Teacher Tune-up

Quick Content Refresher for Busy Professionals

What are the big ideas related to Mendel's experiments?

Gregor Mendel spent much of his life investigating how traits get passed from one generation of organisms to the next. For centuries, people knew that traits sometimes skipped generations, disappearing and then reappearing in later generations. A blue-eyed child might come from two brown-eyed parents, reminding the family of grandma's sparkling blue eyes. This idea was well established. But very little was understood about *how* it happened.

In one significant sense, Mendel never truly understood how it happened. He lived too early to know about the details of molecular biology that explain, concretely, how inheritance works. But he gained extraordinary insight into the *patterns* of inheritance, and did so by the application of a novel mathematical approach. Mendel brought math to biology the way Galileo had brought math to physics some two and a half centuries earlier. In fact, Mendel's methods were so new to biological science that his work was undervalued in his time and disappeared into obscurity. Three and a half decades later, other scientists who rediscovered Mendelian patterns of inheritance also discovered that Mendel had been there before them. Taken together, their work set the agenda for others who would pursue and uncover the cellular and molecular mechanisms of inheritance.

What patterns, then, did Mendel discover?

Mendel's Experiments: Dominant and Recessive Traits

In Mendel's first experiment, he selected seven individual traits of pea plants that came in only one of two varieties, such as pea color (either green or yellow), flower color (either white or purple), or pod shape (either smooth or bumpy). He took control of the pollination process: he prevented plants from self-pollinating by clipping the stamens of blossoms; he prevented wind-borne or insect pollination by covering blossoms with bags; and, wielding a small brush, he became the exclusive and highly selective pollinator of his thousands of pea plants. For two years, he bred plants to make sure he had populations of "purebred" plants: plants that consistently produced offspring with the same traits as their ancestors. The parent generation (P generation) for his experiments was ready to go. Now the fun could begin.

Mendel carefully bred certain purebred plants of the P generation with one another, such as a purebred yellow-pea plant with a purebred green-pea plant. In each of these hybridizations of his purebred lines, he found that all of the offspring in the F_1 ("first filial") generation showed only one trait: all the peas were yellow, all the flowers were purple, and all the pods were smooth. He called these versions of each trait "dominant." He called the versions of the trait that receded from view in the F_1 generation "recessive." These results were not particularly surprising, since breeders had noticed the same thing for many years, though Mendel provided terminology to describe the phenomenon.

Something completely unexpected did happen, though, when Mendel bred the F_1 plants to produce a second hybrid generation, the F_2 generation. The traits that had receded in the F_1 generation now reappeared in some individuals. The astonishing thing was not that the disappearing traits reappeared in some plants—that was known to happen—but that there was a *consistent mathematical pattern* to the reappearance of all the recessive traits in the F_2 generation. The same ratio cropped up for every trait he was studying: for every three F_2 plants that had a given dominant trait, one F_2 plant had the corresponding recessive trait. In other words, there was a 3:1 ratio of dominant to recessive traits in the second filial generation.

The following table shows some of Mendel's results. As you can see in the far right column, the 3:1 ratio emerges imperfectly from large numbers of cases (just a 50/50 distribution of heads and tails tends to grow more exact with more coin tosses).

Mendel's pea traits

Characteristi c	**Dominant** trait (from purebred parent)	Recessive trait (from purebred parent)	1st hybrid (F_1) generation results	2nd hybrid (F_2) generation results	Ratio of **dominant** to recessive traits in 2nd hybrid (F_2) generation
pod color	**green**	yellow	**green** × yellow = all **green**	428 **green**, 152 yellow	2.82 : 1
pod shape	**smooth**	bumpy	**smooth** × bumpy = all **smooth**	882 **smooth**, 299 bumpy	2.95 : 1
seed color	**yellow**	green	**yellow** × green = all **yellow**	6022 **yellow**, 2001 green	3.01 : 1
seed coat color	**colored**	white	**colored** × white = all **colored**	705 **colored**, 224 white	3:15 : 1
seed shape	**round**	wrinkled	**round** × wrinkled = all **round**	5474 **round**, 1850 wrinkled	2.96 : 1
stem length	**long**	short	**long** × short = all **long**	787 **long**, 277 short	2.84 : 1
flower position	**axial**	terminal	**axial** × terminal = all **axial**	651 **axial**, 207 terminal	3.14 : 1

Mendel's First Law: Law of Segregation

To explain this mathematical pattern, Mendel proposed a new model, the first part of which has come to be known as Mendel's First Law, or the Law of Segregation. Each parent, he argued, carries two factors, elements, or versions (what we now call **genes**) for a particular trait; but during reproduction, these genes are segregated (separated), and each parent passes along only one of these genes to each of their offspring.

Imagine: one parent pea plant comes from a long line of plants that only make yellow peas, while the other parent pea plant comes from a family that only makes green peas. Mendel would have designated the dominant yellow pea trait capital "A" and the recessive green pea trait lowercase "a." (Any letter would have worked, but Mendel stuck with the beginning of the alphabet.) All the offspring of the first hybrid generation would get a dominant "A" from one parent and a recessive "a" from the other, making the combination Aa. These first filial plants would all have yellow peas, the dominant trait, but they would all still contain this special something that has the potential to produce green peas.

Different varieties of genes are called **alleles**. In the example above, genes come in the yellow-producing allele "A" and the green-producing allele "a." When a dominant and recessive allele are together, only the trait from the dominant allele shows up, but the plant still has a recessive allele that it can pass on to offspring.

Okay, so far we are up to the first filial generation of hybrid plants with both of the alleles for pea color: Aa. When these F_1 plants are crossed with one another to produce an F_2 (second filial) generation, each parent contributes (at random) only one of the alleles for each trait. Each F_2 plant has 50 percent chance of inheriting the dominant A allele from one of its parents, and also a 50 percent chance of inheriting the dominant A allele from its other parent (and likewise for the recessive allele).

We are now privy to concrete mechanisms unknown to Mendel, modern cellular and molecular models that embody and explain his mathematical model and his mysterious "factors." The cells of pea plants and humans, we now know, have two sets of chromosomes, with a pair of genes for every trait, including—in Mendel's F_1 generation of plants—both of the alleles for pea color, A and a. These alleles become segregated when plants form sex cells; pollen and eggs possess *only one allele* for each trait: either A or a for pea color, not both. When an egg is pollinated, a complete set of chromosomes is reassembled for the new offspring.

Unaware of the mechanism but recognizing the pattern, Mendel predicted the following possible combinations:

If parent #1 gives this gene	and parent #2 gives this gene,	the offspring gets these genes.	The peas will appear	because...
A	A	AA	Yellow	the offspring got 2 dominant yellow genes.
A	a	Aa	Yellow	the offspring got 1 dominant yellow gene and 1 recessive green gene, and if there is mix of genes, dominant shows up.
a	A	Aa	Yellow	the offspring got 1 dominant yellow gene and 1 recessive green gene, and if there is mix of genes, dominant shows up.
a	a	aa	Green	the offspring got 2 recessive green genes.

The four rows in the table above show equally likely cases, and three of them result in yellow peas. Mendel's model explained the ratio that he found in his data: for every 3 plants with the dominant trait (yellow), there was 1 plant with the recessive trait (green). This pattern proved to be true for each trait that he studied.

Mendel confirmed his model by letting his pea plants grow and self-fertilize (rather than cross with other plants). He predicted that his green peas (aa) would only produce more green peas (aa). He predicted that of his yellow peas, 1/3 would have two dominant alleles (AA), and thus would produce only yellow peas (AA). He predicted the other 2/3 of his yellow peas would be hybrids with a mix of alleles (Aa), and would produce the same 3:1 ratio of yellow to green plants that he saw in his earlier round. After counting thousands of peas (more than 300,000 over the course of his research!), he found that his predicted ratios held true, and he found the same pattern held for all seven traits that he studied.

Mendel's Law of Segregation consistently fit his mathematical data.

Mendel's Second Law: Law of Independent Assortment

Mendel also wondered how one trait might affect another trait. He conducted additional experiments using the same techniques, but this time focused on two traits at once, such as looking at seed color and shape at the same time. Observing the mathematical patterns in his data, he observed that the segregation of alleles for one trait did not seem to affect the segregation of alleles for another trait: pea color had no influence on flower color; pea shape had no influence on plant height. He realized that traits were passed along independently of one another, and named this the Law of Independent Assortment (aka Mendel's Second Law).

This discovery meant that novel combinations of traits were possible. To illustrate this, Mendel took two purebred plants that differed on all seven traits he studied, bred them together, and then let the hybrids self-fertilize. He found one hundred and twenty-eight different kinds of offspring, or different combinations of traits, just counting the seven traits he was studying. Mendel's model explained how variety arises in a species, and how siblings, though sharing family resemblances, can also differ so much from each other.

Once again, modern molecular genetics provides mechanistic explanations for the independent assortment of alleles. As previously noted, most of the cells in a pea plant contain two sets of chromosomes, one set from each parent. During the process of meiosis, cells with two sets of chromosomes divide into sex cells with just one set of chromosomes each. But the sex cells do not simply receive a complete, unaltered set of one ancestor's genes. Rather, all up and down the line, chromosomes are chopped up and the sections are passed back and forth during meiosis. In the resulting sex cells, the genes for various traits are still in the original sequence, but the gene for one trait may come from a different ancestor than the gene for another trait next to it in a chromosome. The genes are independently assorted.

(Note that some genes are considered "linked" if they are near each other on the same chromosome, and are therefore likely to stay together when this gene shuffling occurs during meiosis. But the traits Mendel studied in his pea plants—and many other traits in many other organisms—are not linked.)

Look Out! Common Student Misconceptions

At times, students struggle to reconcile their everyday language with the language of genetics, which can lead to confusion and misconceptions. For example, think of the phrase "You've got your mother's eyes, but your father's height." Certainly students are familiar with recognizing family traits, but this phrase contributes to a common misconception that different parents provide trait-specific genes, or that mom gave genes for eyes, but dad gave genes for height. Even though someone may have eyes similar to their mother, the father still contributed genes that are relevant to this trait, even if they don't appear. Students may agree that they get half of their genes from their mother and half from their father, but this understanding may mask common misconceptions that the mother provides genes for half of the traits, or that half of your cells have genes from the mother. In addition, some students may believe that traits are always passed on in a sex-specific way, with fathers passing on traits exclusively to sons and mothers to daughters. Emphasizing that both parents contribute genes for all traits, even if you can't see them, is an important big idea for students to wrestle with. Scientists sometime refer to this concept with the phrase "Phenotype (what a trait looks like) does not reveal genotype (what the actual genes are)."

In addition, the word "dominant" is often confusing for students, who associate the word with layperson usage such as "strong." Students often believe that diseases must be recessive because they make you weak, not strong, or that a gene for strength or height must be dominant, because dominant applies to any trait associated with strength, power, or desirability. "Dominant" in genetics merely refers to the idea that the trait of the gene will show up in an organism, without the implication that it is a better or stronger trait.

Lastly, many words in genetics are very new to students in a scientific context, and are easily confused. "Trait" and "gene" are often used interchangeably in layperson language, which may lead students to believe that if you have a gene for a trait, you inevitably have that trait. Scientists know that an organism can carry a recessive gene for a trait, but you would be unable to see this based on what the organism looked like. Students often confuse new terminology such as chromosome, DNA, and gene, as these are also often used as synonyms in everyday speech. In genetics, DNA is a kind of molecule, known as deoxyribonucleic acid. Chromosomes are long molecules made of DNA. Each chromosome carries on it hundreds to thousands of segments that are known as genes, and each gene is a set of instructions to make a particular kind of protein. These proteins are what cause the traits that we see in an organism. Organisms like humans and pea plants have pairs of chromosomes, and each pair contains a similar, though not identical, set of genes. These chromosomes match with Mendel's observation that parents have two factors contributing to a trait—there's one copy of the gene on one of the chromosomes, and one on its paired chromosome. In 2010, researchers collaborated to finally discover the gene for pea plant flower color, 150 years after Mendel's original predictions. True to his model, the gene occurs in one of two alleles, and each pea plant has two copies of this gene, one on each of a pair of chromosomes made of DNA.