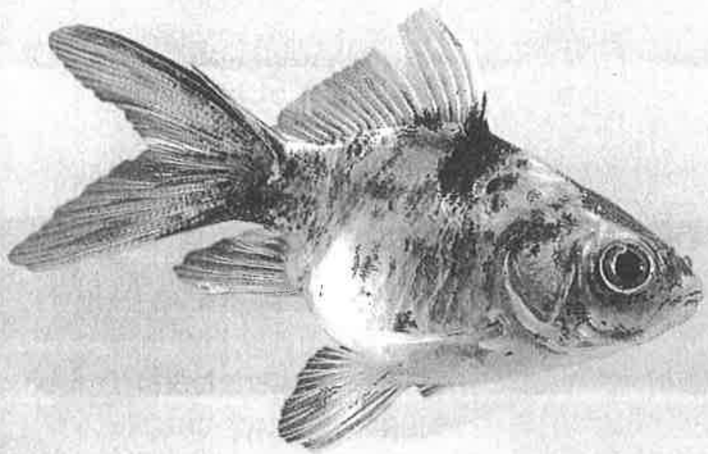
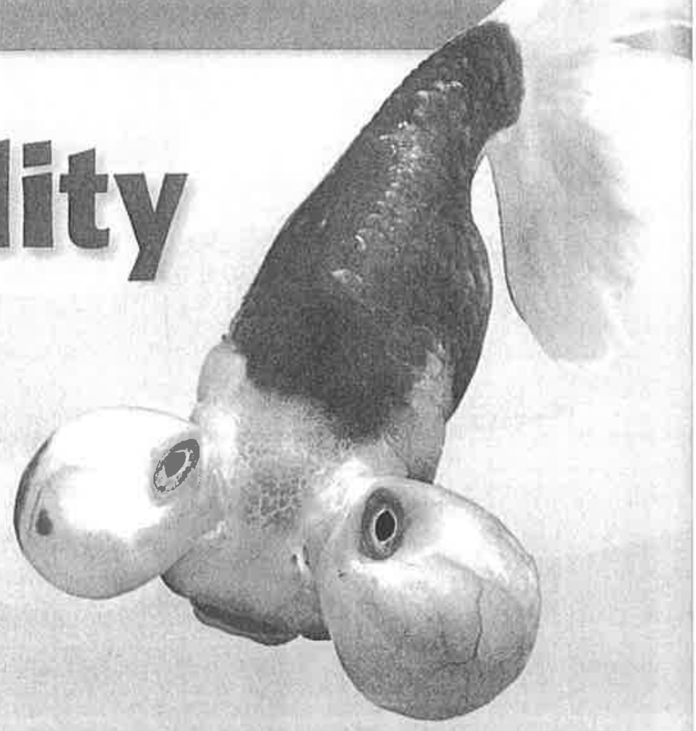
CHAPTER 5

Heredity

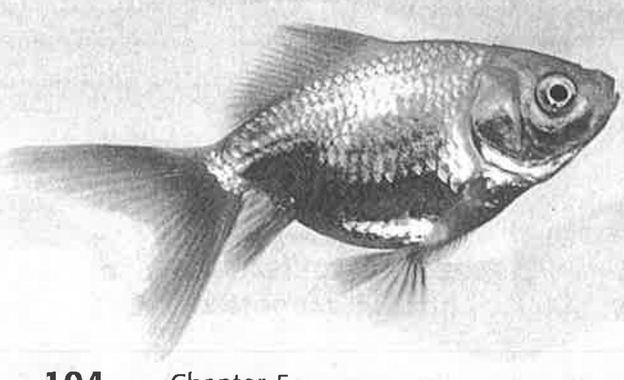




Would You Believe . . . ?

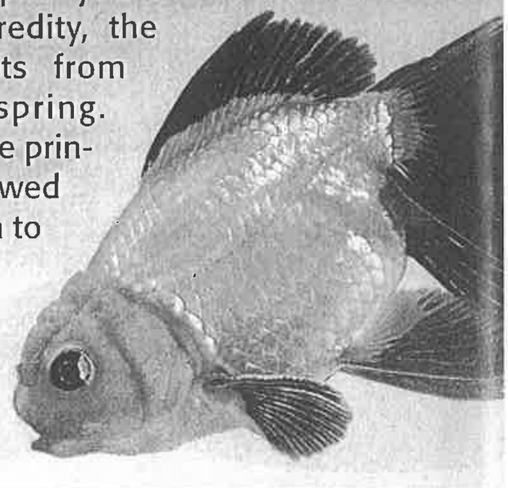
It all started in ancient China. A fisherman caught an unusual carp. Usually these small freshwater fish are drab colored, but this one had a pale golden hue. It was too pretty to eat, so the fisherman took the fish home as a pet.

Months later, the fisherman caught another gold-tinged carp. He kept the two fish in the same bowl. When the fish reproduced, the offspring were even more brightly colored than their parents. The first goldfish had been born!



In the years that followed, people throughout China began keeping and breeding the new, orange-colored pets. Many became goldfish matchmakers, choosing only the most handsome mates for their favorite fish. With each generation of hatchlings, the fish looked more and more distinctive. By A.D. 1500, when the first shipments of goldfish arrived in Japan, goldfish no longer resembled carp. In fact, they were so regal looking that the commoners in Japan were forbidden to keep them as pets.

Without knowing it, these early goldfish breeders were using the principles of genetics to create many new kinds of goldfish. In this chapter you will learn about heredity, the passing of traits from parents to offspring. You'll discover the principles that allowed beautiful goldfish to be bred from rather plain-looking carp.



Section 1

Mendel and His Peas

Terms to Learn

heredity
dominant trait
recessive trait
genes
alleles
genotype
phenotype
probability

What You'll Do

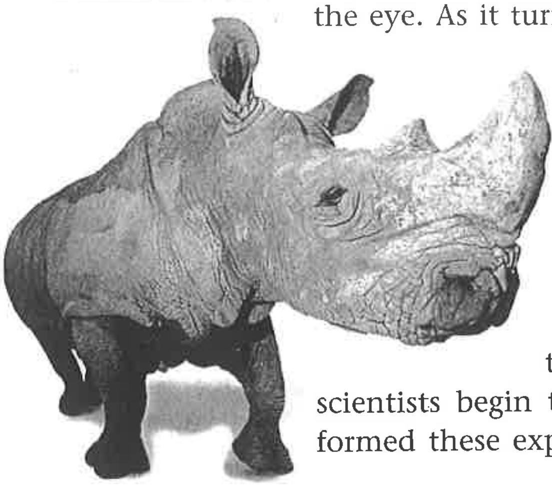
- Explain the experiments of Gregor Mendel.
- Explain how genes and alleles are related to genotypes and phenotypes.
- Use the information in a Punnett square.

There is no one else in the world exactly like you. You are unique. But what sets you apart? If you look around your classroom, you'll see that you share many physical characteristics with your classmates. For example, you all have skin instead of scales and a noticeable lack of antennae. You are a human being very much like all of your fellow human beings.

Yet you are different from everyone else in many ways. The people you most resemble are your parents and your brothers and sisters. But you probably don't look exactly like them either. Read on to find out why this is so.

Why Don't You Look Like a Rhinoceros?

The answer to this question seems simple: Neither of your parents is a rhinoceros. But there's more to this answer than meets the eye. As it turns out, **heredity,** or the passing of traits from parents to offspring, is a very complicated subject. For example, you might have curly hair, while both of your parents have straight hair. You might have blue eyes, even though both of your parents have brown eyes. How does this happen? People have investigated this question for a long time. About 150 years ago, some very important experiments were performed that helped scientists begin to find some answers. The person who performed these experiments was Gregor Mendel.



Activity

Imagine that you are planning to meet your pen pal at the airport, but you have never met. How would you describe yourself? Would you say that you are tall or short, have curly hair or straight hair, have brown eyes or green eyes? Make a list. Put a check mark next to traits you think you inherited.

TRY at HOME

Who Was Gregor Mendel?

Gregor Mendel was born in 1822 in Heinzendorf, Austria. Growing up on his family's farm, Mendel learned a lot about cultivating flowers and fruit trees. After completing his studies at a university, he entered a monastery. He worked in the monastery garden, where he was able to use plants to study the way traits are passed from parents to offspring. **Figure 1** shows an illustration of Mendel in the monastery garden.

Figure 1 Gregor Mendel

Unraveling the Mystery

From his experiences breeding plants, Mendel knew that sometimes the patterns of inheritance seemed simple and sometimes they did not. Mendel wanted to find out why.

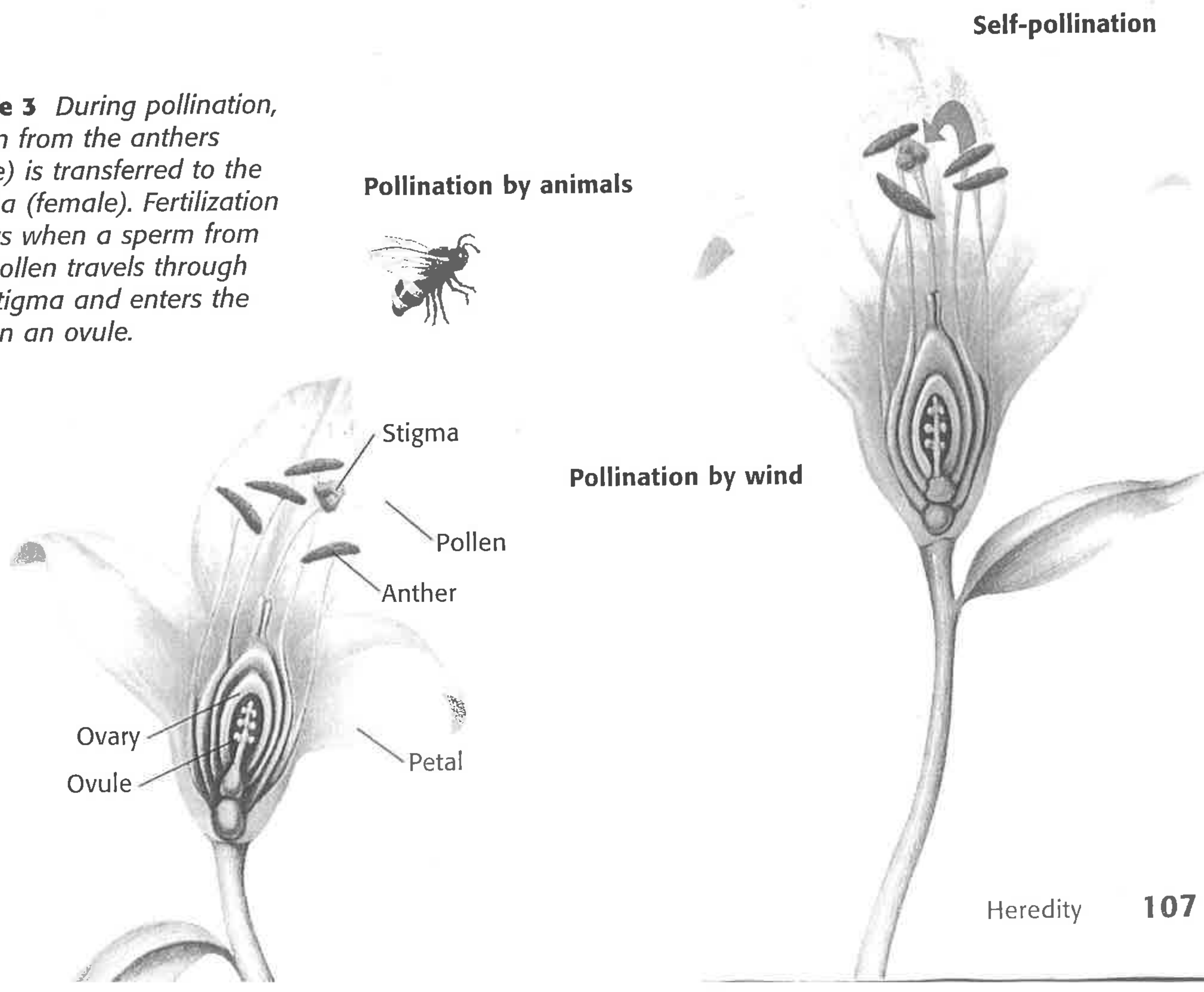
Mendel was interested in the way traits are passed from parents to offspring. For example, sometimes a trait that appeared in one generation did not show up in any of the offspring in the next generation. In the third generation, though, the trait showed up again. Mendel noticed similar patterns in people, plants, and many other living things.

To simplify his investigation, Mendel decided to study only one kind of organism. He had already done studies using the garden pea plant, so he chose this as his subject.

Figure 2 *This photograph of a flower shows the male and female reproductive structures.*

How Do You Like Your Peas? Garden peas were a good choice for several reasons. These plants grow quickly, they are usually self-pollinating, and they come in many varieties. A *self-pollinating plant* contains both male and female reproductive structures, like the flower in **Figure 2.** Therefore, pollen from one flower or plant can fertilize the eggs of the same flower or the eggs of another flower on the same plant. **Figure 3** illustrates the parts of a flower and how fertilization takes place in plants.

Figure 3 *During pollination, pollen from the anthers (male) is transferred to the stigma (female). Fertilization occurs when a sperm from the pollen travels through the stigma and enters the egg in an ovule.*



Peas Be My Podner

Mendel chose to study only one characteristic, such as plant height or pea color, at a time. That way, he could understand the results. Mendel chose plants that had two forms for each of the characteristics he studied. For example, for the characteristic of plant height, one form always produced tall plants, and the other form always produced short plants. Some of the characteristics investigated by Mendel are shown in **Figure 4.** The two different traits of each characteristic are also shown.

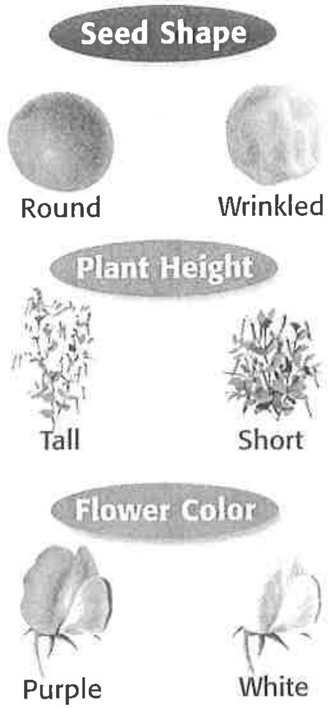


Figure 4 *These are some of the plant characteristics that Mendel studied.*

True-Breeding Plants Mendel was very careful to use plants that were true breeding for each of the traits he was studying. When a *true-breeding plant* self-pollinates, it will always produce offspring with the same trait the parent plant has. For example, a tall true-breeding plant will always produce offspring that are tall.

Mendel decided to find out what would happen if he crossed two plants that had different forms of a single trait. To do this, he used a method known as *cross-pollination.* In cross-pollination, the anthers of one plant are removed so that the plant cannot self-pollinate. Then pollen from another plant is used to fertilize the plant without anthers. This way, Mendel could select which pollen would fertilize which plant. This technique is illustrated in **Figure 5.**

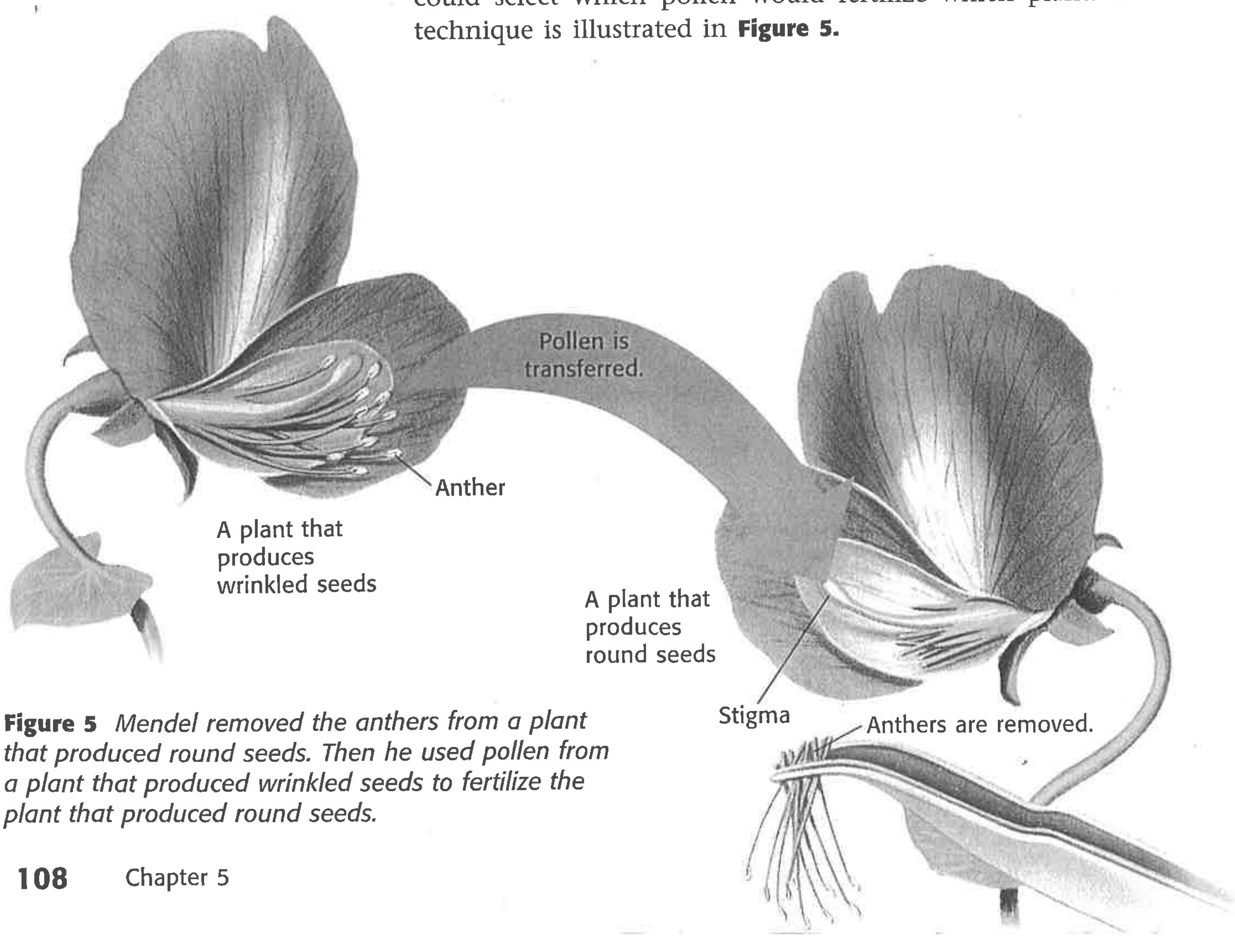


Figure 5 *Mendel removed the anthers from a plant that produced round seeds. Then he used pollen from a plant that produced wrinkled seeds to fertilize the plant that produced round seeds.*

Mendel's First Experiment

In his first experiment, Mendel performed crosses to study seven different characteristics. Each of the crosses was between the two traits of each characteristic. The results of the cross between plants that produce round seeds and plants that produce wrinkled seeds are shown in **Figure 6.** The offspring from this cross are known as the *first generation.* Do the results surprise you? What do you think happened to the trait for wrinkled seeds?

Mendel got similar results for each of the crosses that he made. One trait always appeared, and the other trait seemed to vanish. Mendel chose to call the trait that appeared the **dominant trait.** The other trait seemed to recede into the background, so Mendel called this the **recessive trait.** To find out what might have happened to the recessive trait, Mendel decided to perform another experiment.

Mendel's Second Experiment

Mendel allowed the first generation from each of the seven crosses to self-pollinate. This is also illustrated in Figure 6. This time the plant with the dominant trait for seed shape (which is round) was allowed to self-pollinate. As you can see, the recessive trait for wrinkled seeds showed up again.

Mendel performed this same experiment on the two traits of each of the seven characteristics. No matter which characteristic Mendel investigated, when the first generation was allowed to self-pollinate, the recessive trait reappeared.

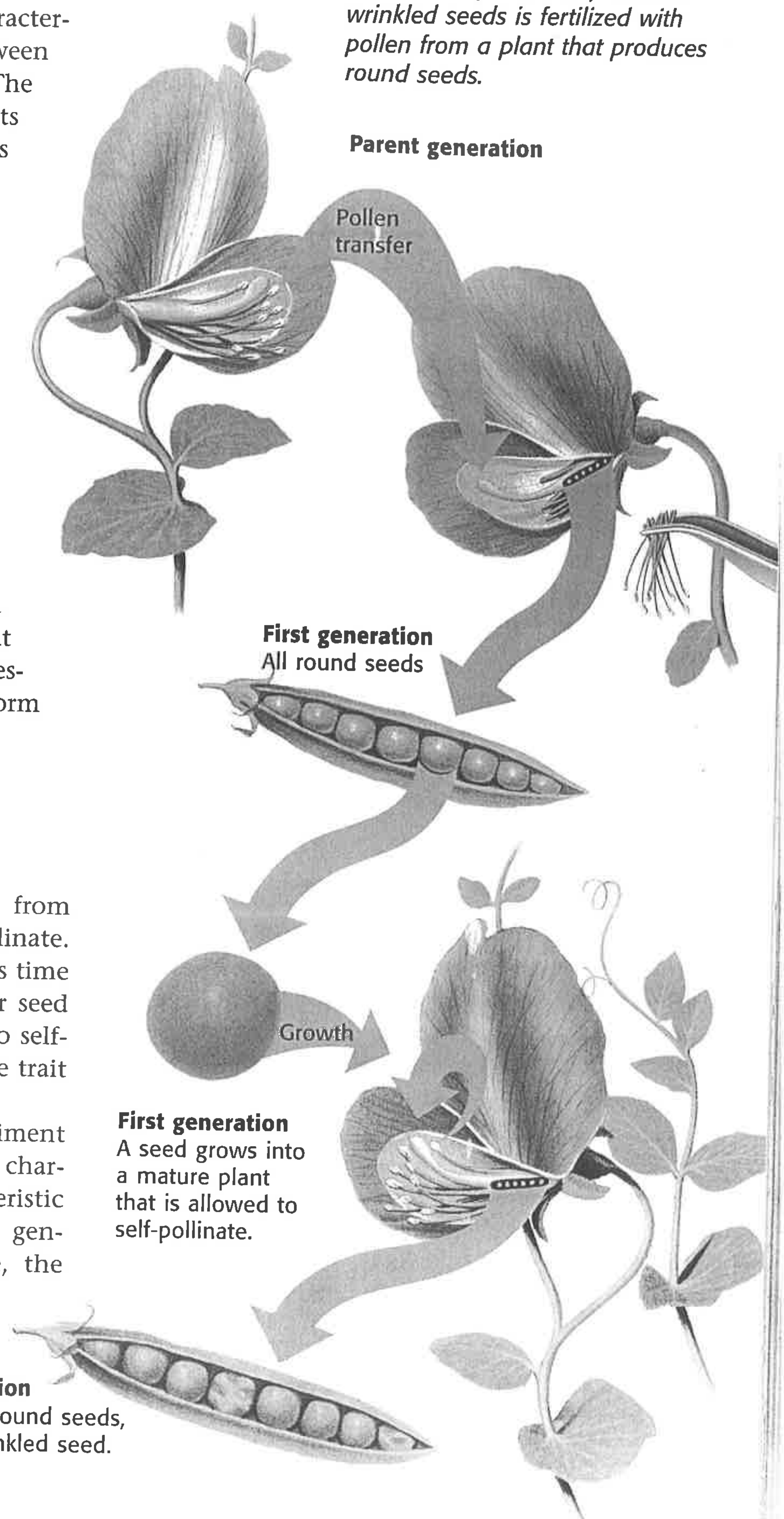


Figure 6 *A plant that produces wrinkled seeds is fertilized with pollen from a plant that produces round seeds.*

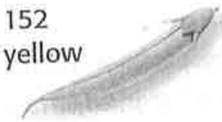
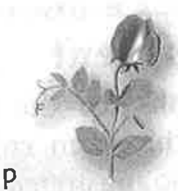
LabBook

Bug Builders, Inc. needs your help to design some new bugs. Turn to page 702 of the LabBook.

A Different Point of View

Mendel then did something that no one else had done before: He decided to count the number of plants with each trait that turned up in the second generation. He hoped that this might help him explain his results. Take a look at Mendel's actual results, shown in the table below.

Mendel's Results

Characteristic	Dominant trait		Recessive trait		Ratio
Flower color	705 purple		224 white		3.15:1
Seed color	6,002 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 along stem		207 at tip		?
Plant height	787 tall		277 short		?

As you can see, the recessive trait showed up again, but not as often as the dominant trait showed up. Mendel decided to calculate the *ratio* of dominant traits to recessive traits for each characteristic. Follow in Mendel's footsteps by calculating the dominant-to-recessive ratio for each characteristic. (If you need help, check out the MathBreak at left.) Can you find a pattern among the ratios?

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MATH BREAK

Understanding Ratios

A ratio is a way to compare two numbers by using division. The ratio of plants with purple flowers to plants with white flowers can be written as 705 to 224 or 705:224. This ratio can be reduced, or simplified, by dividing the first number by the second as follows:

$$\frac{705}{224} = \frac{3.15}{1}$$

which is the same thing as a ratio of 3.15:1.

For every three plants with purple flowers, there will be roughly one plant with white flowers. Try this problem:

In a box of chocolates, there are 18 nougat-filled chocolates and 6 caramel-filled chocolates. What is the ratio of nougat-filled chocolates to caramel-filled chocolates?

A Brilliant Idea

Mendel realized that his results could be explained only if each plant had two sets of instructions for each characteristic. Each parent donates one set of instructions, now known as **genes,** to the offspring. The fertilized egg would then have two forms of the same gene for every characteristic—one from each parent. The two forms of a gene are known as **alleles.**

The Proof Is in the Punnett Square To understand Mendel's conclusions, we'll use a diagram called a Punnett square. A *Punnett square* is used to visualize all the possible combinations of alleles from the parents. Dominant alleles are symbolized with capital letters, and recessive alleles are symbolized with lowercase letters. Therefore, the alleles for a true-breeding purple-flowered plant are written as ***PP.*** The alleles for a true-breeding white-flowered plant are written as ***pp.*** The cross between these two parent plants, as shown in **Figure 7,** is then written as ***PP*** × ***pp***. The squares contain the allele combinations that could occur in the offspring. The inherited combination of alleles is known as the offspring's **genotype.**

Figure 7 shows that all of the offspring will have the same genotype: ***Pp***. The dominant allele, ***P,*** in each genotype ensures that all of the offspring will be purple-flowered plants. An organism's appearance is known as its **phenotype.** The recessive allele, ***p,*** may be passed on to the next generation.

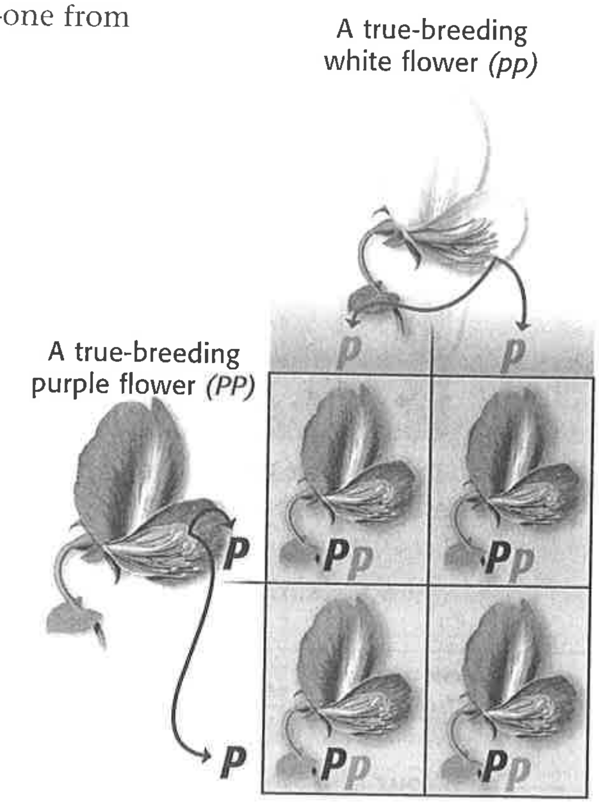
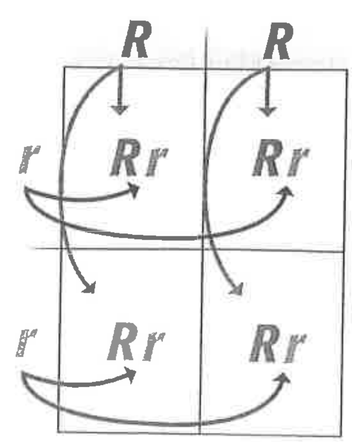


Figure 7 *The possible allele combinations in the offspring for this cross are all the same:* **Pp.**

How to Make a Punnett Square

Draw a square, and divide it into four sections. Next, write the letters that represent alleles from one parent along the top of the box. Write the letters that represent alleles from the other parent along the side of the box.

The cross shown at right is between a plant that produces only round seeds, ***RR,*** and a plant that produces only wrinkled seeds, ***rr.*** Follow the arrows to see how the inside of the box was filled. The resulting alleles inside the box show all the possible genotypes for the offspring from this cross. What would the phenotypes for these offspring be?



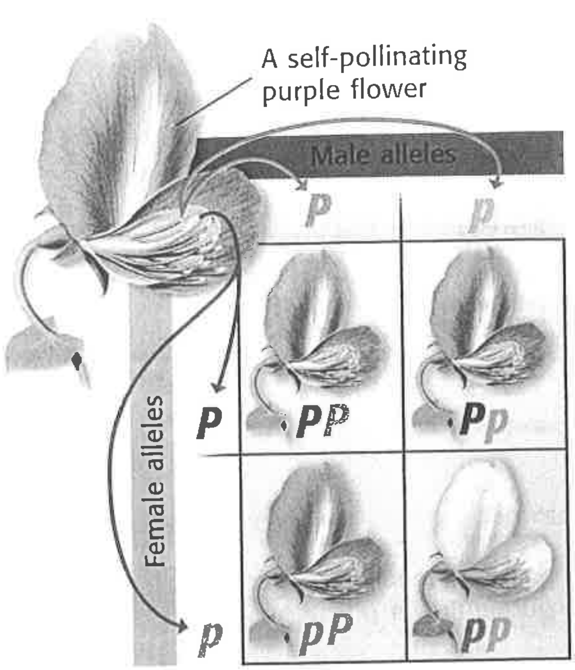


Figure 8 *This Punnett square shows the possible results from the cross* **Pp** × **Pp.**

More Evidence In Mendel's second experiment, he allowed the first-generation plants to self-pollinate. **Figure 8** shows a self-pollination cross of a first-generation plant with the genotype ***Pp***. The parental alleles in the cross indicate that the egg and sperm can contain either a ***P*** allele or a ***p*** allele.

What might the genotypes of the offspring be? Notice that one square shows the ***Pp*** combination, while another shows the ***pP*** combination. These are exactly the same genotype, even though the letters are written in a different order. The other possible genotypes in the offspring are ***PP*** and ***pp***. The combinations ***PP***, ***Pp***, and ***pP*** have the same phenotype—purple flowers—because they each contain at least one dominant allele (***P***). Only one combination, ***pp***, produces plants with white flowers. The ratio of dominant to recessive is 3:1, just as Mendel calculated from his data.

What Are the Chances?

It's important to understand that offspring are equally likely to inherit either allele from either parent. Think of a coin toss. There's a 50 percent chance you'll get heads and a 50 percent chance you'll get tails. Like the toss of a coin, the chance of inheriting one allele or another is completely random.

Probability The mathematical chance that an event will occur is known as **probability.** Probability is usually expressed as a fraction or percentage. If you toss a coin, the probability of tossing tails is $\frac{1}{2}$. This means that half the number of times you toss a coin, you will get tails. To express probability as a percentage, divide the numerator of the fraction by the denominator, and then multiply the answer by 100.

$$\frac{1}{2} \times 100 = 50\%$$

To find the probability that you will toss two heads in a row, multiply the probability of the two events.

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

The percentage would be $1 \div 4 \times 100$, which equals 25 percent.

QuickLab

Take Your Chances

You have two guinea pigs you would like to breed. Each has brown fur and the genotype ***Bb.*** What are the chances that their offspring will have white fur with the genotype ***bb?*** Try this to find out. Stick a piece of **masking tape** on both sides of **two quarters.** Label one side of each quarter with a capital ***B*** and the other side with a lowercase ***b.*** Toss both coins 50 times, making note of your results each time. How many times did you get the ***bb*** combination? What is the probability that the next toss will result in ***bb?***

TRY at HOME

APPLY

Curly Eared Cats

A curly eared cat, like the one at right, mated with a cat that had normal ears. If half the kittens had the genotype ***Cc*** and curly ears, and the other half had the genotype ***cc*** and normal ears, which was the allele for curly ears?

What was the genotype of each parent? (**Hint:** Use a Punnett square to fill in the genotypes of the offspring, and then work backward.)

Genotype Probability The same method is used to calculate the probability that an offspring will inherit a certain genotype. For a pea plant to inherit the white flower trait, it must receive a p allele from each parent. There is a 50 percent chance of inheriting either allele from either parent. So the probability of inheriting two p alleles from a $Pp \times Pp$ cross is $\frac{1}{2} \times \frac{1}{2}$. This equals $\frac{1}{4}$ or 25 percent.

Gregor Mendel—Gone but Not Forgotten Good ideas are often overlooked or misunderstood when they first appear. This was the fate of Gregor Mendel's ideas. In 1865, he published his findings for the scientific community. Unfortunately, his work didn't get much attention. It wasn't until after his death, more than 30 years later, that Mendel finally got the recognition he deserved. Once Mendel's ideas were rediscovered and understood, the door was opened to modern genetics.

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REVIEW

1. The allele for a cleft chin, *C*, is dominant among humans. What would be the results from a cross between a woman with the genotype *Cc* and a man with the genotype *cc*? Create a Punnett square showing this cross.
2. Of the possible combinations you found in question 1, what is the ratio of offspring with a cleft chin to offspring without a cleft chin?
3. **Applying Concepts** The Punnett square at right shows the possible combinations of alleles for fur color in rabbits. Black fur, *B*, is dominant over white fur, *b*. Given the combinations shown, what are the genotypes of the parents?

	?	?
?	Bb	Bb
?	Bb	Bb