur in humans. Give two examples of genetic disorders.
2. Describe two tools that doctors use to detect genetic disorders.
3. How do the cells of people with Down syndrome differ from those of others? How might this difference arise?
4. **Thinking Critically Problem Solving** A couple with a family history of hemophilia is about to have a baby girl. What information about the parents would you want to know? How would this information help you determine whether the baby will have hemophilia?

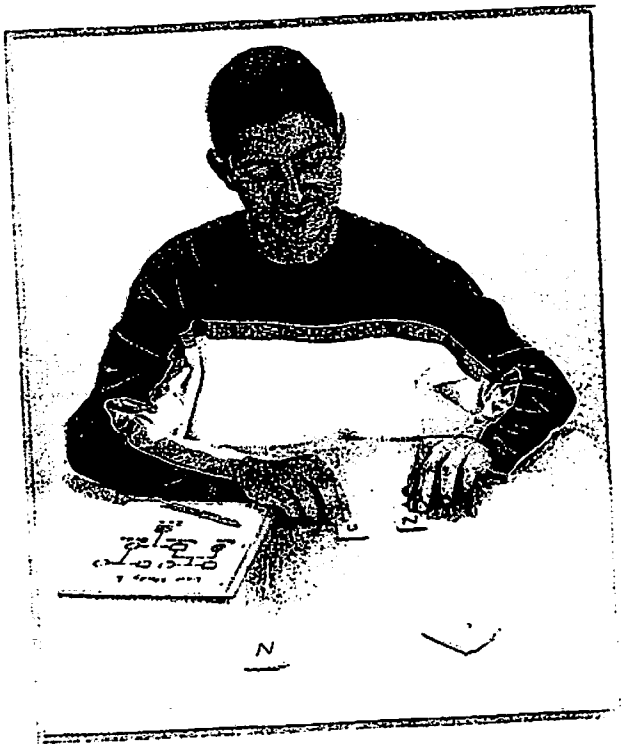
CHAPTER PROJECT

At this point, you should begin to trace the inheritance of another trait through the same family members that are in your first pedigree. Also, start making your family "photo" album. Will you use drawings or some other method to show what the family members look like? (*Hint:* Photo albums show phenotypes. Remember that more than one genotype can have the same phenotype.)

Real-World Lab

Careers in Science

Family Puzzles



Imagine that you are a genetic counselor. Two couples come to you for advice. Their family histories are summarized in the boxes labeled *Case Study 1* and *Case Study 2*. They want to understand more about certain genetic disorders that run in their families. In this lab, you will find answers to their questions.

Problem

How can you investigate inheritance patterns in families?

Materials

12 index cards
scissors
marker

Procedure

Part 1 Investigating Case Study 1

1. Read over Case Study 1. In your notebook, draw a pedigree that shows all the family members. Use circles to represent the females, and squares to represent the males. Shade in the circles or squares representing the individuals who have cystic fibrosis.

Case Study 1: Joshua and Bella

- Joshua and Bella have a son named Ian. Ian has been diagnosed with cystic fibrosis.
- Joshua and Bella are both healthy.
- Bella's parents are both healthy.
- Joshua's parents are both healthy.
- Joshua's sister, Sara, has cystic fibrosis.

2. You know that cystic fibrosis is controlled by a recessive allele. To help you figure out Joshua and Bella's family pattern, create a set of cards to represent the alleles. Cut each of six index cards into four smaller cards. On 12 of the small cards, write *N* to represent the dominant normal allele. On the other 12 small cards, write *n* for the recessive allele.
3. Begin by using the cards to represent Ian's alleles. Since he has cystic fibrosis, what alleles must he have? Write in this genotype next to the pedigree symbol for Ian.
4. Joshua's sister, Sara, also has cystic fibrosis. What alleles does she have? Write in this genotype next to the pedigree symbol that represents Sara.

Case Study 2: Li and Mai

- The father, Li, has a skin condition. The mother, Mai, has normal skin.
- Li and Mai's first child, a girl named Gemma, has the same skin condition as Li.
- Mai's sister has a similar skin condition, but Mai's parents do not.
- Li has one brother whose skin is normal, and one sister who has the skin condition.
- Li's mother has the skin condition. His father does not.
- Li's family lives in a heavily wooded area. His family has always thought the skin condition was a type of allergy.

5. Now use the cards to figure out what genotypes Joshua and Bella must have. Write their genotypes next to their symbols in the pedigree.
6. Work with the cards to figure out the genotypes of all other family members. Fill in each person's genotype next to his or her symbol in the pedigree. If more than one genotype is possible, write in both genotypes.

Part 2 Investigating Case Study 2

7. Read over Case Study 2.
8. You suspect that Gemma and Li's skin condition is caused by an inherited recessive allele. Begin to investigate this possibility by drawing a family pedigree in your notebook. Use shading to indicate which individuals have the skin condition.
9. Fill in the genotype *ss* beside each individual who has the skin condition. Then use cards as you did in Case Study 1 to figure out each family member's genotype. If more than one genotype is possible, fill in both genotypes.

Analyze and Conclude

1. In Case Study 1, what were the genotypes of Joshua's parents? What were the genotypes of Bella's parents?
2. In Case Study 1, Joshua also has a brother. What is the probability that he has cystic fibrosis? Explain.
3. Can you conclude that the skin condition in Case Study 2 is most likely an inherited trait controlled by a recessive allele? Explain.
4. What is the probability that Mai and Li's next child will have the skin condition? Explain.
5. **Apply** Why do genetic counselors need information about many generations of a family in order to draw conclusions about a hereditary condition?

More to Explore

Review the two pedigrees that you just studied. What data suggests that the traits are not sex-linked? Explain.

SECTION 3 Advances in Genetics

DISCOVER ACTIVITY

What Do Fingerprints Reveal?

1. Label a sheet of paper with your name. Then roll one of your fingers from side to side on an ink pad. Make a fingerprint by carefully rolling your inked finger from side to side on the paper.
2. Divide into groups. Each group should choose one member to use the same finger to make a second fingerprint on a sheet of paper. Leave the paper unlabeled.
3. Exchange your group's fingerprints with those from another group. Compare each labeled fingerprint with the fingerprint on the unlabeled paper. Decide whose fingerprint it is.
4. Wash your hands after completing this activity.

Think It Over

Observing Why are fingerprints a useful tool for identifying people?

GUIDE FOR READING

- What are three ways in which an organism's traits can be altered?
- What is the goal of the Human Genome Project?

Reading Tip As you read, make a concept map of the methods used to produce organisms with desirable traits. Include at least one example of each technique.

In the summer of 1996, a lamb named Dolly was born in Scotland. Dolly was an ordinary lamb in every way except one. The fertilized cell that developed into Dolly was produced in a laboratory by geneticists using experimental techniques. You will learn more about the techniques used by the geneticists later in the section.

Although the techniques used to create Dolly are new, the idea of producing organisms with specific traits is not. For thousands of years, people have tried to produce plants and animals with desirable traits. **Three methods that people have used to develop organisms with desirable traits are selective breeding, cloning, and genetic engineering.**

Dolly

Selective Breeding

More than 5,000 years ago, people living in what is now central Mexico discovered that a type of wild grass could be used as food. They saved the seeds from those plants that produced the best food, and planted them to grow new plants. By repeating this process over many generations of plants, they developed an early variety of the food crop we now call corn. The process of selecting a few organisms with desired traits to serve as parents of the next generation is called **selective breeding.**

People have used selective breeding with many different plants and animals. Breeding programs usually focus on increasing the value of the plant or animal to people. For

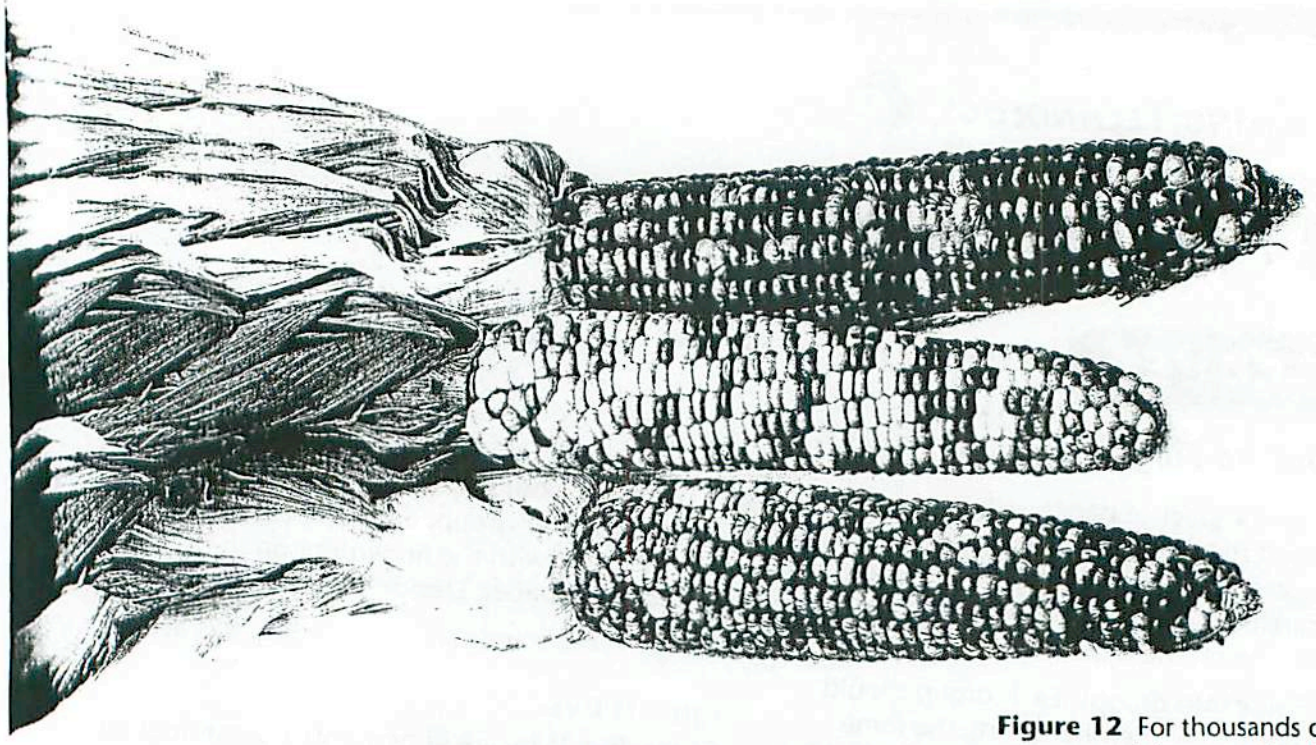


Figure 12 For thousands of years, people have used selective breeding to produce plants and animals with desirable traits. *Making Generalizations What are some traits for which corn may be bred?*

example, dairy cows are bred to produce larger quantities of milk. Many varieties of fruits and vegetables are bred to resist diseases and insect pests.

Inbreeding One useful selective breeding technique is called inbreeding. **Inbreeding** involves crossing two individuals that have identical or similar sets of alleles. The organisms that result from inbreeding have alleles that are very similar to those of their parents. Mendel used inbreeding to produce purebred pea plants for his experiments.

One goal of inbreeding is to produce breeds of animals with specific traits. For example, by only crossing horses with exceptional speed, breeders can produce purebred horses that can run very fast. Purebred dogs, such as Labrador retrievers and German shepherds, were produced by inbreeding.

Unfortunately, because inbred organisms are genetically very similar, inbreeding reduces an offspring's chances of inheriting new allele combinations. Inbreeding also increases the probability that organisms may inherit alleles that lead to genetic disorders. For example, inherited hip problems are common in many breeds of dogs.

Hybridization Another selective breeding technique is called hybridization. In **hybridization** (hy brid ih ZAY shun), breeders cross two genetically different individuals. The hybrid organism that results is bred to have the best traits from both parents. For example, a farmer might cross corn that produces many kernels with corn that is resistant to disease. The result might be a hybrid corn plant with both of the desired traits. Today, most crops grown on farms and in gardens were produced by hybridization.

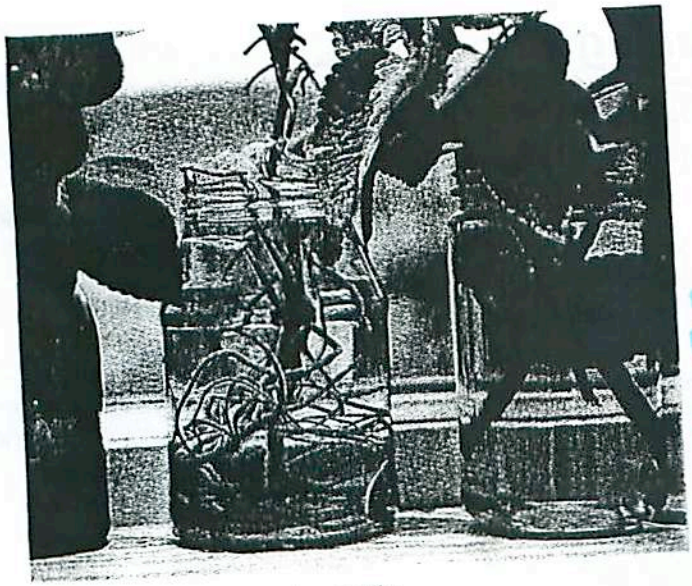


Figure 13 Plants can be easily cloned by making a cutting. Once the cutting has grown roots, it can be planted and will grow into a new plant. ***Applying Concepts*** *Why is the new plant considered to be a clone of the original plant?*

Cloning

One problem with selective breeding is that the breeder cannot control whether the desired allele will be passed from the parent to its offspring. This is because the transmission of alleles is determined by probability, as you learned in Chapter 3. For some organisms, another technique, called cloning, can be used to produce offspring with desired traits. A **clone** is an organism that is genetically identical to the organism from which it was produced. This means that a clone has exactly the same genes as the organism from which it was produced. Cloning can be done in plants and animals, as well as other organisms.

Cloning Plants One way to produce a clone of a plant is through a cutting. A cutting is a small part of a plant, such as a leaf or a stem, that is cut from the plant. The cutting can grow into an entire new plant. The new plant is genetically identical to the plant from which the cutting was taken.

Cloning Animals Producing a clone of an animal is much more difficult than producing a clone of a plant. It isn't possible to use a cutting from a cow to produce a new cow. However, scientists have been experimenting with various techniques to produce clones of animals. Remember Dolly, the lamb described at the beginning of this section? Dolly was the first clone of an adult mammal ever produced.

To create Dolly, researchers first removed an egg cell from one sheep. The cell's nucleus was replaced with the nucleus from a cell of a six-year-old sheep. The egg was then implanted into the uterus of a third sheep. Five months later, Dolly was born. Dolly is genetically identical to the six-year-old sheep that supplied the cell nucleus. Dolly is a clone of that sheep.

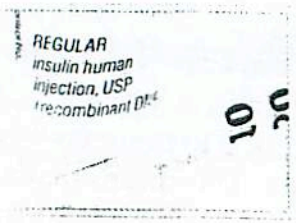
☑ ***Checkpoint*** *How can a clone of a plant be produced?*

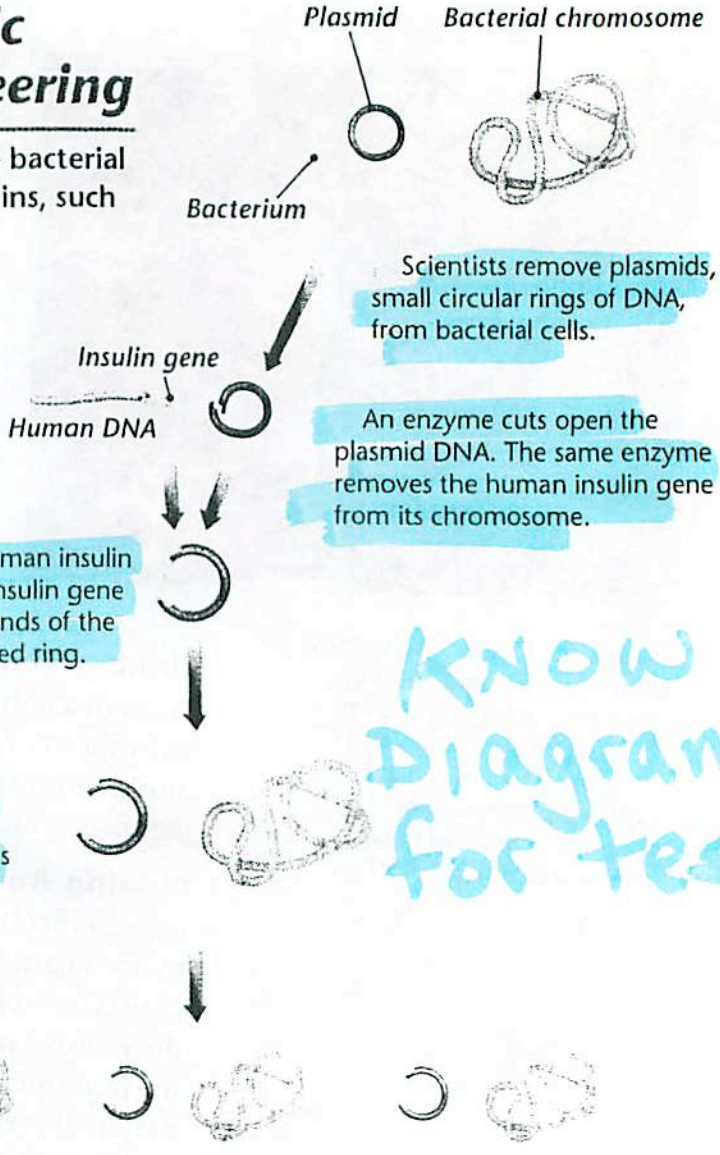
Genetic Engineering

In the past few decades, geneticists have developed another pow
erful technique for producing organisms with desired traits. In thi
process, called **genetic engineering**, genes from one organism ar
transferred into the DNA of another organism. Genetic enginee
ing is sometimes called "gene splicing" because a DNA molecule
cut open and a gene from another organism is spliced into i
Researchers use genetic engineering to produce medicines, t
improve food crops, and to try to cure human genetic disorders.

EXPLORING Genetic Engineering

Scientists use genetic engineering to create bacterial cells that produce important human proteins, such as insulin.





know Diagram for test!

Genetic Engineering in Bacteria Researchers had their first successes with genetic engineering when they inserted DNA from other organisms into bacteria. Recall that the single DNA molecule of bacterial cells is found in the cytoplasm. Some bacterial cells also contain small circular pieces of DNA called plasmids.

In *Exploring Genetic Engineering*, you can see how scientists insert a human gene into the plasmid of a bacterium. Once the DNA is spliced into the plasmid, the bacterial cell and all its offspring will contain this human gene. As a result, the bacteria produce the protein that the human gene codes for, in this case insulin. Because bacteria reproduce quickly, large amounts of insulin can be produced in a short time. The insulin can be collected and used to treat people with diabetes, a disorder in which the body does not produce enough of this protein.

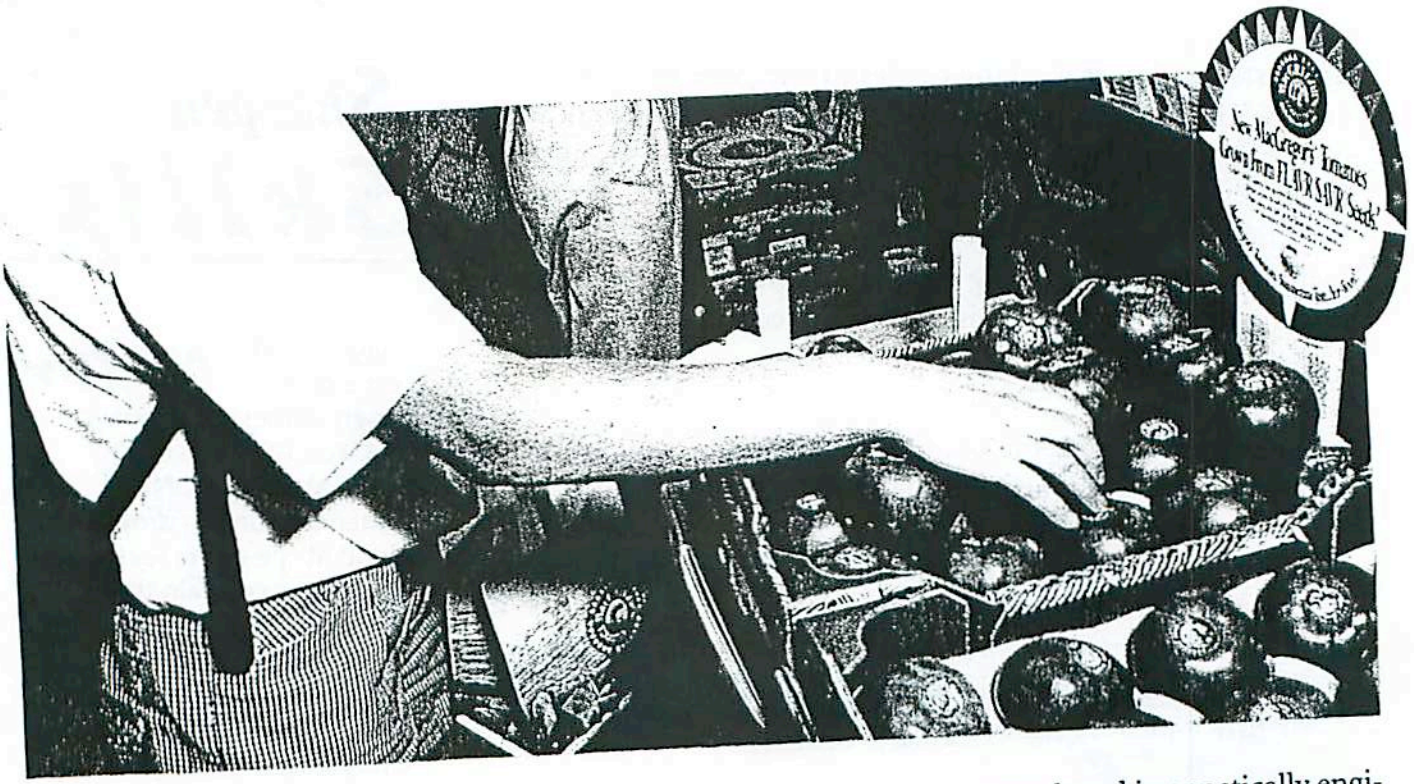


Figure 14 Scientists created this new variety of tomatoes using genetic engineering. The tomatoes taste better and keep longer than other varieties. *Making Judgments What other traits would be desirable in tomatoes?*

Today, many human proteins are produced in genetically engineered bacteria. For example, human growth hormone is a protein that controls the growth process in children. Children whose bodies do not produce enough human growth hormone can be given injections of the hormone. Today, an unlimited supply of the hormone exists, thanks to genetically engineered bacteria.

Genetic Engineering in Other Organisms Genetic engineering has also been used to insert genes into the cells of other organisms. Scientists have inserted genes from bacteria into the cells of tomatoes, wheat, rice, and other important crops. Some of the genes enable the plants to survive in colder temperatures or in poor soil conditions, and to resist insect pests.

Genetic engineering techniques can also be used to insert genes into animals, which then produce important medicines for humans. For example, scientists can insert human genes into the cells of cows. The cows then produce the human protein for which the gene codes. Scientists have used this technique to produce the blood clotting protein needed by people with hemophilia. The protein is produced in the cows' milk, and can easily be extracted and used to treat people with the disorder.

Gene Therapy Researchers are also using genetic engineering to try to correct some genetic disorders. This process, called **gene therapy**, involves inserting working copies of a gene directly into the cells of a person with a genetic disorder. For example, people with cystic fibrosis do not produce a protein that is needed for proper lung function. Both copies of the gene that codes for the protein are defective in these people

Scientists can insert working copies of the gene into harmless viruses. The "engineered" viruses can then be sprayed into the lungs of patients with cystic fibrosis. The researchers hope that the working copies of the gene in the viruses will function in the patient to produce the protein. Gene therapy is still an experimental method for treating genetic disorders. Researchers are working hard to improve this promising technique.

In courtrooms across the country, a genetic technique called DNA fingerprinting is being used to help solve crimes. If you did the Discover activity, you know that fingerprints can help to identify people. No two people have the same fingerprints. Detectives routinely use fingerprints found at a crime scene to help identify the person who committed the crime. In a similar way, DNA from samples of hair, skin, and blood can also be used to identify a person. No two people, except for identical twins, have the same DNA.

In DNA fingerprinting, enzymes are used to cut the DNA in the sample found at a crime scene into fragments. An electrical current then separates the fragments by size to form a pattern of bands, like the ones you see in Figure 15. Each person's pattern of DNA bands is unique. The DNA pattern can then be compared to the pattern produced by DNA taken from people suspected of committing the crime.

Checkpoint *In what way is DNA like fingerprints?*

Sharpen Skills

ACTIVITY

Imagine that you are an expert witness at a murder trial. You will be called to testify about the DNA evidence found in drops of blood at the crime scene. You will need to explain the process of DNA fingerprinting to the jury. Write a paragraph describing what you would say. How would you convince a jury that DNA fingerprinting is a reliable technique?

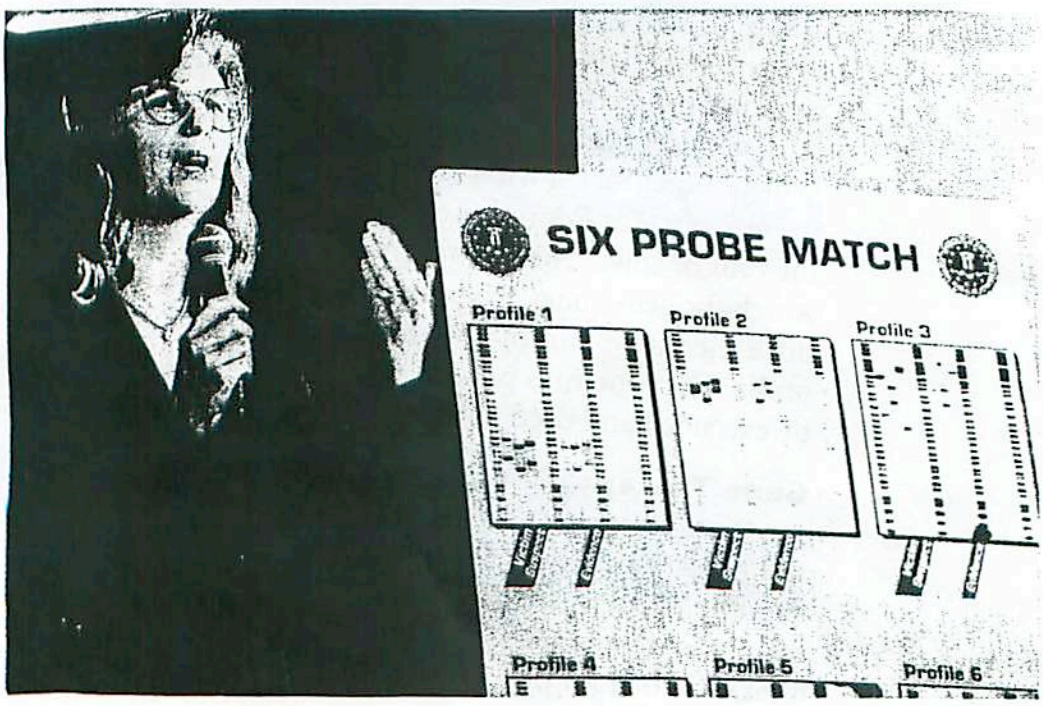


Figure 15 This scientist is explaining how DNA fingerprinting can be used to help solve crimes. DNA from blood or other substances collected at a crime scene can be compared to DNA from a suspect's blood.

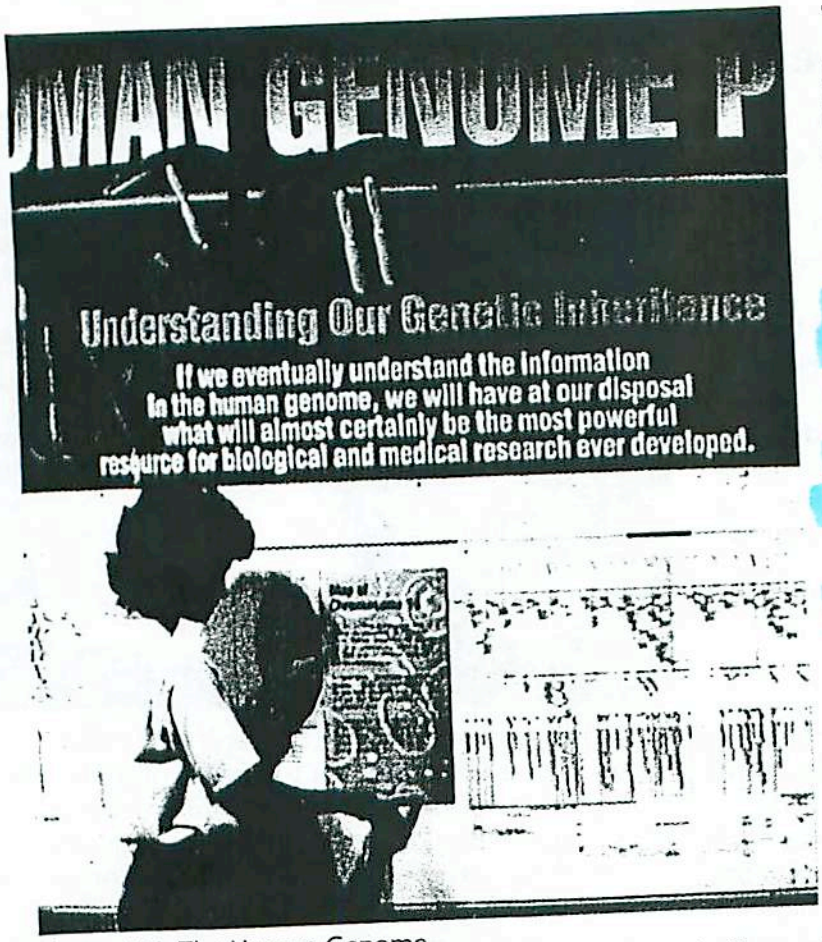


Figure 16 The Human Genome Project is an attempt to identify the sequence of every DNA base pair in the human genome.

The Human Genome Project

Imagine trying to crack a code that is 3 billion characters long. Then imagine working with people all over the world to accomplish this task. That's exactly what scientists working on the Human Genome Project are doing. A **genome** is all the DNA in one cell of an organism. Researchers estimate that the 23 pairs of chromosomes that make up the human genome contain about 60,000 to 80,000 genes—or about 3 billion DNA base pairs.

The main goal of the Human Genome Project is to identify the DNA sequence of every gene in the human genome. When the Human Genome Project is completed, an encyclopedia of genetic information about humans will be available. Scientists will know the DNA sequence of every human gene, and thus the amino acid sequence of every protein.

With the information from the Human Genome Project, researchers may gain a better understanding of how humans develop from a fertilized egg to an adult. They may also learn what makes the body work, and what causes things to go wrong. New understandings may lead to new treatments and prevention strategies for many genetic disorders and for diseases such as cancer.

Section 3 Review

1. Name three techniques that people have used to produce organisms with desired traits.
2. Why do scientists want to identify the DNA sequence of every human gene?
3. What is genetic engineering? Describe three possible benefits of this technique.
4. Explain how a DNA fingerprint is produced. What information can a DNA fingerprint reveal?
5. **Thinking Critically Making Judgments** Do you think there should be any limitations on genetic engineering? Give reasons to support your position.

Science at Home

Grocery Genetics With a parent or other adult family member, go to a grocery store. Look at the different varieties of potatoes, apples, and other fruits and vegetables. Discuss how these varieties were created by selective breeding. Then choose one type of fruit or vegetable and make a list of different varieties. If possible, find out what traits each variety was bred for.

Who Should Have Access to Genetic Test Results?

Scientists working on the Human Genome Project have identified many alleles that put people at risk for certain diseases, such as breast cancer and Alzheimer's disease. Through techniques known as genetic testing, people can have their DNA analyzed to find out whether they have any of these alleles. If they do, they may be able to take steps to prevent the illness or to seek early treatment.

Some health insurance companies and employers want access to this type of genetic information. However, many people believe that genetic testing results should be kept private.

The Issues

Health insurance companies set their rates based on a person's risk of health problems. To determine a person's insurance rate, insurance companies often require that a person have a physical examination. If the examination reveals a condition such as high blood pressure, the company may charge that person more for an insurance policy. This is because he or she would be more likely to need expensive medical care.

Insurance companies view genetic testing as an additional way to gather information about a person's health status. Insurers argue that if they were unable to gather this information, they would need to raise rates for everyone. This would be unfair to people who are in good health.

Federal laws forbid employers with 15 or more workers from choosing job applicants based on their health status. These laws do not apply to smaller companies, however. Employers may not want to hire employees with health problems because they often miss more work time than other employees. In addition, employers who hire people with health problems may be charged higher health insurance rates. Many small companies cannot afford to pay these higher rates.

Some people think that the government should prohibit all access to genetic information. Today, some people fear that they will be discriminated against as a result of genetic test results. Because of this fear, some people avoid genetic testing—even though testing might allow them to seek early treatment for a disorder. These people want tighter control of genetic information. They want to be sure that insurers and employers will not have access to genetic test results.

You Decide

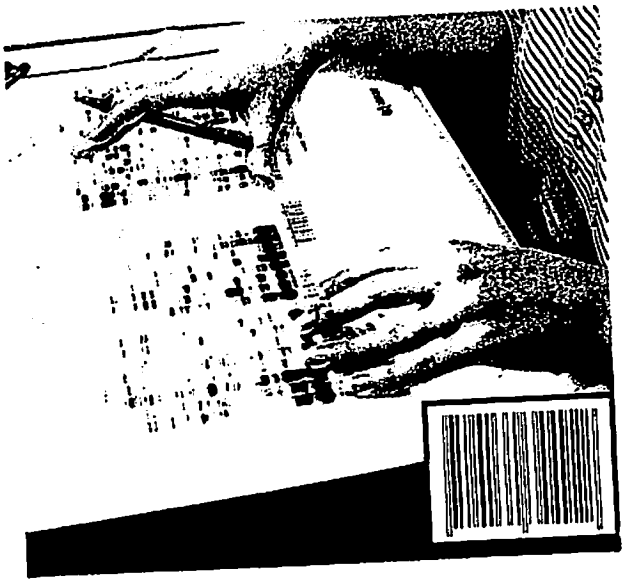
1. **Identify the Problem**
   In your own words, explain the problem of deciding who should have access to genetic test results.
2. **Analyze the Options**
   Examine the pros and cons of keeping genetic test results private. List reasons to maintain privacy. List reasons why test results should be shared.
3. **Find a Solution**
   Create a list of rules to control access to genetic information. Who should have access, and under what circumstances? Explain your reasoning.

Real-World Lab

You Solve the Mystery

Guilty or Innocent?

In this lab, you will investigate how DNA fingerprinting can be used to provide evidence related to a crime.



Problem

How can DNA be used to identify individuals?

Skills Focus

observing, making models, drawing conclusions

Materials

4–6 bar codes

Procedure

1. Look at the photograph of DNA band patterns shown at right. Each person's DNA produces a unique pattern of these bands.
2. Now look at the Universal Product Code, also called a bar code, shown below the DNA bands. A bar code can be used as a model of a DNA band pattern. Compare the bar code with the DNA bands to see what they have in common. Record your observations.
3. Suppose that a burglary has taken place, and you're the detective leading the investigation. Your teacher will give you a bar code that represents DNA from blood found at the crime scene. You arrange to have DNA samples taken from several suspects. Write a sentence describing what you will look for as you try to match each suspect's DNA to the DNA sample from the crime scene.
4. You will now be given bar codes representing DNA samples taken from the suspects. Compare those bar codes with the bar code that represents DNA from the crime scene.
5. Use your comparisons to determine whether any of the suspects was present at the crime scene.

Analyze and Conclude

1. Based on your findings, were any of the suspects present at the crime scene? Support your conclusion with specific evidence.
2. Why do people's DNA patterns differ so greatly?
3. How would your conclusions be affected if you learned that the suspect whose DNA matched the evidence had an identical twin?
4. **Apply** In everyday life, do you think that DNA evidence is enough to determine that a suspect committed the crime? Explain.

More to Explore

Do you think the DNA fingerprints of a parent and a child would show any similarities? Draw what you think they would look like. *Then explain your* thinking.

CHAPTER 4 STUDY GUIDE

SECTION 1 Human Inheritance

Key Ideas

Some human traits are controlled by a single gene that has multiple alleles—three or more forms.

Some human traits show a wide range of phenotypes because these traits are controlled by many genes. The genes act together as a group to produce a single trait.

Traits are often influenced by the organism's environment.

Males have one X chromosome and one Y chromosome. Females have two X chromosomes. Males are more likely than females to have a sex-linked trait controlled by a recessive allele.

Geneticists use pedigrees to trace the inheritance pattern of a particular trait through a number of generations of a family.

Key Terms

multiple alleles
sex-linked gene
carrier
pedigree

SECTION 2 Human Genetic Disorders

Key Ideas

Genetic disorders are abnormal conditions that are caused by mutations, or DNA changes, in genes or chromosomes.

Common genetic disorders include cystic fibrosis, sickle-cell disease, hemophilia, and Down syndrome.

Amniocentesis and karyotypes are tools used to diagnose genetic disorders.

Genetic counselors help couples understand their chances of having a child with a genetic disorder.

Key Terms

genetic disorder
amniocentesis
karyotype

SECTION 3 Advances in Genetics

Integrating Technology

Key Ideas

Selective breeding is the process of selecting a few organisms with desired traits to serve as parents of the next generation.

Cloning is a technique used to produce genetically identical organisms.

Genetic engineering can be used to produce medicines and to improve food crops.

Researchers are also using genetic engineering to try to cure human genetic disorders.

DNA fingerprinting can be used to help determine whether material found at a crime scene came from a particular suspect.

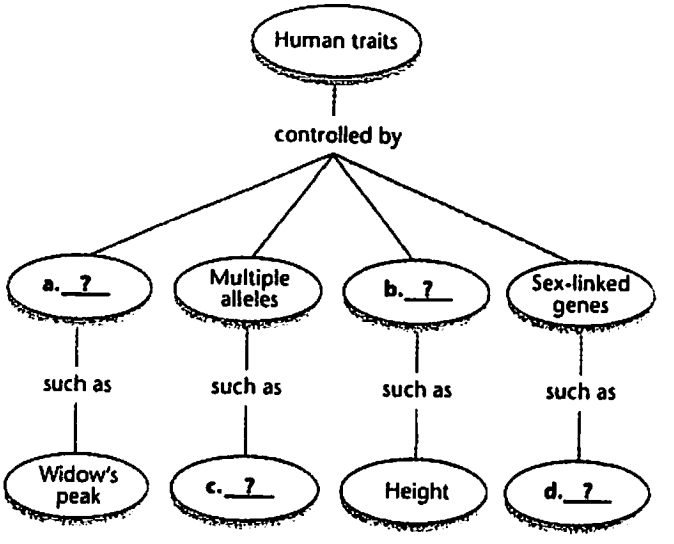
The goal of the Human Genome Project is to identify the DNA sequence of every gene in the human genome.

Key Terms

selective breeding
inbreeding
hybridization
clone
genetic engineering
gene therapy
genome

Organizing Information

Concept Map Copy the concept map about human traits onto a separate sheet of paper. Then complete it and add a title. (For more on concept maps, see the Skills Handbook.)



CHAPTER 4 ASSESSMENT

Reviewing Content

Multiple Choice

Choose the letter of the best answer.

1. A human trait that is controlled by multiple alleles is
   a. dimples. b. blood type.
   c. height. d. skin color.
2. A genetic disorder caused by a sex-linked gene is
   a. cystic fibrosis.
   b. sickle-cell disease.
   c. hemophilia.
   d. Down syndrome.
3. Sickle-cell disease is characterized by
   a. abnormally shaped red blood cells.
   b. abnormally thick body fluids.
   c. abnormal blood clotting.
   d. an extra copy of chromosome 21.
4. Inserting a human gene into a bacterial plasmid is an example of
   a. inbreeding.
   b. selective breeding.
   c. DNA fingerprinting.
   d. genetic engineering.
5. DNA fingerprinting is a way to
   a. clone organisms.
   b. breed organisms with desirable traits.
   c. identify people.
   d. map and sequence human genes.

True or False

If the statement is true, write true. If it is false, change the underlined word or words to make the statement true.

6. A widow's peak is a human trait that is controlled by a single gene.
7. A person who inherits two X chromosomes will be male.
8. A karyotype is a chart that shows the relationships between the generations of a family.
9. Hybridization is the crossing of two genetically similar organisms.
10. A clone is an organism that is genetically identical to another organism.

Checking Concepts

11. Explain how both genes and the environment determine how tall a person will be.
12. Explain why traits controlled by recessive alleles on the X chromosome are more common in males than in females.
13. What is sickle-cell disease? How is this disorder inherited?
14. How can amniocentesis be used to detect a disorder such as Down syndrome?
15. Explain how a horse breeder might use selective breeding to produce horses that have golden coats.
16. Describe how gene therapy might be used in the future to treat a person with hemophilia.
17. **Writing to Learn** As the webmaster for a national genetics foundation, you must create a Web site to inform the public about genetic disorders. Choose one human genetic disorder discussed in this chapter. Write a description of the disorder that you will use for the Web site.

Thinking Critically

18. **Applying Concepts** Why can a person be a carrier of a trait caused by a recessive allele but not of a trait caused by a dominant allele?
19. **Problem Solving** A woman with norm color vision has a colorblind daughter. What are the genotypes and phenotypes both parents?
20. **Calculating** If a mother is a carrier of hemophilia, what is the probability that son will have the trait? Explain your answer.
21. **Inferring** How could ancient people selectively breed corn if they didn't kno about genes and inheritance?
22. **Comparing and Contrasting** How selective breeding and genetic engineeri different? How are they similar?

Applying Skills

Use the information below to answer Questions 23–25.

- Bob and Helen have three children.
- Bob and Helen have one son who has albinism, an inherited condition in which the skin does not have brown pigments.
- Bob and Helen have two daughters who do not have albinism.
- Neither Bob nor Helen has albinism.
- Albinism is neither sex-linked nor codominant.

23. **Interpreting Data** Use the information to construct a pedigree. If you don't know whether someone is a carrier, leave their symbol empty. If you decide later that a person is a carrier, change your pedigree.

24. **Drawing Conclusions** Is albinism controlled by a dominant allele or by a recessive allele? Explain your answer.

25. **Predicting** Suppose Bob and Helen were to have another child. What is the probability that the child will have albinism? Explain.

Performance Assessment — CHAPTER PROJECT

Present Your Project Before displaying your project, exchange it with another group to check each other's work. Make any necessary corrections, and then display your materials to the class. Be ready to explain the inheritance patterns shown in your pedigrees.

Reflect and Record In your journal, describe what you learned by creating the pedigrees. What questions do you have as a result of the project?

Test Preparation

Use these questions to prepare for standardized tests.

Use the information to answer Questions 26–29.

The Punnett square below shows how muscular dystrophy, a sex-linked recessive disorder, is inherited.

Key
X^M = normal allele
X^m = muscular dystrophy allele

Mother X^MX^m (carrier)	Father (normal) X^MY	
	X^M	Y
X^M	X^MX^M	X^MY
X^m	X^MX^m	X^mY

26. What is the probability that a daughter of these parents will have muscular dystrophy?
a. 0% b. 25%
c. 50% d. 100%

27. What is the probability that a son of these parents will have muscular dystrophy?
a. 0% b. 25%
c. 50% d. 100%

28. What is the probability that a daughter of these parents will be a carrier of the disease?
a. 0% b. 25%
c. 50% d. 100%

29. Which of the following statements is true of muscular dystrophy?
a. More men than women have muscular dystrophy.
b. More women than men have muscular dystrophy.
c. More men than women are carriers of muscular dystrophy.
d. No women can have muscular dystrophy.