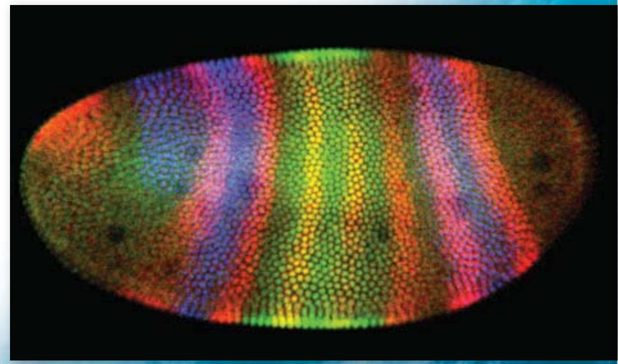
UNIT 4

Heredity

Eggs of the red-eyed tree frog stuck to the underside of a leaf



Fruit fly embryo, marked to show pattern of genes being expressed


Emperor penguin parents with chick

UNIT 4

DISCOVERIES IN SCIENCE

Heredity and Genetics

1865

Gregor Mendel publishes the results of his studies of genetic inheritance in pea plants. Although his work is not widely known until much later, Mendel is remembered as the founder of the science of genetics.

Gregor Mendel

1879

After staining cells with Perkins dye and viewing them under a microscope, Walter Fleming identifies chromatin in cells. Soon after, he observes and describes all stages of mitosis, using terms such as *metaphase, anaphase and telophase.*

1905

Nettie Maria Stephens describes how human gender is determined by the X and Y chromosomes.

Nettie Stevens

1909

The Elements of Heredity, by Wilhelm Johannsen, a Danish biologist, is revised and translated into German. In the book, Johannsen develops many of the concepts of modern genetics, particularly phenotype and genotype. This book becomes a founding text of genetics.

1913

Alfred Henry Sturtevant, an undergraduate student at Columbia University, determines the relative location of genes on a fruit fly chromosome. He publishes a genetic map showing the order of genes and their relative distance from each other.

1915

Thomas Hunt publishes the book *Mechanism of Mendelian Heredity,* which explains the phenomenon of sex-linked traits observed in fruit flies.

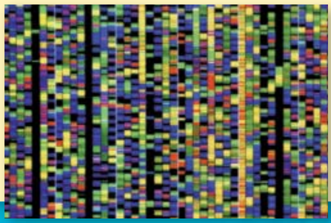
Drosophila melanogaster (fruit fly)

1989

Francis Collins and Lap-Chee Tsui identify a mutant version of a gene on chromosome 7 that causes cystic fibrosis. Discovery of the gene leads to the development of tests that can determine whether potential parents are carriers of the gene.

2003

The Human Genome Project is completed. Research teams around the world collaborated to identify all genes and decode the sequence of all DNA in human cells.



Genetic sequences on a computer screen

Albino peacock

BIOLOGY CAREER

UNIT 4

Genetics Researcher

Rob Desalle

Rob DeSalle is a curator in the Division of Invertebrate Zoology at the American Museum of Natural History in New York City. His current research focuses on molecular evolution in a variety of organisms, including pathogenic bacteria and insects.

DeSalle studies molecular evolution through comparative genomics, which is the study of similarities and differences between the genomes of various species or strains within species. Comparing the genomes of species can help determine how the species are related.

DeSalle also helped found the Conservation Genetics Program at the American Museum of Natural History. This program uses the tools of molecular genetics to help protect wildlife around the world. For example, DeSalle helped develop a genetic test to determine if caviar sold in the United States was illegally harvested from endangered species of sturgeon in the Caspian Sea.

Genetic analysis by gel electrophoresis

Chapter Planner 12

Mendel and Heredity

	Standards	Teach Key Ideas
CHAPTER OPENER, pp. 264–265 (15 min.)	*National Science Education Standards*	
SECTION 1 Origins Of Heredity Science, pp. 267–271 (45 min.) › Mendel's Breeding Experiments › Features of Pea Plants › Mendel's First Experiments › Ratios in Mendel's Results	LSCell 3, UCP3, SI1, SI2, HNS2, HNS3	**Bellringer Transparency** **Transparencies** C1 Three Steps of Mendel's Experiment • C2 Mendel's Crosses and Results **Visual Concepts** Heredity • Mendel's Experiments • Punnett Square with Heterozygous Cross • True Breeding • Parental Generation • First Filial Generation • Second Filial Generation • Mendel's Conclusion
SECTION 2 Mendel's Theory, pp. 272–275 (60 min.) › Explaining Mendel's Results › Random Segregation of Alleles › Mendel's Findings in Modern Terms › Mendel's Second Experiments	LSCell 1, LSCell 3, LSGene 2, UCP2	**Bellringer Transparency** **Transparencies** C3 Mendel's Factors **Visual Concepts** Alllele • Comparing Dominant and Recessive Traits • Comparing Homozygous and Heterozygous Genotypes • Genotype • Phenotype • Comparing Genotype and Phenotype • Segregation • Law of Independent Assortment
SECTION 3 Modeling Mendel's Laws, pp. 276–281 (45 min.) › Using Punnett Squares › Using Probability › Using a Pedigree	LSCell 3, LSGene 2, UCP2, SI1	**Bellringer Transparency** **Transparencies** C4 Probability with Two Coins • C5 Monohybrid Cross of Homozygous Plants • C6 Monohybrid Cross of Heterozygous Plants • C8 Dihybrid Crosses **Visual Concepts** Punnett Square with Homozygous Cross • Testcross • Calculating Probability • Pedigree • Sex Linkage
SECTION 4 Beyond Mendelian Heredity, pp. 282–284 (60 min.) › Many Genes, Many Alleles › Genes Affected by the Environment › Genes Linked Within Chromosomes	LSCell 2, LSCell 3, LSCell 4, LSGene 1, LSGene 2, UCP3, SI2	**Bellringer Transparency** **Transparencies** C7 Incomplete Dominance **Visual Concepts** Comparing Single Allele, Multiple Allele, and Polygenic Traits • Comparing Complete, Incomplete, and Co-Dominance • Comparing X-Linked and Sex-Influenced Traits

See also PowerPoint® Resources

Chapter Review and Assessment Resources

- SE Super Summary, p. 286
- SE Chapter Review, p. 287
- SE Standardized Test Prep, p. 289
- Review Resources
- Chapter Tests A and B
- go.hrw.com Holt Online Assessment

CHAPTER Fast Track

Thorough instruction will require the times shown.

Basic Learners

- TE All Pea Plants Are Not the Same, p. 268
- TE Mendel's Steps, p. 269
- TE Law of Independent Assortment, p. 274
- TE Reading the Signs, p. 279
- TE Create a Chart, p. 283
- Directed Reading Worksheets*
- Active Reading Worksheets*
- Lab Manuals, Level A*
- Study Guide* ■
- Note-taking Workbook*
- Special Needs Activities and Modified Tests*

Advanced Learners

- TE Organizing Concepts, p. 268
- TE Trait Research, p. 273
- Critical Thinking Worksheets*
- Concept Mapping Worksheets*
- Science Skills Worksheets*
- Lab Datasheets, Level C*

Key
- **SE** Student Edition
- **TE** Teacher's Edition
- Chapter Resource File
- Workbook
- Transparency
- CD or CD-ROM
- * Datasheet or blackline master available
- ■ Also available in Spanish

All resources listed below are also available on the Teacher's One-Stop Planner.

Why It Matters	Hands-On	Skills Development	Assessment
Build student motivation with resources about high-interest applications.	**SE Inquiry Lab** What Are the Chances?, p. 265* ■	**TE Reading Toolbox** Assessing Prior Knowledge, p. 264 **SE Reading Toolbox,** p. 266	
TE Demonstration Patterns of Heredity, p. 267 **TE Demonstration** Genetic Make-Up, p. 268 **TE Trends in Genetics,** p. 269 **SE Amazing Mutants,** p. 271	**SE Quick Lab** Mendel's Ratios, p. 270* ■	**TE Math Skills** Ratios, p. 269 **SE Reading Toolbox** Word Parts, p. 269 **TE Reading Toolbox** Word Parts, p. 269 **TE Reading Toolbox** Visual Literacy, p. 271	**SE Section Review** **TE Formative Assessment Spanish Assessment*** ■ **Section Quiz** ■
TE Blood Lines, p. 273 **TE Demonstration** Hairy Knuckles, p. 275	**SE Quick Lab** Dominant and Recessive Traits, p. 273* ■	**SE Reading Toolbox** Word Parts, p. 274 **TE Reading Toolbox** Word Parts, p. 274	**SE Section Review** **TE Formative Assessment Spanish Assessment*** ■ **Section Quiz** ■
TE Recessive Genes, p. 276 **TE Punnett Who?** p. 277 **TE Probability in Real Life,** p. 278 **TE Pedigreed Dogs,** p. 280	**SE Quick Lab** Test Cross, p. 277* ■ **SE Quick Lab** Prrobabilities p. 278* ■ **SE Quick Lab** Pedigree Analysis, p. 281* ■ **Quick Lab** Interpreting Information in a Pedigree*	**TE Reading Toolbox** Visual Literacy, p. 276 **TE Reading Toolbox** Analogies, p. 277 **TE Math Skills** Probability of Two Independent Events, p. 279 **TE Reading Toolbox** Visual Literacy, p. 280	**SE Section Review** **TE Formative Assessment Spanish Assessment*** ■ **Section Quiz** ■
TE Human Inheritance, p. 283	**SE Inquiry Lab** Plant Genetics, p. 285* ■ **Inquiry Lab** Analyzing Corn Genetics*	**TE Math Skills** Phenotypic Ratios, p. 283 **TE Science Skills** Using Punnett Squares, p. 284	**SE Section Review** **TE Formative Assessment Spanish Assessment*** ■ **Section Quiz** ■

See also Lab Generator

See also Holt Online Assessment Resources

Resources for Differentiated Instruction

English Learners
- **TE** Law of Independent Assortment, p. 277
- **TE** Create a Chart, p. 283
- Directed Reading Worksheets*
- Active Reading Worksheets*
- Lab Manuals, Level A*
- Study Guide* ■
- Note-taking Workbook*
- Multilingual Glossary

Struggling Readers
- **TE** Vocabulary, p. 280
- Directed Reading Worksheets*
- Active Reading Worksheets*
- Lab Manuals, Level A*
- Study Guide*
- Note-taking Workbook*
- Special Needs Activities and Modified Tests*

Special Education Students
- **TE** Modeling Punnett Squares, p. 278
- Directed Reading Worksheets*
- Active Reading Worksheets*
- Lab Manuals, Level A*
- Study Guide* ■
- Note-taking Workbook*
- Special Needs Activities and Modified Tests*

Alternative Assessment
- **TE** Phenotypic Ratios, p. 277
- **TE** Mathematical Equivalents, p. 278
- **TE** Evaluating Arguments, p. 282
- Science Skills Worksheets*
- Section Quizzes* ■
- Chapter Tests A, B, and C* ■

Chapter 12

Overview

The purpose of this chapter is to explain how genetic traits are passed from one generation to another. The passing of different genetic traits is fundamental to evolutionary change. The genetic variation that results from various combinations of parental genes is the basis for natural selection.

READING TOOLBOX

Assessing Prior Knowledge Students should understand the following concepts:
- cellular nature of life
- passing of genetic information

Visual Literacy Ask students to list some disadvantages for snakes that lack the genetic information to make red or black skin. (Snakes without red or black skin won't blend well into the background. Prospective mates might not recognize them.) Explain to students that variations in skin color are attractive to some pet owners. However, unusual coloring may limit a snake's survival or it's chances to reproduce.

Chapter 12 Mendel and Heredity

Preview

Why It Matters

Your genetic makeup influences your appearance, your personality, your abilities, and your health. We now know that many human traits, such as talents and diseases, have their origins in genes. As we come to understand how traits are inherited, we can use this information to better our lives.

The common corn snake (*Elaphe guttata*) is a popular pet. Snake breeders have discovered many variations of colors and patterns in this species.

Chapter Correlations — *National Science Education Standards*

LSCell 1 Cells have particular structures that underlie their functions

LSCell 2 Most cell functions involve chemical reaction.

LSCell 3 Cells store and use information to guide their functions.

LSCell 4 Cell functions are regulated.

LSGene 1 In all organisms, the instructions for specifying the characteristics of the organisms are carried in DNA.

LSGene 2 Most of the cells in a human contain two copies of each of 22 different chromosomes. In addition there is a pair of chromosomes that determine sex.

UCP2 Evidence, models, and explanation

UCP3 Change, constancy, and measurement

SI1 Abilities necessary to do scientific inquiry

SI2 Understandings about scientific inquiry

HNS2 Nature of scientific knowledge

HNS3 Historical perspectives

InquiryLab

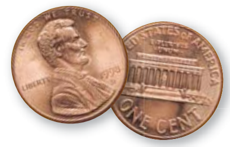
15 min

What Are the Chances?

Do you think you can predict the result of a coin toss? What if you flip the coin many times? In this activity, you will test your predictions.

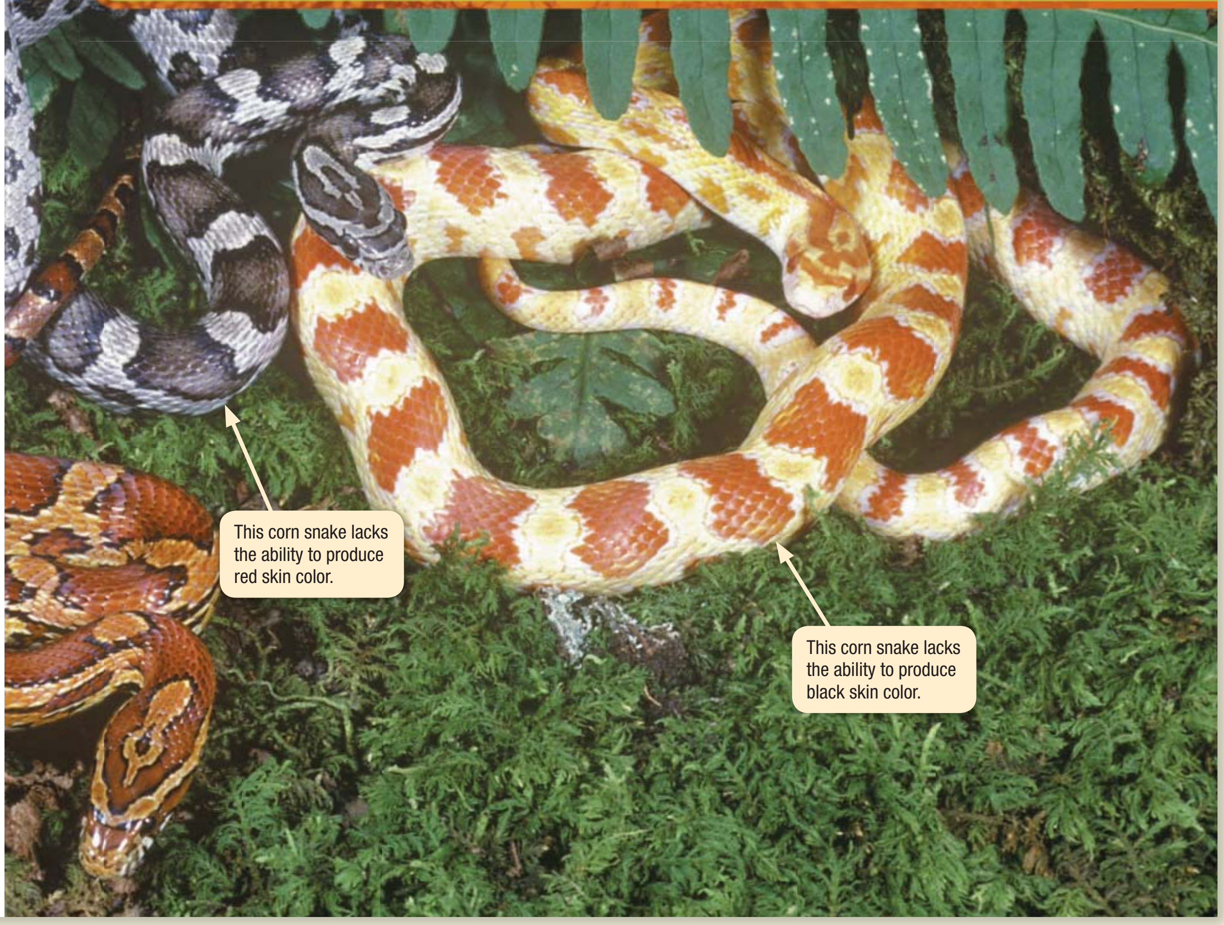
Procedure

1. Read steps 2 and 3. Predict the results, and write down your prediction.
2. Flip a **coin,** and let it land. Record which side is up (heads or tails). Repeat this step 10 times.
3. Calculate what fraction of the total number of flips resulted in heads. Calculate what fraction of flips resulted in tails.
4. Read steps 5 and 6. Predict the results, and write down your prediction.
5. Tally the flip results of the entire class.
6. Calculate the fraction of heads and the fraction of tails in step 5.



Analysis

1. **Compare** your predictions from steps 1 and 4 with the results in steps 3 and 6.
2. **Compare** your own results in step 3 to those of other individuals in your class. Identify how closely each individual result matches the total class results.



InquiryLab

Teacher's Notes The important ideas to learn from this lab are as follows. Multiple samples are averaged to find a *normal* or *probable* ratio of conditions. Individual samples (events) can differ greatly from the average, normal, or probable condition. Knowing about the events that generate a set of possible outcomes allows one to predict, imperfectly, the probable ratio of possible outcomes.

Materials

- one coin per student

Answers to Analysis

1. Answers will vary; many students will reasonably predict that $\frac{1}{2}$ of the flips will result in heads and $\frac{1}{2}$ in tails. However, very few students will obtain this exact result for their individual series of flips. The totaled class results will tend to balance the variations and the average probability will be closer to $\frac{1}{2}$ for both heads and tails.
2. Students will likely find greater differences between individual results (and thus wider variations among them) than between an individual's results and the class average.

Key Resources

Interactive Tutor

READING TOOLBOX

Using Words

1. Students should convey the idea that heredity has to do with traits inherited or left behind.
2. Answers will vary, but students should realize that phenotype relates to visible markings.

Using Language

character

Using Science Graphics

1. 2
2. yellow shirt with shorts
3. 9 combinations

READING TOOLBOX

These reading tools can help you learn the material in this chapter. For more information on how to use these and other tools, see **Appendix: Reading and Study Skills.**

Using Words

Word Parts Knowing the meanings of word parts can help you figure out the meaning of words that you do not know.

Your Turn Use the table to answer the following.

1. Heritage is something handed down from one's ancestors. What do you think *heredity* is?
2. Use the meaning of the prefix *phen-* and the suffix *-type* to figure out what *phenotype* means.

Word Parts

Word part	Type	Meaning
gen-	prefix	born; to become; to produce
her-	prefix	heir; remains; to be left behind
phen-	prefix	to show
-type	suffix	form; mark; kind

Using Language

Analogies An analogy question asks you to analyze the relationship between two words in one pair and to identify a second pair of words that have the same relationship. Colons are used to express the analogy for this type of question. For example, the analogy "up is to down as top is to bottom" is written "up : down :: top : bottom. In this example, the relationship between the words in each pair is the same.

Your Turn Use information in the chapter to complete this analogy.

allele : gene :: trait : __________

(Hint: Finding out how alleles and genes are related will help you figure out which word to use to fill in the blank.)

Using Science Graphics

Punnett Squares A Punnett square is a tool that is used to figure out possible combinations when combining items from a group. For example, if you have a red shirt, a green shirt, and a yellow shirt that you could wear with either blue jeans or shorts, how many combinations could you make?

Your Turn Finish filling in the Punnett square shown here to answer the following questions.

1. How many combinations include a red shirt?
2. What combination of shirt and pants do you find in the bottom right corner of this Punnett square?
3. How many combinations would you have if you added a pair of brown pants to the group?

	Red shirt	*Green shirt*	*Yellow shirt*
Blue jeans	*Red shirt with blue jeans*		
Shorts		*Green shirt with shorts*	

Section 1

Origins of Hereditary Science

Key Ideas	Key Terms	Why It Matters
❯ Why was Gregor Mendel important for modern genetics? ❯ Why did Mendel conduct experiments with garden peas? ❯ What were the important steps in Mendel's first experiments? ❯ What were the important results of Mendel's first experiments?	character trait hybrid generation	Our understanding of genetics, including what makes us unique, can be traced back to Mendel's discoveries.

Since they first learned how to breed plants and animals, people have been interested in heredity. In the 1800s, one person figured out some of the first key ideas of genetics. Recall that *genetics* is the science of heredity and the mechanism by which traits are passed from parents to offspring.

Mendel's Breeding Experiments

A monk named Gregor Johann Mendel lived in the 1800s in Austria. Mendel did breeding experiments with the garden pea plant, *Pisum sativum,* shown in **Figure 1.** Farmers had done similar experiments before, but Mendel was the first person to develop rules that accurately predict the patterns of heredity in pea plants. **❯ Modern genetics is based on Mendel's explanations for the patterns of heredity in garden pea plants.**

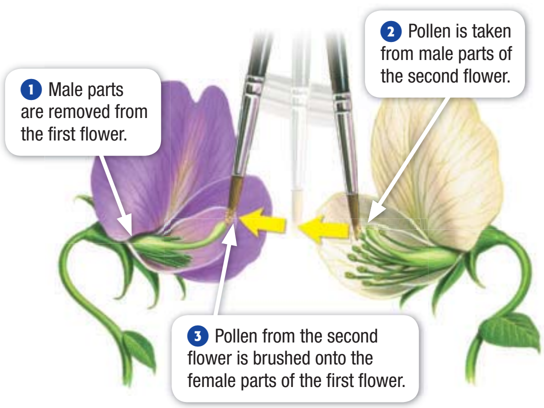
As a young man, Mendel studied to be a priest. Later, he went to the University of Vienna. There, he learned how to study science through experimentation and how to use mathematics to explain natural events. Mendel lived the rest of his life in a monastery, where he taught high school and cared for a garden. It was in this garden that he completed his important experiments.

Most of Mendel's experiments involved crossing different types of pea plants. In this case, the word *cross* means "to mate or breed two individuals." Mendel crossed a type of garden pea plant that had purple flowers with a type that had white flowers. All of the offspring from that cross had purple flowers. However, when two of these purple-flowered offspring were crossed, some offspring had white flowers and some had purple flowers.

The white color had reappeared in the second group of offspring! Mendel decided to investigate this strange occurrence. So, he carefully crossed different types of pea plants and recorded the numbers of each type of offspring. He did this experiment many times.

❯ **Reading Check** ***How did Mendel experiment with pea plants? (See the Appendix for answers to Reading Checks.)***

Figure 1 To cross plants that each had flowers of a different color, Mendel controlled the pollen that fertilized each flower.



Section 1

❯ Focus

This section explains Mendel's discoveries in modern terms and explains traits expressed in ratios.

Bellringer

Use the Bellringer transparency to prepare students for this section.

❯ Teach

Demonstration

Patterns of Heredity Display large pictures of a few flowering plants or bring in real plants. Ask students to come up with a list of traits that could be inherited in plants. Encourage students to think of many different characters, such as flower shape, flower color, leaf position on stem, leaf shape, leaf color, pattern of veins, pattern of stem growth, presence of hairs on stems, and the inner structure of the flower. **LS Visual**

Key Resources

Transparencies
C1 Three Steps of Mendel's Experiment
C2 Mendel's Crosses and Results

Visual Concepts
Heredity
Mendel's Experiments
Punnett Square with Heterozygous Cross
True Breeding
Parental Generation
First Filial Generation
Second Filial Generation
Mendel's Conclusion

❯ Teach, *continued*

Teaching Key Ideas

Benefits of Peas Organize the class into small groups. Have each group design newspaper ads that would have attracted someone such as Mendel to purchase peas for research. The ads should mention all of the benefits of *Pisum sativum* that make it useful for genetic research. Ask students to use illustrations in their ads. Encourage students to be creative. They may use butcher paper, computer paper, construction paper, and so on. Post the ads on a bulletin board, and lead a discussion on the benefits of the garden pea for genetic research. **LS Interpersonal**

Demonstration

Genetic Make-Up Bring photos of animals with interesting traits. Use these props to emphasize that many genes are involved in giving an animal its overall appearance, and that the genes for most traits have two or more versions. Ask students to guess how many genes animals have in common with each other. For example, chimpanzees and humans share approximately 98 percent of their genetic makeup. **LS Visual**

Answers to Caption Questions

Figure 2: The pea plant is a good subject for studying heredity because the plant has contrasting traits, usually self-pollinates, and grows easily.

Features of Pea Plants

Mendel studied seven features in his pea plants, as **Figure 2** shows. **❯ The garden pea plant is a good subject for studying heredity because the plant has contrasting traits, usually self-pollinates, and grows easily.**

Contrasting Traits In the study of heredity, physical features that are inherited are called **characters.** Several characters of the garden pea plant exist in two clearly different forms. The plant's flower color is either purple or white—there are no intermediate forms. A **trait** is one of several possible forms of a character. Purple is one of two possible traits for the flower-color character in pea plants. Other contrasting traits of pea plants are shown in **Figure 2.** (For some characters, more than two traits may be possible). Mendel wanted to see what would happen when he crossed individuals that have different traits. In such a cross, the offspring that result are called **hybrids.**

ACADEMIC VOCABULARY

contrast to show differences when compared.

character a recognizable inherited feature or characteristic of an organism

trait one of two or more possible forms of a character; a recognizable feature or characteristic of an organism

hybrid the offspring of a cross between parents that have contrasting traits

generation the entire group of offspring produced by a given group of parents

Self-Pollination In garden pea plants, each flower contains both male and female reproductive parts. This arrangement allows the plant to *self-pollinate,* or fertilize itself. Pea plants can also reproduce through *cross-pollination*. This process occurs when pollen from the flower of one plant is carried by insects or by other means to the flower of another plant. To cross-pollinate two pea plants, Mendel had to make sure that the plants could not self-pollinate. So, he removed the male parts (which produce pollen) from some of the flowers. But he did not remove the female parts (which produce eggs, fruit, and seeds). Then, he dusted the female parts of one plant with pollen from another plant.

Easy to Grow The garden pea is a small plant that needs little care and matures quickly. Also, each plant produces many offspring. Thus, many results can be compared for each type of cross. Recall that collecting repeated data is an important scientific method.

❯ Reading Check *What is the difference between a trait and a character?*

Figure 2 In the experiments in his garden, Mendel grew and studied many kinds of pea plants. **❯ Why did Mendel study pea plants?**

Seven Characters with Contrasting Traits Studied by Mendel

Flower color	Seed color	Seed shape	Pod color	Pod Shape	Flower position	Plant height
 purple	yellow	 round	 green	 smooth	 mid-stem	 tall
 white	 green	 wrinkled	 yellow	 bumpy	 end of stem	 short

Differentiated Instruction

Basic Learners

All Pea Plants Are Not the Same Review **Figure 2** with students. Be sure they realize that all of the traits shown are options for a single pea plant. Every plant will show some combination of these seven characters. **LS Visual**

Advanced Learners/GATE

Organizing Concepts Have students write and illustrate a chart explaining the meaning of the terms *monohybrid cross, true-breeding, P generation, F_1 generation,* and *F_2 generation.* **LS Visual**

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interact online
Keyword: HX8GENF3

Three Steps of Mendel's First Experiments

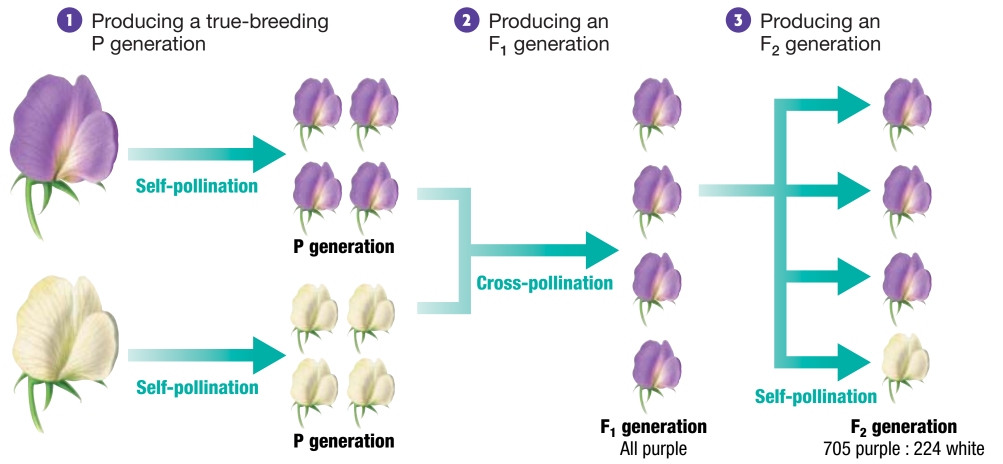


Figure 3 In his garden experiments, Mendel carefully selected and grew specific kinds of pea plants. **What is the relationship between each generation in these experiments?**

Mendel's First Experiments

A *monohybrid cross* is a cross that is done to study one pair of contrasting traits. For example, crossing a plant that has purple flowers with a plant that has white flowers is a monohybrid cross. **Mendel's first experiments used monohybrid crosses and were carried out in three steps.** The three steps are shown in **Figure 3.** Each step involved a new generation of plants. A **generation** is a group of offspring from a given group of parents.

Step 1 Mendel allowed plants that had each type of trait to self-pollinate for several generations. This process ensured that each plant always produced offspring of the same type. Such a plant is said to be *true-breeding* for a given trait. For example, every time a true-breeding plant that has purple flowers self-pollinates, its offspring will have purple flowers. Mendel used true-breeding plants as the first generation in his experiments. The first group of parents that are crossed in a breeding experiment are called the *parental generation,* or *P generation*.

Step 2 Mendel crossed two P generation plants that had contrasting traits, such as purple flowers and white flowers. He called the offspring of the P generation the *first filial generation,* or *F_1 generation*. He recorded the number of F_1 plants that had each trait.

Step 3 Mendel allowed the F_1 generation to self-pollinate and produce new plants. He called this new generation of offspring the *second filial generation,* or *F_2 generation*. He recorded the number of F_2 plants that had each trait.

Reading Check *What is a monohybrid cross?*

READING TOOLBOX

Word Parts The word *filial* is from the Latin *filialis,* which means "of a son or daughter." Thus, F (filial) generations are all of the generations that follow a P (parental) generation. What do you think *filiation* means?

go.hrw.com
interact online

Students can interact with "The Steps of Mendel's First Experiments" by going to go.hrw.com and typing the keycode HX8GENF3.

Teaching Key Ideas

Monohybrid Crosses Ask students if they can tell by looking at the purple pea flowers in **Figure 3** which ones are true-breeding for the purple trait and which ones are not. Point out that you cannot always tell the genetic makeup of an organism by looking at it. Ask students how a cross helps determine if a plant is true-breeding for a trait.

Math Skills

Ratios Ask students to practice reducing ratios to their simplest forms. Survey the class for some numbers to use. For example, ask how many students own a cat. Have them divide each number (class size and cat owners) by the smallest number (cat owners) and write it as a ratio. If there are 30 students in class and 10 own a cat, the ratio is 30:10. Simplified, $\frac{30}{10} = 3$ and $\frac{10}{10} = 1$, so the ratio is 3:1. **LS Logical**

READING TOOLBOX

Word Parts *Filiation* describes the process of determining the parental relationship. **LS Verbal**

Answers to Caption Questions

Figure 3: The F_2 generation is the offspring of the F_1 generation, and the F_1 generation is the offspring of the P generation.

Differentiated Instruction

Basic Learners

Mendel's Steps Be sure that students realize that only one character (flower color) from Figure 2 is shown. Ask students to use **Figure 3** as a model to replicate the three steps in Mendel's experiments, substituting another character from **Figure 2.** Have students draw pictures of the phenotypes produced. Remind them that Mendel studied seven characters. **LS Verbal**

Why It Matters

Trends in Genetics Many scientists who study genetics use the fruit fly *Drosophila melanogaster* or the roundworm *Caenorhabditis elegans* in their research. These organisms show a variety of traits, are easy to obtain and breed, have short generation time (less than 2 weeks for fruit flies and less than 3 days for roundworms), and produce a large number of offspring. How long would it take to study three generations of humans? (approximately 75 years)

Teach, *continued*

QuickLab

Teacher's Notes Review how to calculate ratios.

Answers to Procedure

1. seed color, 6,022:2,001; seed shape, 5,474:1,850; pod color, 428:152; pod shape 882:299; flower position, 651:207; plant height, 787:277.
2. seed color, 3.01:1; seed shape, 2.96:1; pod color, 2.82:1; pod shape 2.95:1; flower position, 3.14:1; plant height, 2.84:1.

Answers to Analysis

1. all are 3:1
2. The sample sizes for each character vary.

Close

Formative Assessment

What makes an organism "true-breeding"?

A. It can self-pollinate. (Incorrect. Self-pollination is one way to produce true-breeding organisms (as Mendel did), but many generations must self-pollinate to guarantee that the offspring will share the traits of the parents.)

B. It always produces offspring with similar traits. (Correct!)

C. It always produces offspring with contrasting traits. (Incorrect. To "breed true" is to produce offspring with the same traits as the parents.)

D. It can mate with other organisms that are like it. (Incorrect. Most organisms can mate with other organisms that are like them, but this does not guarantee that the offspring will share the traits of the parents.)

Data

QuickLab

10 min

Mendel's Ratios

You can calculate and compare the F_2 generation ratios that Mendel obtained from his first experiments.

Procedure

1. Copy this partially complete table onto a separate **sheet of paper**. Then, fill in the ratios of F_2 traits.
2. Simplify the ratios, and round the terms in each ratio to the nearest hundredth digit.

Character	Traits in F_2 generation		Ratio
Flower color	705 purple	224 white	705:224 or 3.15:1.00
Seed color	6,022 yellow	2,001 green	
Seed shape	5,474 round	1,850 wrinkled	
Pod color	428 green	152 yellow	
Pod shape	882 smooth	299 bumpy	
Flower position	651 mid-stem	207 end of stem	
Plant height	787 tall	277 short	

Analysis

1. **Identify** the similarities between the ratios by rounding each term to the nearest whole number.
2. CRITICAL THINKING **Analyzing Data** Why weren't all of the ratios exactly the same?

SCILINKS. www.scilinks.org
Topic: Gregor Mendel
Code: HX80698

Ratios in Mendel's Results

All of Mendel's F_1 plants expressed the same trait for a given character. The contrasting trait had disappeared! But when the F_1 plants were allowed to self-pollinate, the missing trait reappeared in some of the F_2 plants. Noticing this pattern, Mendel compared the ratio of traits that resulted from each cross.

When F_1 plants that had purple flowers were crossed with one another, 705 of the F_2 offspring had purple flowers and 224 had white flowers. So, the F_2 ratio of purple-flowered plants to white-flowered plants was 705:224, or about 3:1. Mendel's studies of the other characters gave a similar pattern. **For each of the seven characters that Mendel studied, he found a similar 3-to-1 ratio of contrasting traits in the F_2 generation.** As you will learn, Mendel tried to explain this pattern.

Reading Check *What was the important difference between Mendel's F_1 and F_2 generations?*

Section 1 Review

KEY IDEAS

1. **Identify** Gregor Mendel's contribution to modern genetics.
2. **Describe** why garden pea plants are good subjects for genetic experiments.
3. **Summarize** the three major steps of Mendel's first experiments.
4. **State** the typical ratio of traits in Mendel's first experiments.

CRITICAL THINKING

5. **Using Scientific Methods** Why did Mendel record the results of so many plant crosses?
6. **Predicting Outcomes** Squash plants do not usually self-pollinate. If Mendel had used squash plants, how might his experiments have differed?

WRITING FOR SCIENCE

7. **Technical Writing** Imagine that you are Gregor Mendel and you need to document your first experiments for a science magazine. Write out your procedure for breeding pea plants. Be sure to explain how you controlled variables and assured that data was reliable.

Answers to Section Review

1. Mendel studied and tried to explain the hereditary patterns in garden pea plants. Modern genetics is based on his conclusions.
2. The plant has numerous discernable contrasting traits, usually self-pollinates, and grows easily.
3. (1) start with a true-breeding P generation by self-pollination; (2) produce an F_1 generation by cross-pollination; (3) produce an F_2 generation by self-pollination
4. 3 to 1
5. Mendel understood that the larger the number of results, the better the data would be statistically.
6. He would have had to pollinate the plants under controlled conditions until he was satisfied that he had a true-breeding P generation. Otherwise he would not have been able to control the ratio of traits in the F_1 and F_2 generations.
7. Check that students provide ample detail for the procedure and describe how they plan to control variables.

Why It Matters

Amazing Mutants

Fruit flies are widely used in genetic research because "mutant" forms provide clues about how genes work. One fly species, *Drosophila melanogaster,* has been studied so much that scientists understand its genes better than those of most other organisms. Still, there are many bizarre mutations yet to be understood.

Popular in the Lab

Fruit flies are popular with scientists because the flies are easy to breed and raise in a laboratory. The flies grow and reproduce quickly and reproduce in large numbers. Also, the flies have been used in important genetic experiments since 1910.

Many Mutations

Most scientists who study fruit flies are interested in genetic variation and mutations. Thousands of "mutant" forms that have unique *alleles* (versions of a gene) have been observed in species of the genus *Drosophila*. Databases on the Internet are used to share information on over 14,000 fruit fly genes. Just a few of the many kinds of fruit fly "mutants" are described here.

Normal "wild" fruit fly

Fly lacking eye color

Different Colors Differences in color are easy to recognize in a lab. Some fruit fly mutations affect eye color and body patterns. Some of the genes for coloration in flies show simple inheritance patterns, like the patterns that Mendel observed in garden pea plants.

Research Find out more about *Drosophila,* such as its life cycle, size, and use in research.

Fly with extra pair of eyes—on antennae!

Fly with malformed wings

Malformed Body Parts Some genes control the development of body parts. Mutations in such genes often cause body parts to develop improperly, as did the malformed wings shown here. This particular trait is seen only when a fly has a normal allele paired with the malformed-wing allele. A fly that has two such alleles will not survive.

Fly with legs in place of antennae

Misplaced Body Parts Imagine growing legs from your head! Some mutations cause legs, antennae, mouthparts, and wings to grow in various places on a fly's body. By studying these oddities, scientists have begun to understand the genes that control the arrangement of body parts in insects and other animals.

Answer to Research

The *Drosophila* is about 3 mm long with a two-week life cycle. It is mostly used for research in genetics, but more recently it has been used in developmental biology.

Why It Matters

Teacher's Notes Scientists find it convenient to study mutations that express themselves phenotypically. When fruit flies mature, scientists anesthetize the flies and examine each fly to identify those that have mutations. Scientists can quickly find the results to many genetic crosses, by sorting and counting flies this way. When mutations cannot be identified visually, more involved tests are used to determine if an organism has a particular mutation.

READING TOOLBOX

Visual Literacy Help students identify the mutations illustrated in the figure. First, have students review the illustration of the fly commonly found in the wild. Then, have students examine the other illustrations to spot the differences in the organisms. There are many mutations that scientists study, but here are some examples.

- Eyes can be red, orange, or white.
- Bodies can be ebony or yellow.
- Wings can be short or curly.

Section 2

Focus

This section covers the logic Mendel used to formulate his theory and explains the laws of segregation and independent assortment.

Bellringer

Use the Bellringer transparency to prepare students for this section.

Teach

Teaching Key Ideas

Traits of Offspring Ask students if it is possible for an offspring to have traits that differ from both parents. Explain that some hidden traits in parents can combine and appear in the offspring. An example would be tongue rolling or earlobe attachment. **LS Interpersonal**

Answers to Caption Questions

Figure 4: Only one allele for seed color is passed on from the parent to each offspring.

Section 2

Mendel's Theory

Key Ideas	Key Terms		Why It Matters
What patterns of heredity were explained by Mendel's hypotheses? What is the law of segregation? How does genotype relate to phenotype? What is the law of independent assortment?	allele dominant recessive genotype	phenotype homozygous heterozygous	Mendel's theory explains why you have some, but not all, of the traits of your parents.

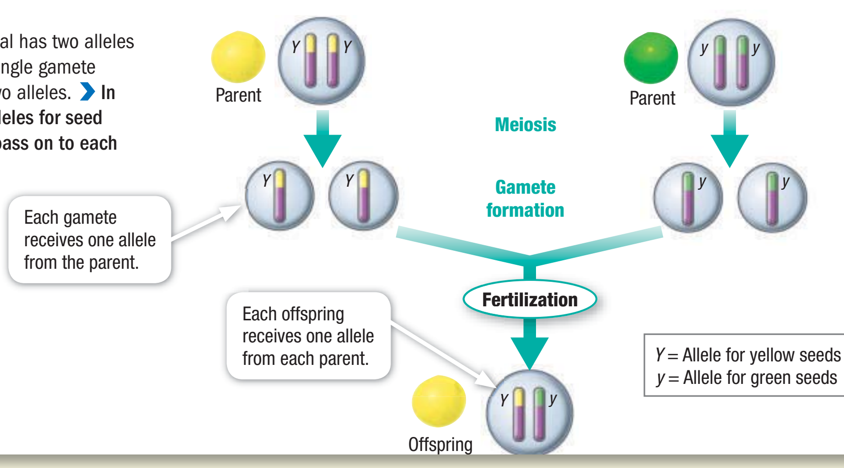
Explaining Mendel's Results

Mendel developed several hypotheses to explain the results of his experiments. His hypotheses were basically correct but have been updated with newer terms and more-complete knowledge. Mendel's hypotheses, collectively called the *Mendelian theory of heredity,* form the foundation of modern genetics. **Mendelian theory explains simple patterns of inheritance. In these patterns, two of several versions of a gene combine and result in one of several possible traits.**

Alternate Versions of Genes Before Mendel's experiments, many people thought that the traits of offspring were always a blend of the traits from parents. If this notion were true, a tall plant crossed with a short plant would result in offspring of medium height. But Mendel's results did not support the blending hypothesis. Mendel noticed that his pea plants would express only one of two traits for each character, such as purple or white flower color. Today, scientists know that different traits result from different versions of genes. Each version of a gene is called an **allele.**

Reading Check *What is the "blending" hypothesis?*

Figure 4 Each individual has two alleles for a given character. A single gamete carries only one of the two alleles. **In pea plants, how many alleles for seed color does each parent pass on to each offspring?**



Key Resources

Transparencies
C3 Mendel's Factors

Visual Concepts
Allele
Comparing Dominant and Recessive Traits
Comparing Homozygous and Heterozygous Genotypes
Genotype
Phenotype
Comparing Genotype and Phenotype
Segregation
Law of Independent Assortment

Data

QuickLab

15 min

Dominant and Recessive Traits

Can you find Mendelian patterns in humans? Look for ratios between these contrasting traits.

Procedure

1. On a separate sheet of paper, draw a table like the one shown here. For each character, circle the trait that best matches your own trait.
2. Tally the class results to determine how many students in your class share each trait.

Dominant trait	Recessive trait
freckles	no freckles
no cleft	cleft chin
dimples	no dimples

Analysis

1. **Summarize** the class results for each character.
2. **Calculate** the ratio of dominant traits to recessive traits for each character.
3. CRITICAL THINKING **Mathematical Reasoning** Are each of the ratios the same? Why is this unlikely to happen?
4. CRITICAL THINKING **Analyzing Results** For which traits must a person who has the given trait receive the same allele from both parents? Explain your answer.

One Allele from Each Parent Mendel also noticed that traits can come from either parent. The reason is related to meiosis, as **Figure 4** shows. When gametes form, each pair of alleles is separated. Only one of the pair is passed on to offspring.

Dominant and Recessive Alleles For every pair of traits that Mendel studied, one trait always seemed to "win" over the other. That is, whenever both alleles were present, only one was fully expressed as a trait. The other allele had no effect on the organism's physical form. In this case, the expressed allele is called **dominant.** The allele that is not expressed when the dominant allele is present is called **recessive.** Traits may also be called *dominant* or *recessive.* For example, in pea plants, the yellow-seed trait is dominant, and the green-seed trait is recessive.

allele (uh LEEL) one of two or more alternative forms of a gene, each leading to a unique trait

dominant (DAHM uh nuhnt) describes an allele that is fully expressed whenever the allele is present in an individual

recessive (ri SES iv) describes an allele that is expressed only when there is no dominant allele present in an individual

Random Segregation of Alleles

Mendel did not understand how chromosomes separate during meiosis, but he learned something important about this process. Because chromosome pairs split up randomly, either one of a pair of homologous chromosomes might end up in any one gamete. As **Figure 4** shows, offspring receive one allele from each parent. But only chance decides which alleles will be passed on through gametes. Mendel showed that segregation is random, and he stated his hypothesis as a law. **In modern terms, the *law of segregation* holds that when an organism produces gametes, each pair of alleles is separated and each gamete has an equal chance of receiving either one of the alleles.**

ACADEMIC VOCABULARY

random without aim

QuickLab

Teacher's Notes Emphasize that dominant phenotypes are not necessarily more common than recessive phenotypes. Point out that the expression of some phenotypes (such as freckles) may be influenced by the environment.

Answers to Analysis

1. Results will vary. Students should total the different traits for each character.
2. Results will vary, but the class total ratios should be rounded to the nearest whole numbers.
3. It is highly unlikely that the ratios would be the same. There's much variety in the human gene pool.
4. The expression of a recessive trait requires that the offspring have a recessive allele from both parents.

Differentiated Instruction

Advanced Learners

Trait Research Have students research other human traits with approximately Mendelian inheritance patterns, such as: widow's peak hairline, eyelash length, earlobe connectedness, tongue rolling, mid-digital hair, and hitch-hiker's thumb. Some of these traits are not purely Mendelian. Other genes or environmental factors may affect the phenotypes. For more information refer to the Web site of the National Center for Biotechnology Information/U.S. National Library of Medicine or other, similar sites. LS **Verbal**

Why It Matters

Blood Lines The Greek philosopher Aristotle associated inheritance with blood. He thought blood carried hereditary information from the body's various structures to the reproductive organs. Though incorrect, this idea is ingrained in many languages. For example, "blue blood," "blood stock," and "It is in the blood" are English phrases that associate inheritance with blood. Likewise, "Corre en la sangre" means "It runs in the blood," in Spanish; "Bon sang ne peut mentir" means "Good blood cannot lie," in French; and "Es liegt im Blute," means "It lies in the blood," in German.

Teach, *continued*

READING TOOLBOX

Word Parts The root of the words *phenomenon* and *phenotype* is *phen-* which means "to make visible." A *phenomenon* is an occurrence, something that can be witnessed, and a *phenotype* is the visible appearance resulting from the genotype.

Teaching Key Ideas

Genotype and Phenotype Have students practice using the important terms in this section by providing several examples. For example, tell them that the gene for plant height has two versions: *T* tall and t short. Ask students to identify the two alleles for plant height. (*T* and *t*) Write *Tt, tt,* and *TT* on the board and ask students to identify the genotype and phenotype of each set of alleles. (genotypes— *Tt, tt, TT*; phenotypes: tall, dwarf, and tall) Ask students to identify whether a plant with *TT* alleles is homozygous or heterozygous. (homozygous)

READING TOOLBOX

Visual Literacy Ask students to describe how **Figure 5** demonstrates dominance, segregation, genotype, and phenotype.

Answers to Caption Questions

Figure 5: If a plant has the dominant allele in its genotype, the flower's phenotype will be purple flowers.

READING TOOLBOX

Word Parts Look up the word *phenomenon* in a dictionary. What is the meaning of the Greek root of this word? How does this meaning apply to the word *phenotype* as used in biology?

genotype (JEE nuh TIEP) a specific combination of alleles in an individual

phenotype (FEE noh TIEP) the detectable trait or traits that result from the genotype of an individual

homozygous (HOH moh ZIE guhs) describes an individual that carries two identical alleles of a gene

heterozygous (HET uhr OH ZIE guhs) describes an individual that carries two different alleles of a gene

Mendel's Findings in Modern Terms

Although Mendel did not use the term allele, he used a code of letters to represent the function of alleles. Today, scientists use such a code along with modern terms, as shown in **Figure 5.** A dominant allele is shown as a capital letter. This letter is usually the first letter of the word for the trait. For example, purple flower color is a dominant trait in pea plants, so the allele is written as *P*. A recessive allele is shown as a lowercase letter. The letter is usually the same as the one used for the dominant allele. So, white flower color is written as *p*.

Genotype and Phenotype Mendel's experiments showed that an offspring's traits do not match one-to-one with the parents' traits. In other words, offspring do not show a trait for every allele that they receive. Instead, combinations of alleles determine traits. The set of alleles that an individual has for a character is called the **genotype.** The trait that results from a set of alleles is the **phenotype.** In other words, **genotype determines phenotype.** For example, if the genotype of a pea plant is *pp,* the phenotype is white flowers. If the genotype is *Pp* or *PP,* the phenotype is purple flowers, as shown in **Figure 5.**

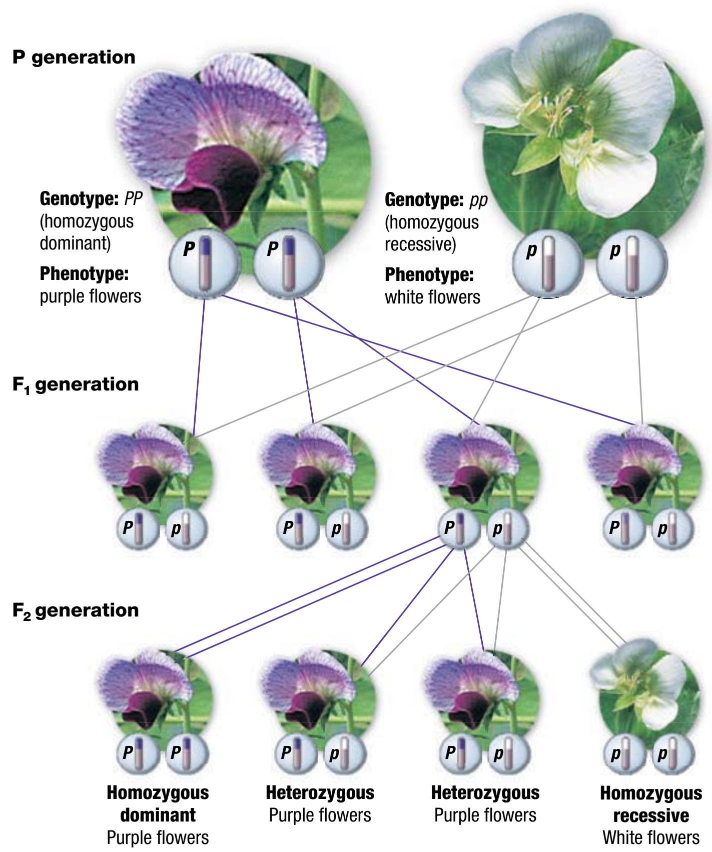
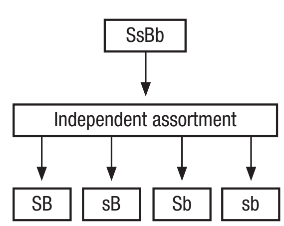


Figure 5 Mendel's first experiments demonstrated dominance, segregation, genotype, and phenotype. **What is the relationship between the genotypes and phenotypes in each generation shown here?**

Differentiated Instruction

Basic Learners/English Learners

Law of Independent Assortment Have students work in pairs to make a graphic organizer to demonstrate the law of independent assortment. Ask students to illustrate their graphic organizer with at least one example showing the inheritance of two pairs of contrasting traits. Have them write a brief explanation. Ask each group to put their examples on the board or overhead projector. Work with the groups to create the best model. **LS Logical**



Homozygous and Heterozygous If an individual has two of the same alleles of a certain gene, the individual is **homozygous** for the related character. For example, a plant that has two white-flower alleles (*pp*) is homozygous for flower color. On the other hand, if an individual has two different alleles of a certain gene, the individual is **heterozygous** for the related character. For example, a plant that has one purple-flower allele and one white-flower allele (*Pp*) is heterozygous for flower color. In the heterozygous case, the dominant allele is expressed. This condition explains Mendel's curious results, as **Figure 5** shows.

Mendel's Second Experiments

Mendel not only looked for patterns, he also looked for a lack of patterns. For example, the round-seed trait did not always show up in garden pea plants that had the yellow-seed trait. Mendel made dihybrid crosses to study these results. A *dihybrid cross*, shown in **Figure 6,** involves two characters, such as seed color and seed shape.

Independent Assortment In these crosses, Mendel found that the inheritance of one character did not affect the inheritance of any other. He proposed another law. **In modern terms, the *law of independent assortment* holds that during gamete formation, the alleles of each gene segregate independently.** For example, in **Figure 6,** the alleles for seed color (*Y* and *y*) can "mix and match" with the alleles for seed shape (*R* and *r*). So, round seeds may or may not be yellow.

Genes Linked on Chromosomes Mendel's second law seems to say that each gene has nothing to do with other genes. But we now know that many genes are linked to each other as parts of chromosomes. So, genes that are located close together on the same chromosome will rarely separate independently. Thus, genes are said to be *linked* when they are close together on chromosomes. The only genes that follow Mendel's law are those that are far apart.

Reading Check *What is a dihybrid cross?*

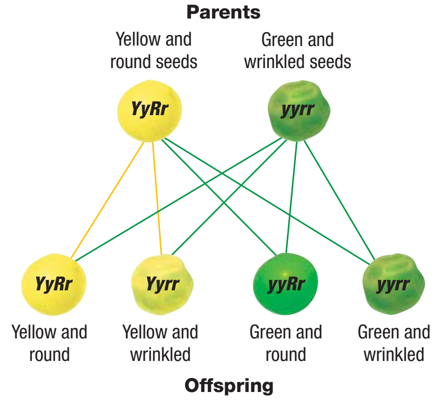


Figure 6 Mendel used dihybrid crosses in his second experiments. He found that the inheritance of one character, such as seed color, did not affect the inheritance of another character, such as seed shape.
What law did Mendel propose to explain these findings?

SCILINKS.
www.scilinks.org
Topic: Mendel's Laws
Code: HX80938

Section 2 Review

KEY IDEAS

1. **Describe** the patterns that Mendelian theory explains.
2. **Summarize** the law of segregation.
3. **Relate** genotype to phenotype, using examples from Mendel's experiments with pea plants.
4. **Summarize** the law of independent assortment.

CRITICAL THINKING

5. **Analyzing Data** The term *gene* did not exist when Mendel formed his hypotheses. What other genetic terms are used today that Mendel did not likely use?
6. **Arguing Logically** Would it be correct to say that a genotype is heterozygous recessive? Explain.
7. **Critiquing Explanations** Identify the strengths and weaknesses of Mendel's law of independent assortment.

METHODS OF SCIENCE

8. **Testing an Hypothesis** How did Mendel test his hypothesis that the inheritance of one character does not affect the inheritance of another character?

Answers to Caption Questions

Figure 6: the law of independent assortment

Demonstration

Hairy Knuckles Have students determine whether or not they have hair on their fingers near their knuckles. Tell students that the presence of this hair is caused by a dominant allele, *H*. Then, ask them to identify the genotype of a person who does not have hair above his or her knuckles. (*hh*) Have students determine how a parent without hair near the knuckles can produce a child with hair above the knuckles. (The second parent must have the *H* allele.) **LS Interpersonal**

Close

Formative Assessment

What is a possible genotype of a pea plant with purple flowers?

A. *pp* (Incorrect. *pp* is a genotype that would result in white flowers. Review the ways that dominant and recessive alleles are represented.)
B. *Pp* (Correct! Either *PP* or *Pp* would result in purple flowers.)
C. purple (Incorrect. Purple flower color is the phenotype, not the genotype.)
D. white (Incorrect. White flower color is a phenotype, not a genotype. Review the meanings of these terms.)

Answers to Section Review

1. Mendelian theory explains simple patterns of inheritance in which two of several versions of an allele combine and result in one of several possible traits.
2. The law of segregation holds that when an organism produces gametes, each pair of alleles is separated and each gamete has an equal chance of receiving either one of the alleles.
3. Genotype determines phenotype. For example, the genotype *PP* or *Pp* results in purple flowers, while the genotype *pp* results in white flowers.
4. The law of independent assortment holds that during gamete formation, the alleles of each gene segregate independently.
5. Sample answers: allele, genetics, chromosome, genotype, phenotype
6. No, in Mendelian inheritance, a heterozygous genotype must always yield a dominant phenotype. The term *recessive,* if referring to the phenotype, would require that two recessive alleles be present, in which case the genotype would be homozygous recessive.
7. strength: explains the inheritance patterns that Mendel observed in pea plants; weakness: does not hold true in many cases where genes are linked on chromosomes
8. He performed many dihybrid crosses with various combinations of characters.

Section 3

❯ Focus

This section explains the use of Punnett squares for predicting outcomes, the concept of probability, and the use pedigrees to show the transmission of traits.

Bellringer
Use the Bellringer transparency to prepare students for this section.

❯ Teach

Teaching Key Ideas

Selective Breeding Ask students to list some examples of selective breeding in domestic animals or crops. Dogs are good examples. Then ask them to explain how to select for a particular character. **LS Verbal**

READING TOOLBOX

Visual Literacy Discuss the use of the Punnett square to predict the outcome of two genetic crosses. Using **Figure 7,** review how the genotype in each square is obtained. Assign several monohybrid crosses for students to practice. **LS Logical**

Answers to Caption Questions

Figure 7: A Punnett square shows the ratio of possible genotypes that could result from a given cross.

Section 3

Modeling Mendel's Laws

Key Ideas	Key Terms	Why It Matters
❯ How can a Punnett square be used in genetics? ❯ How can mathematical probability be used in genetics? ❯ What information does a pedigree show?	Punnett square probability pedigree genetic disorder	Mendel's laws can be used to help breed exotic pets, thoroughbred livestock, and productive crops.

Why are Mendel's laws so important? Mendel's laws can be used to predict and understand the results of certain kinds of crosses. Farmers, gardeners, animal keepers, and biologists need to make predictions when they try to breed organisms that have desired characteristics. Medical professionals need to know about the inheritance of traits in their patients. Graphical models that can help with these tasks include Punnett squares and pedigrees.

Using Punnett Squares

A **Punnett square** is a model that predicts the likely outcomes of a genetic cross. The model is named for its inventor, Reginald Punnett. ❯ **A Punnett square shows all of the genotypes that could result from a given cross.**

The simplest Punnett square consists of a square divided into four boxes. As **Figure 7** shows, the possible alleles from one parent are written along the top of the square. The possible alleles from the other parent are written along the left side. Each box inside the square holds two letters. The combination of letters in each box represents one possible genotype in the offspring. The letters in each box are a combination of two alleles—one from each parent.

Punnett square (PUHN uht SKWER) a graphic used to predict the results of a genetic cross

Homozygous Cross In a cross of homozygous parents that have contrasting traits, 100% of the offspring will be heterozygous and will show the dominant trait.

Heterozygous Cross In a cross of heterozygous parents that have the same traits, the ratio of genotypes will be 1:2:1. The ratio of phenotypes will be 3:1.

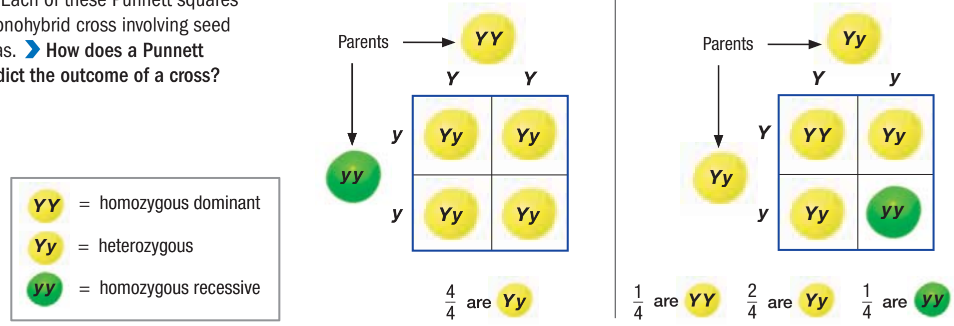


Figure 7 Each of these Punnett squares shows a monohybrid cross involving seed color in peas. ❯ **How does a Punnett square predict the outcome of a cross?**

Key Resources

Transparencies
C4 Probability with Two Coins
C5 Monohybrid Cross of Homozygous Plants
C6 Monohybrid Cross of Heterozygous Plants
C8 Dihybrid Crosses

Visual Concepts
Punnett Square with Homozygous Cross
Testcross
Calculating Probability
Pedigree
Sex Linkage

Why It Matters

Recessive Genes Basenjis are small dogs with pointed ears, short silky hair, and rows of wrinkles on their foreheads. Tell students that the basenjis cannot bark, but they can make yodeling type sounds. Basenjis can mate with barking breeds to produce puppies that bark. Ask students to hypothesize a genetic explanation for why basenjis cannot bark. (The ability to bark is a dominant trait in dogs. Basenjis have two recessive genes for this character.) Ask students to suggest other traits that have been selected for in breeding dogs or cats. **LS Logical**

Data

QuickLab

10 min

Testcross

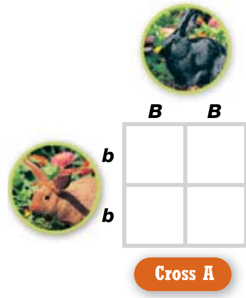
When genotypes are known, Punnett squares can be used to predict phenotypes. But can genotypes be determined if only phenotypes are known?

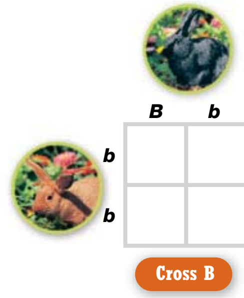
Suppose a breeder has a rabbit that has a dominant phenotype, such as black fur (as opposed to recessive brown fur). How could the breeder know whether the rabbit is homozygous (*BB*) or heterozygous (*Bb*) for fur color? The breeder could perform a testcross.

A *testcross* is used to test an individual whose phenotype for a characteristic is dominant but whose genotype is not known. This individual is crossed with an individual whose genotype is known to be homozygous recessive. In our example, the breeder would cross the black rabbit (*BB* or *Bb*) with a brown rabbit (*bb*).

Procedure

On a separate **sheet of paper,** copy the two Punnett squares shown here. Write the appropriate letters in the boxes of each square.





Analysis

1. **Label** what each pair of letters represents in each of the Punnett squares.
2. **Identify** which figure represents a testcross involving a heterozygous parent.
3. **Identify** which figure shows a cross in which all offspring will have black fur.
4. CRITICAL THINKING **Applying Models** If half of the offspring in a testcross have brown fur, what is the genotype of the parent that has black fur?

Analyzing Monohybrid Crosses Two kinds of monohybrid crosses are shown in **Figure 7.** A simple Punnett square can be used to analyze a monohybrid cross. Recall that this cross involves parents who each have a trait that contrasts with the trait of the other parent. The parents may be homozygous or heterozygous.

Monohybrid Homozygous Crosses Consider a cross between a pea plant that is homozygous for yellow seed color (*YY*) and a pea plant that is homozygous for green seed color (*yy*). The first Punnett square in **Figure 7** shows that all of the offspring in this type of cross will be heterozygous (*Yy*) and will express the dominant trait of yellow seed color. Other results are not possible in this case.

Monohybrid Heterozygous Crosses The second Punnett square in **Figure 7** predicts the results of a monohybrid cross between two pea plants that are heterozygous (*Yy*) for seed color. This cross is more complex than a homozygous cross. About one-fourth of the offspring will be *YY*. About two-fourths (or one-half) will be *Yy*. And about one-fourth will be *yy*. Another way to express this prediction is to say that the genotypic ratio will be 1 *YY* : 2 *Yy* : 1 *yy*. Because the *Y* allele is dominant, three-fourths of the offspring will be yellow (*YY* or *Yy*) and one-fourth will be green (*yy*). Thus, the phenotypic ratio will be 3 yellow : 1 green.

Reading Check *Explain the boxes inside a Punnett square?*

Academic Vocabulary

contrast different when compared

Reading Toolbox

Analogies Use the information on this page to solve the following analogy.

yy : Yy :: Homozygous : _______

QuickLab

Teacher's Notes Remind struggling students that Cross A follows the same pattern as the homozygous cross on the facing page. Have them refer to this cross as model before trying the testcrosses in this lab.

Answers to Procedure

Cross A, all are *Bb*

Cross B, the two squares on the left are *Bb,* the two on the right are *bb.*

Answers to Analysis

1. *Bb* = heterozygous with black fur; *bb* = homozygous recessive with brown fur
2. Cross B
3. Cross A
4. heterozygous, *Bb*

Teaching Key Ideas

Constructing Punnett Squares Write the following genotypes on the board: (1) *PP,* (2) *Pp,* and (3) *pp.* Pair each student with a partner. Have each pair select two of the three genotypes and use them to construct complete Punnett squares showing the crosses.

Reading Toolbox

Analogies The symbol *yy* shows a homozygous condition. Thus, *Yy* is analogous to heterozygous.

Differentiated Instruction

Alternative Assessment

Phenotypic Ratios After reviewing **Figure 7,** ask students to create a Punnett square showing the cross of a homozygous recessive parent with a heterozygous parent. Have them determine the phenotypic ratios.

	Y	*y*	
y	*Yy*	*yy*	$\frac{2}{4}$ are *Yy*
y	*Yy*	*yy*	$\frac{2}{4}$ are *yy*

Why It Matters

Punnett Who? The Punnett square is named after Reginald Punnett, one of the scientists who developed it. Punnett was a student at Cambridge University. Along with William Bateson, Punnett published a paper on the genetics of sweet peas. The square was developed as an elegant way to illustrate their research.

Teach, *continued*

QuickLab

Teacher's Notes Help students get started by demonstrating how to set up and fill in the first Punnett square (ZZ × Zz cross).

Answers to Analysis

1. $\frac{1}{4}$
2. $\frac{1}{2}$
3. The cross is *ZZ* × *zz.* All of the offspring will be heterozygous *(Zz).* Thus, the probability is 1.
4. The cross is *Zz* × *zz.* None of the offspring will be homozygous dominant *(ZZ).* Thus, the probability is 0.

Why It Matters

Probability in Real Life No one can predict the future with absolute certainty, but scientists often use mathematics and computer models to try to determine the probable outcomes of many events and circumstances. Using data from past events, scientists can develop models that show how patterns from the past may be relevant to patterns occurring now.

Data

QuickLab

15 min

Probabilities

Some people are born with extra fingers or toes. This condition, known as *polydactyly,* is rare. However, it is usually the result of a dominant allele.

▲ Polydactyly (extra fingers or toes) is usually a dominant trait.

Procedure

Draw Punnett squares to represent all possible combinations of alleles for each the crosses discussed below. Use *Z* to represent a dominant allele and *z* to represent a recessive allele.

Analysis

1. **Calculate** the probability that a cross of two heterozygous (*Zz*) parents will produce homozygous dominant (*ZZ*) offspring.
2. **Determine** the probability that a cross of a heterozygous parent (Zz) and a homozygous recessive (*zz*) parent will produce heterozygous offspring.
3. **Calculate** the probability that a cross of a homozygous dominant parent and a homozygous recessive parent will produce heterozygous offspring.
4. **Determine** the probability that a cross between a heterozygous parent and a homozygous recessive parent will produce homozygous dominant offspring.

Using Probability

Punnett squares allow direct and simple predictions to be made about the outcomes of genetic crosses, but those predictions are not certain. A Punnett square shows the possible outcomes of a cross, but it can also be used to calculate the probability of each outcome. **Probability** is the likelihood that a specific event will occur.

Academic Vocabulary
occur to take place

probability (PRAHB uh BIL uh tee) the likelihood that a specific event will occur; expressed in mathematical terms

Calculating Probability Punnett squares are one simple way to demonstrate probability. Probability can be calculated and expressed in many ways. Probability can be expressed in words, as a decimal, as a percentage, or as a fraction. For example, if an event will definitely occur, its probability can be expressed as either 1 out of 1 (in words), 100 % (as a percentage), 1.0 (as a decimal), or $\frac{1}{1}$ (as a fraction). If an event is just as likely to occur as to not occur, its probability can be expressed as either 1 out of 2, 50 %, 0.5, or $\frac{1}{2}$. Probability can be determined by the following formula:

$$\textit{probability} = \frac{\textit{number of one kind of possible outcome}}{\textit{total number of all possible outcomes}}$$

Consider the example of a coin tossed into the air. The total number of possible outcomes is two—heads or tails. Landing on heads is one possible outcome. Thus, the probability that the coin will land on heads is $\frac{1}{2}$. Likewise, the probability that it will land on tails is $\frac{1}{2}$. Of course, the coin will not land on tails exactly half of the time, but it will tend to do so. The average number of total flips that result in tails will tend to be $\frac{1}{2}$.

Differentiated Instruction

Special Education Students

Modeling Punnett Squares To help visually impaired students, work with the Punnett square concept, create the Punnett grid on the desktop using thick tape or clay. Provide objects of two different sizes to represent dominant and recessive alleles. For example, game pieces could be used. Use this model to create a 3-dimensional version of Figure 7. These materials can also be used for the Testcross QuickLab. **LS Kinesthetic**

Alternative Assessment

Mathematical Equivalents Ask students to determine the probability of selecting an ace from a single suit of cards. Then, ask them to express this fraction as a decimal and percentage. ($\frac{1}{13}$, 0.08, 8%) **LS Logical**

Probability of a Specific Allele in a Gamete Recall the law of segregation, which states that each gamete has an equal chance of receiving either one of a pair of alleles. If a pea plant has two alleles for seed color, only one of the two alleles (yellow or green) can end up in a gamete. **Probability formulas can be used to predict the probabilities that specific alleles will be passed on to offspring.** For a plant that has two alleles for seed color, the total number of possible outcomes is two—green or yellow. The probability that a gamete from this plant will carry the allele for green seed color is $\frac{1}{2}$. The probability that a gamete will carry the allele for yellow seed color is also $\frac{1}{2}$.

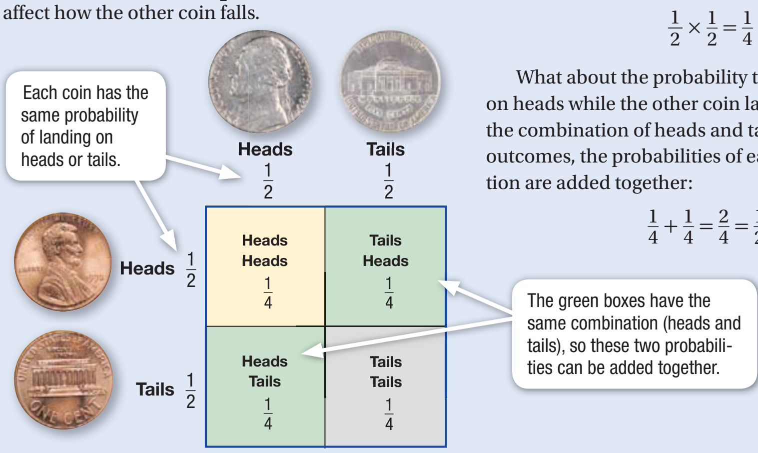
Probability in a Heterozygous Cross The possible results of a heterozygous cross are similar to those of flipping two coins at once. Consider the possible results of a cross of two pea plants that are heterozygous for seed shape (*Rr*). Either parent is equally likely to pass on a gamete that has either an *R* allele or an *r* allele. So, the chance of inheriting either allele is $\frac{1}{2}$. Multiplying the probabilities for each gamete shows that the probability that the offspring will have *RR* alleles is $\frac{1}{4}$. The probability that the offspring will have *rr* alleles is also $\frac{1}{4}$. The combination *Rr* has two possible outcomes, so the probability that the offspring will have *Rr* alleles is $\frac{2}{4}$, or $\frac{1}{2}$.

Reading Check ***What is the probability that a heterozygous cross will produce homozygous recessive offspring?***

SCILINKS.
www.scilinks.org
Topic: Probability
Code: HX81217

Math Skills — Probability of Two Independent Events

Because two parents are involved in a genetic cross, both parents must be considered when predicting the probable outcomes. Consider the example of tossing two coins at the same time. The probability that a penny will land on heads is $\frac{1}{2}$, and the probability that a nickel will land on heads is $\frac{1}{2}$. How one coin falls does not affect how the other coin falls.



What is the probability that the nickel and the penny will both land on heads at the same time? To find the probability that a specific combination of two independent events will occur, multiply the probabilities of each event. Thus, the probability that both coins will land on heads is

$$\frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$$

What about the probability that one coin will land on heads while the other coin lands on tails? Because the combination of heads and tails has two possible outcomes, the probabilities of each possible combination are added together:

$$\frac{1}{4} + \frac{1}{4} = \frac{2}{4} = \frac{1}{2}$$

Teaching Key Ideas

Probabilities in Genetic Crosses Point out that the probability of a specific genotype occurring in a cross can be obtained by setting up a Punnett square similar to that in the **Math Skills** below. The probability of finding a specific allele in a gamete is written next to the possible allele across the top and along the side. **LS Logical**

Math Skills

Probability with Dice Coin flipping is a simple way to demonstrate a probability of one half. To demonstrate statistical analysis in complex systems, ask students to calculate the probability of rolling a single, six-sided die and having it land with six facing up. $\left(\frac{1}{6}\right)$ Then, ask students to calculate the probability of rolling two dice and having two sixes facing up. $\left(\frac{1}{6} \times \frac{1}{6} = \frac{1}{36}\right)$ Ask students: "If you roll two dice, is the likelihood of getting two different numbers greater than getting two identical numbers?" (Yes; Only 6 of the 36 total combinations are matching pairs. There are 30 mixed combinations. So, the probability of getting a matching pair is $\frac{1}{6}$. The probability of getting a mixed pair is $\frac{30}{36}$ or $\frac{5}{6}$.) **LS Logical**

Differentiated Instruction

Basic Learners

Reading the Signs Review the reasons why the probabilities are multiplied in the first example (both heads) and added in the second example (one heads, one tails).

MISCONCEPTION ALERT

Probabilities Students may think that probabilities in genetic crosses show the definite outcome of a genetic cross. Point out that probabilities are used only to *predict* the likely outcome of a genetic cross.

Teach, *continued*

READING TOOLBOX

Visual Literacy Before teaching students to interpret a pedigree such as that shown in **Figure 8,** introduce the symbols: male (square), female (circle), trait expressed (shaded circle or square), and trait not expressed (circle or square not shaded). Once students are comfortable with the meanings of the symbols, have them interpret the pedigree in **Figure 8.** Tell students the gene for this trait not only results in a deficiency of skin, hair, and eye pigmentation but also causes defects in vision. LS **Visual**

Teaching Key Ideas

Human X-Linked Genes Tell the students that some human genes are not inherited equally by both sexes. An X-linked recessive gene is more likely to be expressed in the phenotype of the son. The son gets one X chromosome, so one recessive gene will show in the phenotype. Daughters get two X chromosomes, so to express a recessive X-linked trait, the daughter must get a recessive gene on each X chromosome. Ask students how a male might inherit an X-linked trait from his mother. (The mother carries the recessive allele on one of her X chromosomes. The son inherits this chromosome from his mother and a Y from his father.) LS **Verbal**

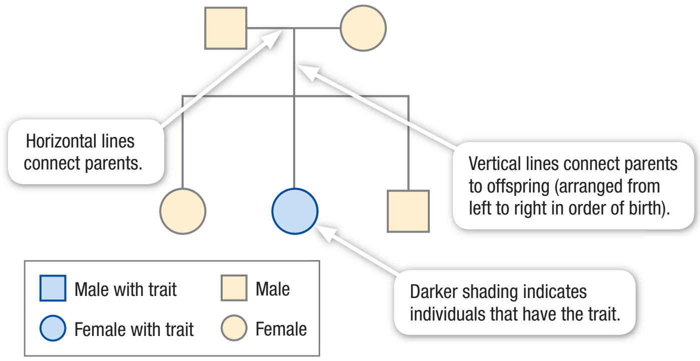


Figure 8 Albinism is a genetic disorder carried by a recessive allele. Because of this disorder, this baby koala's skin and hair cells do not produce pigments, so the baby is mostly white. The pedigree (top right) shows the presence of the albinism trait in a family.

Using a Pedigree

Mendel observed several generations of pea plants to see patterns in the inheritance of traits. A simple way to model inheritance is to use a pedigree. A **pedigree** is a family history that shows how a trait is inherited over several generations. A healthcare worker may use a pedigree to help a family understand a genetic disorder. A **genetic disorder** is a disease or disorder that can be inherited. If a family has a history of a genetic disorder, the parents may want to know if their children could inherit the disorder. Some parents are carriers. Carriers have alleles for a disorder but do not show symptoms. Carriers can pass the allele for the disorder to their offspring.

Figure 8 shows a pedigree for a family in which albinism is present. A body affected by the genetic disorder albinism is unable to produce the pigment that gives dark color to skin, eyes, and hair. Without this pigment, the body may appear white or pink. A recessive allele causes albinism. The pedigree helps show how this trait is inherited. **A pedigree can help answer questions about three aspects of inheritance: sex linkage, dominance, and heterozygosity.**

Sex-Linked Gene The sex chromosomes, X and Y, carry genes for many characters other than gender. A *sex-linked gene* is located on either an X or a Y chromosome, but most are located on the X chromosome. Because it is much shorter than the X chromosome, the Y chromosome holds fewer genes. Females usually have two X chromosomes. A recessive allele on one of the X chromosomes will often have a corresponding dominant allele on the other. Thus, the trait for the recessive allele is not expressed in the female. Males, on the other hand, usually have an X chromosome and the much shorter Y chromosome. Because it has few genes, the shorter Y chromosome may lack an allele that corresponds to a recessive allele on the longer X chromosome. So, the trait for the single recessive allele will be expressed in the male. Traits that are not expressed equally in both sexes are commonly sex-linked traits. Colorblindness is an example of a sex-linked trait that is expressed more in males than in females.

Reading Check *How can one identify a sex-linked trait?*

pedigree (PED i GREE) a diagram that shows the occurrence of a genetic trait in several generations of a family

genetic disorder an inherited disease or disorder that is caused by a mutation in a gene or by a chromosomal defect

Why It Matters

Pedigreed Dogs About 10 percent of Dalmatians are deaf. Because many dogs are inbred—that is, they have closely related parents—some of them are homozygous for certain recessive disorders. Ask students who have purebred dogs to find out if their dog's breed is prone to a genetic disorder. [Some pedigreed dogs that are prone to genetic disorders include Irish setters (blindness), German shepherds (hip dysplasia), and dachshunds (dwarfism).] LS **Verbal**

Differentiated Instruction

Struggling Readers

Vocabulary Ask students to differentiate between *Punnett squares, probabilities,* and *pedigrees.* (*Punnett squares* predict the expected outcome of a cross by considering all possible combinations of gametes in a cross. *Probabilities* predict the mathematical likelihood that a specific event, such as the outcome of a cross, will occur. *Pedigrees* provide a visual representation of how a trait is inherited over several generations.) LS **Verbal**

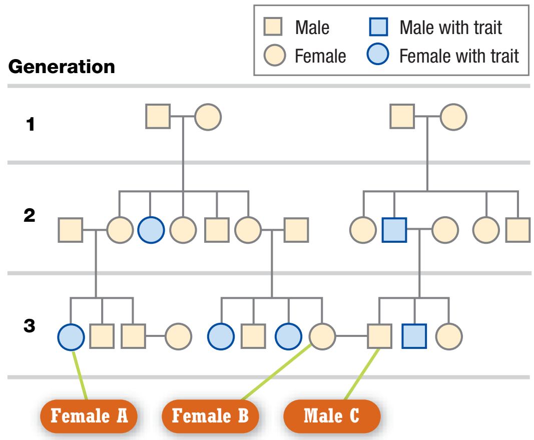
Data

QuickLab

15 min

Pedigree Analysis

You will practice interpreting a pedigree. The pedigree to the right shows the presence or absence of a specific trait in several generations of a family.



Analysis

1. **Determine** whether the trait is dominant or recessive. Explain your reasoning.
2. **Determine** if Female A could be heterozygous for the trait. Do the same for Female B.
3. CRITICAL THINKING **Applying Information** Suppose that Female B is homozygous and produces children with Male C. If Male C is heterozygous, what is the probability that the children will have the trait?

Dominant or Recessive? If a person has a trait that is autosomal and dominant and has even one dominant allele, he or she will show the trait. A dominant allele is needed to pass on the trait. If a person has a recessive trait and only one recessive allele, he or she will not show the trait but may pass it on. So, if a trait appears in a child whose parents lack the trait, it is most likely recessive.

Heterozygous or Homozygous? If a person is either heterozygous or homozygous dominant for an autosomal gene, his or her phenotype will show the dominant trait. If a person is homozygous recessive, his or her phenotype will show the recessive trait. Heterozygous parents can produce a child who is homozygous recessive. Thus, a recessive trait in the child shows that both parents were heterozygous carriers of the recessive allele.

Section 3 Review

KEY IDEAS

1. **Describe** how a Punnett square is used in genetics.
2. **List** ways to express mathematical probability in genetics.
3. **Sketch** a pedigree for an imaginary family of three generations and describe what the pedigree shows.

CRITICAL THINKING

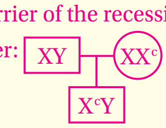
4. **Scientific Methods** How can you determine the genotype of a pea plant that has purple flowers?
5. **Mathematical Reasoning** If you flip two coins at once, will at least one coin land on heads? Explain.
6. **Analyzing Graphics** When analyzing a pedigree, how can you determine if an individual is a carrier (heterozygous) for the trait being studied?

USING SCIENCE GRAPHICS

7. **Pedigree** Some kinds of colorblindness are sex-linked traits carried on the X chromosome. So, males can inherit the trait from mothers that are not colorblind. Draw a pedigree that demonstrates this pattern of inheritance.

Answers to Section Review

1. A Punnett square shows the relative probabilities of all of the possible genotypes that could result from a specified cross for a given character.
2. in words, as a percentage, as a decimal, or as a fraction
3. Look for the following in students' work: three generations; males and females; the presence of traits; and Mendelian inheritance patterns. Students should select one trait to represent in the pedigree, such as freckles or albinism.
4. Sample answer: Perform a test cross with a white-flowered pea plant. If any of the offspring are white, the purple-flowered parent must be heterozygous. If none of the offspring have white flowers, then the purple-flowered parent is probably homozygous dominant. This result assumes that a large number of offspring have been produced.
5. Sample answer: Not necessarily; the chances are only 1/2 that either coin will land on heads, and each flip is independent of the other.
6. Sample answer: If a trait appears in at least one of the offspring and least one of the parents of an individual that lacks the trait, and the trait is known to be recessive, then that individual is probably a carrier of the recessive allele.
7. Sample answer:



QuickLab

Teacher's Notes Encourage students to use "If-then" statements to organize their thoughts and interpret the pedigree. Example: If a gene is expressed by an offspring but not by either parent, then the gene is likely to be inherited recessively.

Answers to Analysis

1. It is recessive, because it sometimes appears in the children of parents who lack the trait, as was the case with Female A.
2. Female A must be homozygous to express the recessive trait. Female B does not have the trait, so she could be heterozygous. (One cannot tell for certain without seeing whether the trait shows up in her descendants.)
3. There is no chance that the children will have the trait.

Close

Formative Assessment

A Punnett Square is used to show ________, while a pedigree is used to show ________.

A. parents, offspring (Incorrect. Both a Punnett square and a pedigree show parents and offspring. Review the section to understand Punnett squares and pedigrees.)
B. offspring, parents (Incorrect. Both a Punnett square and a pedigree show offspring and parents. Review the section to understand Punnett squares and pedigrees.)
C. genotypes, phenotypes (Correct!)
D. phenotypes, genotypes (Incorrect. A Punnett square is mostly used to show genotypes, while a pedigree is mostly used to show phenotypes.)

Section 4

Focus

This section discusses complex patterns of inheritance such as incomplete dominance, codominance, polygenic traits, linked traits, and environmental influences

Bellringer
Use the Bellringer transparency to prepare students for this section.

Teach

Teaching Key Ideas

Multiple Alleles Ask students to look at the variations in human characters shown in **Figure 9**. Ask them to propose a mechanism for the inheritance of a character such as eye color in humans, which can appear as brown, green, blue, and gray. (There are at least three alleles involved, brown, green and blue. Brown is dominant to green and blue, and green is dominant to blue.) LS Logical/Verbal

Section 4

Beyond Mendelian Heredity

Key Ideas	Key Terms	Why It Matters
Are there exceptions to the simple Mendelian pattern of inheritance? How do heredity and the environment interact to influence phenotype? How do linked genes affect chromosome assortment and crossover during meiosis?	polygenic character codominance linked	Some inheritance is more complex than Mendel showed. This complexity helps explain the large variety of human traits.

Suppose a horse that has red hair mates with a horse that has white hair. The offspring of the horses has both red and white hair on its body. How can this be? Shouldn't the colt's hair be one color or the other? Not always! In fact, most characters are not inherited in the simple patterns identified by Mendel. Although Mendel was correct about the inheritance of the traits that he studied, most patterns of inheritance are more complex than those that Mendel identified.

Many Genes, Many Alleles

If you look at people and animals around you, you will notice a variety of physical features, as **Figure 9** shows. Why do so few of these features have only two types? First, not all genes have only two alleles. Second, not all characters are controlled by one gene. **The Mendelian inheritance pattern is rare in nature; other patterns include polygenic inheritance, incomplete dominance, multiple alleles, and codominance.**

Figure 9 A physical feature—such as height, weight, hair color, and eye color—is often influenced by more than one gene.

Polygenic Inheritance When several genes affect a character, it is called a **polygenic character.** For example, eye color is affected by several genes. One gene controls the relative amount of greenness of the eye, and another gene controls brownness. (The recessive condition in both cases is blue eyes.) Other genes also affect eye color. Sorting out the effects of each gene is difficult. The genes may be on the same or different chromosomes. Other examples of polygenic characters in humans are height and skin color. In fact, most characters are polygenic.

Incomplete Dominance Recall that in Mendel's pea-plant crosses, one allele was completely dominant over the other. In some cases, however, an offspring has a phenotype that is intermediate between the traits of its two parents. This pattern is called *incomplete dominance*.

Key Resources

Transparencies
C7 Incomplete Dominance

Visual Concepts
Comparing Single Allele, Multiple Allele, and Polygenic Traits
Comparing Complete, Incomplete, and Co-Dominance
Comparing X-Linked and Sex-Influenced Traits

Differentiated Instruction

Alternative Assessment

Evaluating Arguments Evaluate students' ability to analyze, review, and critique scientific explanations by asking them to identify and describe the limitations of Mendel's understanding of inheritance based on his pea plant experiments. Complete this exercise by comparing and contrasting simple patterns of trait inheritance associated with pea plants with more complex patterns of trait inheritance such as polygenic, incomplete dominance, codominance, and multiple alleles. LS Logical

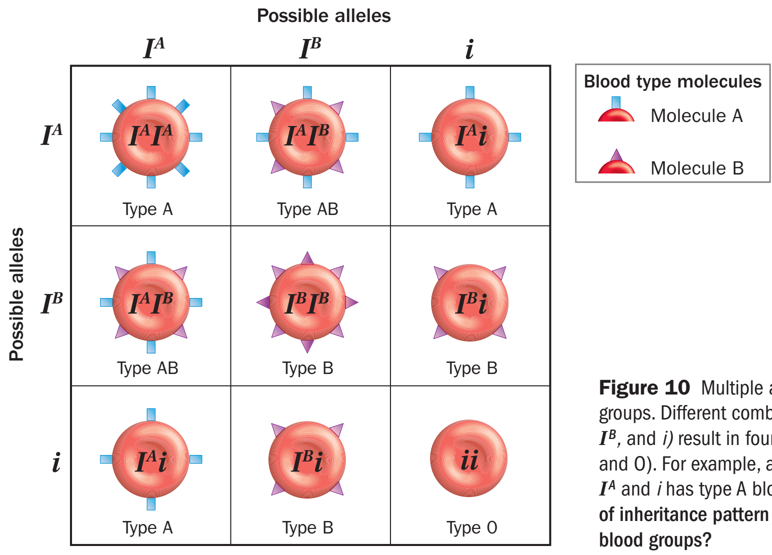


Figure 10 Multiple alleles control the ABO blood groups. Different combinations of three alleles (I^A, I^B, and i) result in four blood phenotypes (A, AB, B, and O). For example, a person who has the alleles I^A and i has type A blood. ❯ **What is another kind of inheritance pattern demonstrated by the ABO blood groups?**

When a snapdragon that has red flowers is crossed with a snapdragon that has white flowers, the offspring have pink flowers. Neither the red allele nor the white allele is completely dominant over the other. The pink flowers simply have less red pigment than the red flowers do.

Multiple Alleles Genes that have three or more possible alleles are said to have *multiple alleles*. For example, multiple alleles exist for hair color in cats. Still, only two alleles for a gene can be present in one individual. The determination of dominance may be complex.

In humans, the ABO blood groups (blood types) are determined by three alleles: I^A, I^B, and i. **Figure 10** shows how various combinations of the three alleles can produce four blood types: A, B, AB, and O. The I^A and I^B alleles cause red blood cells to make certain molecules. The letters *A* and *B* refer to the two kinds of molecules. The i allele does not cause either molecule to be made. So, both the I^A and I^B alleles are dominant over i. But I^A and I^B are not dominant over each other. So, a person who has both I^A and I^B alleles has type AB blood. A person who has two i alleles has type O blood.

Codominance For some characters, two traits can appear at the same time. **Codominance** is a condition in which both alleles for the same gene are fully expressed.

The genetics of human blood groups, which was discussed above, is also an example of codominance. A person who has I^AI^B alleles will have type AB blood because neither allele is dominant over the other. Type AB blood cells make both A-type and B-type molecules.

❯ **Reading Check** ***How does codominance differ from incomplete dominance?***

polygenic (PAHL uh JEN ik) **character**
a character that is influenced by more than one gene

codominance (KOH DAHM uh nuhns)
a condition in which both alleles for a gene are fully expressed

ACADEMIC VOCABULARY

various many kinds of

SCILINKS.
www.scilinks.org
Topic: Mendelian Genetics
Code: HX80940

Answers to Caption Questions

Figure 10: Another inheritance pattern demonstrated by the ABO blood group is codominance.

Teaching Key Ideas

Incomplete Dominance Ask students whether a plant breeder could produce only pink-flowering snapdragons by crossing pink-flowering snapdragons and white-flowering snapdragons. (no) Help students understand that because all pink-flowering snapdragons are heterozygous, mating a pink-flowering snapdragon with a white-flowering one would produce pink-flowering and white-flowering offspring in a ratio of 1:1 **LS Logical**

Math Skills

Phenotypic Ratios Ask students to write the phenotypic ratios for the combinations shown in **Figure 10.** (type A = $\frac{3}{9}$ or $\frac{1}{3}$; type B = $\frac{3}{9}$ or $\frac{1}{3}$; type AB = $\frac{2}{9}$; type O = $\frac{1}{9}$)

Differentiated Instruction

Basic Students/English Learners

Create a Chart Assign pairs of students to create a chart that illustrates three of the following: polygenic inheritance, incomplete dominance, characters controlled by multiple alleles, codominance, and characters influenced by the environment. Students can use drawings or photographs. **LS Interpersonal**

Why It Matters

Human Inheritance Mendel's work with garden-pea plants showed that the characters he studied are controlled by single genes. In humans, single-factor inheritance has been found in about 600 recessively inherited characters, and in such dominant conditions as Huntington's disease. However, many more conditions are determined by polygenic inheritance, which involves several genes. Such conditions include cleft lip and palate, some types of schizophrenia, hypertension, and diabetes.

Teach, *continued*

Answers to Caption Questions

Figure 11: The character for fur color can be affected by conditions in the environment.

Science Skills

Using Punnett Squares Ask students to use a Punnett square to figure out the following problem. The mother of a blood type O child is type A. List the mother's genotype and the possible genotypes for the father. (The mother is $I^A i$; possible genotypes for the father are $I^A i$, $I^B i$, ii) **LS Logical**

Close

Formative Assessment

A cross between a red-flowered plant and a white-flowered plant results in offspring that have pink flowers. This result is an example of ______.

A. polygenic inheritance (Incorrect. Polygenic inheritance occurs when multiple genes affect one character. In this case, a pattern of blending of traits occurs. Review the exceptions to Mendelian inheritance patterns.)

B. incomplete dominance (Correct! Incomplete dominance occurs when a blend or intermediate form results from a cross of two contrasting traits.)

C. multiple alleles (Incorrect. Multiple alleles tend to produce a wide range of phenotypes. The case of pink flowers is simply a blending of two phenotypes.)

D. codominance (Incorrect. Codominance is when both traits are fully expressed.)

Figure 11 Many Arctic mammals, such as the Arctic fox, develop white fur during the winter and dark fur during the summer. **What does this change indicate about the character for fur color in these animals?**

Genes Affected by the Environment

Genes are the key to life, but there is more to life than genes. **Phenotype can be affected by conditions in the environment, such as nutrients and temperature.** For example, temperature affects the fur color of the Arctic fox, shown in **Figure 11.** During summer, genes in the fox's skin cells cause pigments to be made. These pigments make the fox's coat darker. Dark fur color helps the fox blend in with grass or woods. But during cold weather, the genes stop causing pigment to be made. Then, the fox's fur grows white, and the fox can blend in with the winter snow.

In humans, many of the characters that are partly determined by heredity are also affected by the environment. For example, a person's height is partly hereditary. Tall parents tend to produce tall children. But nutrition also affects height. A person who has an unhealthy diet may not grow as tall as he or she could have. Many aspects of human personality and behavior are strongly affected by the environment, but genes also seem to play an important role.

Genes Linked Within Chromosomes

Many traits do not follow Mendel's laws, but Mendel's pea traits did. Why? One reason is that Mendel studied the simplest kinds of heredity: characters determined by one gene that has two alleles. Also, he studied characters that are determined by independent genes.

Recall how meiosis relates to the *law of independent assortment*. If genes are on different chromosomes, the alleles for each gene can be sorted independently. Then, each set of alleles can be recombined in any way. For example, in the pea plants, the two alleles for seed color could be combined in any way with the two alleles for seed shape.

Some genes are close together on the same chromosome. **During meiosis, genes that are close together on the same chromosome are less likely to be separated than genes that are far apart.** Genes that are close together, as well as the traits that they determine, are said to be **linked.**

linked in genetics, describes two or more genes that tend to be inherited together

Reading Check *What term describes genes that are close together on the same chromosome and that are unlikely to be separated?*

Section 4 Review

KEY IDEAS

1. **List** exceptions to the Mendelian pattern of one character controlled by two alleles.
2. **Describe** the relationship between heredity and the environment.
3. **Relate** gene linkage to chromosome assortment and crossover during meiosis.

CRITICAL THINKING

4. **Evaluating an Argument** A classmate states that Mendel's hypotheses are incorrect because they do not consider intermediate forms of a character. Evaluate this argument.
5. **Applying Concepts** Propose another example of a character in humans that seems to be partly affected by heredity and partly affected by environment. Explain your reasoning.

USING SCIENCE GRAPHICS

6. **Punnett Square** Predict the ratios of each of the ABO blood groups in an average population. Use a Punnett square like the one shown in Figure 10 and explain your results. Assume that the population has equal numbers of I^A, I^B, and i alleles.

Answers to Section Review

1. polygenic inheritance, incomplete dominance, multiple alleles, and codominance
2. Although genotype is the initial determinant of phenotype, phenotype can also be affected by conditions in the environment, such as nutrients and temperature.
3. During meiosis, genes that are close (on the same chromosome) are less likely to be separated (due to crossover) than genes that are far apart. Genes that are on separate chromosomes will have complete independent assortment.
4. Sample answer: Mendel's "laws" apply under specific conditions, as in the pea plants he studied. These laws are of limited use to predict or model more complex inheritance patterns, such as polygenic inheritance.
5. Sample answer: Skin color, which seems to be mostly governed by genes but also affected by exposure to sunlight.
6. Type AB $\frac{2}{9}$ or 22.2%

   Type A $\frac{3}{9} = \frac{1}{3}$ or 33.3%

   Type B $\frac{3}{9} = \frac{1}{3}$ or 33.3%

   Type O $\frac{1}{9}$ or 11.1%

Inquiry

Chapter 12 Lab

MULTI-DAY 45 min

Objectives

- Develop a hypothesis to predict the yield of a corn crop.
- Design and conduct an experiment to test your hypothesis.
- Compare germination and survival rates of three lots of corn seeds.

Materials

- lab apron, disposable gloves
- corn seeds, normal (10 from lot A and 10 from lot B)
- corn seeds, 3:1 mix of normal and albino (10 from lot C)
- plant tray or pots
- soil, potting (3 kg)
- water

Safety

Plant Genetics

In plants, albinism is characterized by the failure to produce chlorophyll, a plant pigment necessary for photosynthesis. Because the trait is recessive, parent plants with the normal phenotype may produce offspring (seeds) that carry the alleles for albinism. In this lab, you will investigate a question about albinism alleles in plants.

Preparation

1. SCIENTIFIC METHODS **State the Problem** What might happen to a seed that has one or more albinism alleles?
2. SCIENTIFIC METHODS **Form a Hypothesis** Form a hypothesis about how albinism affects the success of plants grown from seed.

Procedure

Design an Experiment

1. Design an experiment that will determine the germination and survival rates of three lots of corn seeds. Write out a procedure for your experiment on a separate sheet of paper. Be sure to include safety procedures, and construct tables to organize your data. Have your teacher approve your plan before you begin.
2. Predict the outcome of your experiment, and record this prediction.

Conduct Your Experiment

3. **CAUTION: Wear gloves and a lab apron whenever handling soil, seeds, or plants.**
4. Follow your written procedure. Make note of any changes.
5. Record all data in your tables. Also record any other observations.
6. At the end of the experiment, present your results to the class. Devise a way to collect the class data in a common format.
7. Clean up your lab materials according to your teacher's instructions. Wash your hands before leaving the lab.

Analyze and Conclude

1. SCIENTIFIC METHODS **Evaluating Experimental Design** Did you get clear results? How might you improve your design?
2. SCIENTIFIC METHODS **Analyzing Results** Did your results support your hypothesis? Explain your answer.
3. **Analyzing Data** Use the class data to calculate the average germination rate and survival rate for each lot of corn seeds. Describe any patterns that you notice.

Lab

Time Required

One 45 minute class period

Ratings

EASY → HARD

Teacher Prep: 3
Student Setup: 3
Concept Level: 3
Cleanup: 2

Preparation

1. No student answer is expected here, but they might simply copy the question.
2. Sample hypothesis: If seeds have two albinism alleles, then they cannot germinate.

Safety Cautions

Be sure students have read the safety rules for working in the lab.

Tips and Tricks

Corn seeds can be purchased from Ward's. Tell students that lot C is the result of the cross between two corn plants that were heterozygous for the albinism allele. Lots A and B are homozygous dominant and are normal. Ensure that factors such as light, temperature, and water are held constant for all groups to avoid introducing variables other than genotype.

Answers to Procedure

1. Check students' experimental designs at this point. Their plans should include safety procedures and empty data tables.
2. Sample prediction: Albino corn seeds (homozygous recessive) will not grow to adulthood. Heterozygous and homozygous dominant seeds will grow to adulthood normally.
6. Organize an opportunity for brief presentations. Students are presenting results only. Analysis and conclusions should come later.

Answers to Analyze and Conclude

1. Answers will vary depending on the source of the seeds used as lots A, B, and C. Some students may not get clear results if they did not measure carefully or control experimental conditions. All students should suggest improvements to their experimental design.
2. Some students will not get the results they predicted. Students' responses should include terms such as "supporting" or "refuting" a hypothesis, but not "proving" it.
3. Students should note variance among individual data sets. The trend for class data should show that albino corn germinates at about the same rate as non-albino corn, but grows less vigorously and dies early.

Chapter 12

SUPER SUMMARY

Have students connect the major concepts in this chapter through an interactive Super Summary. Visit **go.hrw.com** and type in the keyword **HX8GENS** to access the Super Summary for this chapter.

Reteaching Key Ideas

Mendel's Steps Ask students to replicate the three steps in Mendel's experiments as illustrated in **Figure 3,** substituting two additional characters from **Figure 2.** LS **Verbal**

Segregation of Alleles Students struggling with the random segregation of alleles may benefit from this exercise. Group four students into pairs that stand together. Each pair represents the two alleles of the same gene in each parent. Each student is one allele. Have each pair separate and flip a coin. The winners of each coin-flip join as a new pair. LS **Kinesthetic**

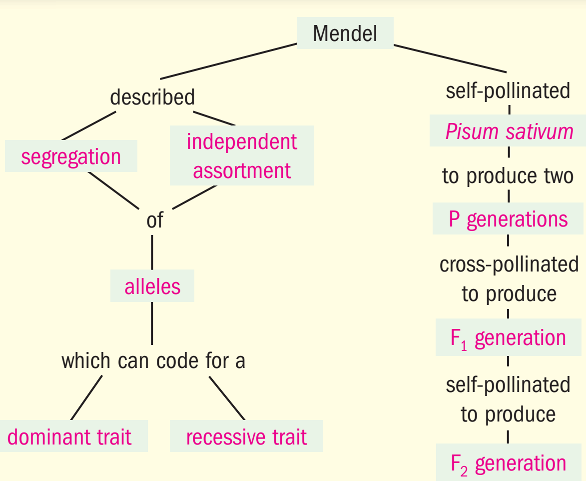
Chapter 12 Summary

go.hrw.com
SUPER SUMMARY
Keyword: HX8GENS

Key Ideas	Key Terms
1 Origins of Hereditary Science › Modern genetics is based on Mendel's explanations for the patterns of heredity that he studied in garden pea plants. › The garden pea plant is a good subject for studying heredity because the plant has contrasting traits, usually self-pollinates, and grows easily. › Mendel's first experiments used monohybrid crosses and were carried out in three steps. › For each of the seven characters that Mendel studied, he found a similar 3-to-1 ratio of contrasting traits in the F_2 generation.	**character** (268) **trait** (268) **hybrid** (268) **generation** (269)
2 Mendel's Theory › Mendelian theory explains simple patterns of inheritance in which each possible combination of alleles results in one of several possible traits. › In modern terms, the *law of segregation* holds that when an organism produces gametes, each pair of alleles is separated and each gamete has an equal chance of receiving either one of the alleles. › Genotype determines phenotype. › In modern terms, the *law of independent assortment* holds that during gamete formation, the alleles of each gene segregate independently.	**allele** (272) **dominant** (273) **recessive** (273) **genotype** (274) **phenotype** (274) **homozygous** (275) **heterozygous** (275)
3 Modeling Mendel's Laws › A Punnett square shows all of the genotypes that could result from a given cross. › Probability formulas can be used to predict the probabilities that specific alleles will be passed on to offspring. › A pedigree can help answer questions about three aspects of inheritance: sex linkage, dominance, and heterozygosity.	**Punnett square** (276) **probability** (278) **pedigree** (280) **genetic disorder** (280)
4 Beyond Mendelian Heredity › Mendelian inheritance is rare in nature; other patterns include polygenic inheritance, incomplete dominance, multiple alleles, and codominance. › Phenotype can be affected by conditions in the environment, such as nutrients and temperature. › Genes that are close together on the same chromosome are linked.	**polygenic character** (282) **codominance** (283) **linked** (284)

Answer to Concept Map

The following is one possible answer to Chapter Review question 2.



Chapter 12 Review

READING TOOLBOX

1. **Punnet Square** Create a Punnet square of a cross between a heterozygous parent and a homozygous parent. Determine the ratio of genotypes and phenotypes.
2. **Concept Map** Make a concept map that describes Mendel's experiments and results. Try to include the following words: *pea plants, alleles, P generation, F_1 generation, F_2 generation, dominant trait, recessive trait, segregation,* and *independent assortment.*

Using Key Terms

Use each of the following terms in a separate sentence.

3. *character*
4. *Punnett square*
5. *codominance*

For each pair of terms, explain how the meanings of the terms differ.

6. *genotype* and *phenotype*
7. *trait* and *allele*
8. *homozygous* and *heterozygous*
9. *incomplete dominance* and *codominance*

Understanding Key Ideas

10. The scientist whose studies formed the basis of modern genetics is
    a. T.A. Knight.
    b. Gregor Mendel.
    c. Louis Pasteur.
    d. Robert Hooke.
11. In Mendel's first experiments with pea plants, the average ratio of contrasting traits in the F_2 generation was
    a. 1:0.
    b. 1:1.
    c. 2:1.
    d. 3:1.
12. Each alternate version of a gene is called a(n)
    a. trait.
    b. allele.
    c. genotype.
    d. phenotype.
13. Some people are born with an extra finger or toe. People who have this trait have inherited either one or two of the same allele. So, the trait is
    a. recessive.
    b. dominant.
    c. phenotypic.
    d. independent.

14. The phenotype of an organism
    a. cannot be seen.
    b. exactly matches its genotype.
    c. is the physical result of its genes.
    d. occurs only in true-breeding organisms.
15. Mendel obtained his P generation by forcing pea plants to
    a. segregate.
    b. self-pollinate.
    c. cross-pollinate.
    d. assort independently.
16. What law states that the inheritance of one trait has no effect on the inheritance of another?
    a. the law of dominance
    b. the law of segregation
    c. the law of universal inheritance
    d. the law of independent assortment
17. Which of the following can help determine if an inherited trait is sex-linked?
    a. a ratio
    b. a testcross
    c. a pedigree
    d. a Punnett square
18. What is the expected phenotypic ratio resulting from a cross of a homozygous dominant parent with a heterozygous parent? Assume complete dominance.
    a. 1:3:1
    b. 1:2:1
    c. 2:1
    d. 1:0

Explaining Key Ideas

19. **Summarize** the design of Mendel's plant studies.
20. **State** the law of segregation in your own words.
21. **Describe** the information that a pedigree shows.
22. **Describe** incomplete dominance.

Assignment Guide

Section	Questions
1	2, 3, 7, 10, 11, 15, 19, 31
2	4, 6, 7, 12, 13, 14, 16, 20, 25
3	1, 17, 18, 21, 23, 24, 26, 29, 30, 32
4	9, 22, 27, 28

Review

Reading Toolbox

1.

	A	*a*
a	*Aa*	*aa*
a	*Aa*	*aa*

1:1

2. See previous page for answer to concept map.

Using Key Terms

3. A *character* can have several traits.
4. A *Punnett square* looks like a small multiplication table.
5. *Codominance* occurs when two traits are expressed at the same time.
6. *Genotype* is what's in the genes. *Phenotype* is what results from the genes.
7. *Traits* are possible variations of a character. *Alleles* are possible variations of a gene.
8. *Homozygous* is two alleles that are the same. *Heterozygous* is two alleles that are different.
9. *Incomplete dominance* results in blended traits. *Codominance* occurs when two traits are fully expressed at the same time.

Understanding Key Ideas

10. b 11. d 12. b 13. b
14. c 15. b 16. d 17. c
18. d

Explaining Key Ideas

19. Mendel's first experiments used monohybrid crosses and were carried out in three steps. (1) The P generation was bred by self-pollination for many generations to obtain true-breeding phenotypes. (2) The F_1 generation was bred by the cross-pollination of two different P parents. (3) The F_2 generation was bred by the self-pollination of F_1.
20. The law of segregation means that chromosome pairs separate when gametes are formed, so each gamete gets one allele for each gene.
21. A pedigree shows the appearance or absence of a trait through several generations of related individuals.
22. Incomplete dominance occurs when the heterozygous phenotype is intermediate between (or a combination of) the homozygous phenotypes.

23. Note: Accept alleles in any order such as *Rr* or *rR*.

	RY	Ry	rY	ry
RY	RRYY	RRYy	RrYY	RrYy
Ry	RRyY	RRyy	RryY	Rryy
rY	rRYY	rRYy	rrYY	rrYy
ry	rRyY	rRyy	rryY	rryy

24. b

Critical Thinking

25. Inheritance involves probability. One can only see patterns by analyzing many sample events and large amounts of data.

26. The statement is true. Sample explanation: Even if a person somehow had all three alleles of the ABO blood-group gene (which is not likely), the alleles I^A and I^B code for surface molecules, while *i* codes for no molecule, so a person with all three alleles would still be type AB and not type ABO.

27. Accept all reasonable answers. Human behavior is influenced partly by the complex interactions of genes, and by environmental factors. Human behavior is not completely understood.

28. The woman could be a carrier of the recessive cystic fibrosis allele.

Writing for Science

29. Student summaries should indicate that the high incidence of Hopi albinism is probably due to the size of the population. Once a few children with albinism are born in a small population, the albinism allele is more likely to be passed on and occur in homozygous form in successive generations.

Methods of Science

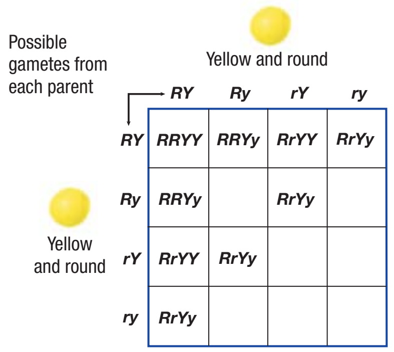
30. Student designs will vary but should be similar to Mendel's dihybrid cross experiments. If the two characters show fully independent assortment, then they are not linked.

Alternative Assessment

31. Student speeches should be realistic and written in a formal style. Consider providing time for interested students to deliver their speeches.

Using Science Graphics

Use the diagram of a dihybrid cross Punnett square to answer the following question(s).



	RY	Ry	rY	ry
RY	RRYY	RRYy	RrYY	RrYy
Ry	RRYy		RrYy	
rY	RrYY	RrYy		
ry	RrYy			

23. Copy the Punnett square onto a separate piece of paper. Then, fill in the missing possible genotypes of offspring.

24. When homologous chromosomes are separated during meiosis, only chance determines which of the pair is passed into any given gamete. This finding is known as the

a. law of chance.
b. law of segregation.
c. law of universal inheritance.
d. law of independent assortment.

Critical Thinking

25. Evaluating Methods Mendel based his conclusion about inheritance patterns on experiments involving large numbers of plants. Why is it important to study many individuals when studying patterns of inheritance?

26. Justifying Conclusions A classmate states that a person cannot have type ABO blood. Is this statement true? Explain your answer.

27. Forming Reasoned Opinions Do you think that human behavior is determined by genes? Explain your answer.

28. Justifying Conclusions A 20-year-old man who has cystic fibrosis has a sister who is planning to have a child. The man encourages his sister to see a genetic counselor. Why do you think the man gave his sister this advice?

Writing for Science

29. Summarizing The Hopi, a Native American people, have an unusually high ratio of persons who have the albinism trait. Research current hypotheses explaining why albinism is more common in people of Hopi ancestry than in other populations. Write a short summary of your findings.

Methods of Science

30. Designing an Experiment In tomato plants, tallness is dominant over dwarfness, and hairy stems are dominant over hairless stems. You can buy true-breeding (homozygous) plants that are tall and have hairy stems or that are dwarf and have hairless stems. Design an experiment to determine whether the genes for height and hairiness of the stem are closely linked on chromosomes.

Alternative Assessment

31. Speech Imagine that you have just been awarded the Nobel Prize in medicine for your research in human genetics and heredity. Write and perform an acceptance speech describing how Gregor Mendel influenced your work.

Math Skills

32. Probability The mathematics of independent assortment applies to any set of independent events, such as the numbers drawn in a lottery. For example, suppose 10 balls are marked from 0 to 9 and placed in a jar. If the balls are mixed thoroughly and one is taken out, the chances are 1 in 10 that a particular number will be drawn. If two jars are used, the chances of the same number being drawn from both jars is

$$\frac{1}{10} \times \frac{1}{10} = \frac{1}{100}$$

or 1 in 100. Suppose you enter a lottery that uses four jars that each contain 10 numbered balls. A number is drawn from each jar in sequence to make a four-digit number. If you choose the number 9,999, what is the chance that your number will be drawn?

Math Skills

32. The chance for the number 9 to be drawn from a jar is $\frac{1}{10}$. The chance that a nine will be drawn from each of the four jars is $(\frac{1}{10} \times \frac{1}{10} \times \frac{1}{10} \times \frac{1}{10}) = \frac{1}{10{,}000}$.

Chapter 12

Standardized Test Prep

TEST TIP If a question uses terms that seem unfamiliar or that you may have forgotten, skip it temporarily. Mark the item, continue with the test, and come back to the item later. Other items on the test may refresh your thinking.

Science Concepts

1. The passing of traits from parents to offspring is called
- **A** heredity.
- **B** probability.
- **C** assortment.
- **D** reproduction.

2. In a breeding experiment, what are the offspring of true-breeding parents called?
- **F** F_1 generation
- **G** F_2 generation
- **H** dominant generation
- **J** recessive generation

3. What characteristic is described in the statement "The dog's coat is brown"?
- **A** pedigree
- **B** genotype
- **C** phenotype
- **D** dominance

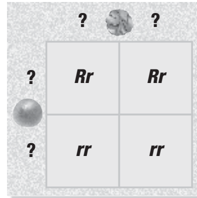
4. What term describes a gene with two dominant alleles that are expressed at the same time?
- **F** polygenic
- **G** mutational
- **H** codominant
- **J** incompletely dominant

5. The owner of a pet store wants to breed more animals that have a certain color of fur. What tool might the pet-store owner use to predict which animals have inherited the fur color gene?
- **A** pedigree
- **B** mutation
- **C** karyotype
- **D** microscope

6. What does the law of segregation state?
- **F** The two alleles for a gene separate when gametes are formed.
- **G** A species can have a variety of different alleles that code for a single characteristic.
- **H** The alleles of different genes separate independently from one another during gamete fromation.
- **J** Populations of a single species divided geographically will change over time to form two separate species.

Using Science Graphics

Use the diagram of a Punnett square to answer the following question(s).



7. What are the genotypes of the parents represented in this cross?
- **F** *Rr* and *Rr*
- **G** *RR* and *rr*
- **H** *Rr* and *rr*
- **J** *rr* and *rr*

8. What genotypic ratio is expected in the offspring of this cross?
- **A** 1:1
- **B** 1:2
- **C** 1:3
- **D** 1:4

Use the table to answer the following question(s).

Experimental group	Dominant trait	Recessive trait
Group 1	77	23
Group 2	74	26
Group 3	75	25
Group 4	73	27

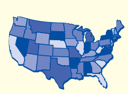
9. What is the approximate average ratio of dominant traits to recessive traits?
- **F** 1:0
- **G** 2:1
- **H** 1:2
- **J** 3:1

10. What kind of cross would result in these ratios?
- **A** two heterozygous parents
- **B** two homozygous recessive parents
- **C** two homozygous dominant parents
- **D** one heterozygous parent and one homozygous recessive parent

Writing Skills

11. Short Response Write a paragraph that summarizes the relationship between chromosomes and genes.

State Resources



For specific resources for your state, visit go.hrw.com and type in the keyword HSHSTR.

Test Practice with Guided Reading Development

Answers

1. A **2.** F **3.** C
4. H **5.** A **6.** F
7. H **8.** A **9.** J
10. A
11. Student paragraphs should be well-formed and free of grammatical and scientific errors. Genes are found on chromosomes.

TEST DOCTOR

Question 5 **A.** Correct. A pedigree would show the hereditary patterns in fur color. **B.** Incorrect. A mutation is not a tool for showing hereditary patterns. **C.** A karyotype is not a tool for showing hereditary patterns. **D.** Incorrect. A microscope cannot provide data on the hereditary patterns for alleles.

Question 7 **F.** Incorrect. The cross of these parents would result in a 1:2:1 genotypic ratio, not the 1:1 ratio shown in the Punnett square. **G.** Incorrect. The cross of these parents would result in a 1:0 genotypic ratio. **H.** Correct. The cross shown could only come from one heterozygous parent and one homozygous recessive parent. **J.** Incorrect. The Punnett square shows dominant alleles, therefore it cannot come from the cross of two homozygous recessive parents.

Question 8 **A.** Correct. The cross shows 2/4 *Rr* and 2/4 *rr*, which yields a 1:1 genotypic ratio. **B.** Incorrect. This ratio is not valid for the cross results shown. **C.** Incorrect. A 1:3 ratio would require two heterozygous parents. **D.** Incorrect. This ratio is not valid for the cross results shown.

Question 9 **F.** Incorrect. The table shows a 3:1 ratio using the following data: 77:23 ≈ 3:1; 74:26 ≈ 3:1. 75:25 ≈ 3:1; 73:27 ≈ 3:1. **G** and **H.** Incorrect. The data reflect a 3:1 ratio. **J.** Correct.