On a brisk fall afternoon, the stands are packed with cheering football fans. Today is the big game between Riverton's North and South high schools, and it's almost time for the kickoff. Suddenly, the crowd becomes silent, as the referee is about to toss a coin. The outcome of the coin toss will decide which team kicks the ball and which receives it. The captain of the visiting North High team says "heads." If the coin lands with heads up, North High wins the toss and the right to decide whether to kick or receive the ball.

What is the chance that North High will win the coin toss? To answer this question, you need to understand the principles of probability.

Principles of Probability

If you did the Discover activity, you used the principles of **probability** to predict the results of a particular event. In this case, the event was the toss of a coin. **Probability is a number that describes how likely it is that an event will occur.**

Mathematics of Probability Each time you toss a coin, there are two possible ways that the coin can land—heads up or tails up. Each of these two events is equally likely to occur. In mathematical terms, you can say that the probability that a tossed coin will land with heads up is 1 in 2. There is also a 1 in 2 probability that the coin will land with tails up. A 1 in 2 probability can also be expressed as the fraction $\frac{1}{2}$ or as a percent—50 percent.

The laws of probability predict what is likely to occur, not necessarily what will occur. If you tossed a coin 20 times, you might expect it to land with heads up 10 times and with tails up 10 times. However, you might not get these results. You might get 11 heads and 9 tails, or 8 heads and 12 tails. The more tosses you make, the closer your actual results will be to the results predicted by probability.

Reading Checkpoint What is probability?

Independence of Events When you toss a coin more than once, the results of one toss do not affect the results of the next toss. Each event occurs independently. For example, suppose you toss a coin five times and it lands with heads up each time. What is the probability that it will land with heads up on the next toss? Because the coin landed heads up on the previous five tosses, you might think that it would be likely to land heads up on the next toss. However, this is not the case. The probability of the coin landing heads up on the next toss is still 1 in 2, or 50 percent. The results of the first five tosses do not affect the result of the sixth toss.

Math Skills

Percentage

One way you can express a probability is as a percentage. A percentage (%) is a number compared to 100. For example, 50% means 50 out of 100.

Suppose that 3 out of 5 tossed coins landed with heads up. Here's how you can calculate what percent of the coins landed with heads up.

1. Write the comparison as a fraction.

$$3 \text{ out of } 5 = \frac{3}{5}$$

2. Multiply the fraction by 100% to express it as a percentage.

$$\frac{3}{5} \times \frac{100\%}{1} = 60\%$$

Practice Problem Suppose 3 out of 12 coins landed with tails up. How can you express this as a percent?

Probability and Genetics

How is probability related to genetics? To answer this question, think back to Mendel's experiments with peas. Remember that Mendel carefully counted the offspring from every cross that he carried out. When Mendel crossed two plants that were hybrid for stem height (*Tt*), three fourths of the F_1 plants had tall stems. One fourth of the plants had short stems.

Each time Mendel repeated the cross, he obtained similar results. Mendel realized that the mathematical principles of probability applied to his work. He could say that the probability of such a cross producing a tall plant was 3 in 4. The probability of producing a short plant was 1 in 4. Mendel was the first scientist to recognize that the principles of probability can be used to predict the results of genetic crosses.

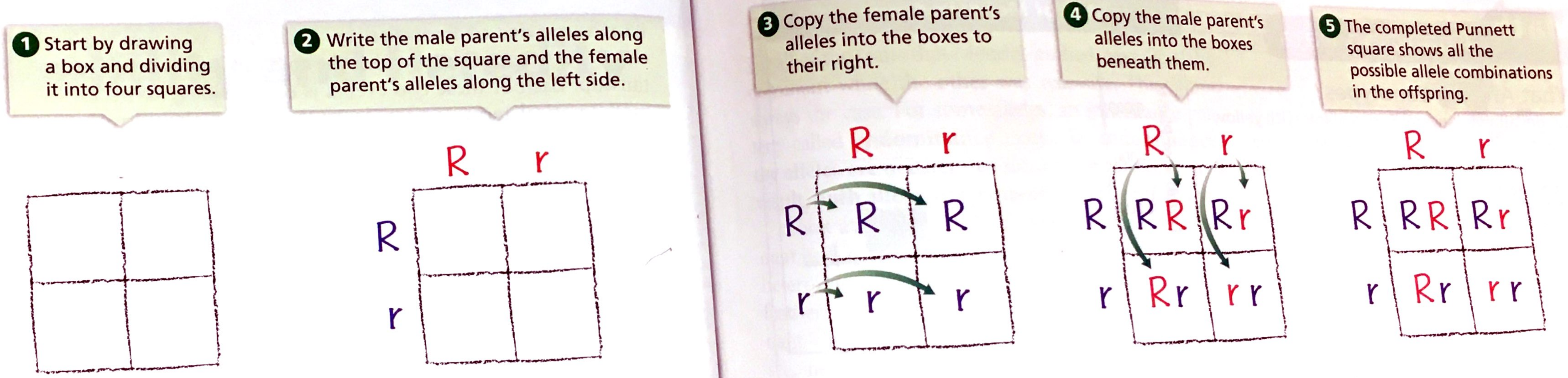
Punnett Squares A tool that can help you understand how the laws of probability apply to genetics is called a Punnett square. A **Punnett square** is a chart that shows all the possible combinations of alleles that can result from a genetic cross. Geneticists use Punnett squares to show all the possible outcomes of a genetic cross, and to determine the probability of a particular outcome.

Figure 7 shows how to construct a Punnett square. In this case, the Punnett square shows a cross between two hybrid pea plants with round seeds (*Rr*). The allele for round seeds (*R*) is dominant over the allele for wrinkled seeds (*r*). Each parent can pass either of its alleles, *R* or *r*, to its offspring. The boxes in the Punnett square represent the possible combinations of alleles that the offspring can inherit.

FIGURE 7

How to Make a Punnett Square

The diagrams show how to make a Punnett square. In this cross, both parents are heterozygous for the trait of seed shape. *R* represents the dominant round allele, and *r* represents the recessive wrinkled allele.

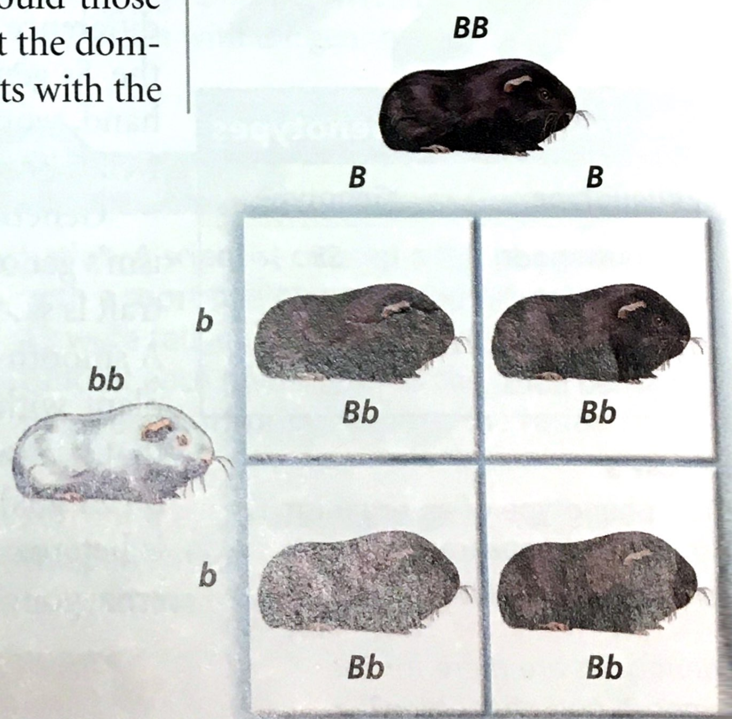


Using a Punnett Square You can use a Punnett square to calculate the probability that offspring with a certain combination of alleles will result. **In a genetic cross, the allele that each parent will pass on to its offspring is based on probability.** The completed Punnett square in Figure 7 shows four possible combinations of alleles. The probability that an offspring will be *RR* is 1 in 4, or 25 percent. The probability that an offspring will be *rr* is also 1 in 4, or 25 percent. Notice, however, that the *Rr* allele combination appears in two boxes in the Punnett square. This is because there are two possible ways in which this combination can occur. So the probability that an offspring will be *Rr* is 2 in 4, or 50 percent.

When Mendel crossed hybrid plants with round seeds, he discovered that about three fourths of the plants (75 percent) had round seeds. The remaining one fourth of the plants (25 percent) produced wrinkled seeds. Plants with the *RR* allele combination would produce round seeds. So too would those plants with the *Rr* allele combination. Remember that the dominant allele masks the recessive allele. Only those plants with the *rr* allele combination would have wrinkled seeds.

Predicting Probabilities You can use a Punnett square to predict probabilities. For example, Figure 8 shows a cross between a purebred black guinea pig and a purebred white guinea pig. The allele for black fur is dominant over the allele for white fur. Notice that only one allele combination is possible in the offspring—*Bb*. All of the offspring will inherit the dominant allele for black fur. Because of this, all of the offspring will have black fur. There is a 100 percent probability that the offspring will have black fur.

FIGURE 8
Guinea Pig Punnett Square
This Punnett square shows a cross between a black guinea pig (*BB*) and a white guinea pig (*bb*).
Calculating *What is the probability that an offspring will have white fur?*



Phenotypes and Genotypes

Two useful terms that geneticists use are **phenotype** (FEE noh typ) and **genotype** (JEN uh typ). **An organism's phenotype is its physical appearance, or visible traits. An organism's genotype is its genetic makeup, or allele combinations.**

To understand the difference between phenotype and genotype, look at Figure 9. The allele for smooth pea pods (*S*) is dominant over the allele for pinched pea pods (*s*). All of the plants with at least one dominant allele have the same phenotype—they all produce smooth pods. However, the plants can have two different genotypes—*SS* or *Ss*. If you were to look at the plants with smooth pods, you would not be able to tell the difference between those with the *SS* genotype and those with the *Ss* genotype. The plants with pinched pods, on the other hand, would all have the same phenotype—pinched pods—as well as the same genotype—*ss*.

Geneticists use two additional terms to describe an organism's genotype. An organism that has two identical alleles for a trait is said to be **homozygous** (hoh moh ZY gus) for that trait. A smooth-pod plant that has the alleles *SS* and a pinched-pod plant with the alleles *ss* are both homozygous. An organism that has two different alleles for a trait is **heterozygous** (het ur oh ZY gus) for that trait. A smooth-pod plant with the alleles *Ss* is heterozygous. Mendel used the term *hybrid* to describe heterozygous pea plants.

Codominance

For all of the traits that Mendel studied, one allele was dominant while the other was recessive. This is not always the case. For some alleles, an inheritance pattern called **codominance** exists. **In codominance, the alleles are neither dominant nor recessive. As a result, both alleles are expressed in the offspring.**

Look at Figure 10. Mendel's principle of dominant and recessive alleles does not explain why the heterozygous chickens have both black and white feathers. The alleles for feather color are codominant—neither dominant nor recessive. As you can see, neither allele is masked in the heterozygous chickens. Notice also that the codominant alleles are written as capital letters with superscripts—F^B for black feathers and F^W for white feathers. As the Punnett square shows, heterozygous chickens have the F^BF^W allele combination.

Reading Checkpoint **How are the symbols for codominant alleles written?**

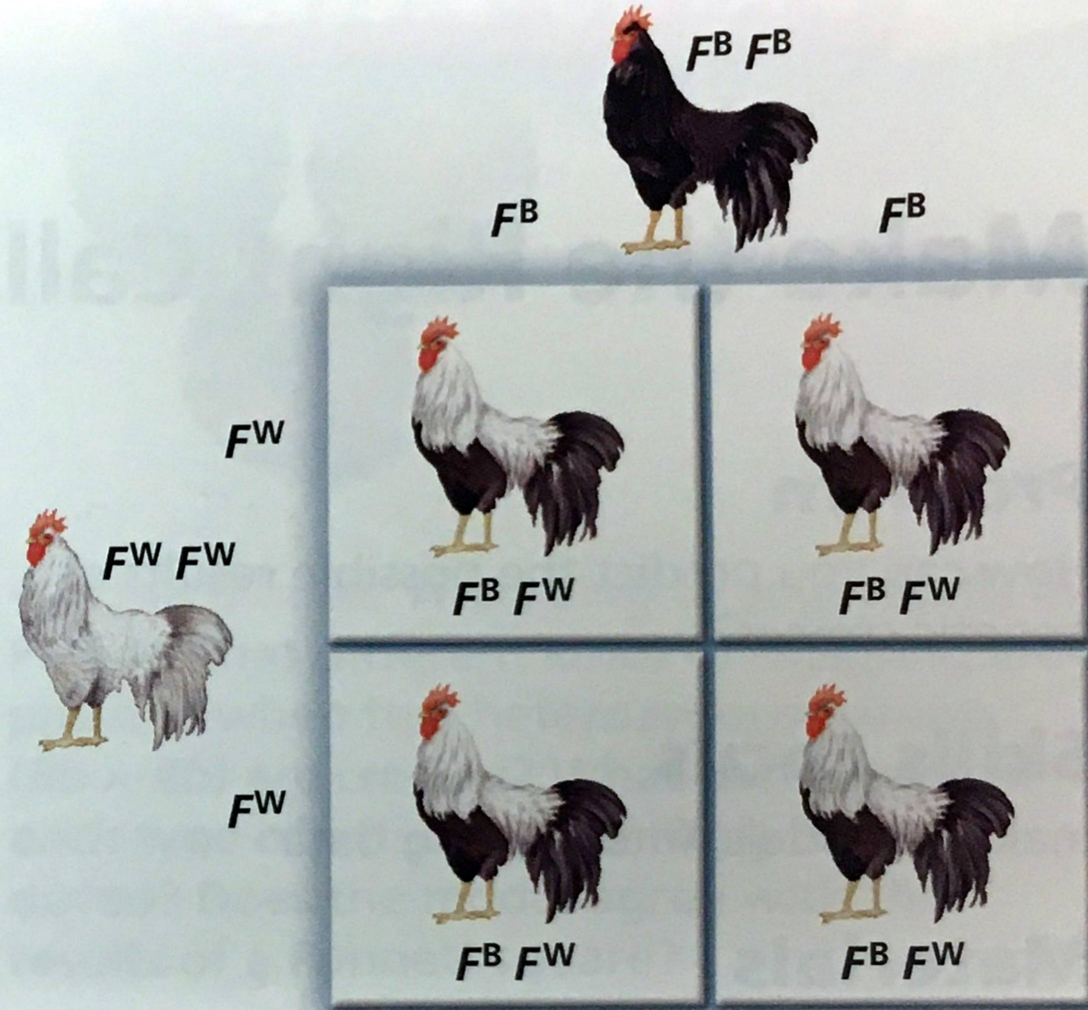


FIGURE 10
Codominance
The offspring of the cross in this Punnett square will have both black and white feathers.
Classifying *Will the offspring be heterozygous or homozygous? Explain your answer.*