Mendel and Punnett Squares

What was Mendel's breakthrough? What did this Austrian monk observe in his garden that established the foundation of modern genetics and the study of heredity?

Gregor Mendel (1822–1884) was a keen observer of nature. He observed that garden peas have lots of variation from plant to plant. He focused his experiments on several **features** of the pea plant. These included flower color, seed color, and plant height. Mendel chose plants with two possible traits for these features. Some plants produced purple flowers, and some produced white flowers. Some plants produced green seeds, and some produced yellow seeds. Some plants were tall, and others were short. Mendel decided to look for patterns in these traits over multiple generations.

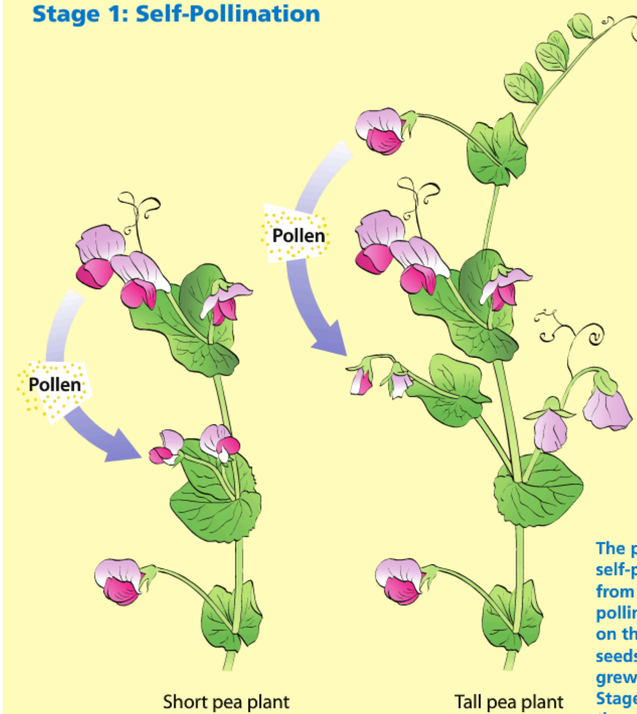
Mendel patiently bred and observed the garden pea plant, *Pisum sativum*. These plants were ideal for his experiments because they grow and reproduce very quickly.

Methods

Mendel designed three stages for his experiment.

Stage 1. Mendel raised several generations of pea plants. He used pollen from a plant to pollinate other flowers on that *same* plant. He planted seeds from the mature plants, raising generations of self-pollinated plants. After a few generations, they bred pure. Breeding pure means all offspring have exactly the same traits as the parent. In Mendel's case, tall plants produced seed that resulted in only tall offspring. Short plants produced seed that resulted in only short offspring. These pure-breeding tall or pure-breeding short plants became the stage 2 parents. Mendel identified them as the **parent generation (P generation)**.

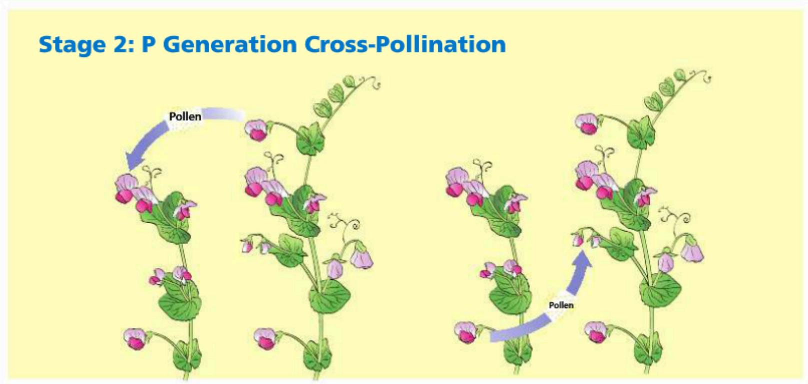
Stage 1: Self-Pollination



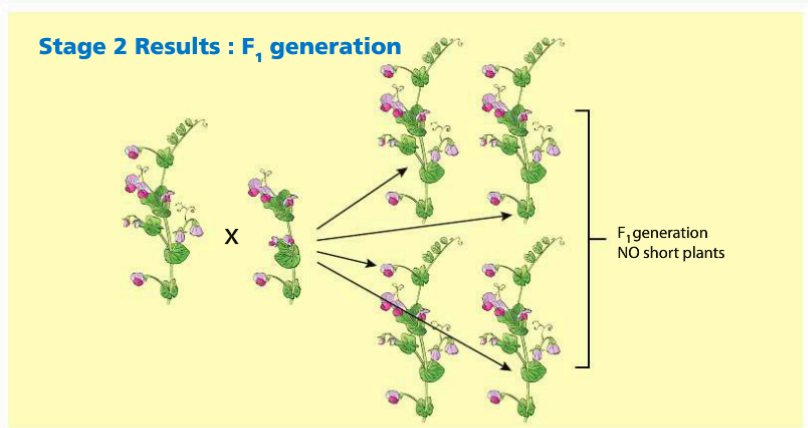
The pea plant can self-pollinate. Pollen from one flower can pollinate other flowers on the same plant. The seeds from these plants grew into Mendel's Stage 2 parent plants, the parent generation.

Stage 2. Mendel carefully cross-pollinated tall parent plants with short parent plants. He placed pollen from tall plants on the flowers of short plants, and pollen from short plants on the flowers of tall plants.

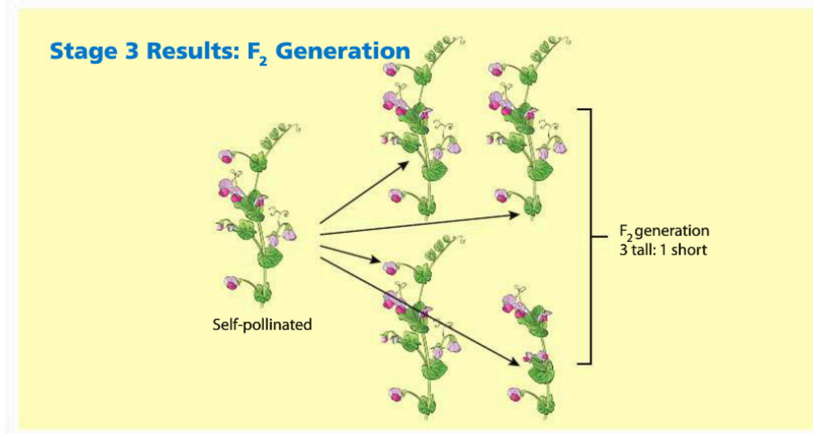
Mendel called the first offspring from the P generation the first **filial** generation. (*Filial* means sons and daughters.) He identified them as the **F_1 generation**. When Mendel cross-pollinated the P generation to produce an F_1 generation, all the F_1 plants were tall. The short trait disappeared.



Mendel prevented natural self-pollination by removing stamens from the flowers of certain plants. He then controlled cross-pollination by dusting pollen by hand between different plants.



In Stage 2, Mendel crossed tall and short pure-breeding plants. The results were consistent: only tall plants appeared in the next generation.

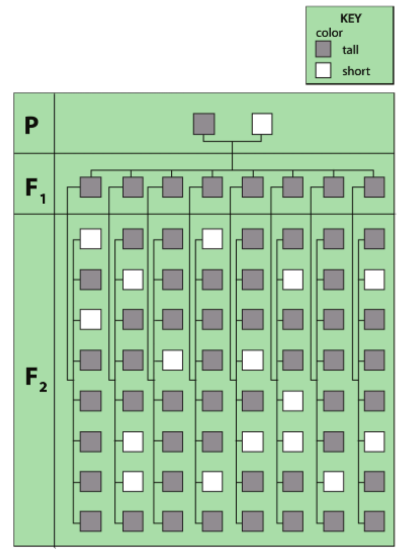


Self-pollinating the plants from the F_1 generation resulted in some tall plants and some short plants. The short plants reappeared in the F_2 generation.

Stage 3. Mendel pollinated each plant from the F_1 generation with its own pollen. The offspring were called the **F_2 generation**. When he pollinated all the tall F_1 plants with their own pollen, some plants in the F_2 generation were tall and some were short! The trait of short height disappeared in the F_1 generation and reappeared in the F_2 generation.

Here is a diagram of Mendel's results. Count the number of short and tall plants. What ratio do you find in the F_2 generation?

When Mendel counted the number of tall and short plants in the F_2 generation, he found that the ratio of tall to short plants was 3:1. How could one out of four plants be short, when short plants were absent from the F_1 generation?



Mendel's painstaking experiments established that traits pass from parents to offspring in mathematically predictable ways.

Children may inherit traits that are expressed in their grandparents but not in their parents. Mendel's observation of dominant and recessive alleles explains how traits can skip a generation.

Mendel's Breakthrough

Mendel had a breakthrough idea. He reasoned that offspring inherit something that determines their traits. He called the inherited thing a factor. These factors are now called genes. Mendel concluded that genes come in pairs. Each member of a gene pair is called an **allele**. An organism has two alleles for each trait, one from the mother and one from the father.

Mendel used the terms **dominant** and **recessive** to describe what he observed. When he crossed a pure tall plant (both alleles for tall height) with a pure short plant (both alleles for short height), all the F_1 offspring received one tall-plant allele and one short-plant allele. Only the tall trait appeared. So he called the tall-plant allele dominant.

Mendel reasoned that the short-plant allele was still there, but was hidden by the dominant tall-plant allele. He called the short-plant allele recessive. The recessive trait would appear only if the offspring inherited the recessive allele from both parents. In the F_2 generation, that combination would happen one time for every three dominant combinations, explaining the 3:1 ratio of tall to short plants.

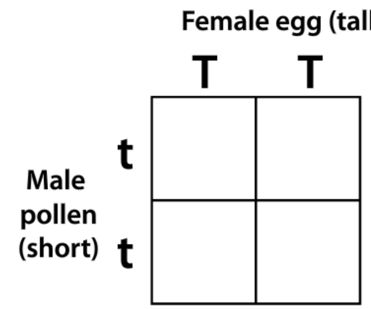
In 1865, Mendel announced that organisms pass units of information to their offspring during reproduction. This inheritance allows the offspring to develop like their parents. He didn't know what the units were, but he understood how they acted. Without being able to see them, Mendel had discovered the existence of genes and described how they work.

Genes and Punnett Squares

By the early 1900s, chromosomes had been discovered. Walter S. Sutton (1877–1916) was the first scientist to recognize that chromosomes carried Mendel's factors. In 1905, Reginald Punnett (1875–1967), published a textbook called *Mendelism* that introduced **genetics** to the public. He also made a model that predicts the probability of possible genotypes and the **phenotypes** (the appearance of the traits) they produce. Punnett's model is still used. It is a simple two-coordinate system called the **Punnett square**. Let's use Mendel's pea-plant discoveries to see how it works.

Use the letter t to represent the gene that determines plant height. T represents the dominant allele and t the recessive allele.

Mendel's pure tall pea plants had two dominant alleles (TT). The pure short pea plants had two recessive alleles (tt). Both plants were **homozygous** for the height feature. This means the alleles were identical. The tall plant was homozygous dominant (TT) and the short plant homozygous recessive (tt).



Mendel's published findings from his pea plant experiments were ignored by the scientific community for more than half a century. But the principles he proposed in 1866 are the basis for our understanding of inheritance.

Filling in the squares with the alleles produces four possible offspring. Each offspring has only one possible combination of alleles (Tt). Because all the offspring have a dominant allele, they all have the tall-plant phenotype. The genotypes of these plants are **heterozygous**. The gene is represented by one dominant and one recessive allele.

Male pollen (short) \ Female egg (tall)	T	T
t	Tt	Tt
t	Tt	Tt

Let's see what happened when Mendel pollinated the F_1 generation of tall plants with their own pollen. Remember that each plant was tall, but had one dominant and one recessive allele (Tt).

Male pollen (tall) \ Female egg (tall)	T	t
T	TT	Tt
t	Tt	tt

The result was a ratio of three tall to one short offspring. The Punnett square explains this ratio. Of the four possible offspring, three have the dominant allele (one TT and two Tt), resulting in three tall plants. The fourth has two recessive alleles (tt), resulting in one short plant.

We can **infer** two things. Each offspring of a cross between peas with the Tt genotype has a 75 percent chance of inheriting the tall phenotype and a 25 percent chance of inheriting the short phenotype. In a **population** of peas, the ratio of traits of the plants will be close to 75 percent tall and 25 percent short.

Farmers have long known the usefulness of selective breeding—breeding plants over many generations to achieve certain desirable traits in crops.

Most physical traits, including hair texture and eye color, are inherited traits. Some traits, like dimples, are determined by only one gene. Others, like eye color, are controlled by many genes.

Summary

Mendel's work predicted that traits could disappear in one generation and reappear in the next. His factor idea explained the observations he made in his experiments. Furthermore, he could predict the number of offspring that would have a dominant trait and a recessive trait.

Mendel's experiments uncovered two important principles in the science of heredity. 1) Two factors (alleles) determine traits. One allele comes from each parent. 2) Alleles can be dominant or recessive. Recessive alleles can be present but invisible in an organism.

Punnett's model was based on Mendel's understanding. The Punnett square allows us to calculate the probability that certain genetic combinations will appear in offspring.

Predicting traits in offspring is simple only for traits that are determined by one gene. Mendel was fortunate to choose traits that were determined by only one gene. However, most traits are influenced by many genes.