Dear Colleague,

A few months ago, I had the honor of speaking at a symposium in honor of Gregor Mendel. To prepare for my talk for the meeting, I read over Mendel’s famous paper, a dry scientific report with the unassuming title of “Investigations of Plant Hybridization.” As I turned the pages, I wondered if Mendel himself had any idea what he was starting. It would take decades, of course, but eventually his work led to a revolution in biology. Once, we naturalists were merely observers of life. Biologists today, of course, are active participants who study, shape, analyze, and even change living things.

What struck me most as I looked over Mendel’s paper was not the way in which it laid out the basic principles of genetics. Mendel’s great contribution, it seems to me, was his insistence that life itself could be studied, analyzed, and understood along systematic, rational lines. This attitude infuses every paragraph of his work, and it was picked up, almost unconsciously, by the scientists who rediscovered and extended that work at the beginning of the twentieth century.

Today, we have an opportunity to bring that sense of discovery to our students as never before. The rise of Mendelian genetics led to intense curiosity about the chemical nature of the gene. That, in turn, led to the identification of DNA as the genetic material, as well as the discovery of its double-helical structure. The result of all that curiosity, of course, is a new understanding of life that we can bring to all of our students. DNA carries the genetic code, and with it the fundamental instructions that operate our cells and interact with the environment to build our bodies. It’s both our heritage and the legacy that we pass along to new generations. It’s also something we share with every other living thing on this planet. That revolution in understanding may have begun with Gregor Mendel, but it hasn’t stopped, even today. Indeed, the most important message we may be able to give our students is that the really interesting work is just beginning.
Introduction to Genetics

Information and Heredity

Q: How does biological information pass from one generation to another?

Connect to the Big Idea

Have students look at the photo and describe their observations. Ask students whether they think the dogs in the photo are related to one another. (Students might say that they are all the same breed, so they could be from the same family.) Explain that the colors of the dogs’ coats are determined by heredity, or the passing of traits from parents to offspring. Then, have students read the question, How does biological information pass from one generation to another? Tell students that, in this chapter, they will learn how offspring can inherit information from both parents, yet show traits that do not appear in either parent.

Have students read over the Chapter Mystery and brainstorm a list of reasons why none of the chicks look like their parents. As a hint, suggest students reread the chapter’s Big Idea and Essential Question. Have students refer back to this list as they gather more evidence throughout the chapter.

Have students preview the chapter vocabulary using the Flash Cards.

Understanding by Design

In Chapter 11, students discover how cellular information passes from one generation to another. The graphic organizer at right shows how chapter content frames their exploration of the Unit 4 Enduring Understanding: DNA is the universal code for life; it enables an organism to transmit hereditary information and, along with the environment, determines an organism’s characteristics.

PERFORMANCE GOALS

In Chapter 11, students are introduced to many basic genetics concepts. Lesson assessments provide real-life genetics problems for students to solve using their knowledge of chapter concepts. At the end of the chapter, students will complete assessment tasks that require creative writing and critical thinking skills to synthesize knowledge of meiosis, patterns of inheritance, and gene linkage.
GREEN PARAKEETS

Susan’s birthday was coming up. Parakeets make great pets, so Susan’s parents decided to give two birds to her as a birthday present. At the pet store, they selected two healthy green parakeets—one male and one female. They knew that green was Susan’s favorite color.

Susan was delighted about her birthday present. She fed the birds and kept their cage clean. A few weeks later, Susan found three small eggs in the birds’ nest. She couldn’t wait to welcome three new green parakeets. When the eggs finally hatched, however, Susan was amazed. None of the chicks was green—one chick was white, one was blue, and one was yellow. Why weren’t any of them green? What had happened to the green color of the birds’ parents? As you read this chapter, look for clues to help you identify why the parakeet chicks were differently colored than their parents. Then, solve the mystery.

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

What’s Online
Extend your reach by using these and other digital assets offered at Biology.com.

CHAPTER MYSTERY
As students delve into the principles of heredity, they uncover clues that help them solve the seeming paradox of yellow, blue, and white offspring from green parents.

UNTAMED SCIENCE VIDEO
Take a trip back in time with the Untamed Science crew in Genetics Takes Root to see Mendel in action.

INTRODUCTORY ART
Students can use this interactive activity to learn more about Punnett squares.

ART REVIEW
Students can use this drag-and-drop activity to review inheritance patterns using Punnett squares.

ART IN MOTION
This short animation shows students how genetic material is separated during meiosis.

TUTOR TUBE
To help students better understand the process of meiosis, the tutor makes connections between meiosis and Punnett squares.

DATA ANALYSIS
Students analyze the connection between crossing-over and gene location.
Getting Started

Objectives

11.1.1 Describe Mendel’s studies and conclusions about inheritance.

11.1.2 Describe what happens during segregation.

Build Background

Show students a picture of a large family that includes at least two generations. Ask students to list some physical characteristics that the younger family members likely inherited from their parents or grandparents. Invite volunteers to share one or two items on their list. Then, encourage students to share their ideas about the inheritance of traits.

The Work of Gregor Mendel

THINK ABOUT IT What is an inheritance? To many people, it is money or property left to them 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 hair, and so much more. Most people leave their money and property behind by writing a will. But what kind of inheritance makes a person’s face round or their hair curly?

The Experiments of Gregor Mendel

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 that inheritance is passed from generation to generation. The delivery of characteristics from parent to offspring is called heredity. The scientific study of heredity, known as genetics, is the key to understanding what makes each organism unique.

The modern science of genetics was founded by an Austrian monk named Gregor Mendel. Mendel, shown in Figure 11–1, was born in 1822 in what is now the Czech Republic. After becoming a priest, Mendel spent several years studying science and mathematics at the University of Vienna. He spent the next 14 years working in a monastery and teaching high school. 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 and easy to grow. A single pea plant can produce hundreds of offspring. Today we call peas a “model system.” Scientists use model systems because they are convenient to study and may tell us how other organisms, including humans, actually function. 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 that would have taken decades—if not centuries—to do with pigs, horses, or other large animals.

FIGURE 11–1 Gregor Mendel

Teach for Understanding

ENDURING UNDERSTANDING DNA is the universal code for life; it enables an organism to transmit hereditary information and, along with the environment, determines an organism’s characteristics.

GUIDING QUESTION How does an organism pass its characteristics on to its offspring?

EVIDENCE OF UNDERSTANDING After completing the lesson, give students the following assessment to show they understand how Gregor Mendel contributed to our knowledge of how an organism passes its characteristics on to its offspring. Have each student write a short story about Mendel’s experiments using the first person point of view, as if Gregor Mendel was writing the story himself. Tell them that their stories should clearly explain Mendel’s experiments and his conclusions.
**The Role of Fertilization** When Mendel began his experiments, he knew that the male part of each flower makes pollen, which contains the plant’s male reproductive cells, called sperm. Similarly, Mendel 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 self-pollinating, which means that sperm cells 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 would produce offspring identical to themselves. In other words, the traits of each successive generation would be the same. A trait is a specific characteristic, such as seed color or plant height, of an individual. Many traits vary from one individual to another. For instance, one stock of Mendel’s seeds produced only tall plants, while another produced only short ones. One line 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 had to prevent self-pollination. He did so by cutting away the pollen-bearing male parts of a flower. He then dusted the pollen from a different plant onto the female part of that flower, as shown in Figure 11–2. This process, known as cross-pollination, produces a plant that has two different parents. Cross-pollination allowed Mendel to breed plants with traits different from those of their parents and then study the results.

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

**IN YOUR NOTEBOOK** Explain, in your own words, what fertilization is.

---

**Teach**

**Build Science Skills**

Explain that much of Mendel’s success came from his choice of experimental organism. Pea plants are useful for genetic study because they have many contrasting characteristics, reproduce sexually, have easily controlled crosses, have short life cycles, produce a large number of offspring, and are also easy to grow.

**Ask** What other characteristics of pea plants made them useful for Mendel’s studies? (self-pollination and true-breeding)

Emphasize that offspring from one plant continued to have the same traits because hereditary information came from only one parent.

Then, give students lilies, tulips, or other flowers with large stamens and pistils. Help them observe the intact flower with a hand lens and identify the male and female parts. Instruct them to cut off the stamens and pistils and examine these parts individually. Students may be able to observe pollen and egg cells with a compound microscope on low power. Then, have students draw a labeled diagram of their observations. Finally, have them write an explanation of how Mendel accomplished cross-pollination and how this procedure affected the information passed from parents to offspring.

**DIFFERENTIATED INSTRUCTION**

**Struggling Students** Some students may have difficulty understanding how identical offspring can result during sexual reproduction. Explain that self-pollination can occur in the same flower or different flowers from the same plant. The offspring of self-pollinating, true-breeding plants get a combination of hereditary information from the egg cell and the sperm cell. But, because the hereditary information is the same in the egg and in the sperm, these combinations still result in the same traits.

**Answers**

**FIGURE 11–2** The flower with the female part intact no longer had its own source of pollen.

**IN YOUR NOTEBOOK** Explanations should include that male and female reproductive cells join to form a new cell.
LESSON 11.1

**Teach continued**

**Use Visuals**

Use Figure 11–3 to review the different forms of each trait in the peas Mendel studied. Explain that the traits in pea plants have two distinct forms. Direct students’ attention to the trait of seed shape.

**Ask** What does it mean for the trait of roundness to be dominant in the F₁ generation? (If a plant has one allele for round and one for wrinkled, the offspring will have a round seed shape.)

**DIFFERENTIATED INSTRUCTION**

**ELL** Special Needs Check that students understand the symbols P and F₁ in Figure 11–3. Then, explain that the symbol × stands for “cross,” and point out the example of a round-seeded plant crossed with a wrinkled-seeded plant. Draw the chart on the board in a new orientation with Trait, Parent 1, Parent 2, and Offspring as column heads. Start filling in the chart by writing × between Parent 1 and Parent 2 and → between Parent 2 and Offspring. Write “seed shape” under Trait, “round” under Parent 1, “wrinkled” under Parent 2, and “round” under Offspring. Have students complete the chart in this way for the rest of the traits from Figure 11–3.

**Focus on ELL:**

**Access Content**

**ALL SPEAKERS** Model how a recessive allele can be masked by a dominant allele. Start by tapping both of your pointer fingers on your desktop. Tell students that a tapping finger models the expression of a dominant allele. The recessive allele for this trait is modeled by a silent, still finger. Show two fingers tapping, for homozygous dominant, and then two still fingers, for homozygous recessive. Then, tap one finger while keeping the other still. Point out that you can still hear tapping, or the dominant allele, even though only one finger is moving. Suggest pairs of students come up with their own models of dominance. Then, have each pair share their model with the class.

Remind students that an allele is one form of a gene. Then, have them make predictions about the number of alleles there might be for feather color. Guide them to conclude that there is likely more than two alleles since there are four possible phenotypes. Students can go online to Biology.com to gather their evidence.

Genes and Alleles When doing genetic crosses, we call each original pair of plants the P, or parental, generation. Their offspring are called the F₁, or first filial, generation. (Père and fille are the Latin words for “son” and “daughter.”)

What were Mendel’s F₁ hybrid plants like? To his surprise, for each trait studied, all the offspring had the characteristics of only one of its parents, as shown in Figure 11–3. 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, scientists call the factors that are passed from parent to offspring 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, the gene for plant height occurred in one form that produced tall plants and in another form that produced short plants. The different forms of a gene are called alleles (uh leez).

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 at least one dominant allele for a particular form of a trait will exhibit that form of the trait. An organism with a recessive allele for a particular form of a trait will exhibit its form only when the dominant allele for the trait is not present. In Mendel’s experiments, the allele for tall plants was dominant and the allele for short plants was recessive. Likewise, the allele for yellow seeds was dominant over the recessive allele for green seeds.

**Check for Understanding**

**QUESTION BOX**

Establish a question box or email address where students may post questions about the concepts in this lesson they do not understand. Collect the questions at the end of each class session and review them. At the beginning of the next class session, discuss the questions and answers with the class.

**ADJUST INSTRUCTION**

If several students are having difficulty understanding a concept, set up small study groups that each include at least one student who understands the material and can communicate well with other members. Have groups meet for a few minutes at the beginning or end of class to go over difficult concepts.
Use Visuals
Walk students through the crosses shown in Figure 11–4. Make sure they understand that the short trait reappeared because the F₁ generation had both tall and short alleles.

Ask Why didn’t the allele for shortness show in the F₁ generation? (The short allele is recessive. It was masked by the dominant allele for tallness.)

Ask Was the recessive allele for shortness lost in the F₁ generation? How do you know? (No, it reappeared in the F₂ generation.)

DIFFERENTIATED INSTRUCTION

Less Proficient Readers Help struggling readers make connections between the text and Figure 11–4. Explain that the text on this page focuses primarily on the bottom two parts of the figure. Have student volunteers read the text on the page a couple of sentences at a time. After each volunteer finishes reading, discuss how the text he or she just read is shown by or relates to Figure 11–4.

Advanced Students Challenge students to create a poster on which they identify Mendel’s question and hypothesis and outline his experimental design.

In Your Notebook Make a diagram that explains Mendel’s principle of dominance.

Segregation
How are different forms of a gene distributed to offspring?
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 F₁ hybrids to self-pollinate. The offspring of an F₁ cross are called the F₂ (second filial) generation. In effect, Mendel crossed the F₁ generation with itself to produce the F₂ offspring, as shown in Figure 11–4.

The F₁ Cross When Mendel compared the F₁ plants, he made a remarkable discovery: The traits controlled by the recessive alleles reappeared in the second generation. Roughly one fourth of the F₂ plants showed the trait controlled by the recessive allele. Why, then, did the recessive alleles seem to disappear in the F₁ generation, only to reappear in the F₂ generation?

### Trait Survey

<table>
<thead>
<tr>
<th>Feature</th>
<th>Dominant Trait</th>
<th>Number</th>
<th>Recessive Trait</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Free ear lobes</td>
<td>Attached ear lobes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B Hair on fingers</td>
<td>No hair on fingers</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C Widow’s peak</td>
<td>No widow’s peak</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D Curly hair</td>
<td>Straight hair</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E Cleft chin</td>
<td>Smooth chin</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. Form a Hypothesis Why do you think recessive traits are more common in some cases?

### Answers

**FIGURE 11-4** Three-fourths of the F₂ plants had a trait controlled by a dominant allele.

**IN YOUR NOTEBOOK** Students’ diagrams should have content similar to that in Figure 11–3.
Teach continued

Use Visuals

Make sure students understand the results of the F2 generation in Figure 11–5 by tracing the inheritance pattern. Point out how the F1 gametes segregated to produce new combinations of alleles in the F2 plants.

Differentiated Instruction

1L English Language Learners. Point out that, usually, the first letter of the dominant trait is used to represent a gene (T for Tall), though any letter could be used. Have students redraw Figure 11–5 using the letter and word for tall in their native language.

Assess and Remediate

Evaluate Understanding

Assign students a trait in pea plants from Figure 11–3. Have them set up a cross to show the hybrid F1 and resulting F2 offspring. Then, have them complete the 11.1 Assessment.

Remediation Suggestion

Lq Struggling Students If your students have trouble with Question 2b, choose a pea trait from Figure 11–3 besides height. Draw the alleles and gametes for the P generation through the F1 and F2 generations. Walk through each step, using the terms dominant, recessive, allele, gamete, and segregation.

Assessment Answers

1a. factors that are passed from one generation to the next
1b. dominant: form of an allele whose trait always shows up if it is present; recessive: form of an allele whose trait shows up only when the dominant allele is not present
1c. They have two identical alleles for a gene, so in a genetic cross, each parent contributes only one form of a gene, making inheritance patterns more detectable.
2a. separation of alleles
2b. The two alleles of the P generation separate during gamete formation. Each gamete carries only a single allele from each parent, which pairs at random in the F1 generation. The process repeats when F1 plants cross and produce F2 plants. As a result, the F2 generation has new combinations of alleles that may be different from those of preceding generations.
2c. A short plant appeared in the F1 generation, indicating that this plant had only recessive alleles, so the alleles in the F1 generation must have separated and then recombined when the plants were crossed.

Explaining the F1 Cross

To begin with, Mendel assumed that a dominant allele had masked the corresponding recessive allele in the F1 generation. However, the trait controlled by the recessive allele did show up in some of the F1 plants. This reappearance indicated that, at some point, the allele for shortness had separated from the allele for tallness. How did this separation, or segregation, of alleles occur? Mendel suggested that the alleles for tallness and shortness in the F1 plants must have segregated from each other during the formation of the sex cells, or gametes (gam-etz). Did that suggestion make sense?

The Formation of Gametes

Let’s assume, as Mendel might have, that all the F1 plants inherited an allele for tallness from the tall parent and one for shortness from the short parent. Because the allele for tallness is dominant, all the F1 plants are tall. 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 F1 plant produces two kinds of gametes—those with the tall allele and those with the short allele.

Look at Figure 11–5 to see how alleles separate during gamete formation and then pair up again in the F2 generation. A capital letter represents a dominant allele. A lowercase letter represents a recessive allele. Now we can see why the recessive trait for height, t, reappeared in Mendel’s F2 generation. Each F1 plant in Mendel’s cross produced two kinds of gametes—those with the allele for tallness and those with the allele for shortness. Whenever a gamete that carried the t allele paired with the other gamete that carried the T allele to produce an F2 plant, that plant was short. Every time one or both gametes of the pairing carried the T allele, a tall plant was produced. In other words, the F2 generation had new combinations of alleles.

Visual Thinking

3. Diagrams should be similar to Figures 11–4 and 11–5 and clearly show single alleles, as well as which alleles are dominant and which are recessive.
11.2 Applying Mendel’s Principles

THINK ABOUT IT 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 Punnett Squares

How can we use probability to predict traits?
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 stem height (Tt), about three fourths of the resulting plants were tall and about one fourth were short.

Upon analyzing his data, Mendel realized that the principles of probability could be used to explain the results of his genetic crosses. Probability is a concept you may have learned about in math class. It 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 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 1/2 probability of landing heads up. Therefore, the probability of flipping three heads in a row is:

\[
\frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} = \frac{1}{8}
\]

As you can see, you have 1 chance in 8 of flipping heads three times in a row. The multiplication of individual probabilities illustrates an important point: Past outcomes do not affect future ones. Just because you’ve flipped three heads in a row does not mean that you're more likely to have a coin land tails up on the next flip. The probability for that flip is still 1/2.

FIGURE 11–6 Probability
Probability allows you to calculate the likelihood that a particular event will occur. The probability that the coin will land heads up is \( \frac{1}{2} \), or 50 percent.

Teach for Understanding

ENDURING UNDERSTANDING DNA is the universal code for life; it enables an organism to transmit hereditary information and, along with the environment, determines an organism’s characteristics.

GUIDING QUESTION How can you predict the outcome of a genetic cross?

EVIDENCE OF UNDERSTANDING After completing the lesson, give students the following assessment to show they understand how to predict the outcome of a genetic cross. Have students create a “how-to” book based on lesson concepts. Their books should explain how to apply the principles of probability to predict outcomes of genetic crosses as well as how to construct and use Punnett squares.

Getting Started

Objectives

11.2.1 Explain how geneticists use the principles of probability to make Punnett squares.
11.2.2 Explain the principle of independent assortment.
11.2.3 Explain how Mendel’s principles apply to all organisms.

Student Resources

Study Workbook A and B, 11.2 Worksheets
Spanish Study Workbook, 11.2 Worksheets
Lab Manual A, 11.2 Quick Lab Worksheet
Lab Manual B, 11.2 Hands-On Activity

For corresponding lesson in the Foundation Edition, see pages 266–270.
Teach

Connect to Math

To explain how probability principles work in genetic crosses, model the cross shown in Figure 11–7. Write Tt on the board, and draw a circle around it to represent the cell of one of the parents in the figure. Draw ten gamete circles under the parent cell. Then, draw an arrow from the parent cell to each gamete. To determine which allele (T or t) will go in each gamete circle, flip a coin. Tell students that heads represents the dominant allele (T) and tails represents the recessive allele (t). As you fill in each circle, flip the coin and repeat that the probability of a T or a t going to a gamete is one in two, or 1/2. Emphasize that each event is random and independent of the others and that probability predicts outcomes; it does not guarantee them. Then, do the same with another parent cell. Show two gametes joining, and explain that this event also is random and independent. Therefore, the probability of an F₁ cell having a particular combination of alleles is found by multiplying 1/2 × 1/2.

DIFFERENTIATED INSTRUCTION

Less Proficient Readers If students have trouble understanding the subsection Probabilities Predict Averages, have each student toss a coin 20 times and record the outcomes. Then, combine the data from the entire class. As you add in each student’s results, the overall data should get closer and closer to the expected ratio of one head to one tail.

Focus on ELL: Extend Language

BEGINNING, INTERMEDIATE, AND ADVANCED SPEAKERS Have students construct a three-column chart to record lesson vocabulary terms and any other terms they may find difficult. Label column 1 Words I Understand, column 2 Words I Think I Understand, and column 3 Words I Have Never Seen. Ask students to write the definitions in their own words for columns 2 and 3. Allow beginning speakers to dictate their definitions as you record them. Intermediate and advanced speakers should write their own definitions. Use the information in the chart to focus ELL instruction.

Answers

FIGURE 11–7 All of the offspring would be tall (TT or Tt).

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 F₁ cross, shown in Figure 11–7. This cross produced a mixture of tall and short plants. Why were just 1/4 of the offspring short? Well, the F₁ plants were both tall. If each plant had one tall allele and one short allele (Tt), and if the alleles segregated as Mendel thought, then 1/2 of the gametes produced by the plants would carry the short allele (t). Yet, the t allele is recessive. The only way to produce a short (tt) plant is for two gametes, each carrying the t allele, to combine.

Like the coin toss, each F₁ gamete has a one in two, or 1/2, chance of carrying the t allele. There are two gametes, so the probability of both gametes carrying the t allele is 1/2 × 1/2 = 1/4. In other words, roughly one fourth of the F₁ offspring should be short, and the remaining three fourths should be tall. 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 3/4 of the plants showed the trait controlled by the dominant allele. About 1/4 showed the trait controlled by the recessive allele. Segregation did occur according to Mendel’s model.

As you can see in the F₂ generation, not all organisms with the same characteristics have the same combinations of alleles. Both the TT and Tt allele combinations resulted in tall pea plants, but only one of these combinations contains identical alleles. Organisms that have two identical alleles for a particular gene—TT or tt in this example—are said to be homozygous (hoh oh zy gus). Organisms that have two different alleles for the same gene—such as Tt—are heterozygous (het ur oh zy gus).

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 head and one tail. 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.

The larger the number of offspring, the closer the results will be to the predicted values. If an F₁ generation contains just three or four offspring, it may not match Mendel’s ratios. When an F₂ generation contains hundreds or thousands of individuals, the ratios usually come very close to matching predictions.

Check for Understanding

HAND SIGNALS

Focus students’ attention on Figure 11–7, and present them with the following statements. Ask them to show a thumbs-up sign if they understand, a thumbs-down sign if they are confused, or a waving-hand sign if they partially understand.

• A tall plant can be homozygous or heterozygous. A short plant must be homozygous.
• One-half of the F₂ generation is heterozygous and one-half is homozygous, but three-fourths are tall and one-fourth is short.

Adjust Instruction

If students showed a thumbs-down or waving-hand sign, review the terms homozygous and heterozygous. Then, have small groups discuss why each statement is true.
Genotype and Phenotype  One of Mendel’s most revolutionary insights followed directly from his observations of F1 crosses: Every organism has a genetic makeup as well as a set of observable characteristics. All of the tall pea plants had the same genotype, or physical traits. They did not, however, have the same phenotype, or genetic makeup. Look again at Figure 11–7 and you will find three different genotypes among the F2 plants: TT, Tt, and tt. The genotype of an organism is inherited, and the phenotype is largely determined by the genotype. Two organisms may share the same phenotype but have different genotypes.

Using Punnett Squares  One of the best ways to predict the outcome of a genetic cross is by drawing a simple diagram known as a **Punnett square**. A Punnett square uses 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 into the boxes within the square, just as they might appear in the F2 generation. Figure 11–8 on the next page shows step-by-step instructions for constructing Punnett squares.

In Your Notebook  In your own words, write definitions for the terms homozygous, heterozygous, phenotype, and genotype.

### Quick Lab

**How Are Dimples Inherited?**

1. Write the last four digits of any telephone number. These four random digits represent the alleles of a gene that determines whether a person will have dimples. Odd digits represent the allele for the dominant trait of dimples. Even digits represent the allele for the recessive trait of no dimples.

2. Use the first two digits to represent a father’s genotype. Use the symbols D and d to write his genotype as shown in the example.

3. Use the last two digits the same way to find the mother’s genotype. Write her genotype.

4. Use Figure 11–8 on the next page to construct a Punnett square for the cross of these parents. Then, using the Punnett square, determine the probability that their child will have dimples.

5. Determine the class average of the percent of children with dimples.

**Analyze and Conclude**

1. **Apply Concepts**  How does the class average compare with the result of a cross of two heterozygous parents?

2. **Draw Conclusions**  What percentage of the children will be expected to have dimples if one parent is homozygous for dimples (DD) and the other is heterozygous (Dd)?

### Answers

**IN YOUR NOTEBOOK**  Sample answer: homozygous – an individual with two copies of the same allele of a gene; heterozygous – an individual with two different alleles for a gene; phenotype – the outward appearance of an individual; genotype – an individual’s genetic makeup.

---

### Lead a Discussion

Make sure students understand the difference between phenotype and genotype. Have students look at Figure 11–7 and note that tall plants have one phenotype but two possible genotypes.

**Ask** What are the two possible genotypes of a tall plant? (TT and Tt)

**Ask** What is the phenotype of a plant that has two alleles for shortness? (short)
### Lesson 11.2

#### Visual Summary

**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 asperry, or fish hawk, that are heterozygous for large beaks. They each have genotypes of Bb.

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

- **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.

- **Fill in the table** by combining the gametes’ genotypes.

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

**Two-Factor Cross**

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

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

- **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.

---

#### Differentiated Instruction

**Struggling Students** Students might need extra help figuring out the gametes in step 2 of the two-factor cross. Make sure they understand that each parent’s genotype includes two genes and that gametes get only one allele for each gene. Thus, for TtGg, there are two choices for height: T or t. No matter which of these goes into a gamete, there are two choices for color: G or g. So the number of possible combinations is 4; 2 x 2 = 4. Tell students that one way to double-check their work in step 4 is to make sure the letter above each column appears in the cells below it. Similarly, the letter to the left of the rows must appear in each cell in that row.

**English Language Learners** As you describe each step, use vocabulary terms as often as possible. For example, in step 4, point out that in the completed table on the right, BB is homozygous dominant, bb is homozygous recessive, and Bb is heterozygous. Phrase questions so that students answer using vocabulary terms.

---

**How Science Works**

**Inventor of the Punnett Square**

Reginald Punnett (1875–1967) was an English geneticist at Cambridge University who, along with William Bateson, was one of the first scientists to use Mendelian experimentation on plants and animals. Punnett devised the Punnett square to graphically represent the results of hybrid crosses. He also wrote a textbook on the subject of genetics and, together with Bateson, co-founded the Journal of Genetics, which is still in print today.
Independent Assortment

How do alleles segregate when more than one gene is involved?

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: F1
First, Mendel crossed true-breeding plants that produced only round yellow peas with plants that produced wrinkled green peas. The round yellow peas had the genotype RRYY, and the wrinkled green peas had the genotype rryy. All of the F1 offspring produced round yellow peas. These results showed that the alleles for yellow and round peas are dominant. As the Punnett square in Figure 11–9 shows, the genotype in each of these F1 plants is RrYy. In other words, the F1 plants were all heterozygous for both seed shape and seed color. This cross did not indicate whether genes assort, or segregate independently. However, it provided the hybrid plants needed to breed the F2 generation.

The Two-Factor Cross: F2
In the second part of this experiment, Mendel crossed the F1 plants to produce F2 offspring. Remember, each F1 plant was formed by the fusion of a gamete carrying the dominant RY alleles with another gamete carrying the recessive ry alleles. Did this mean that the two dominant alleles would always stay together, or would they segregate independently, so that any combination of alleles was possible?

In Mendel’s experiment, the F2 plants produced 556 seeds. Mendel compared their variation. He observed 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 11–10 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.

Use Visuals
Tell students the two-factor cross they learned about in Figure 11–8 is called a “dihybrid cross” because it involves two different traits. Refer them to Figure 11–9, and discuss the results of the F1 cross.

Ask Why didn’t Mendel know, from the results of the first cross, whether two genes segregated independently? (All the offspring had dominant alleles.)

Ask What evidence did Mendel have that alleles segregated independently in the cross shown in Figure 11–10? (All combinations of phenotypes resulted.)

Ask What phenotypes would Mendel have observed if the alleles did not segregate independently—in other words, if the RY always stayed together and the ry always stayed together? (round, yellow seeds and wrinkled, green seeds)

Differently, The offspring are heterozygous for each trait (RrYy).

Quick Facts

Calculating Probabilities Without Punnett Squares
You can obtain the outcomes of dihybrid or trihybrid crosses without setting up a Punnett square by multiplying probabilities. The ratio of dominant to recessive phenotypes in a monohybrid cross is 3:1. Using the example of seed color and shape, the chance of showing the dominant phenotype, having YY (or RR) or Yy (or Ry), in a monohybrid cross is 3/4. The chance of showing the recessive phenotype, having yy (or rr) is 1/4. You can find the chance of yellow, round peas by multiplying those two probabilities (3/4 x 3/4 = 9/16). If a third trait is added, for example, pod color, the same rules apply. Green pod color is dominant over yellow, so the chance of GG or Gg is 3/4 and the chance of gg is 1/4. For example, the probability of offspring with green, wrinkled peas and green pods is 3/64 (1/4 x 1/4 x 3/4).

Answers

Figure 11–9 The offspring are heterozygous for each trait (RrYy).
LESSON 11.2

Assess and Remediate

EVALUATE UNDERSTANDING

Assign students different pea traits from Figure 11–3. Instruct them to set up a Punnett square to show a cross between two pea plants that are heterozygous for the trait. They should give both the genotypic and phenotypic ratio of the offspring. Then, have them complete the 11.2 Assessment.

REMEDIATION SUGGESTION

Struggling Students If your students have trouble with Question 4, show them how to calculate that 29% (31/106) of the plants have white flowers. Explain that this is close to the 25% you would expect from a heterozygous cross, similar to the 3:1 ratio in the tall to short plants in the F₁ generation in Figure 11–7.

Students can check their understanding of lesson concepts with the Self-Test assessment. They can then take an online version of the Lesson Assessment.

A Summary of Mendel’s Principles

What did Mendel contribute to our understanding of genetics?

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 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 11–11. Drosophila can produce plenty of 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 can be used to study the inheritance of human traits and to calculate the probability of certain traits appearing in the next generation. You will learn more about human genetics in Chapter 14.

Assessment Answers

1a. the likelihood that a particular event will occur

1b. Punnett squares are used to show all of the combinations of alleles that might result from a cross and the likelihood that each might occur.

2a. During gamete formation, pairs of alleles for a gene segregate, or separate, independently of each other.

2b. 50 percent; the Punnett square should show a cross between a homozygous short plant (tt) and a heterozygous tall plant (Tt).

3a. The patterns of inheritance he observed form the basis of modern genetics.

3b. Fruit flies are small, easy to keep in the laboratory, and produce large numbers of offspring in a short period of time.

4. Of the 106 plants, 31 had white flowers; this is 29%, or approximately one-fourth, of the plants. To get an approximate 3:1 ratio of lavender to white flowers, the parent plant was heterozygous with the allele for lavender flowers being dominant. The Punnett square should show the self-pollination of a plant that is heterozygous for lavender flowers (Ll).
Beyond Dominant and Recessive Alleles

What are some exceptions to Mendel’s principles?

Despite the importance of Mendel’s work, there are important exceptions to most of his principles. For example, not all genes show simple patterns of inheritance. In most organisms, genetics is more complicated, because the majority of genes have more than two alleles. Also, many important traits are controlled by more than one gene. Understanding these exceptions allows geneticists to predict the ways in which more complex traits are inherited.

Incomplete Dominance

A cross between two four o’clock (Mirabilis jalapa) plants shows a common exception to Mendel’s principles. Some alleles are neither dominant nor recessive. As shown in Figure 11–12, the F₁ generation produced by a cross between red-flowered (RR) and white-flowered (WW) Mirabilis plants consists of pink-colored flowers (RW). 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.

Codominance

A similar situation arises from codominance, in which the phenotypes produced by both alleles are clearly expressed. For example, in certain varieties of chicken, 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. Unlike the blending of red and white colors in heterozygous four o’clocks, 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.

Key Questions

- What are some exceptions to Mendel’s principles?
- Does the environment have a role in how genes determine traits?

Vocabulary

- incomplete dominance
- codominance
- multiple allele
- polygenic trait

Taking Notes

Outline Make an outline using the green and blue headings. As you read, write bulleted notes below each heading to summarize its topic.

THINK ABOUT IT

Mendel’s principles offer a tidy set of rules with which to predict various patterns of inheritance. Unfortunately, biology is not a tidy science. There are exceptions to every rule, and exceptions to the exceptions. What happens if one allele is not completely dominant over another? What if a gene has several alleles?

ACTIVATE PRIOR KNOWLEDGE

Tell students to think about all the different shades of hair color that humans have. Then, ask if they think that hair color is controlled by just one gene. Lead students to conclude that there is likely more than one gene responsible for the color of human hair.

Teach for Understanding

ENDURING UNDERSTANDING

DNA is the universal code for life; it enables an organism to transmit hereditary information and, along with the environment, determines an organism’s characteristics.

GUIDING QUESTION

How can interactions between alleles, genes, and the environment affect an organism’s traits?

EVIDENCE OF UNDERSTANDING

After completing the lesson, give students the following assessment to show they understand different patterns of heredity. Have students write a short poem or rap using the following lesson vocabulary terms: incomplete dominance, codominance, multiple allele, and polygenic trait. Tell students their lyrics should show they understand what each term means. Have volunteers share their work with the class.

ACTIVITIES

- Lab Manual B, 11.3 Data Analysis Worksheet
- Biology.com, Lesson Overview • Lesson Notes • Activities: Art Review • Assessment: Self-Test, Lesson Assessment
- Spanish Study Workbook, 11.3 Worksheets
- Study Workbook A and B, 11.3 Worksheets

NATIONAL SCIENCE EDUCATION STANDARDS

UNIFYING CONCEPTS AND PROCESSES

CONTENT

C.2.a, C.2.b, G.2

INQUIRY

A.1.c, A.2.a
LESSON 11.3

Lead a Discussion

Explain that there being more than two alleles for a gene is common in a population. Make sure students understand, though, that any given individual in this population will have only two of those alleles. To illustrate this point, write the symbols for four alleles for rabbit coat color on the board in order from the most dominant to the least dominant: C = full color, C\textsuperscript{h} = chinchilla color, C\textsuperscript{H} = Himalayan color, c = albino (no color). Have students make up genetic crosses for coat color in rabbits. If desired, have them exchange their proposed crosses with a partner who can then use Punnett squares to solve the problems.

DIFFERENTIATED INSTRUCTION

Less Proficient Readers Help struggling students better understand lesson concepts by completing a Jigsaw Review activity. Form small learning circles of four students each. Assign each group member a number from 1 to 4. Have students regroup into study groups according to number (for example, all 1s together). Assign each group one of the four sections of text with blue heads under Beyond Dominant and Recessive Alleles. Have groups review the topic and create a brief lesson on it. Then, instruct students to re-form their original learning circles, and have each member of a circle teach the other members about his or her topic. If you have more students, add Genes and the Environment as a topic.

Study Wkbks A/B, Appendix S7, Jigsaw Review.

Have students discuss whether they think feather color is polygenic. Lead them to conclude that there are likely two genes controlling feather color, one for each pigment. Students can go online to Biology.com to gather their evidence.

Address Misconceptions

Polygenic Traits Many students think that one gene is always responsible for one trait. Explain that such a case is actually rare. Most traits—such as hair and eye color in humans—are influenced by multiple genes.

Answers

IN YOUR NOTEBOOK Students’ descriptions should reflect that multiple alleles are more than two forms of the same gene in a population and polygenic traits have more than one gene contributing to the phenotype of an individual.

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 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.

Another gene controls a second type of antigen, known as Rh factor. Rh\textsuperscript{+} individuals carry this antigen, while Rh\textsuperscript{−} ones don’t. This chart of the U.S. population shows the percentage of each blood type.

1. Interpret Graphs Which blood type makes up the greatest percentage of the U.S. population?
2. Calculate What percentage of the total U.S. population has a positive Rh factor? What percentage has a negative Rh factor?
3. Infer Which blood type can be used for transfusion into the largest percentage of individuals? Which type has the smallest percentage of possible donors available?
4. Predict Could a person with O\textsuperscript{−} blood have two parents with O\textsuperscript{−} blood? Could that person have a daughter with AB\textsuperscript{+} blood? Explain your answers.

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. 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.

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. Polygenic means “many genes.” For example, at least three genes are involved in making the reddish-brown pigment in the eyes of fruit flies. Polygenic traits often show a wide range of phenotypes. The variety of skin color in humans comes about partly because more than four different genes probably control this trait.

In Your Notebook In your own words, describe multiple alleles and polygenic traits. How are they similar? How are they different?

ANSWERS

1. O\textsuperscript{+}
2. 85% are Rh\textsuperscript{+}; 15% are Rh\textsuperscript{−}.
3. O\textsuperscript{−} can be used for 100% of individuals; AB\textsuperscript{+} can be used for only 4%.
4. No, because both parents would be homozygous recessive for the Rh factor. They do not have any Rh\textsuperscript{+} alleles to pass on. This person could not have an AB\textsuperscript{+} daughter, because a person with O\textsuperscript{+} blood has only O alleles to pass on.
Genes and the Environment

Does the environment have a role in how genes determine traits?

The characteristics of any organism—whether plant, fruit fly, or human being—are not determined solely by the genes that 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 western white butterfly, *Ponita occidentalis*, shown in Figure 11–13. It is found throughout western North America. Butterfly enthusiasts had noted for years that western whites hatching in the summer (right) had different color patterns on their wings than those hatching in the spring (left). Scientific studies showed the reason—butterflies hatching in the shorter days of springtime 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 determined by its environment as well as its genes.

In the case of the western white butterfly, these changes in wing pigmentation are particularly important. In order to fly effectively, the body temperature of the butterfly must be 28ºC–40ºC (about 84ºF–104ºF). 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 moths to avoid overheating.

**Review Key Concepts**

1. **a. Review** What does incomplete dominance mean? Give an example.
   
   **b. Design an Experiment** Design an experiment to determine whether the pink flowers of petunia plants result from incomplete dominance.

2. **a. Review** What is the relationship between the environment and phenotype?
   
   **b. Infer** What might be the result of an exceptionally hot spring on wing pigmentation in the western white butterfly?

**Environmental Temperature and Butterfly Needs**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>28–40ºC</td>
<td>26.5ºC</td>
<td>34.8ºC</td>
</tr>
</tbody>
</table>

**FIGURE 11–13 Temperature and Wing Color**

Western white butterflies that hatch in the spring have darker wing patterns than those that hatch in 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. **Calculate** What is the difference between the minimum temperature these butterflies need to fly and the average spring temperature? **Would the same calculation apply to butterflies developing in the summer?**

**Assessments and Remediation**

**EVALUATE UNDERSTANDING**

Ask volunteers to explain the four patterns of inheritance described in this lesson, as well as how environmental factors can influence phenotypes. Then, have students complete the 11.3 Assessment.

**REMEDICATION SUGGESTIONS**

- **Struggling Students** If your students have trouble with Question 1b, have them work in pairs or small groups to brainstorm possible experiments.

- **Students** Students can check their understanding of lesson concepts with the Self-Test assessment. They can then take an online version of the Lesson Assessment.

**Answers**

**FIGURE 11–13** 1.5ºC; No, because the average summer temperature is greater than the minimum temperature the butterflies need to fly.

**Practice Problem**

3. Students’ problems should follow the rules of genetics and include correct and complete answers.
If you enjoy learning about genetics, you may want to pursue one of the careers listed below.

**FORENSIC SCIENTIST**
Do you enjoy solving puzzles? That’s what forensic scientists do when they solve crimes. Local, state, and federal agencies employ forensic scientists to use scientific approaches that support criminal investigations. Criminalists are forensic scientists who specialize in the analysis of physical evidence, such as hair, fiber, DNA, fingerprints, and weapons. They are often called to testify in trials as expert witnesses.

**PLANT BREEDER**
Did you ever wonder how seedless watermelons become seedless? They are the product of a plant breeder. Plant breeders use genetic techniques to manipulate crops. Often, the goal is to make a crop more useful by increasing yield or nutritional value. Some breeders introduce new traits, such as pesticide resistance, to the plant’s genetic makeup.

**POPULATION GENETICIST**
Why are certain populations more susceptible to particular diseases? This is the kind of question that population geneticists answer. Their goal is to figure out why specific traits of distinct groups of organisms occur in varying frequencies. The patterns they uncover can lead to an understanding of how gene expression changes as a population evolves.

---

**Quick Facts**

**THE GENETICS OF LUPUS**
Lupus presents in different forms, but the most common type damages joints, skin, blood vessels, and organs such as the kidneys and brain. The disease has no cure. Lupus has a complex inheritance pattern. It runs in families but is not solely a genetic disease, leading scientists to think lupus has a genetic susceptibility and is polygenic. The genes involved in lupus vary in populations. The prevalence of lupus is higher in African Americans, Latinos, Asians, and Native Americans. Because lupus is rare in Africa, some scientists think environmental risk factors that are common in the United States and Europe but rare in Africa might trigger the disease.

---

**Answers**

**WRITING** Students’ explanations might include financial burdens, inadequate health care, and decreased quality of life.

---

**NATIONAL SCIENCE EDUCATION STANDARDS**

**UCP I, II**

**CONTENT** C.2.a, G.1

**INQUIRY** A.2.b
11.4 Meiosis

THINK ABOUT IT 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

How many sets of genes are found in most adult organisms? 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—are the carriers of genes. The genes are located in specific positions on chromosomes.

Diploid Cells Consider the fruit fly that Morgan used, Drosophila. A body cell in an adult fruit fly has eight chromosomes, as shown in Figure 11–14. Four of the chromosomes come from its male parent, and four come from its female parent. These two sets of chromosomes are homologous (hoh maht ih guh), meaning that each of the four chromosomes from the male parent has a corresponding chromosome from the female parent. A cell that contains both sets of homologous chromosomes is said to be diploid, meaning “two sets.” 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, which can be written as 2N = 8, where N represents the single set of chromosomes found in a sperm or egg cell.

Haploid Cells Some cells contain only a single set of chromosomes, and therefore a single set of genes. Such cells are haploid, meaning “one set.” The gametes of sexually reproducing organisms, including fruit flies and peas, are haploid. For Drosophila gametes, the haploid number is 4, which can be written as N = 4.

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?

Vocabulary

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

Taking Notes

Compare/Contrast Table Before you read, make a compare/contrast table to show the differences between mitosis and meiosis. As you read, complete the table.

FIGURE 11–14 Fruit Fly Chromosomes These chromosomes are from a fruit fly. Each of the fruit fly’s body cells is diploid, containing eight chromosomes.

Getting Started

Objectives

11.4.1 Contrast the number of chromosomes in body cells and in gametes.
11.4.2 Summarize the events of meiosis.
11.4.3 Contrast meiosis and mitosis.
11.4.4 Describe how alleles from different genes can be inherited together.

Student Resources

Study Workbook A and B, 11.4 Worksheets
Spanish Study Workbook, 11.4 Worksheets
Lab Manual B, 11.4 Data Analysis Worksheet

Build Background

Create a class Cluster Diagram for meiosis. Write the term on the board, and have student volunteers add any facts, terms, or concepts they know to the diagram. Refer to the cluster diagram as you work through the lesson.

Study Wkbks A/B, Appendix S19, Cluster Diagram.
Transparencies, GO2.

Teach for Understanding

ENDURING UNDERSTANDING DNA is the universal code for life; it enables an organism to transmit hereditary information and, along with the environment, determines an organism’s characteristics.

GUIDING QUESTION How does a cell divide to create cells with exactly half of the original cell's genetic information?

EVIDENCE OF UNDERSTANDING After completing the lesson, give students the following assessment to show they understand how a cell divides to create cells with exactly half of the original cell's genetic information. Have students use colored pencils to draw their own labeled diagrams of the phases of meiosis. In their diagrams, have them show how genes assort independently. Suggest they use homzygous alleles Y and y.

NATIONAL SCIENCE EDUCATION STANDARDS

UNIFYING CONCEPTS AND PROCESSES

I, II

CONTENT

C.2.a, C.2.b

INQUIRY

A.1.c, A.2.a, A.2.b
During meiosis I, a diploid cell undergoes a series of events that result in the production of two daughter cells. Neither daughter cell has the same sets of chromosomes that the original diploid cell had.

**Interpret Graphics** How does crossing-over affect the alleles on a chromosome?

**Differential Instruction**

**Struggling Students** Some students might be confused by the number of chromosomes at each stage. Remind them that haploid and diploid refer to the number of sets of chromosomes in a cell. Help them understand that at the beginning of interphase, the cell is diploid or 2N. In this case, it contains two chromosomes. Emphasize that this is not shown in the figure. Explain that, during interphase, the chromosomes replicate and the cell becomes 4N (it has 8 chromatids, or 4 chromosomes). Have students verify that the cells are still 4N in the prophase, metaphase, and anaphase stages. When the cells divide in telophase I and cytokinesis, each cell has half the number of chromosomes, but it is not considered diploid because it contains only one duplicated set of chromosomes.

**Focus on ELL:**

**Build Background**

Refer students to Figure 11–15, and have them identify the cell structures they learned about when they studied mitosis. Point out the centrioles, chromosomes, centromeres, and spindles. Use previously learned and new vocabulary terms frequently as you walk them through the visual and ask questions requiring them to use those terms. Then, have students draw and label their own diagrams of the phases of meiosis. Beginning speakers can use single words or phrases or their native language to write captions. Intermediate speakers should write complete sentences. Ask students to describe their diagrams to a partner.

**Answers**

**Figure 11–15** During crossing-over, the alleles can be exchanged between chromatids of homologous chromosomes to produce new combinations of alleles.

**Biology In-Depth**

**Genetic Variation in Meiosis Phases**

Genetic variation occurs during meiosis in several phases. During prophase I crossing-over, sister chromatids become attached and swap sections at points called chiasmata. The sections are portions of adjacent DNA molecules. Neither chromatid gains or loses any genes. In humans (23 chromosomes), if only one cross-over event occurs in each tetrad (and it is usually two or three), over 70 trillion combinations are possible ($4^{23}$). During metaphase I, homologous pairs of chromosomes line up randomly with respect to orientation; each pair can line up in two different ways. The number of possible combinations is over 8 million ($2^{23}$). When those numbers are multiplied together and that result is multiplied by two because of fertilization, you can see why each person is unique!
Meiosis I results in two cells, called daughter cells. However, because each pair of homologous chromosomes was separated, neither daughter cell has the two complete sets of chromosomes that it would have 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 are different from each other and from the diploid cell that entered meiosis I.

**Meiosis II** The two cells now enter a second meiotic division. 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 receive two chromosomes. These four daughter cells now contain the haploid number (N)—just two chromosomes each.

**Gametes to Zygotes** The haploid cells produced by meiosis II are the gametes that are so important to heredity. In male animals, these gametes are called sperm. In some plants, pollen grains contain haploid sperm cells. In female animals, generally only one of the cells produced by meiosis is involved in reproduction. The female gamete is called an egg in animals and an egg cell in some plants. After it is fertilized, the egg is called a zygote (zy goht). The zygote undergoes cell division by mitosis and eventually forms a new organism.

**In Your Notebook** Describe the difference between meiosis I and meiosis II. How are the end results different?

**Use Visuals**

Draw students’ attention to the two cells at the top of Figure 11–16. Reinforce that, while each has a 2N number of chromosomes, the cells are not considered diploid because the chromatid strands in the replicated chromosomes came from the same parent. Then, have volunteers use their own words to describe what occurs during each step of meiosis II.

**Ask** How many haploid (N) daughter cells are produced at the end of meiosis II? (four)

**Ask** What are some differences between meiosis I and meiosis II? (Sample answer: homologous chromosomes separate during meiosis I but not during meiosis II. The centromeres and sister chromatids separate during meiosis II.)

**DIFFERENTIATED INSTRUCTION**

**Special Needs** Help students model the steps in meiosis using pipe cleaners of the same color to represent chromosome pairs, with different pairs having different colors. Monitor students to make sure they double each chromosome before meiosis begins by adding another pipe cleaner of the same color. They can use beads to hold the chromatids together or twist the pipe cleaners together in the middle. Make sure they separate the chromosome pairs during meiosis I and the chromatids during meiosis II.

**Less Proficient Readers** Have students write an outline of meiosis in which each major step is a main heading. Suggest they include the information in the boldface Key Concepts as details.

Students can view the phases of meiosis online in [Art in Motion: Meiosis](#). For extra help, have students view [Tutor Tube: Connecting Punnett Squares to Meiosis](#).

**Answers**

**IN YOUR NOTEBOOK** Answers should include the following: Meiosis I involves chromosome replication, formation of tetrads, crossing-over, separation of paired homologous chromosomes, and division into two cells. Meiosis II includes separation of sister chromatids as each cell divides. The end result of meiosis I is two genetically different cells, each containing the same number of chromosomes as the original cell but recombined due to crossing-over. The end result of meiosis II is four different haploid cells.
Teach continued

Differentiated Instruction

L Special Needs Provide students with beads and pipe cleaners of different colors, and have them model the steps in mitosis. Help them to arrange this model next to the model they made of meiosis earlier. Then, ask them to explain what is happening in each phase of mitosis and tell how those phases are similar and different to those of meiosis. Suggest students glue their models to poster board to use as a study guide.

L Struggling Students Students who have difficulty understanding the Visual Summary might benefit from drawing diagrams that show only the chromosomes without the distraction of other structures, such as the spindle fibers. Help them draw circles for each phase of mitosis and meiosis and fill in only the chromosomes at each stage. Then, have them write simple captions that describe what is happening in each phase.

L Advanced Students To add detail to the students’ comparisons of mitosis and meiosis, have them create a third column for Figure 11–17 on a separate sheet of paper labeled Meiosis II. Have students use Figure 11–16 as a model for drawing corresponding diagrams for prophase II, metaphase II, anaphase II, and telophase II. Then, have students use their extended visual summary to compare the two processes in more detail.

Biology In-Depth

Polar Bodies

In many female animals, cytokinesis at the end of meiosis I and meiosis II is uneven. At the end of meiosis I, one of the cells receives most of the cytoplasm and is called a secondary oocyte. The cell that receives very little is the polar body. At the end of meiosis II, the secondary oocyte divides so that once again one cell receives most of the cytoplasm; this cell becomes the egg, and the other cell is another polar body. The polar body formed at the end of meiosis I divides into two polar bodies in meiosis II. The three polar bodies eventually die. The reason for the uneven divisions is the allotment of more materials in the egg cell to nourish the zygote.
Comparing Meiosis and Mitosis

How is meiosis different from mitosis?

The words mitosis and meiosis may sound similar, but the two processes are very different, as you can see in Figure 11–17. Mitosis can be a form of asexual reproduction, whereas meiosis is an early step in sexual reproduction. There are three other ways in which these two processes differ.

Replication and Separation of Genetic Material

Mitosis and meiosis are both preceded by a complete copying, or replication, of the genetic material of chromosomes. However, the next steps differ dramatically: In mitosis, when the two sets of genetic material separate, each daughter cell receives one complete set of chromosomes. In meiosis, homologous chromosomes line up and then move to separate daughter cells. As a result, the two alleles for each gene are segregated, and end up in different cells. The sorting and recombination of genes in meiosis result in a greater variety of possible gene combinations than could result from mitosis.

Changes in Chromosome Number

Mitosis does not normally change the chromosome number of the original cell. This is not the case for meiosis, which 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.

Calculating Haploid and Diploid Numbers

Haploid and diploid numbers are designated by the algebraic notations N and 2N, respectively. Either number can be calculated when the other is known. For example, if the haploid number (N) is 3, the diploid number (2N) is 2 × 3, or 6. If the diploid number (2N) is 12, the haploid number (N) is 12/2, or 6.

The table shows haploid or diploid numbers of a variety of organisms. Copy the table into your notebook and complete it. Then, use the table to answer the questions that follow.

<table>
<thead>
<tr>
<th>Organism</th>
<th>Haploid Number</th>
<th>Diploid Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amoeba</td>
<td>N=25</td>
<td></td>
</tr>
<tr>
<td>Chimpanzee</td>
<td>N=24</td>
<td></td>
</tr>
<tr>
<td>Earthworm</td>
<td>N=18</td>
<td></td>
</tr>
<tr>
<td>Fern</td>
<td>N=22</td>
<td>2N=1010</td>
</tr>
<tr>
<td>Hamster</td>
<td>N=22</td>
<td>2N=1010</td>
</tr>
<tr>
<td>Human</td>
<td>N=22</td>
<td>2N=46</td>
</tr>
<tr>
<td>Onion</td>
<td>N=22</td>
<td>2N=16</td>
</tr>
</tbody>
</table>

1. Calculate What are the haploid numbers for the fern and onion plants?

2. Interpret Data In the table, which organisms’ diploid numbers are closest to that of a human?

3. Apply Concepts Why is a diploid number always even?

4. Evaluate Which organism’s haploid and diploid numbers do you find the most surprising? Why?

ANSWERS

1. fern—505; onion—8
2. chimpanzee and hamster
3. Any number multiplied by 2 is always even.
4. Sample answer: A fern’s numbers were most surprising, because the number of chromosomes is so large.

Lead a Discussion

After students have read through Comparing Meiosis and Mitosis, have pairs of students reread the three Key Concepts and discuss why each one is important. Then, have them share their ideas with the class.

DIFFERENTIATED INSTRUCTION

L1 Special Needs Provide students with three different pairs of items to represent three gene pairs. Each member of a pair should be different from the other. Examples are two differently shaped buttons, two differently colored pencils, and two different kinds of coins. Tell students to use these objects to contrast the results of mitosis and meiosis. (After mitosis, a cell would have the same six items. After meiosis, a gamete could have any combination of button, pencil, and coin.) Students should show the different possible combinations as a result of meiosis.

L3 Advanced Students Provide various art materials for students, and challenge them to illustrate what might happen if sex cells, or gametes, did not have half the number of chromosomes as body cells. Have them present their models to the class and explain why sex cells must have half the number of chromosomes as body cells.
Use Models

Have students demonstrate why genes that are close together do not usually assort independently. Ask them to use two differently colored markers to draw two paired chromosomes. Have them place three symbols (in the same color as the chromosome) along each chromosome to indicate the relative positions of the genes for star eye, dumpy wing, and speck wing as indicated in Figure 11–18. Then, have another student point to the same spot on both chromosomes to identify a location for crossing-over. Have pairs redraw the chromosomes as if crossing-over occurred, using the two colors to show the parts of the chromosomes that have exchanged. Then, have them use the symbols to check for gene linkage.

Ask Which genes are most likely inherited together? Why? (Star eye and dumpy wing. Because these genes are so close together on the chromosome, the chance that crossing-over would separate them is smaller.)

DIFFERENTIATED INSTRUCTION

ELL Struggling Students Refer students who need extra help to the close-up image of crossing-over in Figure 11–15. Point out that chunks of the chromosomes, not individual genes, are exchanged between chromosomes. Have students model gene linkage in crossing-over by using different colors of modeling clay to represent each chromosome. Students can pull apart chunks of one color clay and attach them to the other color.

ELL English Language Learners Show students a road map, and point out how maps show where things such as cities and roads are located. Then, point to Figure 11–18, and tell them a gene map shows where genes are located.

Biology.com Students can analyze the connection between crossing-over and gene location in Data Analysis: Gene Location and Crossing-Over.

Answers

FIGURE 11–18 The “purple eye” gene is located at 54.5.

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.

Gene Linkage and Gene Maps

How can two alleles from different genes be inherited together?

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 fruit flies led him to the principle of gene linkage. After identifying more than 50 Drosophila genes, Morgan discovered that many of them 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. Only rarely did the genes separate from each other. 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.

FIGURE 11–18 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 Graphics Where on the chromosome is the “purple eye” gene located?

<table>
<thead>
<tr>
<th>Exact location on chromosome</th>
<th>Chromosome 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>Aristless (no bristles on antenna)</td>
</tr>
<tr>
<td>1.3</td>
<td>Star eye</td>
</tr>
<tr>
<td>13.0</td>
<td>Dumpy wing</td>
</tr>
<tr>
<td>31.0</td>
<td>Dachs (short legs)</td>
</tr>
<tr>
<td>48.5</td>
<td>Black body</td>
</tr>
<tr>
<td>51.0</td>
<td>Reduced bristles</td>
</tr>
<tr>
<td>54.5</td>
<td>Purple eye</td>
</tr>
<tr>
<td>55.0</td>
<td>Light eye</td>
</tr>
<tr>
<td>67.0</td>
<td>Vestigial (small) wing</td>
</tr>
<tr>
<td>75.5</td>
<td>Curved wing</td>
</tr>
<tr>
<td>99.2</td>
<td>Arc (bent wings)</td>
</tr>
<tr>
<td>104.5</td>
<td>Brown eye</td>
</tr>
<tr>
<td>107.0</td>
<td>Speck wing</td>
</tr>
</tbody>
</table>

Ubd Check for Understanding

FOLLOW-UP PROBES

Ask students the following questions:

• Why are the alleles for reddish-orange eyes and miniature wings in fruit flies usually inherited together? (The genes are located near each other on the same chromosome.)

• Morgan found that fruit flies, with their four pairs of chromosomes, had four linkage groups. Why does this make sense? (Each chromosome is a set of linked genes.)

ADJUST INSTRUCTION

If students have difficulty answering the questions, have them reread the text on gene linkage and Morgan’s work. Have pairs of students summarize Morgan’s work. Ask several pairs to share their summaries with the class.
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, or design, several of the genes he studied are on different chromosomes. Others are on the same chromosome.

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. 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 11–18, ever since this discovery.

Assess and RemEDIATE

EVALUATE UNDERSTANDING

Have students verbally list the stages of meiosis in order and describe in their own words what occurs during each stage. Then, have them complete the 11.4 Assessment.

REMEDICATION SUGGESTION

Struggling Students If your students have trouble with Question 3, review with them the text of Diploid Cells and the first paragraph of Meiosis I. Then, have them draw diagrams to show how homologous chromosomes are formed from two parent cells joining and how sister chromatids are formed by replication within a single cell.

Students can check their understanding of lesson concepts with the Self-Test assessment. They can then take an online version of the Lesson Assessment.

Assessment Answers

1a. Meiosis results in four haploid cells that are genetically different from one another and from the original cell.
1b. Each gamete cell has 23 chromosomes.
2a. Check that student answers include accurate summaries of interphase I, prophase I and II, metaphase I and II, anaphase I and II, telophase I and II, and cytokinesis I and II.
2b. Shoes are in pairs as are chromosomes in a diploid cell. A “haploid” shoe collection would have only one shoe of each kind.
3a. Mitosis produces two genetically identical diploid cells. Meiosis produces four genetically different haploid cells.
3b. The sister chromatids are identical, because one is a copy of the other. The homologous pairs are not identical; one chromosome comes from the mother and one comes from the father.
4a. It is the chromosomes that assort independently, not individual genes.
4b. The two genes are located very far apart from each other.
5. Sexual reproduction; during meiosis, the shuffling and separating of homologous chromosomes and crossing-over events produce gametes genetically different from each other and from the original cell. Fertilization with a gamete from a different parent further increases genetic variation.
Pre-Lab

Introduce students to the concepts they will explore in the chapter lab by assigning the Pre-Lab questions.

Lab

Tell students they will perform the chapter lab Modeling Meiosis described in Lab Manual A.

Struggling Students A simpler version of the chapter lab is provided in Lab Manual B.

Look online for Editable Lab Worksheets.

For corresponding pre-lab in the Foundation Edition, see page 280.

Pre-Lab Answers

BACKGROUND QUESTIONS

a. Alleles are different forms of the same gene.

b. During prophase I, homologous chromosomes form tetrads. The tetrads line up across the center of the cell during metaphase I and are pulled to opposite ends of the cells during anaphase I.

c. During meiosis, homologous chromosomes separate, two cell divisions occur, and daughter cells have half as many chromosomes. During mitosis, homologous chromosomes are not separated, only one cell division occurs, and the number of chromosomes per cell does not change.

PRE-LAB QUESTIONS

1. There must be an allele for each gene on each chromosome in the homologous pair.

2. Genes that are on the same chromosome are likely to be linked. The chances of crossing-over are greater on the longer chromosome.

3. There could be four different combinations (ignoring any variation due to crossing-over).
11 Study Guide

11.1 The Work of Gregor Mendel
- An individual’s characteristics are determined by factors that are passed from one parental generation to the next.
- During gamete formation, the alleles for each gene segregate from each other so that each gamete carries only one allele for each gene.

11.2 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.

11.3 Other Patterns of Inheritance
- Some alleles are neither dominant nor recessive. Many genes exist in several different forms and are therefore said to have multiple alleles. Many traits are produced by the interaction of several genes.

11.4 Meiosis
- The diploid cells of most adult organisms contain two complete sets of inherited chromosomes and two complete sets of genes.
- In prophase I, replicated chromosomes pair with corresponding homologous chromosomes. At metaphase I, paired chromosomes line up across the center of the cell. In anaphase I, chromosome pairs move toward opposite ends of the cell. In telophase I, a nuclear membrane forms around each cluster of chromosomes. Cytokinesis then forms two new cells. As the cells enter prophase II, their chromosomes become visible. The final four phases of meiosis II result in four haploid daughter cells.
- In mitosis, when the two sets of genetic material separate, each daughter cell receives one complete set of chromosomes. In meiosis, homologous chromosomes line up and then move to separate daughter cells. Mitosis does not normally 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.

Performance Tasks

SUMMATIVE TASK Have students write a story about a chromosome going through meiosis for the first time. Encourage them to use illustrations and to be creative, but they must give accurate information about the movement of chromosomes.

TRANSFER TASK Tell students to imagine they are dog breeders for a particular breed. Spotted coats are dominant over solid coats, and curly coats are dominant over straight coats. They mate two dogs with spotted, curly coats. Two puppies have spotted, curly coats, and two have solid, straight coats. Another breeder claims the phenotypes must be due to gene linkage and cannot be due to a two-factor cross in which the two genes are not linked. Have students explain how either explanation is plausible and draw diagrams to demonstrate their reasoning. Then, have them explain why it is important to a dog breeder to know whether the phenotypes are from a gene linkage or a dihybrid cross.

Answers

THINK VISUALLY
Students’ concept maps should include that a gene has two alleles, genes are located on chromosomes, genes help determine traits, and alleles can be dominant or recessive.

Introduction to Genetics 331
Lesson 11.1

UNDERSTAND KEY CONCEPTS
1. c  2. c
3. True-breeding organisms self-fertilize to produce offspring like themselves.
4. Mendel removed the pollen-producing parts from the flowers of his pea plants so they would not self-pollinate.

THINK CRITICALLY
5. Cross the white ram with a number of black ewes. If any offspring are black, then the white ram is heterozygous.
6. The original genotypes and the crosses could have been $Tt \times tt$ or $Tt \times Tt$. The genotype $TT$ could not have been present; if it were, all the offspring would be tall.

Lesson 11.2

UNDERSTAND KEY CONCEPTS
7. a  8. c  9. c
10. (1) The inheritance of biological characteristics is determined by genes. (2) Where there are two or more forms (alleles) of the gene for a single trait, some forms of the gene may be dominant and others recessive. (3) In most sexually reproducing organisms, each adult has two copies of each gene, one from each parent. These genes are segregated when gametes form. (4) The alleles for different genes (actually, the chromosomes) usually segregate independently.
11. 1 $YY$ : 2 $Yy$ : 1 $yy$; the Punnett square should show a cross between two heterozygous plants ($Yy$).

THINK CRITICALLY
12. The result of each fertilization is independent of any previous fertilizations, so it is possible for all offspring to have smooth coats. Each offspring could receive a recessive allele from both its parents.

Lesson 11.3

UNDERSTAND KEY CONCEPTS
13. d  14. a
15. A single gene has multiple alleles if it has more than two alleles. Two or more genes control polygenic traits.
16. Many different phenotypes are possible, because, while individuals only have two alleles each, there can be many different alleles present in the population. Different possible allele combinations can yield different phenotypes.

17. No, genes provide a plan for development, but how the plan unfolds depends on the environment.

THINK CRITICALLY
18. The color helps the ptarmigan hide from predators. In winter, its white coat color blends in with its snowy surroundings.

10. List the four basic principles of genetics that Mendel discovered in his experiments. Briefly describe each of these principles.
11. 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.

Think Critically
12. Apply Concepts 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.
17. Are an organism’s characteristics determined only by its genes? Explain.

**Think Critically**

18. **Interpret Visuals** Genes that control hair or feather color in some animals are expressed differently in the winter than in the summer. How might such a difference be beneficial to the ptarmigan shown here?

**Lesson 11.4**

**UNDERSTAND KEY CONCEPTS**

19. a. prophase I b. anaphase II c. metaphase I d. telophase I

20. 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.

21. 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.

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

23. Describe the process of meiosis.

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

**Think Critically**

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

**GREEN PARAKEETS**

After consulting with the owner of the pet store, Susan realized she had a rare gift. White parakeets are very uncommon. The pet shop owner told Susan that two genes control feather color. A dominant Y allele results in the production of a yellow pigment. The dominant B allele controls melanin production. If the genotype contains a capital Y (either YY or Yy) and a capital B, the offspring will be green. If the genotype contains two lowercase y alleles, and a capital B, the offspring will be blue. If the genotype contains two lowercase y’s and two lowercase b’s, the offspring will be white.

1. **Use Models** Draw a Punnett square that accounts for the inheritance of blue pigment.

2. **Apply Concepts** Solve the mystery by determining the genotypes and phenotypes of the parents and offspring.

3. **Connect to the Big Idea** What ratio of colored offspring would you expect if Susan breeds her original pair of parakeets in the years ahead? Would any offspring be green?

4. The ratios would reflect the probability of the different combinations in a two-factor heterozygous cross, 9:3:3:1, green:blue:yellow:white. 9/16 of the offspring could be expected to be green.

Have students read through the Chapter Mystery. Ask them to identify which two pigments blend to form green. (blue and yellow) Then, have them recall an example they have studied in which colors blended and identify the inheritance pattern. (incomplete dominance) Lead students to hypothesize that incomplete dominance could have led to the green color of the parents. To test this idea, have students assume each parent has two dominant alleles, B (blue) and Y (yellow), similar to the plants in Figure 11–12. Ask them to draw a Punnett square and explain the phenotype of the offspring. (1/4 would be blue, 1/2 would be green, and 1/4 would be yellow.) Help students see that the genotypes of the parents cannot be simply BY and BY, because that does not account for the white offspring. Then, have them answer the questions, which will help them solve the mystery.

**CHAPTER MYSTERY ANSWERS**

1. Students’ Punnett squares should show a two-factor cross between green parents that are heterozygous for both yellow and blue pigment. The offspring with BbYy or BByy genotypes would account for the blue offspring.

2. Students’ Punnett squares should show a two-factor cross between green parents that are heterozygous for both yellow and blue pigment. The offspring with bbyy genotypes would account for the white offspring.

3. Parents: genotype BbYy, phenotype green; Offspring: (1) genotype BbYy or Bbyy, phenotype blue; (2) genotype bbYY or bbYy, phenotype yellow; (3) genotype bbyy, phenotype white

4. Students’ Punnett squares should show a two-factor cross between green parents that are heterozygous for both yellow and blue pigment. The offspring with bbyy genotypes would account for the white offspring.

Have students read through the Chapter Mystery. Ask them to identify which two pigments blend to form green. (blue and yellow) Then, have them recall an example they have studied in which colors blended and identify the inheritance pattern. (incomplete dominance) Lead students to hypothesize that incomplete dominance could have led to the green color of the parents. To test this idea, have students assume each parent has two dominant alleles, B (blue) and Y (yellow), similar to the plants in Figure 11–12. Ask them to draw a Punnett square and explain the phenotype of the offspring. (1/4 would be blue, 1/2 would be green, and 1/4 would be yellow.) Help students see that the genotypes of the parents cannot be simply BY and BY, because that does not account for the white offspring. Then, have them answer the questions, which will help them solve the mystery.

**CHAPTER MYSTERY ANSWERS**

1. Students’ Punnett squares should show a two-factor cross between green parents that are heterozygous for both yellow and blue pigment. The offspring with BbYy or BByy genotypes would account for the blue offspring.

2. Students’ Punnett squares should show a two-factor cross between green parents that are heterozygous for both yellow and blue pigment. The offspring with bbyy genotypes would account for the white offspring.

3. Parents: genotype BbYy, phenotype green; Offspring: (1) genotype BbYy or Bbyy, phenotype blue; (2) genotype bbYY or bbYy, phenotype yellow; (3) genotype bbyy, phenotype white

4. The ratios would reflect the probability of the different combinations in a two-factor heterozygous cross, 9:3:3:1, green:blue:yellow:white. 9/16 of the offspring could be expected to be green.

Have students read through the Chapter Mystery. Ask them to identify which two pigments blend to form green. (blue and yellow) Then, have them recall an example they have studied in which colors blended and identify the inheritance pattern. (incomplete dominance) Lead students to hypothesize that incomplete dominance could have led to the green color of the parents. To test this idea, have students assume each parent has two dominant alleles, B (blue) and Y (yellow), similar to the plants in Figure 11–12. Ask them to draw a Punnett square and explain the phenotype of the offspring. (1/4 would be blue, 1/2 would be green, and 1/4 would be yellow.) Help students see that the genotypes of the parents cannot be simply BY and BY, because that does not account for the white offspring. Then, have them answer the questions, which will help them solve the mystery.

**CHAPTER MYSTERY ANSWERS**

1. Students’ Punnett squares should show a two-factor cross between green parents that are heterozygous for both yellow and blue pigment. The offspring with BbYy or BByy genotypes would account for the blue offspring.

2. Students’ Punnett squares should show a two-factor cross between green parents that are heterozygous for both yellow and blue pigment. The offspring with bbyy genotypes would account for the white offspring.

3. Parents: genotype BbYy, phenotype green; Offspring: (1) genotype BbYy or Bbyy, phenotype blue; (2) genotype bbYY or bbYy, phenotype yellow; (3) genotype bbyy, phenotype white

4. The ratios would reflect the probability of the different combinations in a two-factor heterozygous cross, 9:3:3:1, green:blue:yellow:white. 9/16 of the offspring could be expected to be green.

Have students read through the Chapter Mystery. Ask them to identify which two pigments blend to form green. (blue and yellow) Then, have them recall an example they have studied in which colors blended and identify the inheritance pattern. (incomplete dominance) Lead students to hypothesize that incomplete dominance could have led to the green color of the parents. To test this idea, have students assume each parent has two dominant alleles, B (blue) and Y (yellow), similar to the plants in Figure 11–12. Ask them to draw a Punnett square and explain the phenotype of the offspring. (1/4 would be blue, 1/2 would be green, and 1/4 would be yellow.) Help students see that the genotypes of the parents cannot be simply BY and BY, because that does not account for the white offspring. Then, have them answer the questions, which will help them solve the mystery.

**CHAPTER MYSTERY ANSWERS**

1. Students’ Punnett squares should show a two-factor cross between green parents that are heterozygous for both yellow and blue pigment. The offspring with BbYy or BByy genotypes would account for the blue offspring.

2. Students’ Punnett squares should show a two-factor cross between green parents that are heterozygous for both yellow and blue pigment. The offspring with bbyy genotypes would account for the white offspring.

3. Parents: genotype BbYy, phenotype green; Offspring: (1) genotype BbYy or Bbyy, phenotype blue; (2) genotype bbYY or bbYy, phenotype yellow; (3) genotype bbyy, phenotype white

4. The ratios would reflect the probability of the different combinations in a two-factor heterozygous cross, 9:3:3:1, green:blue:yellow:white. 9/16 of the offspring could be expected to be green.
Connecting Concepts

USE SCIENCE GRAPHICS
26. 66 smooth and 66 wrinkled
27. Yes, the observed numbers are close to the expected values. No other cross would predict a ratio close to 50 percent for each trait.
28. No, a similar outcome would result from a cross like this if wrinkled seeds were dominant.

WRITE ABOUT SCIENCE
29. Students’ explanations should be clear and concise and include examples. They should explain that a gene has at least two alleles. Some alleles are dominant and others are recessive. An organism with a dominant allele will always exhibit that form of the trait. Recessive alleles are expressed only in the absence of dominant alleles.
30. Students’ explanations should include that these two traits are located close together on the same chromosome. When alleles of different genes are close to each other, they are said to be linked. These genes tend to be inherited together. Diagrams should indicate the alleles’ positions on one chromosome as being close together throughout meiosis.
31. Pairs of genes are found on pairs of chromosomes. The pairs of chromosomes and their genes separate during meiosis and gamete formation. Each gamete gets only one of each pair of chromosomes and one of each pair of genes. In fertilization, chromosome pairs and their genes come together from each parent to form new combinations.

Use Science Graphics
Seed coat was one trait that Mendel studied in pea plants. The coat, or covering, of the seed is either smooth or wrinkled. Suppose a researcher has two plants—one that makes smooth seeds and another that makes wrinkled seeds. The researcher crosses the wrinkled-seed plants and the smooth-seed plants, obtaining the following data. Use the data to answer questions 26–28.

<table>
<thead>
<tr>
<th>Phenotype</th>
<th>Number of Plants in the F₁ Generation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smooth seeds</td>
<td>Expected: 60, Observed:</td>
</tr>
<tr>
<td>Wrinkled seeds</td>
<td>72</td>
</tr>
</tbody>
</table>

26. Predict Mendel knew that the allele for smooth (R) seeds was dominant over the allele for wrinkled (r) seeds. If this cross was Rr × rr, what numbers would fill the middle column?
27. Analyze Data Are the observed numbers consistent with the hypothesis that the cross is Rr × rr? Explain your answer.
28. Draw Conclusions Are the data from this experiment alone sufficient to conclude that the allele for smooth seeds is dominant over the allele for wrinkled seeds? Why or why not?

Analyze Data
A researcher studying fruit flies finds a mutant fly with brown-colored eyes. Almost all fruit flies in nature have bright red eyes. When the researcher crosses the mutant fly with a normal red-eyed fly, all of the F₁ offspring have red eyes. The researcher then crosses two of the F₁ red-eyed flies and obtains the following results in the F₂ generation.

<table>
<thead>
<tr>
<th>Eye Color in the F₂ Generation</th>
<th>Expected</th>
<th>Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red eyes</td>
<td>37</td>
<td></td>
</tr>
<tr>
<td>Brown eyes</td>
<td>14</td>
<td></td>
</tr>
</tbody>
</table>

32. Calculate What is the ratio of red-eyed flies to brown-eyed flies? 
   a. 1 : 1  
   c. 3 : 1  
   b. 1 : 3  
   d. 4 : 1

33. Draw Conclusions The allele for red eyes in fruit flies is
   a. dominant over brown eyes.  
   b. recessive to brown eyes.  
   c. codominant with the brown-eyed gene.  
   d. a multiple allele with the brown-eyed gene and others.

ANSWERS 
32. c  
33. a
**Standardized Test Prep**

**Multiple Choice**

1. What happens to the chromosome number during meiosis?
   - A It doubles.
   - B It stays the same.
   - C It halves.
   - D It becomes diploid.

2. Which ratio did Mendel find in his F2 generation?
   - A 3 : 1
   - B 1 : 3 : 1
   - C 1 : 2
   - D 3 : 4

3. During which phase of meiosis is the chromosome number reduced?
   - A anaphase I
   - B metaphase I
   - C telophase I
   - D telophase II

4. Two pink-flowering plants are crossed. The offspring flower as follows: 25% red, 25% white, and 50% pink. What pattern of inheritance does flower color in these flowers follow?
   - A dominance
   - B multiple alleles
   - C incomplete dominance
   - D polygenic traits

5. Which of the following is used to construct a gene map?
   - A chromosome number
   - B mutation rate
   - C rate of meiosis
   - D recombination rate

6. Alleles for the same trait are separated from each other during the process of
   - A cytokinesis.
   - B meiosis I.
   - C meiosis II.
   - D telophase II.

7. Which of the following is NOT one of Gregor Mendel’s principles?
   - A The alleles for different genes usually segregate independently.
   - B Some forms of a gene may be dominant.
   - C The inheritance of characteristics is determined by factors (genes).
   - D Crossing-over occurs during meiosis.

8. How many map units apart are genes A and D?
   - A 5
   - B 8
   - C 10
   - D 12.5

9. Which gene map best reflects the student’s data?
   - A
   - B
   - C
   - D

Open-Ended Response

10. Explain why meiosis allows organisms to maintain their chromosome numbers from one generation to the next.

---

**Test-Taking Tip**

**ANTICIPATE THE ANSWER**

Tell students to read the question stem and try to anticipate what the answer will be. Then, have them read all the answer choices carefully to see which choice best matches the answer they anticipated. Reinforce that they should read all the answer choices before selecting one.