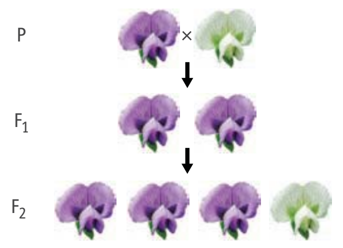
Predicting Generations

Gregor Mendel's trials with purebred white-flowered (*pp*) and purple-flowered (*PP*) pea plants yielded a heterozygous purple (*Pp*) F_1 generation. When the F_1 plants self-pollinated, the white flowers reappeared. The F_2 plants were one-fourth *PP*, one-half *Pp*, and one-fourth *pp*.

Predict If you crossed two plants from the F_2 generation, what procedure would you follow to determine the genotypes of the next generation?

FIGURE 2: Purple plants in the F_1 generation self-pollinated to produce the F_2 generation.



Modeling Genetic Crosses

In the early 1900s, several British scientists expanded upon Mendel's work. One, R. C. Punnett, explored genetic crosses with chickens and other species. The model he developed tracks the alleles each parent can donate to predict the outcome of crosses.

FIGURE 3: The common vizsla has smooth hair, but the wirehaired vizsla has a wiry coat.

a Smooth vizsla

b Wirehaired vizsla

Coat texture in dogs is a heritable characteristic. Some dogs, like the vizsla, can have a smooth coat or a wiry coat, and this trait is controlled by one gene. The wire-coated allele is dominant, noted as *W*, and the smooth-coated allele is recessive, noted as *w*.

Imagine a dog breeder wants to cross two wirehaired vizslas and that both dogs are heterozygous for the trait. Each parent is heterozygous for the wirehaired trait, so each one has two different alleles for coat texture. The alleles are separated into gametes during meiosis. There are two possible gametes for each parent, one for each allele he or she carries.

Analyze What alleles can each heterozygous vizsla parent pass on in his or her gametes?

The genotype of an organism indicates which alleles the organism carries for a certain characteristic. Each gamete contains one allele for each trait in an organism's DNA. Punnett recognized a relationship between parental gametes and the genotypes of offspring. He used this relationship to develop a simple table, now known as a Punnett square, that predicts all possible offspring genotypes resulting from a specific cross. This model is a quick and easy way to determine the probable outcome of a cross.

FIGURE 4: A Punnett square is used to model the cross between two parents with known genotypes.

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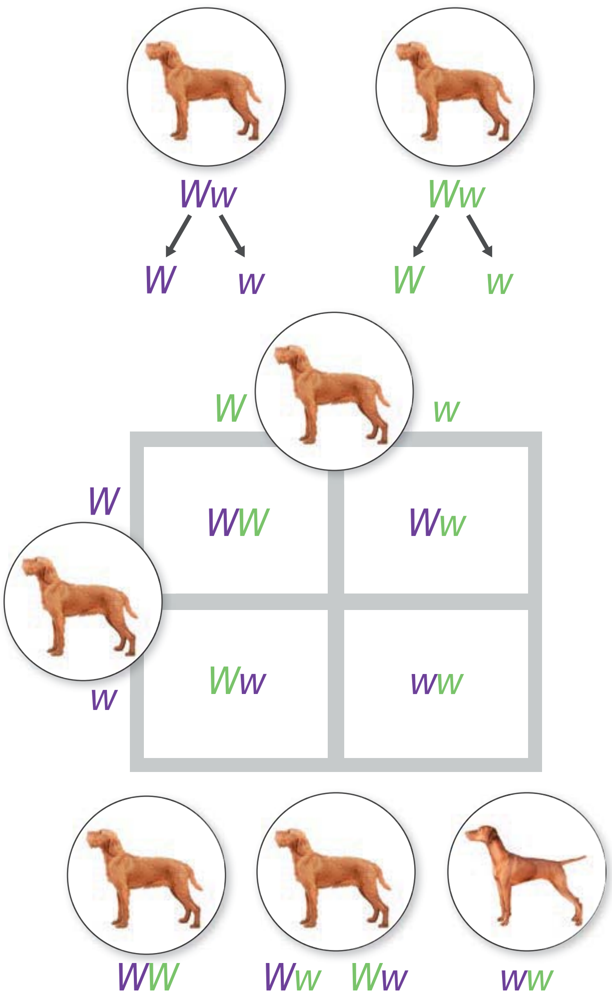

A model for the cross between two heterozygous, wirehaired vizslas is shown in Figure 4. Because each parent donates one gamete to each offspring, gametes will have either a dominant, wire-coated allele (*W*) or a recessive, smooth-coated allele (*w*).

To complete a Punnett square, divide a square into four equal sections. Write the alleles of each parent on the outside of the square, one set above the columns and one set to the left of the rows. Write the dominant allele first.

Next fill in each box in the Punnett square with the parent allele from the top of the column and the parent allele from the beginning of the row. When complete, each box will contain one allele from each parent.

The completed Punnett square shows three possible genotypes for coat type: homozygous dominant (*WW*), heterozygous (*Ww*), or homozygous recessive (*ww*). From these genotypes, we can predict that there is a one in four chance that the *WW* genotype will occur. There is a two in four chance that the *Ww* genotype will occur. Finally, there is a one in four chance that the *ww* genotype will occur.

In this cross, both the homozygous dominant and heterozygous genotypes will have wire coats. Only the homozygous recessive genotype will have a smooth coat.

Math Connection The wire-coated allele (*W*) is dominant to the smooth-coated allele (*w*). Use the Punnett square to answer the following questions:

1. What percentage of puppies will have the same genotype as the parents, *Ww*?
2. What percentage of puppies will have the wire-coat phenotype?
3. What percentage of puppies will have the smooth-coat phenotype?

A Punnett square models complex processes by focusing on desired traits rather than a genome. Pulling the letters that represent the parental genotype apart and placing them along the outside of the Punnett square shows the segregation of homologous chromosomes and possibly different alleles during meiosis. Each gamete contains only one version of the gene, and there is an equal opportunity for a gamete to contain either allele.

The assignment of alleles to the empty boxes models fertilization. Just as haploid gametes join to make a diploid zygote, the parental alleles join to make letter pairs in the Punnett square. The letter pairs represent potential offspring genotypes. This is the real value of a Punnett square. Modeling these processes makes it possible to predict the genotypes of offspring from a specific cross.

Analyze What do the letters on the top and side of a Punnett square represent?

Calculating Probabilities

Scientists use a branch of mathematics called *probability* to determine the likelihood that offspring will be born with certain characteristics. Probability is the chance that an outcome will occur, such as the birth of a dog with a wire coat. The probability of an event occurring can be determined using the following equation:

$$\text{probability} = \frac{\text{number of ways a specific event can occur}}{\text{number of total possible outcomes}}$$

An easy way to explore probability is by flipping a coin. Each flip has two possible outcomes: the coin either lands heads up or it lands tails up. The probability of the coin landing heads up is one out of two, or $\frac{1}{2}$. The probability of the coin landing tails up is also one out of two, or $\frac{1}{2}$. Probability is usually expressed on a scale of 0 to 1, with 0 being an impossible outcome and 1 being a certain outcome.

FIGURE 5: A Punnett square reflects the probability of two independent events occurring at the same time.

Now, consider what happens when you flip two coins at the same time, as shown in Figure 5. The results of the two flips are independent, so the result of one coin flip does not impact the result of the other. Both coins are free to land heads up or tails up. Calculate the probability of two independent events occurring together by multiplying the probability of the individual events. The probability of flipping heads is $\frac{1}{2}$. Therefore, the probability of flipping two heads together is $\frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$.

Probabilities are averages, not exact numbers. If you flip a coin twice, you will not always get one heads and one tails. You may get two heads or two tails. The more you repeat an event, the closer you will get to the average described by probability.

Math Connection Determine each of the following probabilities using Figure 4.

1. What is the probability of a *Ww* genotype? Of a *WW* genotype?
2. What is the probability of a puppy with a smooth coat being born?

In the cross modeled in Figure 4, what events would have to occur to produce a heterozygous puppy? The father could donate the dominant allele (*W*) and the mother could donate the recessive allele (*w*). The reverse could also occur. Both of these events would produce a heterozygous puppy, and both are equally likely to occur.

The probability of an event that can occur in more than one way is equal to the probability of the individual events added together. So, the probability of a sperm with a dominant allele fertilizing an egg with a recessive allele is $\frac{1}{4}$. The probability of a sperm with a recessive allele fertilizing an egg with a dominant allele is also $\frac{1}{4}$. Therefore, the probability of producing a heterozygote can be calculated as $\frac{1}{4} + \frac{1}{4} = \frac{1}{2}$. In other words, there is a one in two chance that a puppy will be born that is heterozygous (*Ww*) for a wire coat.

Patterns

The pattern of inheritance observed in sexually reproducing organisms is explained by chance. This makes probabilities particularly useful for analyzing some of the mathematics behind inheritance.

Explain How can a Punnett square help you explain the phenotypes of the kittens discussed at the beginning of this lesson? Use your knowledge of meiosis to help support your answer.