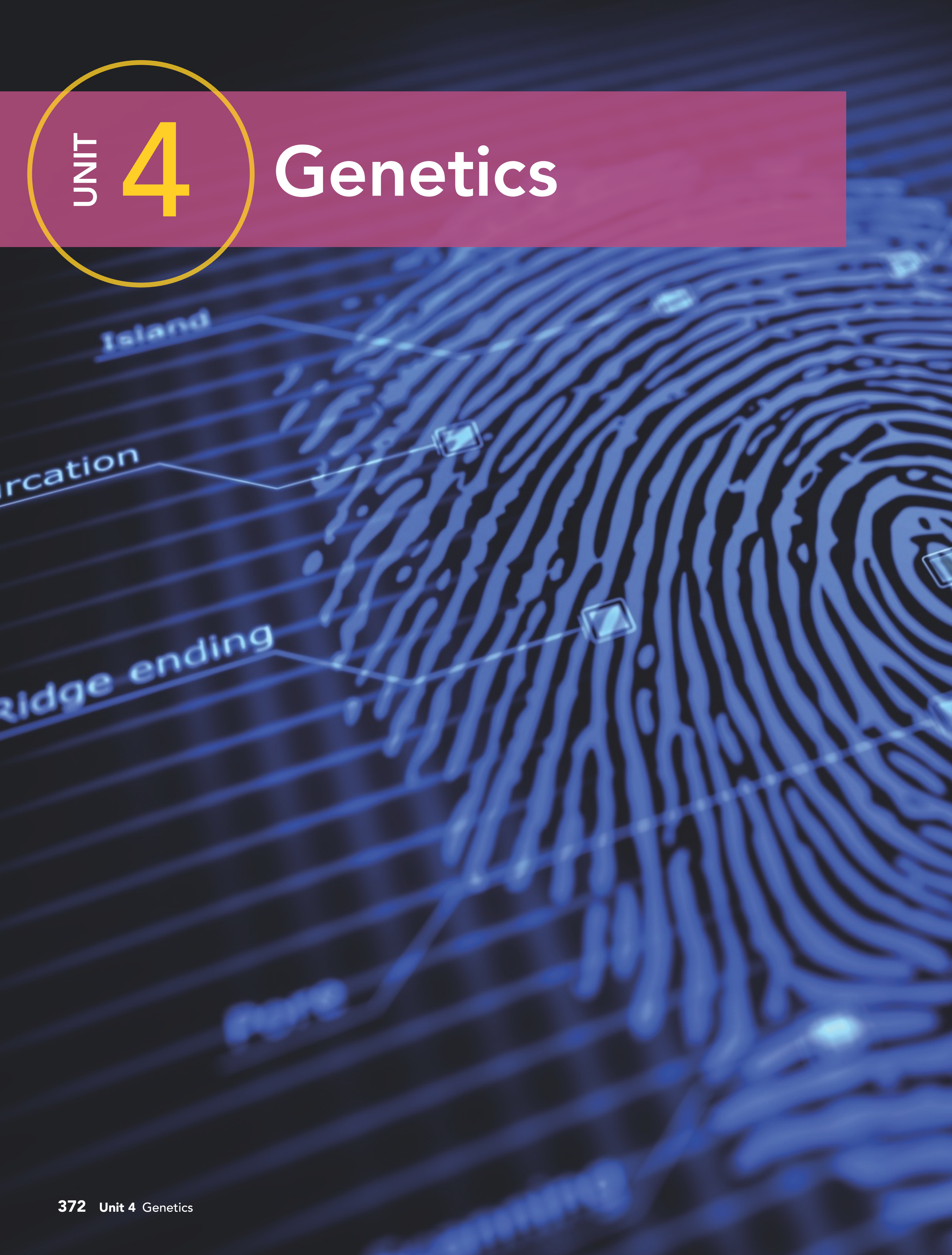
UNIT 4

Genetics



Fingerprint identification system

Crosscutting Concepts Cells are built from molecules, and none are more essential to life than DNA. The science of heredity began with experiments in a garden, and now touches every aspect of our lives, from the food we eat to medical care to personal identification. As a result, historians of the future may well call ours the golden age of biology.

BOUNCE TO ACTIVATE

VIDEO

Author Ken Miller talks about how studying patterns of inheritance can help explain how genes work.

UNIT 4 PROBLEM-BASED LEARNING

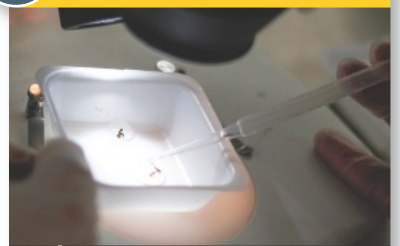
Genetic Modification

OF ANIMALS

Humans have a long history of breeding animals. Breeders choose parents that have useful traits, such as sheep with thick wool, or chickens that lay large eggs. Our familiar farm animals are the result of these efforts repeated over many generations. Now, however, scientists can use genetic technology to modify animals. New technologies can directly change the DNA of an animal, often by introducing genes from another organism. The technology raises ethical questions that are not easy to answer.

PROBLEM LAUNCH
Conduct research on a current or proposed genetically modified animal.

VIDEO



BOUNCE TO ACTIVATE

Watch a video about the current uses of genetically modified animals.

PROBLEM: For what purposes should humans genetically modify animals?

TO SOLVE THIS PROBLEM, perform these activities as they come up in the unit, and record your findings in your Explorer's Journal.

LAB INVESTIGATION
Model the inheritance of genetically modified traits from parents to offspring.

CLASS DISCUSSION
Discuss the structure of DNA and how it is similar and different among organisms.

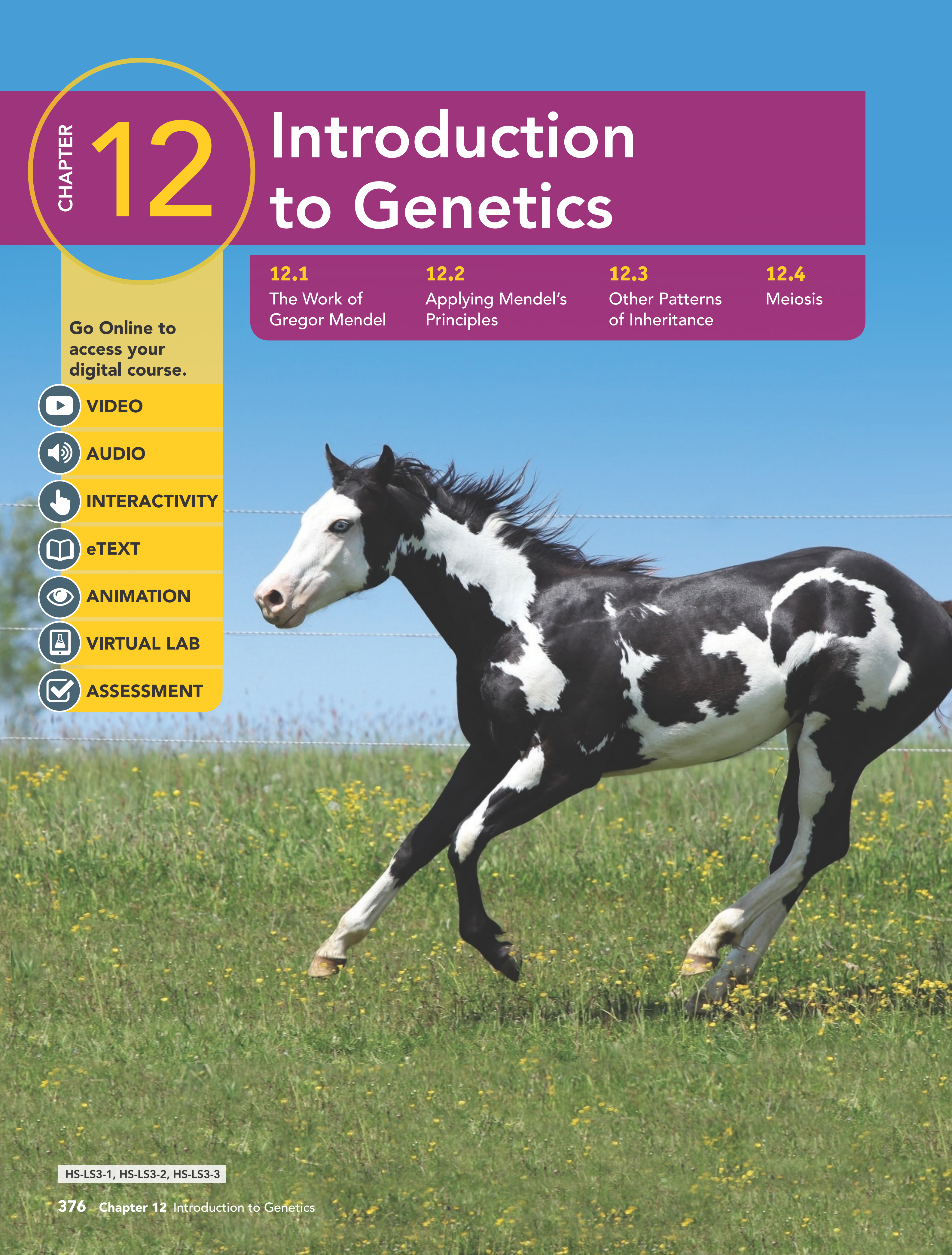
INTERACTIVITY
Investigate the science behind genetically modifying insect populations to help control the spread of disease.

INTERACTIVITY
Complete the steps to isolate, splice, and transfer a gene to genetically modify an animal.

AUTHENTIC READING
Read about scientists that are studying the mouse genome to better understand human diseases.

STEM PROJECT
Create a survey to gauge the opinions of your classmates or community members on specific uses of genetically modified animals.

PROBLEM WRAP-UP
Organize the results of your survey to create an opinion piece for the use of genetically modified animals.



CHAPTER 12

Introduction to Genetics

Go Online to access your digital course.

- VIDEO
- AUDIO
- INTERACTIVITY
- eTEXT
- ANIMATION
- VIRTUAL LAB
- ASSESSMENT

HS-LS3-1, HS-LS3-2, HS-LS3-3

CASE STUDY

Genetic disorders: understanding the odds

It should have been a perfect morning. There was excitement on the ranch over the birth of a new foal the night before. Both of his parents were champion paint horses bearing distinctive *frame overo* markings.

The overo coat pattern is beautiful, and highly valued. Overo horses look as if someone has splashed white paint on a solid-colored horse. In *frame overo* horses, it looks like the white spots have been framed by the horse's dark back and legs and the dark markings on the sides that separate the spots.

But when the veterinarian saw the white foal with blue eyes, she frowned. Her concern was not that the foal had failed to inherit his parents' pretty overo pattern. White horses with blue eyes can be perfectly healthy—but not when their parents are both *frame overos*.

The little colt's stark white color and blue eyes indicated he had been born with overo lethal white syndrome (OLWS). In foals with OLWS, the digestive system has failed to form properly. There is no way to treat this, and affected foals will die within a few days of being born.

Because their death is painful and unavoidable, foals with OLWS need to be euthanized. In fact, dying from OLWS is so painful that owners and veterinarians once euthanized any foals suspected of having OLWS.

This colt was actually the third foal from this mare and stallion pairing, and their first two offspring had been perfectly healthy. Why had this one been born with such a serious problem?

Should the mare's owner try again to breed the mare with the same stallion? If so, what would be the odds of producing another foal with OLWS?

Meanwhile, a couple held their day-old baby girl in the soft fluorescent light of a local hospital ward. They were waiting for the results of a blood test that had been performed the day before. Even though both parents were healthy, their family histories had led their physician to suggest they be tested for a potentially lethal genetic disorder known as cystic fibrosis (CF). Sure enough, they both carried a gene that might put their child at risk of the disorder, and were told their baby's chances of having CF would be one in four. Today they would learn the results of the baby's blood test.

Their pediatrician opened the door with the test report tucked under his arm. They held their breath. The doctor told them that their baby did not have cystic fibrosis. However, he cautioned them that any future children would still be at risk.

What causes disorders like OLWS and CF? How are they passed from parent to child? And how can an adult be perfectly healthy and still have a child with an inherited disorder?

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

LESSON

12.1 The Work of Gregor Mendel

Gregor Mendel and a pea plant

KEY QUESTIONS

- *Where does an organism get its unique characteristics?*
- *How are different forms of a gene distributed to offspring?*

HS-LS3-3: Apply concepts of statistics and probability to explain the variation and distribution of expressed traits in a population.

VOCABULARY

genetics
fertilization
trait
hybrid
gene
allele
principle of dominance
segregation
gamete

READING TOOL

Identify the sequence of events that influenced Mendel's conclusions about genetics. Fill in the graphic organizer in your **Biology Foundations Workbook.**

What is an inheritance? It might be money or property left by relatives who have passed away. That kind of inheritance matters, of course, but there is another kind that matters even more. It is something we each receive from our parents—a contribution that determines our blood type, the color of our eyes and hair, and so much more. This is the biological form of inheritance we call genetics.

Mendel's Experiments

Every living thing—plant or animal, microbe or human being—has a set of characteristics inherited from its parent or parents. Since the beginning of recorded history, people have wanted to understand how inheritance is passed from generation to generation. The scientific study of biological inheritance is called **genetics**.

The modern science of genetics began with the work of an Austrian scientist and priest named Gregor Mendel, who is shown above. Mendel was born in 1822 in what is now the Czech Republic. After studying science and mathematics at the University of Vienna, he spent the next 14 years working in a monastery and teaching local students. In addition to his teaching duties, Mendel was in charge of the monastery garden. In this simple garden, he was to do the work that changed biology forever.

Mendel carried out his work with ordinary garden peas, partly because peas are small, easy to grow, and can produce hundreds of offspring. Today, we would say that Mendel used peas as a "model system," an organism that is convenient to study and may help us learn about other species, including humans. By using peas, Mendel was able to carry out, in just one or two growing seasons, experiments that would have been impossible to do with humans and would have taken years—if not decades—with other organisms.

The Role of Fertilization Mendel knew that part of each flower produces pollen grains containing the male reproductive cells, or sperm. Similarly, he knew that the female portion of each flower produces reproductive cells called eggs. During sexual reproduction, male and female reproductive cells join in a process known as **fertilization** to produce a new cell. In peas, this new cell develops into a tiny embryo encased within a seed.

Pea flowers are normally mostly self-pollinating, which means that sperm fertilize egg cells from within the same flower. A plant grown from a seed produced by self-pollination inherits all of its characteristics from the single plant that bore it; it has a single parent.

Mendel's monastery garden had several stocks of pea plants. These plants were "true breeding," meaning that they were self-pollinating, and produced offspring with traits identical to themselves. A **trait** is a specific characteristic, like seed color or plant height. One stock of Mendel's seeds produced only tall plants, while another produced only short ones. One produced only green seeds, another produced only yellow seeds.

To learn how these traits were determined, Mendel decided to "cross" his stocks of true-breeding plants—that is, he caused one plant to reproduce with another plant. To do this, he prevented self-pollination by cutting away the pollen-bearing male parts of a flower. He then dusted pollen from a different plant onto the female part of that flower, as shown in **Figure 12-1**. This process, known as cross-pollination, allowed Mendel to cross plants with different traits and then study the results.

Mendel examined seven different traits of pea plants. Each of these seven traits had two contrasting characteristics, such as green or yellow pod color. Mendel crossed plants with each of the seven contrasting characteristics and then studied their offspring. The offspring of crosses between parents with different contrasting characteristics are called **hybrids**.

BUILD VOCABULARY

Multiple Meanings The word *hybrid* is often used to describe anything that combines two or more parts or ideas. In genetics, the parts are the characteristics of organisms.

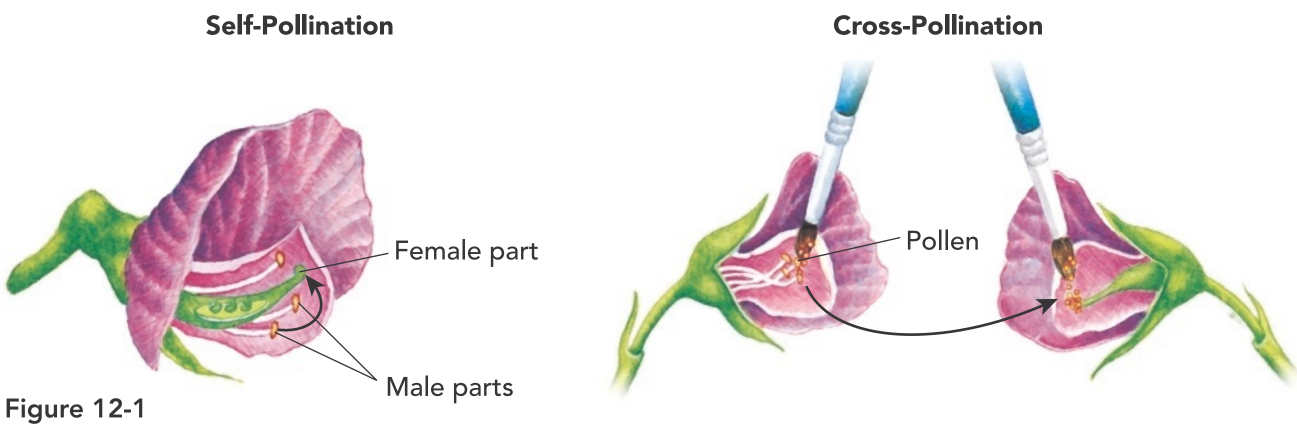


Figure 12-1

Pollination in Pea Plants

Pea plants are usually self-pollinating, which means that the sperm cells fertilize the egg cells within the same flower. To cross-pollinate pea plants, Mendel cut off the male parts of one flower and then dusted the female part with the pollen from another flower.

Mendel's Seven F_1 Crosses on Pea Plants

	Seed Shape	Seed Color	Flower Color	Pod Shape	Pod Color	Flower Position	Plant Height
P	Round × Wrinkled	Yellow × Green	Purple × White	Smooth × Constricted	Green × Yellow	Axial × Terminal	Tall × Short
F_1	Round	Yellow	Purple	Smooth	Green	Axial	Tall

Figure 12-2

Mendel's F_1 Crosses

When Mendel crossed plants with contrasting traits, the resulting hybrids had the traits of only one of the parents.

INTERACTIVITY

Explore Mendel's experiments on pea plants and the conclusions he reached.

Genes and Alleles When doing genetic crosses, we call the original pair of plants the P, or parental, generation. Their offspring are called the F_1, or first filial, generation. (*Filius* and *filia* are the Latin words for "son" and "daughter.")

What were Mendel's F_1 hybrid plants like? To his surprise, for each trait studied, the offspring had the characteristics of only one of its parents, as shown in **Figure 12-2**. In each cross, the nature of the other parent, with regard to each trait, seemed to have disappeared. From these results, Mendel drew two conclusions. His first conclusion formed the basis of our current understanding of inheritance. ***An individual's characteristics are determined by factors that are passed from one parental generation to the next.*** Today we call these factors **genes**.

Each of the traits Mendel studied was controlled by a single gene that occurred in two contrasting varieties. These variations produced different expressions, or forms, of each trait. For example, one form of the gene for height produced tall plants and another form produced short plants. The different forms of a single gene are called **alleles** (uh LEELZ).

Dominant and Recessive Alleles Mendel's second conclusion is called the **principle of dominance**. This principle states that some alleles are dominant and others are recessive. An organism with both a dominant allele and a recessive allele for a particular trait will exhibit the dominant characteristic. For example, Mendel found that the allele for tall plants was dominant over the recessive allele for short plants. Likewise, the allele for green pods was dominant over the recessive allele for yellow pods.

READING CHECK **Explain** How did the results of the F_1 crosses influence Mendel's thinking?

Segregation

Mendel didn't just stop after crossing the parent plants, because he had another question: Had the recessive alleles simply disappeared, or were they still present in the new plants? To find out, he allowed all seven kinds of F_1 hybrids to self-pollinate. In effect, Mendel crossed the F_1 generation with itself to produce a F_2 (second filial) generation, as shown in **Figure 12-3**.

INTERACTIVITY

Discover how Mendel's ideas apply to the genetics of flies.

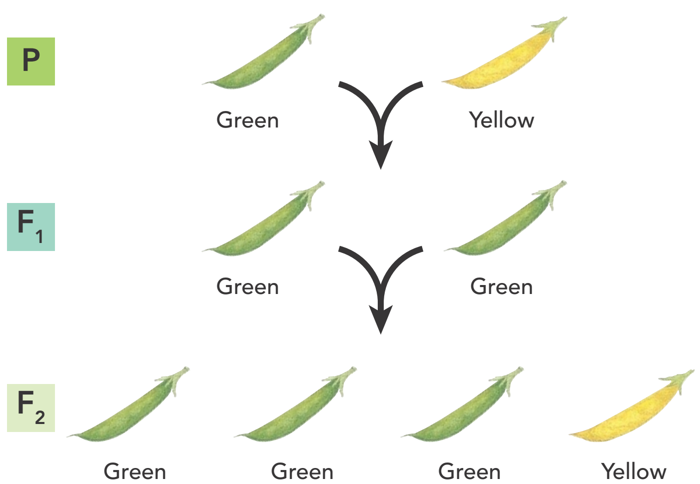
The F_1 Cross When Mendel examined the F_2 plants, he made a remarkable discovery: Traits produced by the recessive alleles reappeared in the second generation. Roughly one fourth of the F_2 plants showed the trait controlled by the recessive allele. Why, then, did the recessive alleles seem to disappear in the F_1 generation, only to reappear in the F_2 generation?

READING TOOL

As you read this section, identify the observation Mendel made about recessive traits. Then, describe the experimental results that explained his observation.

Explaining the F_1 Cross To begin with, Mendel assumed that a dominant allele had masked the corresponding recessive allele in the F_1 generation. However, the trait controlled by the recessive allele did show up in some of the F_2 plants. This reappearance indicated that, at some point, the allele for yellow pods had separated from the allele for green pods. How did this separation, or **segregation**, of alleles occur? Mendel suggested that the alleles for green pods and yellow pods in the F_1 plants must have segregated from each other during the formation of the reproductive cells, or **gametes** (GAM eetz). Did that suggestion make sense?

The Formation of Gametes Let's assume, as Mendel might have, that all the F_1 plants inherited an allele for green pods from the green parent and one for yellow pods from the yellow parent. Because the allele for green pods is dominant, all the F_1 plants have green pods. ***During gamete formation, the alleles for each gene segregate from each other, so that each gamete carries only one allele for each gene.*** Thus, each F_1 plant produces two kinds of gametes—those with the green pod allele and those with the yellow pod allele.



CASE STUDY

Figure 12-3

Results of the F_1 Cross

When Mendel allowed the F_1 plants to reproduce by self-pollination, the traits controlled by recessive alleles reappeared in about one fourth of the F_2 plants in each cross. **Infer** The allele responsible for cystic fibrosis is recessive. How are the inheritances of yellow pod color in peas and cystic fibrosis in humans similar to each other?

CASE STUDY

HS-LS3-3

Quick Lab — Guided Inquiry

Simulating Segregation

1. Create a data table with the column headings Trial Number, Results, and Phenotype.
2. With a partner, obtain one cup of beans labeled Parent 1 and one cup of beans labeled Parent 2. Each person will be responsible for one parental cup. Each cup contains a total of 30 beans: 15 red (*R*) and 15 white (*r*). The beans represent gametes.
3. At the same time as your partner, and without looking, pull out one bean from your cup. Record the gamete pulled from each cup (*R* or *r*) in your data table.
4. Return the beans to their original cups and repeat Step 2 of this procedure 14 times.

ANALYZE AND INTERPRET DATA

1. **Use Models** Determine whether each offspring is white or red. Then, calculate the percentage of offspring for each color. Assume red color is dominant.
2. **Refine Your Plan** How would you revise this investigation to simulate the crossing of two genes, each with two alleles?

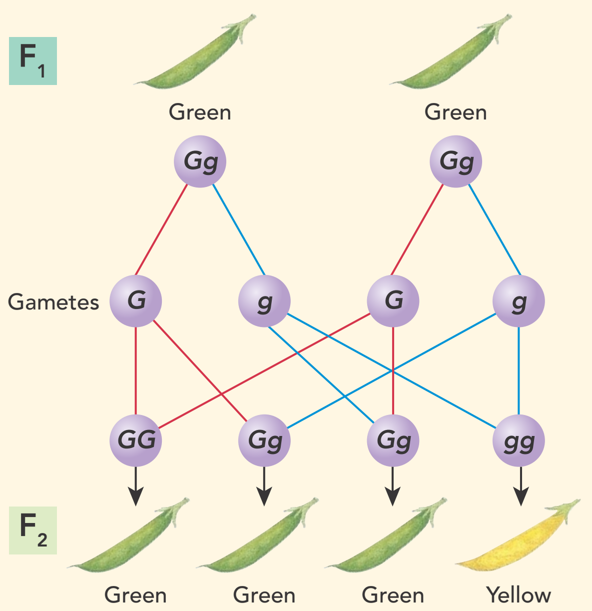
Look at **Figure 12-4** to see how alleles separate during gamete formation and then pair up again in the F_2 generation. A capital letter represents a dominant allele. A lowercase letter represents a recessive allele. Now we can see why the recessive trait for yellow pods, *g*, reappeared in Mendel's F_2 generation. Each F_1 plant in Mendel's cross produced two kinds of gametes—those with the allele for green pods and those with the allele for yellow pods. Whenever a gamete that carried the *g* allele paired with another gamete with the *g* allele to produce an F_2 plant, that plant had yellow pods. Every time one or both gametes of the pairing carried the *G* allele, a plant with green pods was produced. The genes of the F_1 plants had been reshuffled to produce new combinations of alleles.

INTERACTIVITY

Figure 12-4

Segregation

During gamete formation, alleles segregate from each other so that each gamete carries only a single copy of each gene.



HS-LS3-3

LESSON 12.1 Review

KEY QUESTIONS

1. What did Mendel conclude determines biological inheritance?
2. What is segregation?

CRITICAL THINKING

3. **Compare and Contrast** How is self-pollination similar to cross-pollination? How is it different?
4. **Infer** What evidence did Mendel use to explain how segregation occurs?
5. **Construct an Argument** In pea plants, the allele for tallness (*T*) is dominant over the allele for shortness (*t*). If two tall pea plants are crossed, can you predict the height of the offspring? Use logical reasoning to support your answer.

Applying Mendel's Principles

LESSON 12.2

KEY QUESTIONS

- *How can we use probability to predict traits?*
- *How do alleles segregate when more than one gene is involved?*
- *What did Mendel contribute to our understanding of genetics?*

HS-LS3-3: Apply concepts of statistics and probability to explain the variation and distribution of expressed traits in a population.

VOCABULARY

probability
homozygous
heterozygous
phenotype
genotype
Punnett square
independent assortment

READING TOOL

Before you read, preview **Figure 12-7** and try to infer the purpose of this diagram. After you read, revise your inference and answer the questions about punnett squares in your **Biology Foundations Workbook.**

Nothing in life is certain. There's a great deal of wisdom in that old saying, and genetics is a fine example. If a parent carries two different alleles for a certain gene, we can't be sure which of those alleles will be inherited by any one of the parent's offspring. However, think carefully about the nature of inheritance and you'll see that even if we can't predict the exact future, we can do something almost as useful—we can figure out the odds.

Probability and Heredity

Whenever Mendel performed a cross with pea plants, he carefully categorized and counted the offspring. Consequently, he had plenty of data to analyze. For example, whenever he crossed two plants that were hybrids for pod color (*Gg*), about three fourths of the resulting plants had green pods and about one fourth had yellow pods.

Upon analyzing his data, Mendel realized that the principles of probability could be used to explain the results of his genetic crosses. **Probability** is the likelihood that a particular event will occur. As an example, consider an ordinary event, such as flipping a coin. There are two possible outcomes of this event: The coin may land either heads up or tails up. The chance, or probability, of either outcome is equal. Therefore, the probability that a single coin flip will land heads up is 1 chance in 2. This amounts to $\frac{1}{2}$, or 50 percent.

If you flip a coin three times in a row, what is the probability that it will land heads up every time? Each coin flip is an independent event with a $\frac{1}{2}$ probability of landing heads up. Therefore, the probability of flipping three heads in a row is:

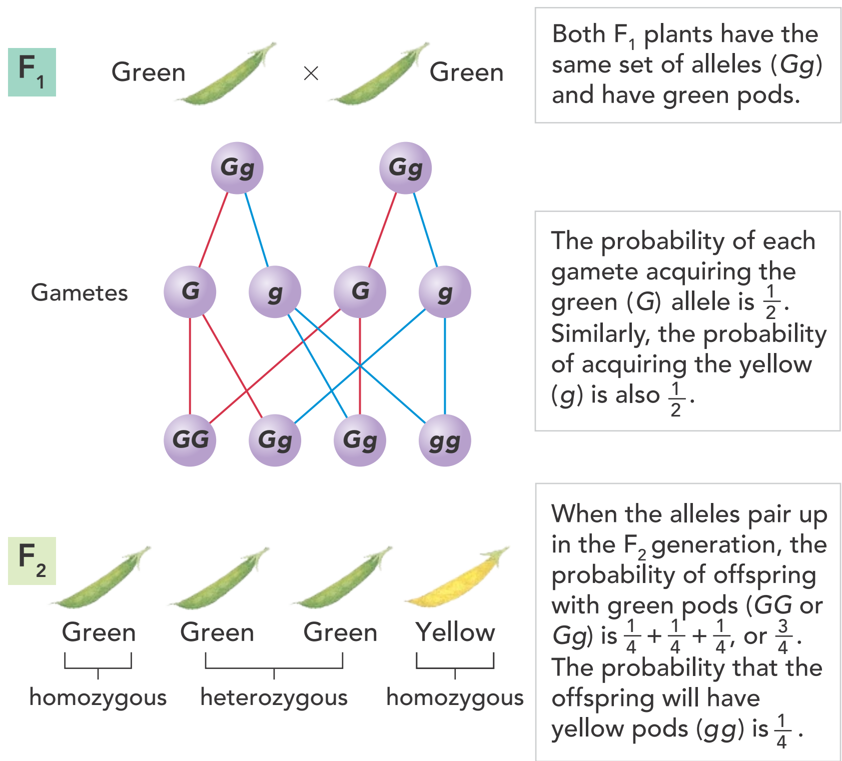
$$\frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} = \frac{1}{8}$$

CASE STUDY

Figure 12-5

Segregation and Probability

In this cross, the *GG* and *Gg* allele combinations produced three plants with green pods, while the *gg* allele combination produced one plant with yellow pods. These quantities follow the laws of probability. **Reason Quantitatively** What is the probability that an offspring from a hybrid cross has the recessive phenotype?



Using Segregation to Predict Outcomes

The way in which alleles segregate during gamete formation is every bit as random as a coin flip. Therefore, the principles of probability can be used to predict the outcomes of genetic crosses.

Look again at Mendel's F_1 cross, shown in **Figure 12-5**. This cross produced a mixture of plants with green and yellow pods. Each F_1 plant had one green pod allele and one yellow pod allele (*Gg*), so $\frac{1}{2}$ of the gametes produced by the plants would carry the yellow allele (*g*). Because the *g* allele is recessive, the only way to produce a plant with yellow pods (*gg*) is for two gametes, each carrying the *g* allele, to combine.

Like the coin toss, each F_2 gamete has a one in two, or $\frac{1}{2}$, chance of carrying the *g* allele. There are two gametes, so the probability of both gametes carrying the *g* allele is $\frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$. In other words, roughly one fourth of the F_2 offspring should have yellow pods, and the remaining three fourths should have green pods. This predicted ratio—3 offspring exhibiting the dominant trait to 1 offspring exhibiting the recessive trait—showed up consistently in Mendel's experiments. For each of his seven crosses, about $\frac{3}{4}$ of the plants showed the trait controlled by the dominant allele. About $\frac{1}{4}$ showed the trait controlled by the recessive allele. Segregation did occur according to Mendel's model.

As you can see in the F_2 generation, not all organisms with the same characteristics have the same alleles. Both the *GG* and *Gg* allele combinations resulted in green pea pods. Organisms that have two identical alleles for a particular gene—*GG* or *gg* in this example—are **homozygous**. Organisms that have two different alleles for the same gene—such as *Gg*—are **heterozygous**.

BUILD VOCABULARY

Prefixes The prefix *homo-* means "the same." The prefix *hetero-* means "different." The term **homozygous** refers to identical alleles for the same gene. The term **heterozygous** refers to two different alleles for the same gene.

Probabilities Predict Averages Probabilities predict the average outcome of a large number of events. If you flip a coin twice, you are likely to get one heads and one tails. However, you might also get two heads or two tails. To get the expected 50:50 ratio, you might have to flip the coin many times. The same is true of genetics. Think, for example, of two horses each of which carries a dominant allele for normal coat color along with the recessive allele for overo lethal white syndrome. The odds are that three out of four of their foals will be healthy. But there is one chance in four they will produce a foal with the OLWS, the lethal syndrome, and this could occur in their very first birth.

Statistically, the larger the number of offspring, the closer the results will be to the predicted values. If an F_2 generation contains just three or four offspring, it may not match Mendel's ratios. When an F_2 generation contains hundreds or thousands of individuals, the ratios usually come very close to matching predictions.

INTERACTIVITY

Explore the genetics behind the fur color, coat type, and eye color of guinea pigs.

Genotype and Phenotype One of Mendel's most revolutionary insights followed directly from his observations of F_1 crosses: Every organism has a genetic makeup as well as a set of observable characteristics. All of the pea plants with green pods had the same **phenotype**, or physical traits. They did not, however, have the same **genotype**, or genetic makeup. Look again at **Figure 12-5**. There are three different genotypes among the F_2 plants: *GG*, *Gg*, and *gg*. Plants with *GG* or *Gg* combinations of alleles have different genotypes, but the same phenotype—they have green pods. Now look at the pea plant in **Figure 12-6**. Can you tell its phenotype and genotype for flower color?

Using Punnett Squares One of the best ways to predict the outcome of a genetic cross is with a diagram known as a **Punnett square**. ***Punnett squares use mathematical probability to help predict the genotype and phenotype combinations in genetic crosses***. Constructing a Punnett square is fairly easy. You begin with a square. Then, following the principle of segregation, all possible combinations of alleles in the gametes produced by one parent are written along the top edge of the square. The other parent's alleles are then segregated along the left edge. Next, every possible genotype is written inside the boxes within the square, just as they might appear in the F_2 generation. **Figure 12-7** describes how to construct Punnett squares.

READING CHECK **Define** In your own words, define the terms *genotype* and *phenotype*.

Figure 12-6

Genotype and Phenotype

Phenotype is the physical trait of an organism, such as the purple flower color of this pea plant. Genotype is the genetic makeup, which is hidden inside it.

Visual Summary

Figure 12-7

Constructing a Punnett Square

By drawing a Punnett square, you can determine the allele combinations that might result from a genetic cross.

INTERACTIVITY

Practice using Punnett squares by performing crosses using pea pod characteristics.

1 Start With the Parents

One-Factor Cross

Write the genotypes of the two organisms that will serve as parents in a cross. In this example we will cross a male and female osprey, or fish eagle, that are heterozygous for large beaks. They each have genotypes of *Bb*.

Bb and *Bb*

Two-Factor Cross

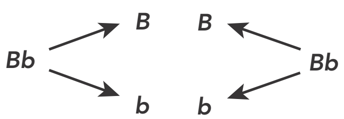
In this example we will cross two pea plants that are heterozygous for size (tall and short alleles) and pod color (green and yellow alleles). The genotypes of the two parents are *TtGg* and *TtGg.*

TtGg and *TtGg*

2 Figure Out the Gametes

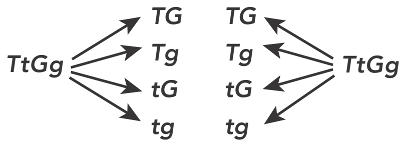
One-Factor Cross

Determine what alleles would be found in all of the possible gametes that each parent could produce.



Two-Factor Cross

Determine what alleles would be found in all of the possible gametes that each parent could produce.



3 Line Them Up

One-Factor Cross

Draw a table with enough squares for each pair of gametes from each parent. In this case, each parent can make two different types of gametes, *B* and *b*. Enter the genotypes of the gametes produced by both parents on the top and left sides of the table.

	B	*b*
B		
b		

Two-Factor Cross

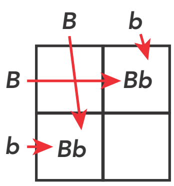
In this case, each parent can make 4 different types of gametes, so the table needs to be 4 rows by 4 columns, or 16 squares.

	TG	*tG*	*Tg*	*tg*
TG				
tG				
Tg				
tg				

4 Write Out the New Genotypes

One-Factor Cross

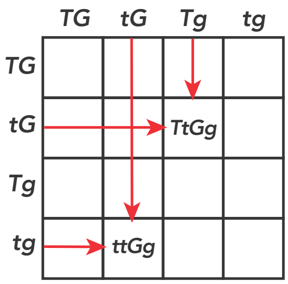
Fill in the table by combining the gametes' genotypes.



	B	*b*
B	*BB*	*Bb*
b	*Bb*	*bb*

Two-Factor Cross

Fill in the table by combining the gametes' genotypes.



	TG	*tG*	*Tg*	*tg*
TG	*TTGG*	*TtGG*	*TTGg*	*TtGg*
tG	*TtGG*	*ttGG*	*TtGg*	*ttGg*
Tg	*TTGg*	*TtGg*	*TTgg*	*Ttgg*
tg	*TtGg*	*ttGg*	*Ttgg*	*ttgg*

5 Figure Out the Results

One-Factor Cross

Determine the genotype and phenotype of each offspring. Calculate the percentage of each. In this example, $\frac{3}{4}$ of the chicks will have large beaks, but only $\frac{1}{2}$ will be heterozygous for this trait *(Bb).*

	B	*b*
B	*BB*	*Bb*
b	*Bb*	*bb*

Two-Factor Cross

In this example, the color of the squares represents pod color. Alleles written in black indicate short plants, while alleles written in red indicate tall plants.

	TG	*tG*	*Tg*	*tg*
TG	*TTGG*	*TtGG*	*TTGg*	*TtGg*
tG	*TtGG*	*ttGG*	*TtGg*	*ttGg*
Tg	*TTGg*	*TtGg*	*TTgg*	*Ttgg*
tg	*TtGg*	*ttGg*	*Ttgg*	*ttgg*

Independent Assortment

After showing that alleles segregate during the formation of gametes, Mendel wondered if the segregation of one pair of alleles affects another pair. For example, does the gene that determines the shape of a seed affect the gene for seed color? To find out, Mendel followed two different genes as they passed from one generation to the next. Because it involves two different genes, Mendel's experiment is known as a two-factor, or dihybrid, cross. Single-gene crosses are monohybrid crosses.

The Two-Factor Cross: F_1 First, Mendel crossed true-breeding plants that produced only round yellow peas with plants that produced only wrinkled green peas. The round yellow peas had the genotype *RRYY*, and the wrinkled green peas had the genotype *rryy*. All of the F_1 offspring produced round yellow peas. These results showed that the alleles for yellow and round peas are dominant. As **Figure 12-8** shows, the genotype in each of these F_1 plants is *RrYy*. In other words, the F_1 plants were all heterozygous for both seed shape and seed color.

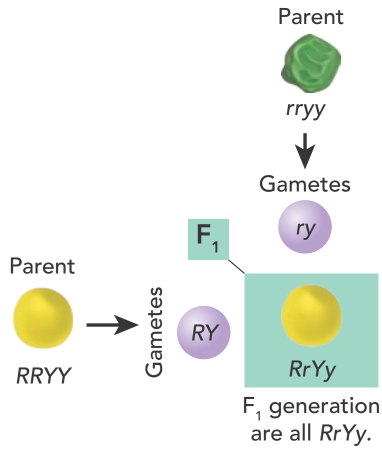


Figure 12-8

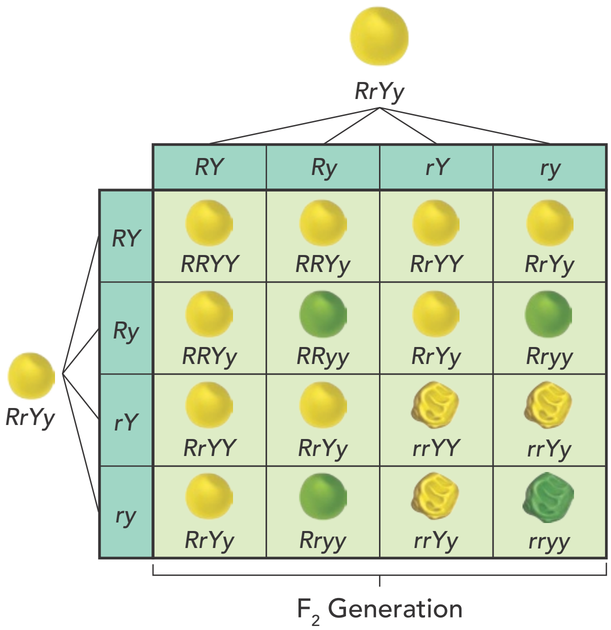
Two-Factor Cross: F_1

Mendel crossed plants that were homozygous dominant for round yellow peas (*RRYY*) with plants that were homozygous recessive (*rryy*) for wrinkled green peas. All of the F_1 offspring were heterozygous dominant for round yellow peas.

The Two-Factor Cross: F_2 Next, Mendel crossed the F_1 plants to produce F_2 offspring. Remember, each F_1 plant was formed by the fusion of a gamete carrying the dominant *RY* alleles with another gamete carrying the recessive *ry* alleles. Would the two dominant alleles always stay together, or would they segregate independently, so that any combination of alleles was possible?

In Mendel's experiment, the F_2 plants produced 556 seeds. Mendel noted that 315 of the seeds were round and yellow, while another 32 seeds were wrinkled and green—the two parental phenotypes. However, 209 seeds had combinations of phenotypes—and, therefore, combinations of alleles—that were not found in either parent. This clearly meant that the alleles for seed shape segregated independently of those for seed color. Put another way, genes that segregate independently (such as the genes for seed shape and seed color in pea plants) do not influence each other's inheritance.

Mendel's experimental results were very close to the 9 : 3 : 3 : 1 ratio that the Punnett square shown in **Figure 12-9** predicts. Mendel had discovered the principle of **independent assortment**. ***The principle of independent assortment states that genes for different traits can segregate independently during the formation of gametes.*** Independent assortment helps account for the many genetic variations observed in plants, animals, and other organisms—even when they have the same parents.



INTERACTIVITY

Figure 12-9

Two-Factor Cross: F_2

Mendel's F_2 plants produced seeds with four different phenotypes.

READING CHECK Review How did Mendel's experiments provide evidence for the principle of independent assortment?

A Summary of Mendel's Principles

As you have seen, Mendel's principles of segregation and independent assortment can be observed through one- and two-factor crosses. ***Mendel's principles of heredity, observed through patterns of inheritance, form the basis of modern genetics.*** These principles of heredity are as follows:

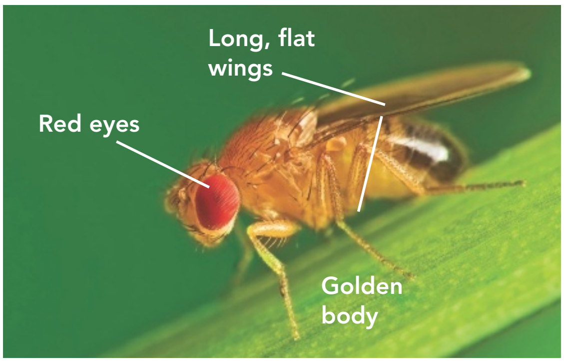
- The inheritance of biological characteristics is determined by individual units called genes, which are passed from parents to offspring.
- Where two or more forms (alleles) of the gene for a single trait exist, some alleles may be dominant and others may be recessive.
- In most sexually reproducing organisms, each adult has two copies of each gene—one from each parent. These genes segregate from each other when gametes are formed.
- Alleles for different genes usually segregate independently of each other.

Mendel's principles don't apply only to plants. At the beginning of the 1900s, the American geneticist Thomas Hunt Morgan wanted to use a model organism of another kind to advance the study of genetics. He decided to work on a tiny insect that kept showing up, uninvited, in his laboratory. The insect was the common fruit fly, *Drosophila melanogaster*, shown in **Figure 12-10**.

Figure 12-10

Modeling Genetics

The common fruit fly is an ideal organism for genetic research. Traits that are commonly studied by geneticists include eye color, body color, and wing shape.



Drosophila can produce many offspring—a single pair can produce hundreds of young. Before long, Morgan and other biologists had tested all of Mendel's principles and learned that they applied to flies and other organisms as well. In fact, Mendel's basic principles of inheritance can even be used to study the inheritance of human traits and genetic disorders such as cystic fibrosis.

HS-LS3-3

LESSON 12.2 Review

KEY QUESTIONS

1. What is probability?
2. How does the principle of independent assortment help explain Mendel's results?
3. Describe Gregor Mendel's contribution to our understanding of inherited traits.

CRITICAL THINKING

4. **Use Models** Draw a Punnett square to represent the cross of two pea plants, each heterozygous for tallness (*Tt*). Use the Punnett square to identify the probability of an offspring that is short.
5. **Synthesize Information** In pea plants, the allele for yellow seeds (*Y*) is dominant over the allele for green seeds (*y*). Describe the genotypes and phenotypes of pea plants that are homozygous dominant, homozygous recessive, and heterozygous for this trait.
6. **CASE STUDY** A man and woman are deciding whether to have a child. The genotype of the man includes a recessive allele for an inherited disease. The genotype of the woman does not include this allele. Both parents have a normal phenotype. Could the child inherit the disease? Explain your reasoning.

Other Patterns of Inheritance

LESSON 12.3

Feather color in parakeets is controlled by multiple genes.

KEY QUESTIONS

- *What are some exceptions to Mendel's principles?*
- *How does the environment play a role in how genes determine traits?*

HS-LS3-3: Apply concepts of statistics and probability to explain the variation and distribution of expressed traits in a population.

VOCABULARY

incomplete dominance
codominance
multiple alleles
polygenic trait

READING TOOL

As you read, identify the different types of non-traditional inheritance. Fill in the graphic organizer in your **Biology Foundations Workbook.**

Mendel's principles offer a tidy set of rules with which to predict various patterns of inheritance. Unfortunately, biology is not a tidy science, and there are exceptions to every rule, including Mendel's.

Beyond Dominant and Recessive Alleles

Most genes do not behave quite so neatly as the two-allele pattern of simple dominance shown by Mendel's peas. Many genes are quite a bit more complicated.

Incomplete Dominance A cross between two four o'clock (*Mirabilis jalapa*) plants shows a common exception to Mendel's principles. ***Some alleles are neither completely dominant nor recessive.*** As shown in **Figure 12-11**, the F_1 generation produced by a cross between red-flowered (*RR*) and white-flowered (*rr*) *Mirabilis* plants consists of pink-colored flowers (*Rr*). Which allele is dominant in this case? Neither one. Cases in which one allele is not completely dominant over another are called **incomplete dominance**. In incomplete dominance, the heterozygous phenotype lies somewhere between the two homozygous phenotypes.

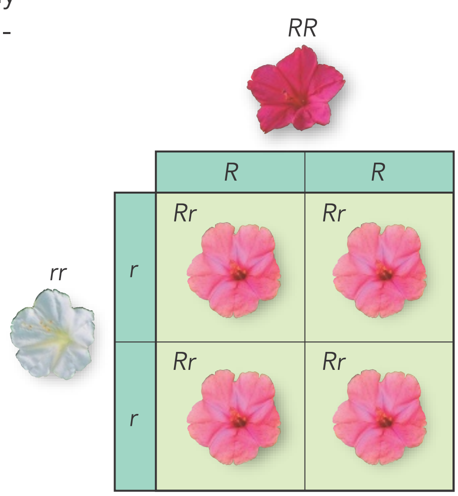


Figure 12-11

Incomplete Dominance

In four o'clock plants, the alleles for red and white flowers show incomplete dominance. Heterozygous (*Rr*) plants have pink flowers—a mix of red and white coloring.

INTERACTIVITY

Figure 12-12

Other Patterns of Inheritance

Codominance is one type of inheritance that does not follow the simple dominance Mendel observed. Codominant white and black alleles result in a mixture of white and black feathers.

Codominance

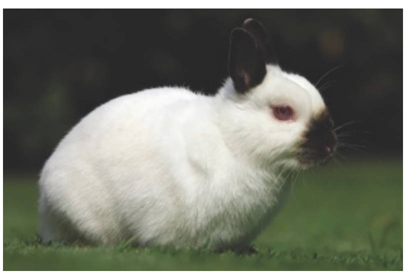
A similar situation arises from **codominance**. ***Codominance is a situation in which the phenotypes produced by both alleles are clearly expressed.*** For example, in certain varieties of chickens, the allele for black feathers is codominant with the allele for white feathers. Heterozygous chickens have a color described as "erminette," speckled with black and white feathers, as shown in **Figure 12-12**. Unlike the blending of red and white colors in heterozygous four o'clock flowers, black and white colors appear separately in chickens. Many human genes, including one for a protein that controls cholesterol levels in the blood, show codominance, too. People with the heterozygous form of this gene produce two different forms of the protein, each with a different effect on cholesterol levels.

Multiple Alleles

So far, our examples have described genes for which there are only two alleles, such as *a* and *A*. In nature, such genes are the exception rather than the rule. ***Many genes exist in several different forms and are therefore said to have multiple alleles.*** A gene with more than two alleles is said to have **multiple alleles**. An individual, of course, usually has only two copies of each gene, but many different alleles are often found within a population. One of the best-known examples is coat color in rabbits. A rabbit's coat color is determined by a single gene that has at least four different alleles as shown in **Figure 12-13**. The four known alleles display a pattern of simple dominance that can produce four coat colors. Many other genes have multiple alleles, including the human genes for blood type.

Full color: CC, Cc^{ch}, Cc^{h}, or Cc

Chinchilla: $c^{ch}c^{h}$, $c^{ch}c^{ch}$, or $c^{ch}c$



Himalayan: $c^{h}c$ or $c^{h}c^{h}$

Albino: cc

C = full color; dominant to all other alleles

c^{ch} = chinchilla; partial defect in pigmentation; dominant to c^{h} and c alleles

c^{h} = Himalayan; color in certain parts of the body; dominant to c allele

c = albino; no color; recessive to all other alleles

Figure 12-13

Multiple Alleles

Coat color in rabbits is determined by a single gene that has at least four different alleles. Different combinations of alleles result in the four colors you see here.

Polygenic Traits ***Many traits are produced by the interaction of several genes.*** Traits controlled by two or more genes are said to be **polygenic traits**, meaning "many genes." At least two and as many as a dozen genes are responsible for the many different shades of human eye color. As you might expect, polygenic traits often show a wide range of phenotypes.

Non-Mendelian Inheritance Nearly one hundred years ago, botanists realized that some traits did not follow the patterns of inheritance described by Mendel. One example is leaf color in the morning glory (*Mirabilis jalapa*), which is determined solely by the color of petal tissue in the maternal parent. This pattern, known as *maternal inheritance*, would not be predicted from Mendel's principles. ***Some traits follow non-Mendelian patterns of inheritance.***

What causes maternal inheritance? Chloroplasts and mitochondria contain genes of their own on small DNA molecules within both organelles. Chloroplasts in the morning glory plant are inherited from the egg cell, and these determine the leaf colors of the offspring. Similarly, human mitochondria are inherited from the mother's egg cell. As a result, genetic disorders in human mitochondrial DNA also follow a pattern of maternal inheritance.

Another source of non-Mendelian inheritance is caused by chemical modification of certain genes, a process known as genetic imprinting. In mice, for example, a gene regulating body size is imprinted in a way that silences it in the next generation whenever it is carried by a female. Mice inheriting the gene from their mothers may suffer from dwarfism. However, mice inheriting the very same gene from their fathers do not. Genetic imprinting occurs in many human genes as well.

INTERACTIVITY

Use Punnett squares to predict the results of crosses in examples of non-Mendelian inheritance.

Analyzing Data

Human Blood Types

Red blood cells carry antigens, molecules that can trigger an immune reaction, on their surfaces. Human blood type A carries an A antigen, type B has a B antigen, type AB has both antigens, and type O carries neither antigen. The gene for these antigens has three alleles: A, B, and O.

For a blood transfusion to succeed, it must not introduce a new antigen into the body of the recipient. So, a person with type A blood may receive type O, but not vice versa.

Blood Transfusions

Blood Type of Donor	Blood Type of Recipient			
	A	B	AB	O
A	√	X	√	X
B	X	√	√	X
AB	X	X	√	X
O	√	√	√	√

X = Unsuccessful transfusion √ = Successful transfusion

ANALYZE AND INTERPRET DATA

1. **Draw Conclusions** Which blood type is sometimes referred to as the "universal donor"? Which is known as the "universal recipient"?
2. **Analyze Data** In a transfusion involving the A and O blood types, does it make a difference which blood type belongs to the recipient and which to the donor?
3. **Apply Concepts** Write a brief explanation for the results in the table using information about phenotypes and genotypes in blood group genes.

Environmental Temperature and Butterfly Needs		
Temp. Needed for Flight	Average Spring Temp.	Average Summer Temp.
28–40°C	26.5°C	34.8°C

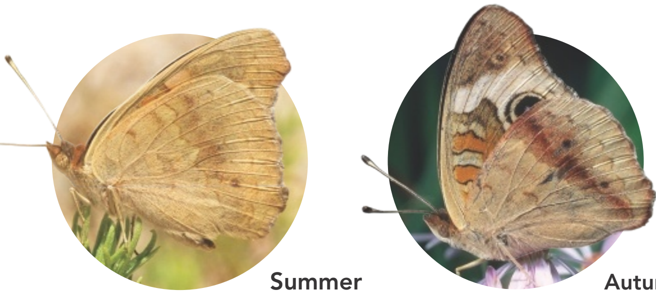


Figure 12-14

Temperature and Wing Color

The buckeye butterflies shown in the photographs are darker in the autumn than they are in the summer. Similarly, western white butterflies that hatch in the spring have darker wing patterns than those that hatch in the summer. The dark wing color helps increase their body heat. This trait is important because the butterflies need to reach a certain temperature in order to fly (see table).

INTERACTIVITY

Use a simulation to explore genetics in lilies.

Genes and the Environment

The characteristics of any organism—whether plant, fruit fly, or human being—are not determined solely by the genes that the organism inherits. Genes provide a plan for development, but how that plan unfolds also depends on the environment. In other words, the phenotype of an organism is only partly determined by its genotype.

Consider the buckeye butterfly, *Precis coenia*, shown in **Figure 12-14**. It is found throughout North America. Butterfly enthusiasts had noted for years that buckeyes hatching in the summer had different color patterns on their wings than those hatching in the fall. Scientific studies suggested a reason—butterflies hatching in the shorter days of autumn had greater levels of pigment in their wings, making their markings appear darker than those hatching in the longer days of summer. In other words, the environment in which the butterflies develop influences the expression of their genes for wing coloration. ***Environmental conditions can affect gene expression and influence genetically determined traits.*** An individual's actual phenotype is influenced by its environment as well as its genes.

Studies on another species, the western white butterfly, have shown the importance of changes in wing pigmentation. In order to fly effectively, the body temperature of the butterfly must be 28°C–40°C (about 84°F–104°F). Since the spring months are cooler in the West, greater pigmentation helps them reach the body temperature needed for flight. Similarly, in the hot summer months, less pigmentation enables the butterflies to avoid overheating.

HS-LS3-3

LESSON 12.3 Review

KEY QUESTIONS

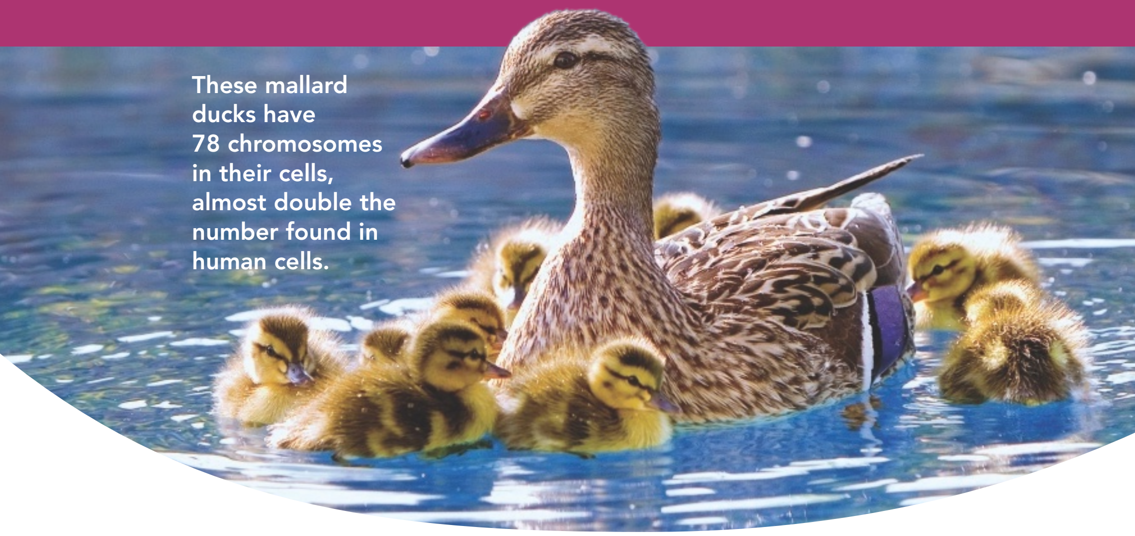
1. Why is incomplete dominance considered an exception to Mendel's principles of inheritance?
2. What is the relationship between the environment and phenotype?

CRITICAL THINKING

3. **Construct an Explanation** The iris of the human eye can have many colors, including brown, blue, green, and hazel. How does polygenic inheritance explain why many iris colors are possible?
4. **Plan an Investigation** Based on observational evidence, variations in the color of flamingos appears to be determined by their diet, and not their genes. Describe the steps of an investigation to provide evidence to support or refute this hypothesis.
5. **Develop a Model** Petal color in roses is an example of incomplete dominance. Draw a Punnett square to show the results of a cross between two pink roses (*Rr*). Use the model to predict the petal colors of the offspring.

Meiosis

LESSON 12.4



These mallard ducks have 78 chromosomes in their cells, almost double the number found in human cells.

KEY QUESTIONS

- *How many sets of genes are found in most adult organisms?*
- *What events occur during each phase of meiosis?*
- *How is meiosis different from mitosis?*
- *How can two alleles from different genes be inherited together?*

HS-LS3-1: Ask questions to clarify relationships about the role of DNA and chromosomes in coding the instructions for characteristic traits passed from parents to offspring.
HS-LS3-2: Make and defend a claim based on evidence that inheritable genetic variations may result from: (1) new genetic combinations through meiosis, (2) viable errors occurring during replication, and/or (3) mutations caused by environmental factors.

VOCABULARY
homologous
diploid
haploid
meiosis
tetrad
crossing-over

READING TOOL

Identify the sequence of events of meiosis and fill in the diagram in your **Biology Foundations Workbook.**

As geneticists in the early 1900s applied Mendel's principles, they wondered where genes might be located. They expected genes to be carried on structures inside the cell, but *which* structures? What cellular processes could account for segregation and independent assortment as Mendel had described?

Chromosome Number

In order to hold true, Mendel's principles require at least two events to occur. First, an organism with two parents must inherit a single copy of every gene from each parent. Second, when that organism produces gametes, those two sets of genes must be separated so that each gamete contains just one set of genes. As it turns out, chromosomes —those strands of DNA and protein inside the cell nucleus—fit that description perfectly. Genes are located on chromosomes.

Diploid Cells Each cell of the fruit fly, *Drosophila,* has eight chromosomes. Four of these chromosomes came from its male parent, and four came from its female parent. These two sets of chromosomes are **homologous**, meaning that each of the four chromosomes from the male parent has a corresponding chromosome from the female parent. A cell with two sets of homologous chromosomes is said to be **diploid**, meaning "double." ***The diploid cells of most adult organisms contain two complete sets of inherited chromosomes and two complete sets of genes.*** The diploid number of chromosomes is sometimes represented by the symbol 2N. Thus, for *Drosophila*, the diploid number is 8, or 2N = 8, where *N* represents the single set of chromosomes found in a sperm or egg cell.

Figure 12-15

Fruit Fly Chromosomes

These chromosomes are from a fruit fly. Each of the fruit fly's body cells is diploid, containing eight chromosomes. The gametes of the fruit fly are haploid, containing four chromosomes.

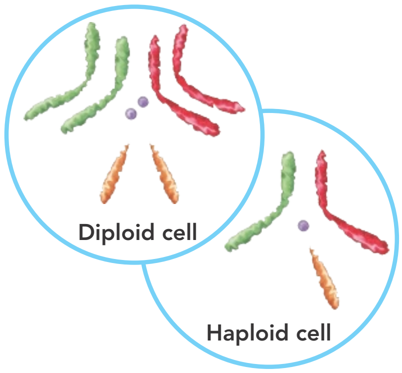
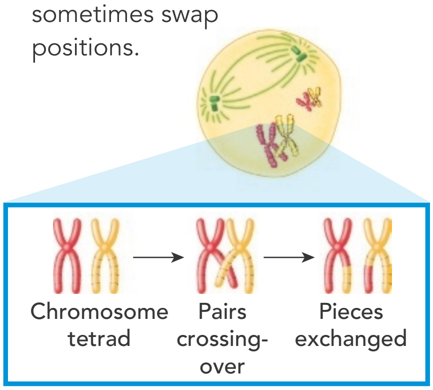


Figure 12-16

Crossing-Over

Crossing-over occurs during Prophase I, when pieces of homologous chromosomes sometimes swap positions.



BUILD VOCABULARY

Prefixes The prefix *tetra-* means "four." A **tetrad** contains four chromatids.

Haploid Cells Some cells have a single set of chromosomes and, therefore, a single set of genes. Such cells are **haploid**, meaning "single." The gametes of sexually reproducing organisms, including fruit flies and peas, are haploid. Compare the diploid and haploid cells of *Drosophila* in **Figure 12-15.**

READING CHECK Calculate The diploid number for most human cells is 46. What is the haploid number in human gametes?

Phases of Meiosis

How do sexually-reproducing organisms produce haploid (N) gamete cells from diploid (2N) cells? That's where meiosis (my OH sis) comes in. **Meiosis** is a process in which the number of chromosomes per cell is cut in half through the separation of homologous chromosomes in a diploid cell. Meiosis usually involves two distinct divisions called meiosis I and meiosis II. By the end of meiosis, a single diploid cell has produced four haploid cells.

Meiosis I Just prior to meiosis I, the cell undergoes a round of chromosome replication during interphase. Each replicated chromosome from the male and the female consists of two identical chromatids joined at the center.

Prophase I After interphase I, the cell begins to divide, and the chromosomes pair up. ***In prophase I of meiosis, each replicated chromosome pairs with its corresponding homologous chromosome.*** This pairing forms a structure called a **tetrad**, which contains four chromatids. As the chromosomes pair, they sometimes undergo a process called **crossing-over** in which bits and pieces of the homologous chromosomes are exchanged. As shown in **Figure 12-16**, crossing-over produces new combinations of alleles on each chromosome.

Metaphase I and Anaphase I As prophase I ends, a spindle forms and attaches to each tetrad. ***During metaphase I of meiosis, paired homologous chromosomes line up across the center of the cell.*** As the cell moves into anaphase I, the homologous pairs of chromosomes separate. ***During anaphase I, spindle fibers pull each homologous chromosome pair toward opposite ends of the cell.***

Telophase I and Cytokinesis When anaphase I is complete, the separated chromosomes cluster at opposite ends of the cell. ***The next phase is telophase I, in which a nuclear membrane forms around each cluster of chromosomes. Cytokinesis follows, forming two new cells.***

Meiosis I produces two daughter cells. However, because each pair of homologous chromosomes was separated, neither cell has the two complete sets of chromosomes in a diploid cell. Those two sets have been shuffled and sorted almost like a deck of cards. The two cells produced by meiosis I have sets of chromosomes and alleles that differ from each other and from the diploid cell that entered meiosis I.

Meiosis II The two cells now enter a second meiotic division called meiosis II, which is shown along with meiosis I in **Figure 12-17**. Unlike the first division, neither cell goes through a round of chromosome replication before entering meiosis II.

Prophase II ***As the cells enter prophase II, their chromosomes—each consisting of two chromatids—become visible.*** The chromosomes do not pair to form tetrads, because the homologous pairs were already separated during meiosis I.

Metaphase II, Anaphase II, Telophase II, and Cytokinesis During metaphase of meiosis II, chromosomes line up in the center of each cell. As the cell enters anaphase, the paired chromatids separate. ***The final four phases of meiosis II are similar to those in meiosis I. However, the result is four haploid daughter cells.*** In the example shown here, each of the four daughter cells produced in meiosis II receives two chromosomes. These four daughter cells now contain the haploid number (N)—just two chromosomes each.

The haploid cells produced by meiosis develop into the gametes for sexual reproduction. In males, these gametes are usually called sperm. In females, they are known as egg cells.

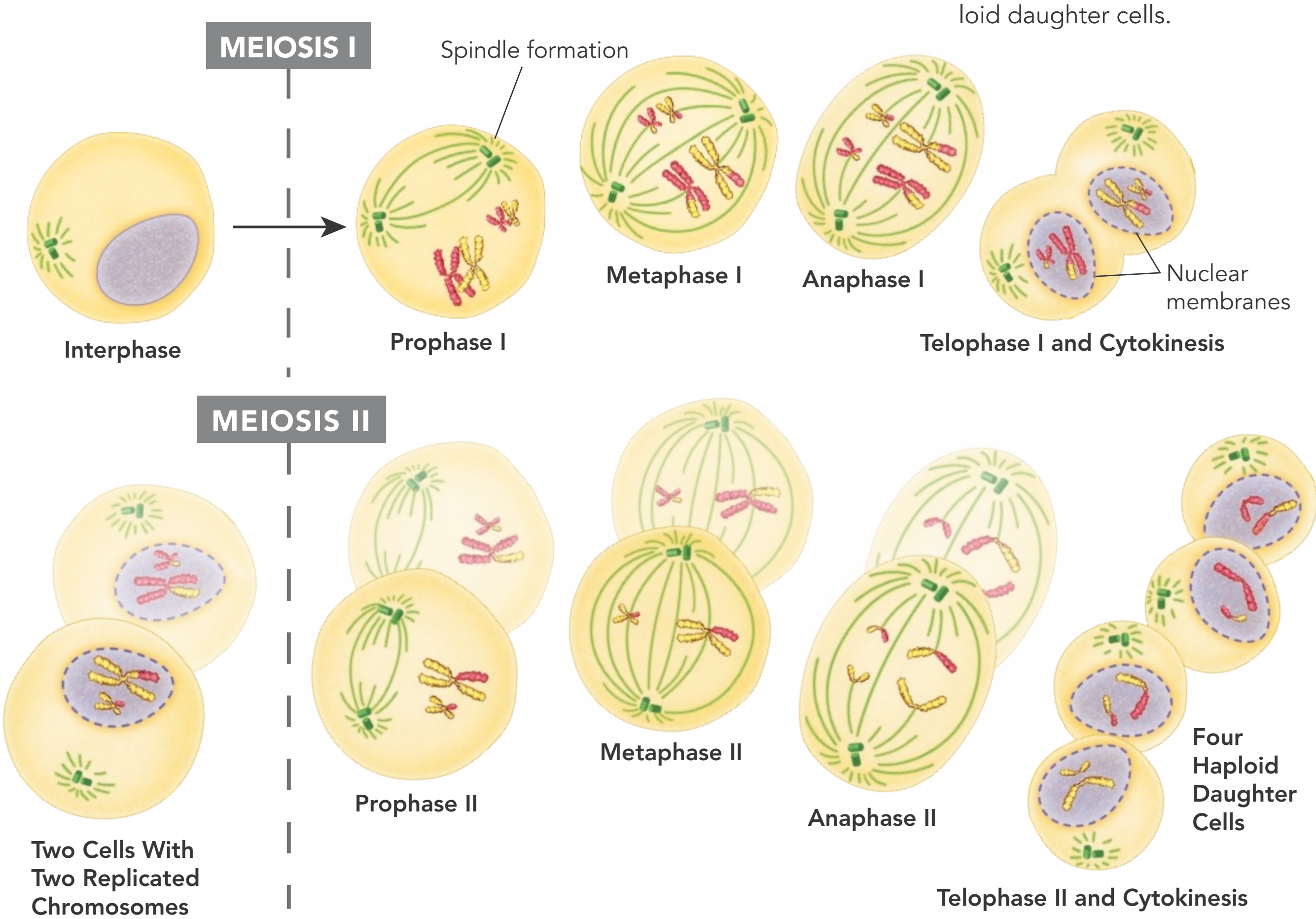
READING CHECK **Interpret Graphics** Describe the differences between meiosis I and meiosis II.

ANIMATION

Figure 12-17

Meiosis I and Meiosis II

During meiosis I, a diploid cell undergoes a series of events that results in the production of two daughter cells. Neither daughter cell has the same sets of chromosomes that the original diploid cell had. The second meiotic division, called meiosis II, produces four haploid daughter cells.



> **INTERACTIVITY**
>
> Investigate the steps of meiosis, and compare meiosis and mitosis.

> **READING TOOL**
>
> Draw and complete a two-column table to compare and contrast meiosis and mitosis.

Comparing Meiosis and Mitosis

The words *mitosis* and *meiosis* may sound similar, but the two processes are very different, as you can see in **Figure 12-18**. Mitosis can be a form of asexual reproduction, whereas meiosis is an early step in sexual reproduction. Mitosis and meiosis also differ in the way chromosomes move and in their number of cell divisions.

Replication and Separation of Genetic Material A cell replicates, or copies, all of its chromosomes before entering either mitosis or meiosis. However, the next steps differ dramatically. ***In mitosis, each daughter cell receives a complete diploid set of chromosomes. In meiosis, homologous chromosomes are separated, and each daughter cell receives only a haploid set of chromosomes.*** As a result, in meiosis the two alleles for each gene are segregated, and end up in different gamete cells. The sorting and recombination of genes that takes place in meiosis helps to increase genetic variation from one generation to the next.

Changes in Chromosome Number ***Mitosis does not change the chromosome number of the original cell. Meiosis reduces the chromosome number by half.*** A diploid cell that enters mitosis with eight chromosomes will divide to produce two diploid daughter cells, each of which also has eight chromosomes. On the other hand, a diploid cell that enters meiosis with eight chromosomes will pass through two meiotic divisions to produce four haploid gamete cells, each with only four chromosomes.

Number of Cell Divisions Mitosis is a single cell division, resulting in the production of two identical daughter cells. On the other hand, meiosis requires two rounds of cell division, and, in most organisms, produces a total of four daughter cells. ***Mitosis results in the production of two genetically identical diploid cells, whereas meiosis produces four genetically different haploid cells.***

HS-LS3-2

Modeling Lab — Open-Ended Inquiry

A Model of Meiosis

Problem How does meiosis change a diploid cell into haploid gametes?

In this lab, you will plan and develop a model of meiosis. You will choose materials to represent the cell and chromosomes, assemble and manipulate the materials to represent the stages of meiosis, and use the model to explain the process.

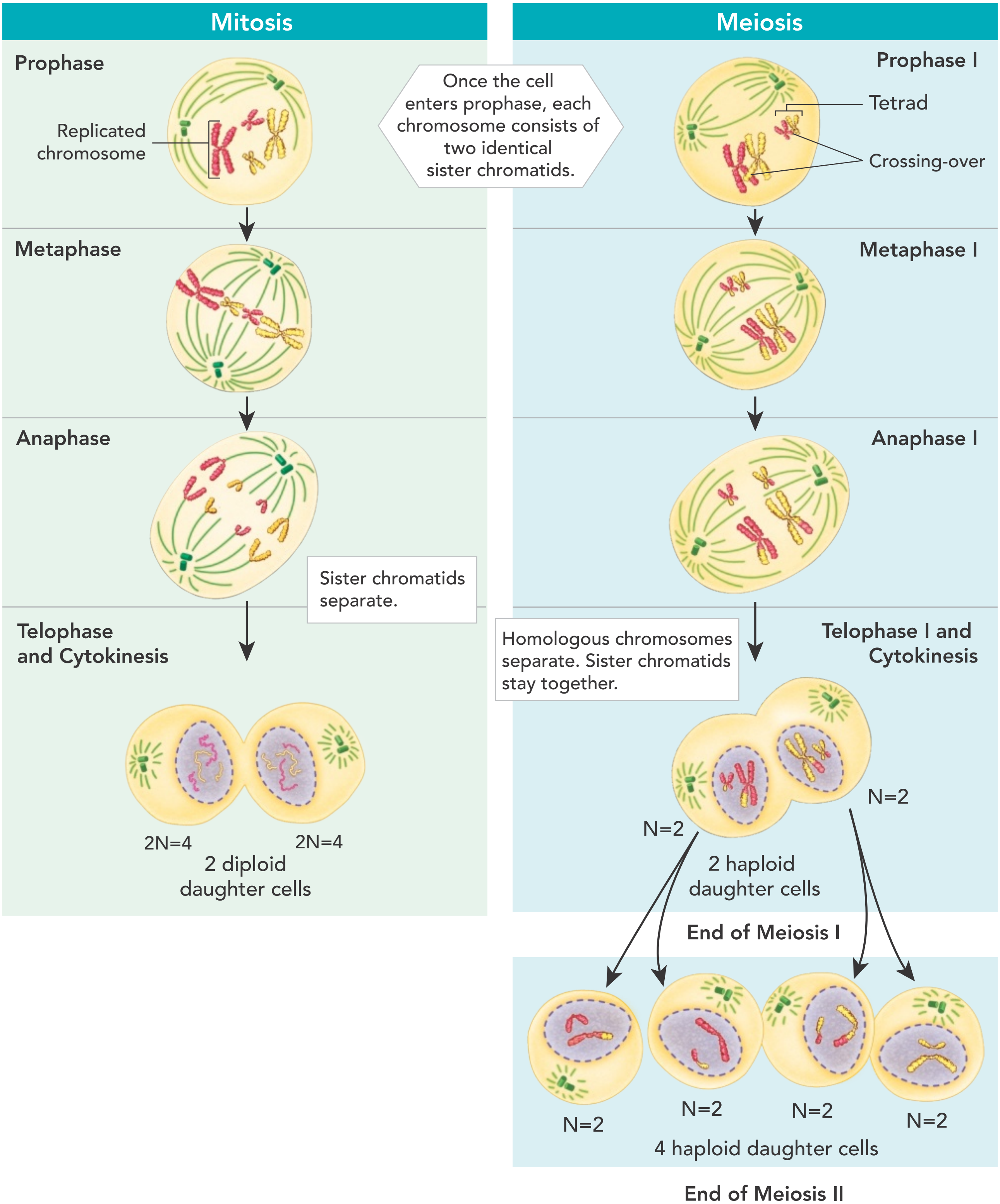
You can find this lab in your digital course.

Visual Summary

Figure 12-18

Comparing Mitosis and Meiosis

Mitosis and meiosis both ensure that cells inherit genetic information. Both processes begin after interphase, when chromosome replication occurs. However, the two processes differ in the separation of chromosomes, the number of cells produced, and the number of chromosomes each cell contains.



VIDEO

Investigate the work of Thomas Hunt Morgan and his colleagues.

Gene Linkage and Gene Maps

If you think carefully about Mendel's principle of independent assortment in relation to meiosis, one question might bother you. Genes that are located on different chromosomes assort independently, but what about genes that are located on the same chromosome? Wouldn't they generally be inherited together?

Gene Linkage The answer to this question, as Thomas Hunt Morgan first realized in 1910, is yes. Morgan's research on *Drosophilia*, a type of fruit fly, led him to the principle of gene linkage.

Morgan identified more than 50 genes and the traits they caused, some of which are shown in **Figure 12-19**. He discovered that many of the genes appeared to be "linked" together in ways that, at first glance, seemed to violate the principle of independent assortment. For example, Morgan used a fly with reddish-orange eyes and miniature wings in a series of test crosses. His results showed that the genes for those two traits were almost always inherited together. Morgan and his associates observed so many genes that were inherited together that, before long, they could group all of the fly's genes into four linkage groups. The linkage groups assorted independently, but all of the genes in one group were inherited together. As it turns out, *Drosophila* has four linkage groups and four pairs of chromosomes.

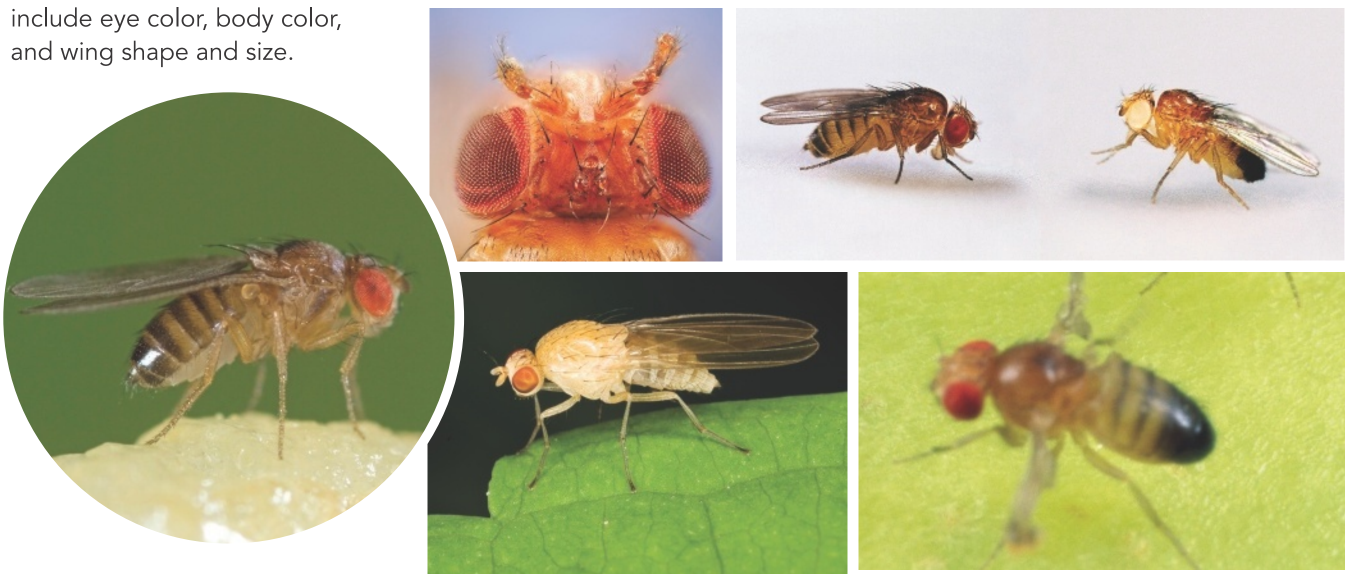
Morgan's findings led to two remarkable conclusions. First, each chromosome is actually a group of linked genes. Second, Mendel's principle of independent assortment still holds true. It is the chromosomes, however, that assort independently, not individual genes. ***Alleles of different genes tend to be inherited together from one generation to the next when those genes are located on the same chromosome.***

How did Mendel manage to miss gene linkage? By luck, several of the genes he studied are on different chromosomes. Others are on the same chromosome but are so far apart that they also assort independently.

Figure 12-19

Variability in Fruit Flies

Fruit flies proved ideal for Morgan's work because they were easy to breed and showed genetic variability. Differences among fruit flies include eye color, body color, and wing shape and size.



Gene Mapping In 1911, a Columbia University student was working part time in Morgan's lab. This student, Alfred Sturtevant, wondered if the frequency of crossing-over between genes during meiosis might be a clue to the genes' locations. Sturtevant reasoned that the farther apart two genes were on a chromosome, the more likely it would be that crossing-over would occur between them. If two genes are close together, then crossovers between them should be rare. If two genes are far apart, then crossovers between them should be more common, reducing the frequency with which they are linked. By this reasoning, he could use the frequency of crossing-over between genes to determine their distances from each other.

Sturtevant gathered up several notebooks of lab data and took them back to his room. The next morning, he presented Morgan with a gene map showing the relative locations of each known gene on one of the *Drosophila* chromosomes. Sturtevant's method has been used to construct gene maps, like the one in **Figure 12-20**, ever since.

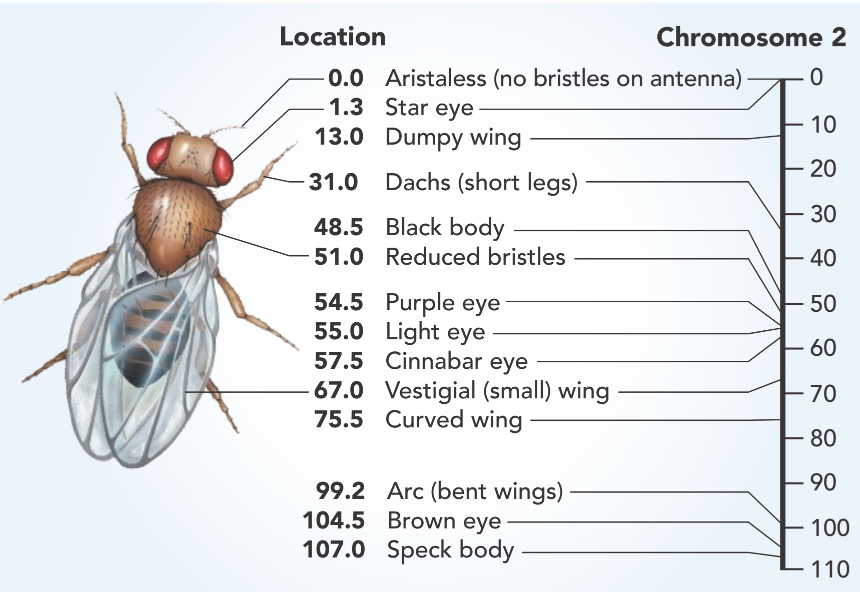


Figure 12-20

Gene Map

This gene map shows the location of a variety of genes on chromosome 2 of the fruit fly. The genes are named after the problems that abnormal alleles cause, not after the normal structures. **Interpret Diagrams** Where on the chromosome is the "purple eye" gene located?

HS-LS3-1, HS-LS3-2

LESSON 12.4 Review

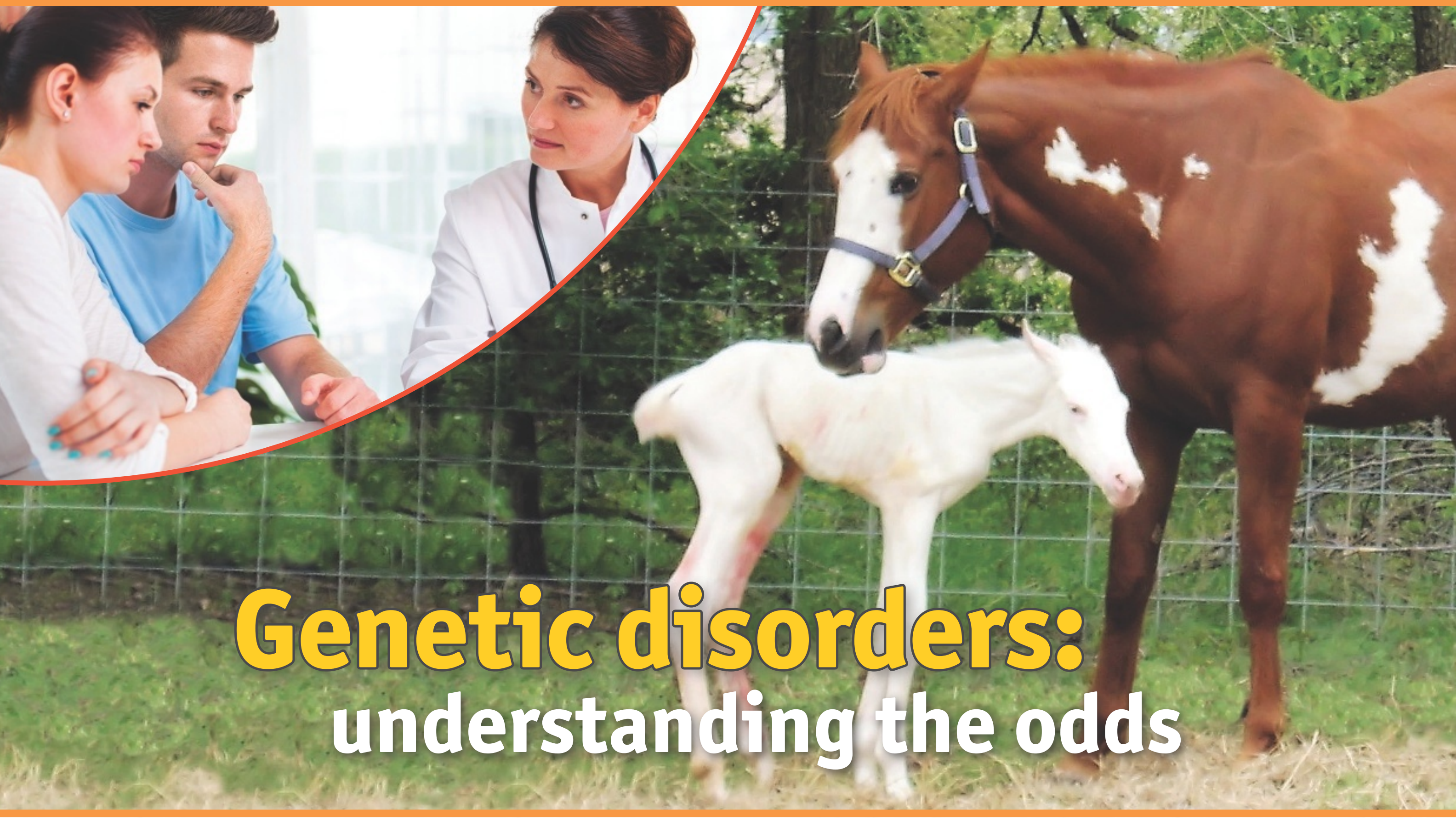
KEY QUESTIONS

1. Why are human gametes haploid instead of diploid?
2. What events occur during meiosis I and meiosis II?
3. How is meiosis similar to mitosis? How is it different?
4. Why can chromosomes be described as units of linked genes?

CRITICAL THINKING

5. **Synthesize Information** How does meiosis help explain Mendel's principle of independent assortment?
6. **Use Models** Refer to the stages of meiosis shown in **Figure 12-17**. Events in which stages determine the assortment of genes in the gametes? Explain your answer.
7. **Construct an Explanation** In asexual reproduction, mitosis occurs but meiosis does not occur. Which type of reproduction—sexual or asexual—results in offspring with greater genetic variation? Explain your answer.

CASE STUDY WRAP-UP



Genetic disorders: understanding the odds

The birth of a foal with OLWS was a tragic surprise to the horse owner. To the proud parents of a baby girl, cystic fibrosis was a known risk, but happily they had beaten the odds.

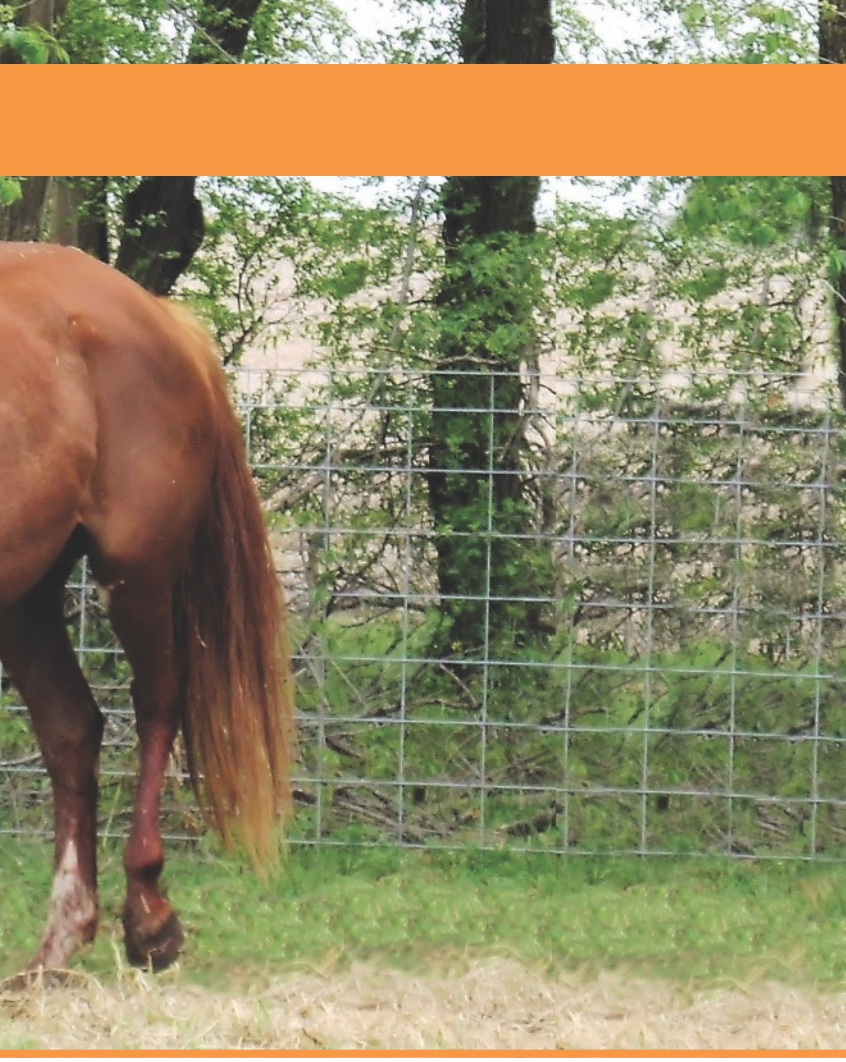
HS-LS3-3, CCSS.ELA-LITERACY.RST.9-10.7, CCSS.ELA-LITERACY.WHST.9-10.9

Make Your Case

Research either cystic fibrosis or overo lethal white syndrome, and learn what is known about the causes of both disorders. Find out why the overo white coat color is linked to problems in the equine digestive system. Similarly, try to find out why the sweat of children with cystic fibrosis is abnormally salty. Then, link this information to the way in which both disorders are inherited.

Translate Scientific Information

1. **Synthesize Information** How do you explain to the horse owner why this foal was born with OLWS while two previous foals were perfectly healthy? What would you tell the new parents of the baby girl about their prospects for having more children?
2. **Support Your Explanation with Evidence** The parents of the newborn baby girl are happy that their first child was born without cystic fibrosis. But now they worry the odds have increased that their next child will suffer from the disorder. Are their concerns justified? Why or why not?



Careers on the Case

Work Toward a Solution

Understanding the principles of genetics is needed for a wide variety of careers. A genetic counselor is one such career.

Genetic Counselor

Many hospitals and clinics employ counselors specially trained to help potential parents understand the chances of having children with certain inherited disabilities. Genetic counselors must have a detailed knowledge of human genetics, and must also possess exceptional personal skills to advise potential parents.

VIDEO

Watch this video to learn more about a career in genetic counseling.

hhmi | BioInteractive

Technology on the Case

The Fight Against CF

Cystic fibrosis (CF) is a recessive genetic disorder caused by a defective allele for a gene on chromosome 7. This gene normally produces a cell membrane protein that allows chloride ions (Cl^-) to enter and leave the cell. In most cases of CF, a missing or incorrect amino acid causes the protein to become misfolded so that it is not transported to the cell membrane. As a result, many tissues, such as the lungs and small intestine, cannot function properly. CF is the most common fatal genetic disorder among Americans of European ancestry.

Short of actually correcting the defective allele, researchers have tried to find ways to treat CF by going after that misfolded protein. Several teams of pharmaceutical researchers have developed drugs that help to prevent protein misfolding. In some cases, these drugs seem to "rescue" the protein by helping it to fold properly so that the cell is able to transport it to the cell membrane.

Another approach makes use of the fact that in many patients, a reduced number of the chloride ion channel proteins do find their way to the cell membrane, but don't function properly. Drugs have now been developed that help to keep these channels in an "open" position so they can function more effectively, relieving some of the symptoms of CF.

To date, while combinations of these two approaches look promising, neither provides a cure for the disorder. Therefore, knowing that more than 30,000 people in the United States suffer from cystic fibrosis, research will continue.

CHAPTER 12

STUDY GUIDE

Lesson Review

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

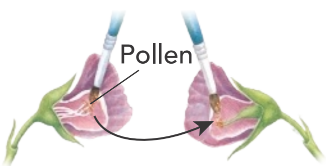
12.1 The Work of Gregor Mendel

The scientific study of biological inheritance is called genetics. Gregor Mendel's experiments of cross-pollinating pea plants led to two basic discoveries: first, traits or characteristics are passed from one generation to the next by means of genes, and second, different forms of a single gene, called alleles, exhibit dominance and recessiveness.

Recessive traits may disappear in one individual or one generation because the recessive alleles are masked by the dominant allele. During gamete formation, alleles are segregated so that each gamete carries only one allele for each gene. If a recessive allele is paired with another recessive allele during fertilization, then the recessive trait will reappear.

- genetics
- fertilization
- trait
- hybrid
- gene
- allele
- principle of dominance
- segregation
- gamete

Cross-Pollination



Draw Conclusions How can cross-pollination be used to produce hybrid organisms?

12.2 Applying Mendel's Principles

Punnett squares use mathematical probability to help predict the genotype and phenotype combinations in genetic crosses.

The principle of independent assortment states that genes for different traits can segregate independently during the formation of gametes.

Mendel's principles of heredity, observed through patterns of inheritance, form the basis of modern genetics.

- probability
- homozygous
- heterozygous
- phenotype
- genotype
- Punnett square
- independent assortment

	TG	*tG*	*Tg*	*tg*
TG				
tG				
Tg				
tg				

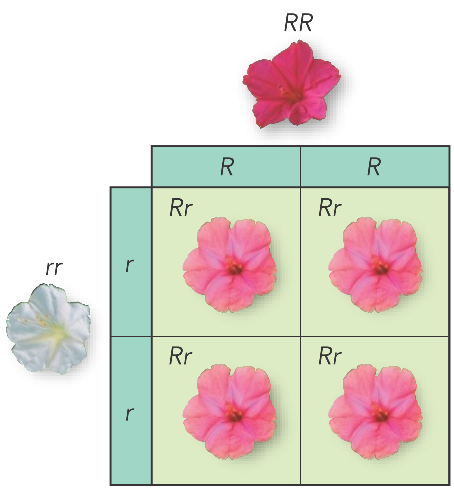
Interpret Diagrams Complete the Punnett square for the cross between two pea plants that are heterozygous for size (*Tt*) and pod color (*Gg*).

12.3 Other Patterns of Inheritance

In incomplete dominance, the alleles for a particular trait are neither completely dominant nor completely recessive. Codominance is a situation in which the phenotypes produced by both alleles are clearly expressed. Many genes exist in several different forms and are therefore said to have multiple alleles. Many traits, known as polygenic traits, are produced by the interaction of several genes. Some traits follow non-Mendelian patterns of inheritance.

Environmental conditions can affect gene expression and influence genetically determined traits.

- incomplete dominance
- codominance
- multiple alleles
- polygenic trait



Interpret Diagrams What pattern of inheritance is shown in the diagram above? How do you know?

12.4 Meiosis

In prophase I of meiosis, each replicated chromosome pairs with its corresponding homologous chromosome. During metaphase I of meiosis, paired homologous chromosomes line up across the center of the cell. During anaphase I, spindle fibers pull each homologous chromosome pair toward opposite ends of the cell. The next phase is telophase I, in which a nuclear membrane forms around each cluster of chromosomes. Cytokinesis follows, forming two new cells. As the cells enter prophase II, their chromosomes—each consisting of two chromatids—become visible. The final four phases of meiosis II are similar to those in meiosis I. However, the result is four haploid daughter cells.

In mitosis, each daughter cell receives a complete diploid set of chromosomes. In meiosis, homologous chromosomes are separated, and each daughter cell receives only a haploid set of chromosomes. Mitosis does not change the chromosome number of the original cell. Meiosis reduces the chromosome number by half. Mitosis results in the production of two genetically identical diploid cells, whereas meiosis produces four genetically different haploid cells.

Alleles of different genes tend to be inherited together from one generation to the next when those genes are located on the same chromosome. This is called gene linkage.

- homologous
- diploid
- haploid
- meiosis
- tetrad
- crossing-over

Organize Information

Complete the table to compare mitosis and meiosis.

	Role in Organism	Daughter Cells	Chromosomes	Number of Cell Divisions
Mitosis	1.	2.	No change to chromosome number	3.
Meiosis	4.	Four haploid cells	5.	6.

PERFORMANCE-BASED ASSESSMENT

Growing More and Better Corn

Evaluating Information

HS-LS3-3, CCSS.ELA-LITERACY.WHST.9-10.2

STEM By observing the seeds in this photograph, can you make inferences about the traits of the adult plants that will grow from these seeds? Probably not. The key information is carried on the inside of the seeds, not the outside. The genes of the seeds code for their growth and development.

Even small changes in the genes of seeds can make a huge difference in the plants they produce. One important example comes from the corn plant (*Zea mays*). Corn is native to North America, where it was first developed by Native American farmers several thousand years ago. It is now grown worldwide.

Up until the 1930s, farmers could expect to harvest about 30 bushels of corn for every acre they planted. But then something remarkable happened. The corn yields began increasing. By the 1960s, yields of 60 bushels per acre were common. After another 40 years, average yields had doubled again. Today, farmers can expect an acre of corn plants to yield more than 140 bushels.

What caused this huge increase in corn yields? The main reason is hybrid seeds. A field of hybrid corn plants will all grow to the same size and height, making the crop easier to harvest. Hybrid plants also tend to be healthier and grow more vigorously.

Seed companies produce hybrid seeds by developing two inbred strains, meaning strains that have homozygous genotypes. Then, they cross the two strains to produce hybrid plants. The procedure is shown in the diagram and explained here.

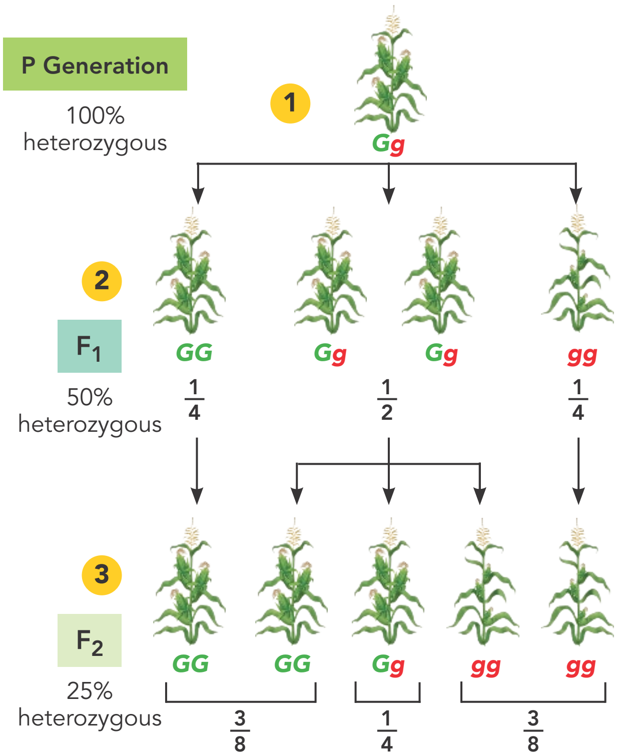
1. Heterozygous plants self-pollinate to produce a F_1 generation.

2. In F_1, $\frac{1}{2}$ of the plants are homozygous (*GG* or *gg*). All of the plants self-pollinate to produce an F_2 generation.

3. In F_2, $\frac{3}{4}$ of the plants are homozygous. With each new self-pollinated crop, more and more of the plants are homozygous.

4. After 7 or more generations, nearly pure homozygous strains have been produced. Two such strains are then crossed to produce hybrid seeds ready for farmers to plant.

SCIENCE PROJECT



1. **Use Models** Construct four Punnett squares to represent each F_1 plant self-pollinating. Then, using colored pencils, shade *GG*, *Gg*, and *gg* (each with a different color).

2. **Patterns** Identify a pattern in the number of heterozygotes for the first three generations. What do you see? Continue the pattern for a total of 7 generations.

3. **Construct an Explanation** When Step 2 of the procedure is repeated, do the percentages of homozygous plants always increase? Explain why or why not.

4. **Identify** Why does the procedure lead to hybrid seeds after Step 4?

5. **Construct an Explanation** Which is easier to produce: a strain of plants that are homozygous dominant (*GG*) or homozygous recessive (*gg*)? Explain your reasoning.

6. **Apply Scientific Reasoning** A farmer grows a corn crop from hybrid seeds. Then, the farmer gathers and plants some of the seeds from the hybrid corn plants. How will the new corn crop compare to the first crop?

7. **Conduct Research** Choose another popular garden plant or crop plant, such as pumpkins, sunflowers, squash, or tomatoes. Research the breeding techniques for the plant. Also research the useful and variable traits of the plant, such as fruit size, shape, or color.

8. **Communicate** Present your research findings in a poster, essay, or computer slide show. Your presentation should include answers to these questions:

   - How can a breeder control reproduction in the plant?
   - Which traits have breeders selected to produce purebred or hybrid strains?
   - What new or modified strain has proven useful for the plant, or what improvements might be developed in the future?

CHAPTER 12

ASSESSMENT

KEY QUESTIONS AND TERMS

12.1 The Work of Gregor Mendel

HS-LS3-3

1. Different forms of a gene are called
   a. hybrids.
   b. dominant factors.
   c. alleles.
   d. recessive factors.
2. Organisms that have two identical alleles for a particular trait are said to be
   a. hybrid.
   b. heterozygous.
   c. homozygous.
   d. dominant.
3. Mendel had many stocks of pea plants that were true-breeding. What is meant by this term?
4. Explain how Mendel kept his pea plants from self-pollinating.

12.2 Applying Mendel's Principles

HS-LS3-3

5. A Punnett square is used to determine the
   a. probable outcome of a cross.
   b. actual outcome of a cross.
   c. result of incomplete dominance.
   d. result of meiosis.
6. The physical characteristics of an organism are called its
   a. genetics.
   b. heredity.
   c. phenotype.
   d. genotype.
7. What is the probability of flipping a coin twice and getting two heads?
   a. 1
   b. $\frac{1}{2}$
   c. $\frac{1}{4}$
   d. $\frac{3}{4}$
8. Summarize the four basic principles of genetics that Mendel discovered in his experiments.
9. In pea plants, the allele for yellow seeds is dominant over the allele for green seeds. Predict the genotypic ratio of offspring produced by crossing two parents that are heterozygous for this trait. Draw a Punnett square to illustrate your prediction.

12.3 Other Patterns of Inheritance

HS-LS3-3

10. A situation in which a gene has more than two alleles is known as
    a. complete dominance.
    b. codominance.
    c. polygenic dominance.
    d. multiple alleles.
11. A pink-flowered *Mirabilis* plant (*Rr*) is crossed with a white-flowered *Mirabilis* (*rr*). What is the chance that a seed from this cross will produce a red-flowered plant (*RR*)?
    a. 0
    b. $\frac{1}{4}$
    c. $\frac{1}{2}$
    d. 1
12. What is the difference between multiple alleles and polygenic traits?
13. Why can multiple alleles result in many different phenotypes for a trait?
14. Are an organism's characteristics determined only by its genes? Explain.

12.4 Meiosis

HS-LS3-1, HS-LS3-2

15. The illustration below represents which stage of meiosis?

    a. prophase I
    b. anaphase II
    c. telophase I
    d. metaphase I
16. Unlike mitosis, meiosis in male mammals results in the formation of
    a. one haploid gamete.
    b. three diploid gametes.
    c. four diploid gametes.
    d. four haploid gametes.

17. A gene map shows
   a. the number of possible alleles for a gene.
   b. the relative locations of genes on a chromosome.
   c. where chromosomes are in a cell.
   d. how crossing-over occurs.

18. Suppose that an organism has the diploid number 2N = 8. How many chromosomes do this organism's gametes contain?

19. Describe the process of meiosis.

20. Explain why chromosomes, not individual genes, assort independently.

CRITICAL THINKING

HS-LS3-1, HS-LS3-2, HS-LS3-3

21. **Infer** Suppose Mendel crossed two pea plants and got both tall and short offspring. What could have been the genotypes of the two original plants? What genotype could not have been present?

22. **Construct an Explanation** Complete the Punnett square with the probable offspring of these two parents: *RrYy* × *RrYy*, where *R* is round seed shape and *r* is wrinkled, *Y* is yellow seed color and *y* is green. Explain how the different phenotypes are produced.

	RY	*Ry*	*rY*	*ry*
RY				
Ry				
rY				
ry				

F_2 Generation

23. **Compare and Contrast** Compare the phases of meiosis I and meiosis II in terms of number and arrangement of the chromosomes.

24. **Use Models** Identify the steps in meiosis that support the independent assortment of inherited genes. Make a diagram that illustrates how independent assortment ensures that the DNA in daughter cells is different from the DNA of the parent cell.

25. **Design a Solution** In sheep, the allele for white wool (*A*) is dominant over the allele for black wool (*a*). Design an experiment to determine the genotype of a white sheep.

26. **Construct an Explanation** Explain why it is possible for several offspring of the same parents to have the same phenotype but different genotypes.

27. **Draw Conclusions** In guinea pigs, the allele for a rough coat (*R*) is dominant over the allele for a smooth coat (*r*). A heterozygous guinea pig (*Rr*) and a homozygous recessive guinea pig (*rr*) have a total of nine offspring. The Punnett square for this cross shows a 50-percent chance that any particular offspring will have a smooth coat. Explain how all nine offspring can have smooth coats.

	R	*r*
r	*Rr*	*rr*
r	*Rr*	*rr*

28. **Interpret Visuals** Genes that control hair or feather color in some animals are expressed differently in the winter than in the summer. Ptarmigans are birds that live in the Arctic, where there is snow in the winter, but not in the summer. How might such a difference be beneficial to the ptarmigan shown here?

29. **Construct an Explanation** A red bull is bred with a white cow. The offspring has a coat known as roan because it is made up of both red and white hairs. Is the expression of the roan coat an example of incomplete dominance or codominance? Explain how you can identify the difference between these two patterns of inheritance.

ASSESSMENT

CROSSCUTTING CONCEPTS

30. **Cause and Effect** As Mendel concluded, what was the cause of recessive traits disappearing after a parental cross, but then reappearing in the next generation?

31. **Cause and Effect** Explain why the alleles for reddish-orange eyes and miniature wings in *Drosophila* are usually inherited together. Describe the pattern of inheritance these alleles follow, and explain the cause for this pattern as it relates to gene linkage. (**Hint:** To organize your ideas, draw a cause-effect diagram that shows what happens to the two alleles during meiosis.)

32. **Scale, Proportion, and Quantity** A scientist conducts a hybrid cross for tallness in pea plants ($Tt \times Tt$). Then, the scientist plants the seeds that the cross produces. What can the scientist predict about the new generation of plants, regardless of the number of seeds that are harvested?

MATH CONNECTIONS

Analyze and Interpret Data

HS-LS3-3, CCSS.MATH.CONTENT.MP2, CCSS.MATH.CONTENT.MP4

Use the paragraph and table to answer questions 33 to 35.

A researcher studying fruit flies finds a fly with brown-colored eyes. Almost all fruit flies in nature have bright red eyes. When the researcher crosses the brown-eyed fly with a red-eyed fly, all of the F_1 offspring have red eyes. The researcher then crosses two of the F_1 red-eyed flies and obtains the following results in the F_2 generation:

Results of Eye Color Experiment

Phenotype	Number of Flies in F_2 Generation
Red Eyes	37
Brown Eyes	14

33. **Calculate** What is the approximate ratio of red-eyed flies to brown-eyed flies in the F_2 generation?

a. 1 : 1
b. 1 : 3
c. 3 : 1
d. 4 : 1

34. **Use Models** Based on the information in this table, how would you describe the pattern of inheritance for brown- and red-colored eyes in fruit flies? Cite data from the researcher's experiments to support your description.

35. **Reason Quantitatively** Propose genotypes for the fruit flies in the P generation and the F_1 generation. Then draw a Punnett square to describe the F_2 generation.

LANGUAGE ARTS CONNECTIONS

Write About Science

CCSS.ELA-LITERACY.WHST.9-10.2, CCSS.ELA-LITERACY.WHST.9-10.9

36. **Write Explanatory Texts** A litter of seven puppies is born to a female dog. No two puppies have exactly the same fur color or pattern of markings even though they all have the same parents. Write an explanation of how new genetic combinations that occur during meiosis may account for the differences in their fur.

37. **Draw Evidence** How did Mendel's observations of the traits expressed in the F_1 and F_2 generations of pea plants lead him to propose the idea of segregation of alleles?

Read About Science

CCSS.ELA-LITERACY.RST.9-10.1, CCSS.ELA-LITERACY.RST.9-10.3

38. **Follow a Multistep Procedure** Review the steps that Mendel took starting with his crossing of tall and short pea plants to produce both F_1 and F_2 offspring. List each step in order for both crosses. Identify the question(s) Mendel was trying to answer with each cross.

39. **Cite Textual Evidence** Describe the exceptions to Mendel's principles of inheritance presented in the chapter. What evidence does the chapter offer to support the claim that these are exceptions to Mendel's principles?

END-OF-COURSE TEST PRACTICE

1. Gregor Mendel crossed true-breeding plants that had green pea pods with true-breeding plants that had yellow pea pods. The resulting F_1 generation all had green pea pods. What did he observe in the F_2 generation?

A. Mendel observed green and yellow pea pods in a 3:1 ratio because the F_1 generation was heterozygous.

B. Mendel observed green and yellow pea pods in a 4:1 ratio because the allele for green pea pods is dominant.

C. Mendel observed green and yellow pea pods in a 1:1 ratio because the F_2 generation had the same characteristics as the parent generation.

D. Mendel observed only green pea pods because both parents had green pea pods.

E. Mendel observed green and yellow pea pods in a 1:2 ratio because the allele for yellow pea pods is dominant.

2. Rory made the Punnett square below to show the possible genotypes of a cross between two pea plants that are heterozygous for tall stems and smooth pea pods.

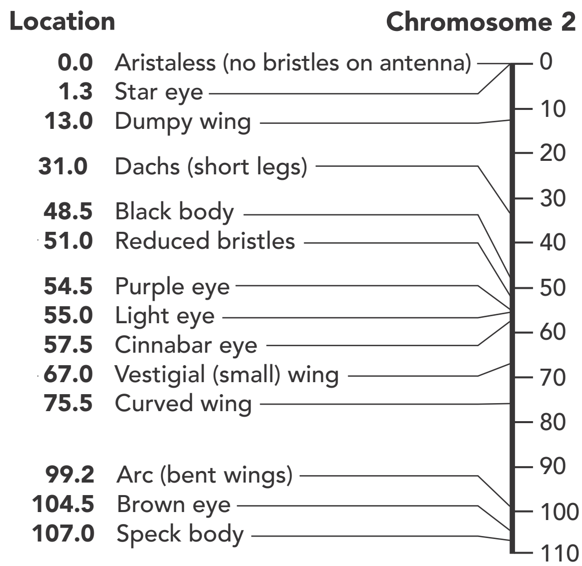
T = tall stems *S* = smooth pod
t = short stems *s* = constricted pod

	TS	**Ts**	**tS**	**ts**
TS	*TTSS*	*TTSs*	*TtSS*	*TtSs*
Ts	*TTSs*	*TTss*	*TtSs*	*Ttss*
tS	*TtSS*	*TtSs*	*ttSS*	*ttSs*
ts	*TtSs*	*Ttss*	*ttSs*	*ttss*

What is the ratio of the phenotypes expressed by the offspring in this cross?

A. 3 : 1
B. 4 : 1
C. 9 : 3 : 3 : 1
D. 1 :1
E. 1 : 9 : 16

3. The gene map below shows some of the genes on chromosome 2 of the fruit fly *Drosophila melanogaster*.



Which pair of traits is MOST LIKELY to be inherited together?

A. purple eye and brown eye because they are both eye traits

B. aristaless and speck body because they have the greatest chance of crossing over

C. curved wing and arc (bent wings) because they have the least chance of crossing-over

D. dachs (short legs) and black body because there are no other genes between them on the gene map

E. black body and light eye because they are closest together on chromosome 2

ASSESSMENT

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

If You Have Trouble With...			
Question	1	2	3
See Lesson	12.1	12.2	12.4
Performance Expectation	HS-LS3-3	HS-LS3-3	HS-LS3-2