



Dolan  
DNA Learning Center  
[www.dnalc.org](http://www.dnalc.org)

# Mendelian Inheritance



## Background

In populations, individuals of the same species vary greatly. In fact, within sexually reproducing populations, no two individuals have exactly the same genetic make-up. When mates produce offspring sexually, the offspring receives half of its genes from one parent, and half from the other parent, creating a new being with a unique combination of genes from both parents. This combination of genetic information is what leads to variation among individuals. The question of how traits or characteristics are passed from one generation to the next has been pondered for hundreds of years. Although many questions on inheritance have been answered thus far, the connection between genes and traits, and the passage of these genes from parents to children still amazes scientists and lay people alike. Genes have many intricate interactions with each other inside cells, which still have yet to be understood, but several laws of inheritance have been observed and documented. These basic principles are understood to be some of the underlying rules that genes follow as they are passed from parent to offspring.

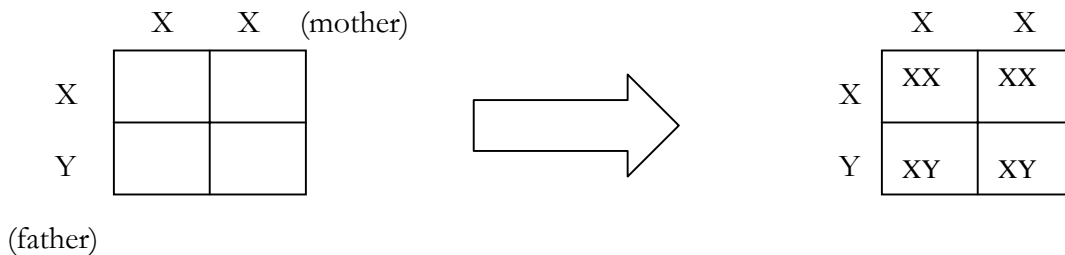
Amazingly enough, a few of these laws were documented in the 1800's, before DNA was identified as the hereditary molecule of the cell. Gregor Mendel (1822-1884) was the man that made some of the very first groundbreaking scientific observations of inheritance. Sadly, when Mendel presented his findings to the rest of the world, he was met with rejection and disbelief. Later, in the early 1900's after his death, three other scientists had the very same data, and finally he received proper recognition.

Gregor Mendel was a monk who lived at a monastery in an area that is now the Czech Republic. He was interested in mathematics and science, but had a passion for his garden. Mendel grew pea plants, and through his observation and cross-fertilization of these plants he discovered that certain traits, such as seed color, seed shape, flower color and plant height were inherited in specific patterns. He was able to cross plants with specific traits by transferring pollen from the stamen of one plant to the stigma of another. In this manner he could observe and record the traits of the offspring from a specific cross. The first observation that Mendel made was that many of the observable traits come in two forms. For example, a pea plant can be either tall or short, or a seed can be either green or yellow. Secondly, he discovered that some of the pea plants "bred true" for specific traits. For example, if a short plant is allowed to self-pollinate for several generations, eventually the offspring will only be short. Thus the plant is purely short; it "breeds true" for shortness. Many of Mendel's experiments began with the crossing of plants that were pure for certain traits.

In one experiment, Mendel crossed a purely tall plant with a purely short plant, collected the seeds and planted them. The results of the cross were a surprise: all of the offspring were tall plants. It seemed as if the short trait just disappeared. The experiment was repeated several times, with the same results each time. The offspring of such a cross, between pure parents with different traits, are called **hybrids**. As a result of his surprise, Mendel let the hybrids self-pollinate, collected the seeds and planted them. This time the results were different. Most of the plants appeared tall, but some were short. The short trait reappeared in the second generation. This demonstrated to Mendel that the short factor (he used the word factor instead of gene) didn't disappear, but was somewhat hidden. He described that the tall trait was **dominant**, which is why all the offspring in the first generation were tall, and that the short trait was **recessive**, which is why it was not expressed in the first generation. His conclusion was that in a hybrid offspring (hybrid for different traits), only the dominant trait is expressed. This is called the **law of dominance**.

Next, Mendel attempted to explain why the recessive trait disappeared in the first generation, and reappeared in the second. He hypothesized that every trait in an organism is controlled by two factors, one from each parent. All factors occur in pairs (for every trait there is a pair of genes that control that trait). A parent can only pass one of two factors to an offspring for each trait, and the factors from both parents recombine to create a new being. This is called the **law of segregation**. If an offspring inherits 2 identical factors for a trait (one from Mom and one from Dad) that trait will be expressed. If an offspring inherits 2 different factors for a trait, the dominant factor will be expressed, while the recessive factor will not. Although the recessive factor is not expressed, it is still present, and can be passed on to further generations. For an organism to express a recessive trait, only the recessive factors can be present.

These laws are in fact true for humans as well as all other sexually reproducing organisms. In all human cells (except egg and sperm) there are 23 pairs of chromosomes. The first 22 pairs are called autosomes and the 23<sup>rd</sup> pair are the sex chromosomes. Within each pair, one of the set is inherited maternally and the other paternally. In autosomes, this means that for each gene has a match on the pairing chromosome. The sex chromosomes are a special case. For males, the last pair of chromosomes isn't a matching set! Males inherit an X chromosome maternally, but paternally inherit a Y chromosome. Females on the other hand, inherit an X chromosome from both parents. This means that at fertilization, the sperm cell's genetic information determines gender. A Punnett square, developed by Reginald Punnett (1875-1967), can be used to demonstrate the statistics involved in gender determination.



Use this tool like a multiplication table, simply drag the gene or chromosome represented on the outside edge of the square into each of the center squares to see the number of possible outcomes each time there is a cross. For gender, there are 2 possible outcomes: XX (x 2) or XY (x 2). Statistically, there is a 50% chance of having a boy or a girl each time a woman conceives.

The same procedure can be used for individual genes, such as the genes for plant height or seed color in Mendel's peas, or for a simple human trait such as a widow's peak. As a rule, letters are used to represent each allele, or gene form in a pair. For plant height, tall is the dominant trait and short is the recessive. The possible genotypes (or inherited alleles) for this trait are: TT (pure bred tall), tt (pure bred short) and Tt (hybrid). A capital letter is always used to represent the dominant allele, and a lower case letter is always used for the recessive. To investigate the statistical inheritance of the trait, use a Punnett square. Start with something simple: TT x tt. If you cross a purely tall plant with a purely short plant, the resulting offspring will all be tall, but they will be hybrids (Tt), inheriting the tall (T) allele from one parent and the short (t) allele from the other. Because tall is dominant, it is more readily expressed and the resulting phenotype, or trait, is being tall even though the short allele is present. Now try a hybrid cross: Tt x Tt. What are the statistical probabilities of having tall or short plants from this cross? Using a Punnett square you will see a 75% tall and 25% short ratio for each cross. 50% of the tall plants will be hybrids. This hybrid cross ratio was observed by Mendel as well!



## Description of Activity

This 1-hour lesson is an introduction Mendel's laws of inheritance for students in grades 5 through 8. By studying inherited traits in maize, we can understand how our own traits are passed down over generations. A discussion of dominant and recessive traits in humans will encourage students to study themselves as well as family members in this exciting activity.

## Learning Outcomes

Students will:

- discuss the historical aspect of genetics as it relates to Gregor Mendel.
- review DNA and chromosome structure.
- discover that traits can be either dominant or recessive.
- use maize as a model organism to illustrate Mendelian inheritance
- identify traits in themselves that are either dominant or recessive.
- learn basic genetics terminology such as; phenotype, genotype, allele, heterozygous and homozygous.
- use Punnett squares to learn more about the laws of inheritance.

## Assumptions of Prior Knowledge

Students should know that the structure of DNA is called a double helix and that chromosomes are packages of DNA found in the nucleus of our cells. DNA contains genetic information for all living organisms. Students should also have a basic understanding of cell division.

## Misconceptions

Students may believe that dominant traits are "better than" or "more common than" recessive traits.

## Lesson

### Materials and Equipment

- PTC paper strips: 1 per student
- 3:1 ratio hybrid corn: 1 ear per student

### Purchasing Information

- 3:1 ratio hybrid ears of corn – Carolina Biological
- PTC paper strips – Carolina Biological

## Before Class

- Photocopy the corresponding student worksheets (Punnett square diagrams, Human Traits Activity and Human Traits Wheel).
- Take time to familiarize yourself with Mendelian genetics and the use of Punnett squares by visiting the DNA from the beginning website and click on the link for "classical genetics": <http://www.dnafb.org>

## During Class

- Review how all living things are composed of cells and that they are considered "the building blocks of life." DNA is found within the nucleus of most cells.
- Explain that our DNA is like a cookbook that contains recipes, or genes, to give us our traits or characteristics. Everyone's DNA is unique.
- Ask students where their DNA comes from.
- Discuss that when an egg cell is fertilized by sperm cell, the chromosomes combine. After fertilization, the zygote contains 46 chromosomes, which includes 23 from the egg cell and 23 from the sperm cell. Through cell division, this single fertilized egg will become a fetus, and eventually a newborn.
- Ask students from whom their parents inherited chromosomes. This should lead to the conclusion that DNA is passed down or inherited over generations, and that explains why certain physical traits are present every generation.
- Ask students to complete the human traits worksheet with a partner, circling each trait, either dominant or recessive. Make sure they also have a chance to taste the PTC paper.
- Tally up the results on the board (how many students have each trait), and ask what happens if two parents with different traits (tongue roller/non-tongue roller) have a child. What trait will the child have?
- Explain that there is sometimes an interaction between the alleles (different versions of the same gene), which depends on whether the allele is dominant or recessive.
- Discuss what the words dominant and recessive mean. Make sure not to mislead students in to thinking that dominant means better, or stronger.
- Introduce the Punnett square. This is a tool we can use to predict the probability that specific traits will be expressed in a child (phenotype), if we know the genetic makeup of the parents (genotype.)
- Start with tongue rolling. Using the Punnett square worksheet provided, give the students a possible cross. We usually start with a homozygous dominant cross, then a homozygous recessive cross, a



homozygous recessive crossed with homozygous dominant, and finally a heterozygous cross. With each example, make sure to review both the genotype and phenotype for each offspring represented in the Punnett square.

- Discuss the history of genetics and introduce Gregor Mendel as the “father of modern genetics”
- Using [www.dnafb.org](http://www.dnafb.org), review the classic pea crossing experiments of Gregor Mendel, and discuss his observation of traits being passed from one generation to the next in specific ratios. You might need to briefly describe plant reproduction.
- Use the 3:1 ratio hybrid corn as a model of the inheritance of pigment in corn. Ask students to count out 100 kernels and determine how many out of that 100 are yellow and how many are purple.
- Students should work in pairs, and record their finding in a collective table on the board. Once all lab groups are finished, ask the class to find the average number of purple and yellow kernels.
- The results should be very close to a 3:1 ratio.

### Analysis and Discussion

- Ask the students to construct a Punnett square that demonstrates what the genotypes of the parent corn had to be, to get a 3:1 ratio in the progeny. As Mendel witnessed in his peas, the answer is that they had to be hybrid!
- For practice, present the students with various scenarios, for which they need to produce a Punnett square to either explain specific phenotypes in offspring, or to predict the probability of inheriting specific traits.
- For fun, students can also color in the Human Traits Wheel activity. Starting in the middle, and working outward, students can use a marker to shade in the traits that they have. Each student should end with a number. This number doesn't mean anything, but with any luck, there should be a great diversity in the numbers throughout the class. Although the wheel only spotlights a small number of traits, the combinations in which these traits are inherited lend themselves to the great diversity within the classroom population.
- For a graphing or math extension, ask the students to tally all of the individual trait information collected during the course of the activity, and produce a bar graph. This graph could also be an accumulation of data from multiple classes. Performing a mini “population study”, students can calculate the presence of various traits by percent. Are dominant traits more common than recessive traits? Why might someone think that is true?

### Further Explorations

Study some of the mutations that cause genetic disease and investigate which mutations are dominant or recessive. Create Punnett squares to explain the modes of inheritance.

Investigate co-dominance and incomplete dominance to understand that genes don't always behave in a Mendelian fashion.

Study some famous family trees and learn about constructing pedigrees. For example, the pedigree of Queen Victoria of England is used across the globe as a demonstration of the inheritance of a sex-linked mutation that causes hemophilia.

Ask students to create a pedigree of their own, for a fictitious family with fictitious traits. Make sure they demonstrate on the family tree which traits are dominant or recessive.

### Resources

#### Websites

[www.vgyh.org](http://www.vgyh.org)

A Dolan DNA Learning Center Internet site.

Use this site to learn more about specific genetic diseases.

<http://www.dnafb.org>

A Dolan DNA Learning Center Internet site.

Use this site to explore various genetics concepts from inheritance to genetic engineering.

<http://www.dnai.org>

A Dolan DNA Learning Center Internet site.

Use this site to learn about the past, present and future of DNA science.

#### Films

“The Secret of the Code”

3-2-1 Contact, Children's Television Workshop, 1991.

#### Books

[Enjoy Your Cells](#)

Fran Balkwill and Mic Rolph, CSHL Press, 2002.

[Have a Nice DNA](#)

Fran Balkwill and Mic Rolph, CSHL Press, 2002.



### **New York State**

NYS Standard 4: Science

The Living Environment

- Living things are both similar to and different from each other and nonliving things.
- Organisms inherit genetic information in a variety of ways that result in continuity of structure and function between parents and offspring.
- Individual organisms and species change over time.
- Human decisions and activities have a profound impact on the physical and living environment.

### **National Science Standards**

Content Standard C: Life Sciences

Reproduction and Heredity

- Hereditary information is contained in genes, located in the chromosomes of each cell. Each gene carries a single unit of information. An inherited trait of an individual can be determined by one or by many genes, and a single gene can influence more than one trait. A human cell contains many thousands of different genes.
- The characteristics of an organism can be described in terms of a combination of traits. Some traits are inherited and others result from interactions with the environment.

### **AAAS Benchmarks**

Chapter 5: The Living Environment

Standard B: Heredity

- Some new gene combinations make little difference, some can produce organisms with new and perhaps enhanced capabilities, and some can be deleterious.
- Genes are segments of DNA molecules. Inserting, deleting, or substituting DNA segments can alter genes. An altered gene may be passed on to every living cell that develops from it. The resulting features may help, harm, or have little or no effect on the offspring's success in its environment.
- In some kinds of organisms, all the genes come from a single parent, whereas in organisms that have sexes, typically half of the genes come from each parent.



# Gregor Mendel

## The Father of Genetics

Gregor Mendel was a monk who lived in a region of Austria that is now part of the Czech Republic. He was interested in mathematics and science, but had a passion for gardening. Mendel grew pea plants and through his observation and cross fertilization of these plants he discovered that certain traits, such as seed color, seed shape, flower color and plant height were inherited in specific patterns. He was able to cross plants with specific traits by transferring pollen from the stamen of one plant to the stigma of another. In this manner he could observe and record the traits of the offspring from a specific cross.



Gregor Mendel

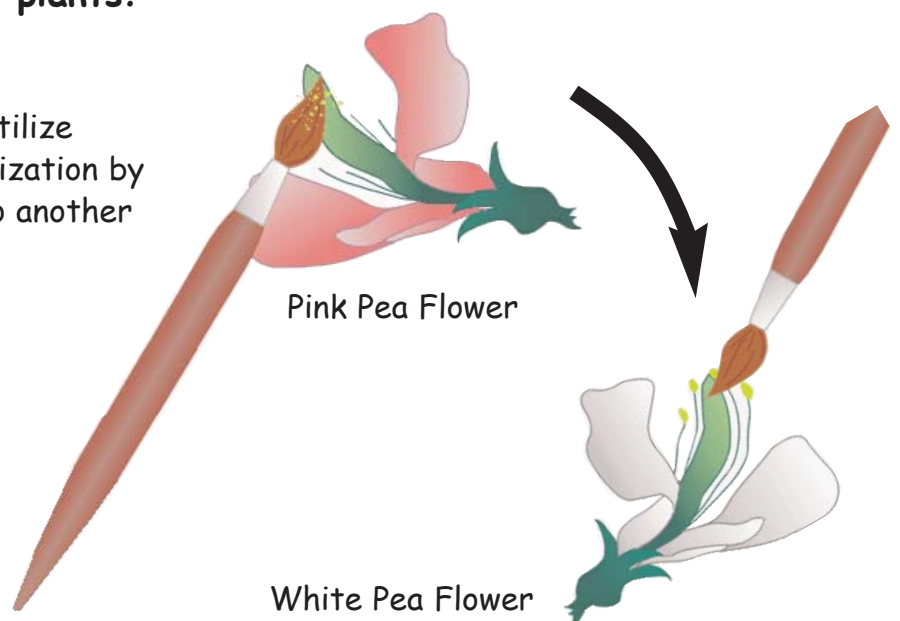
Mendel observed that when he crossed two plants with different traits, the next generation of plants expressed one trait more readily than another. He called these plants hybrids. In hybrids, the trait that is expressed is called a **dominant trait**. The trait that is not expressed is called the **recessive trait**.



The pollen of the pea plant contains the male genes; the egg cells of the plant, located in the ovary, contain the female genes. When pollen lands on the stigma, the pollen tube connects it to an egg. The nucleus of the pollen cell then travels down the tube until it fertilizes the egg to form a zygote. The zygote grows into a new plant, with a full set of DNA from each parent plant.

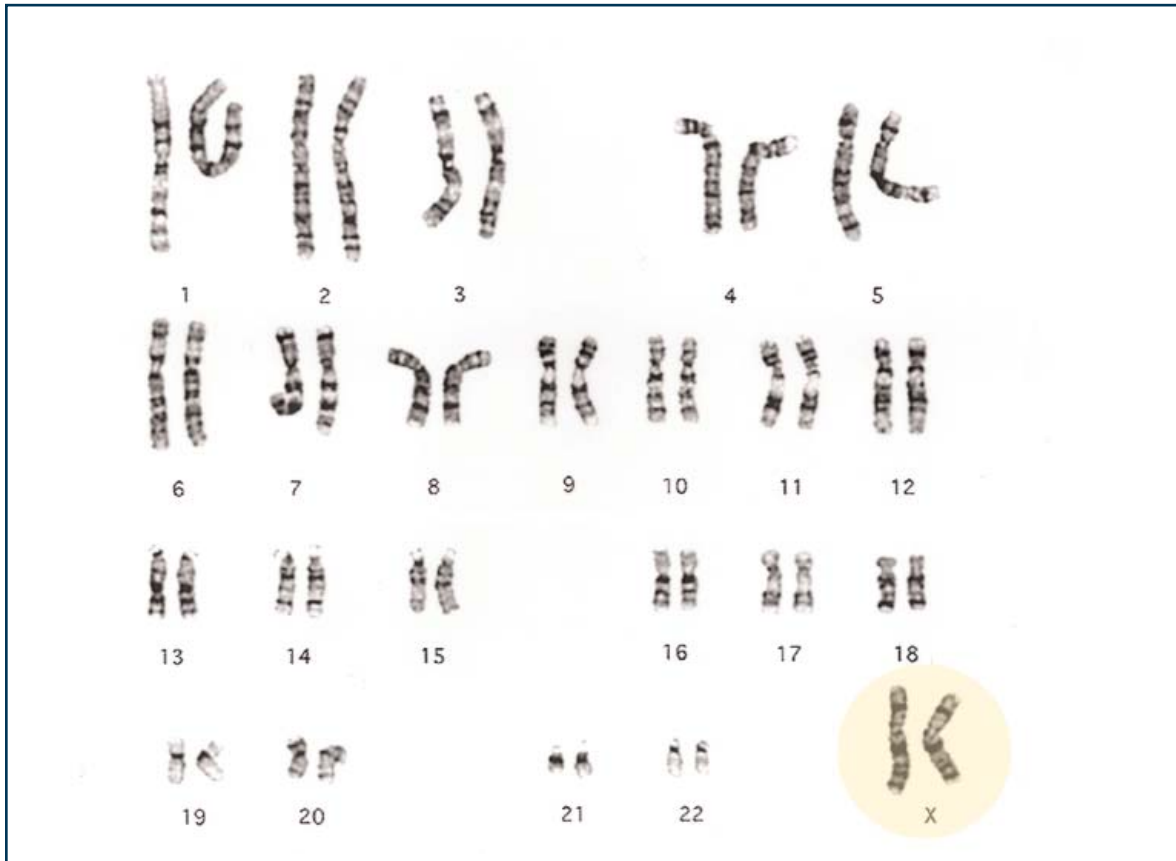
## How did Mendel cross his pea plants?

Instead of letting his pea plants fertilize themselves, Mendel controlled fertilization by transferring pollen from one plant to another using a brush.

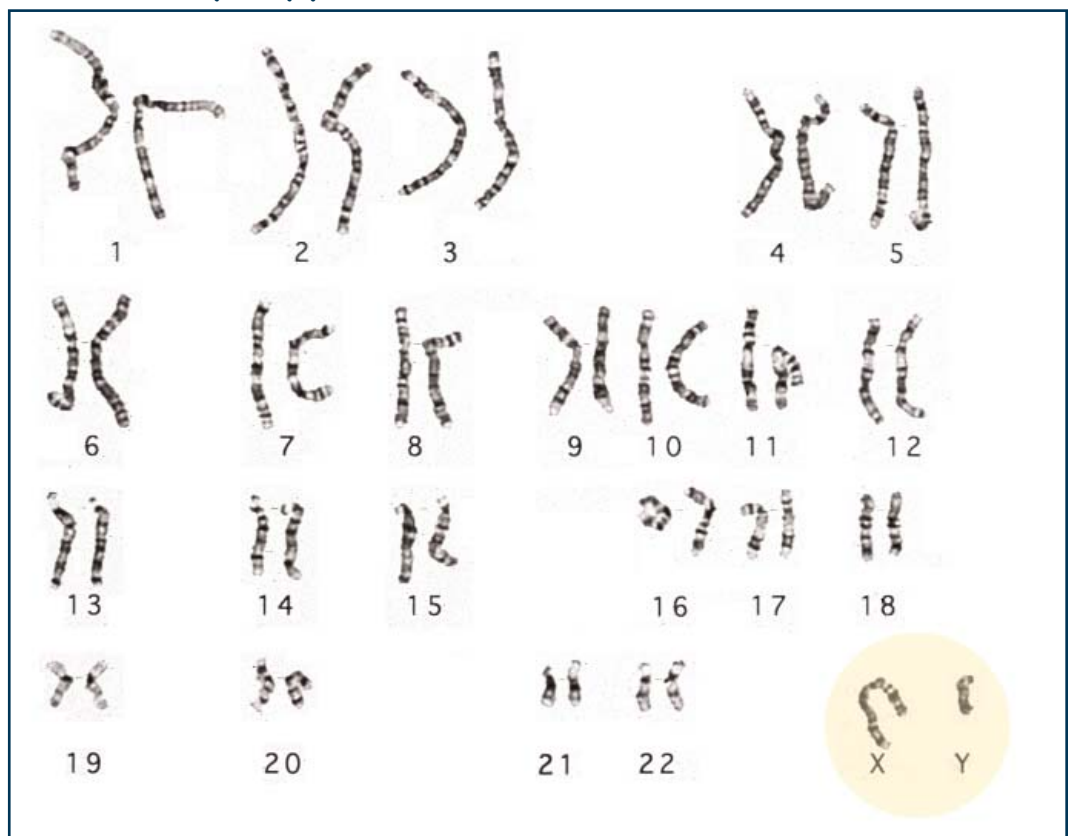


# Human Karyotypes

## Female Karyotype



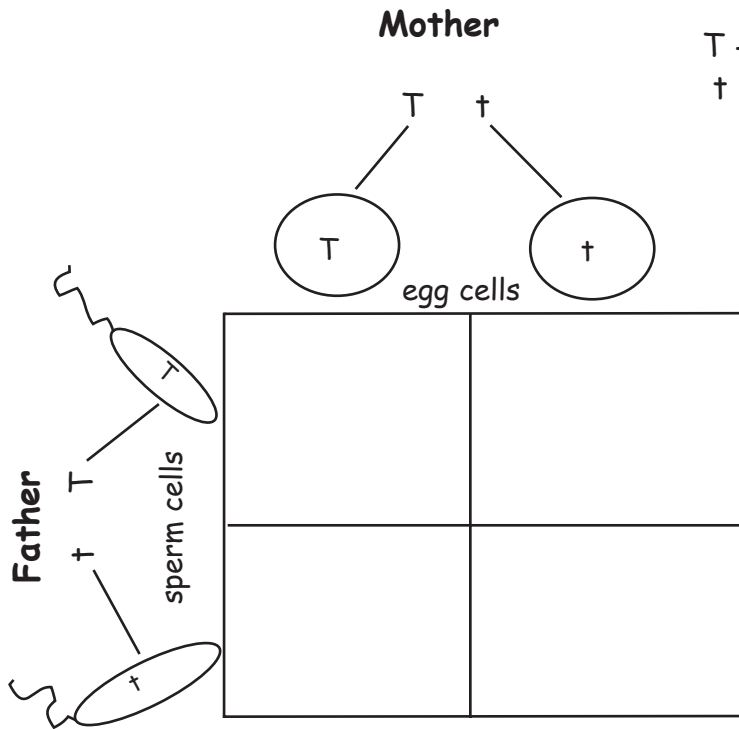
## Male Karyotype





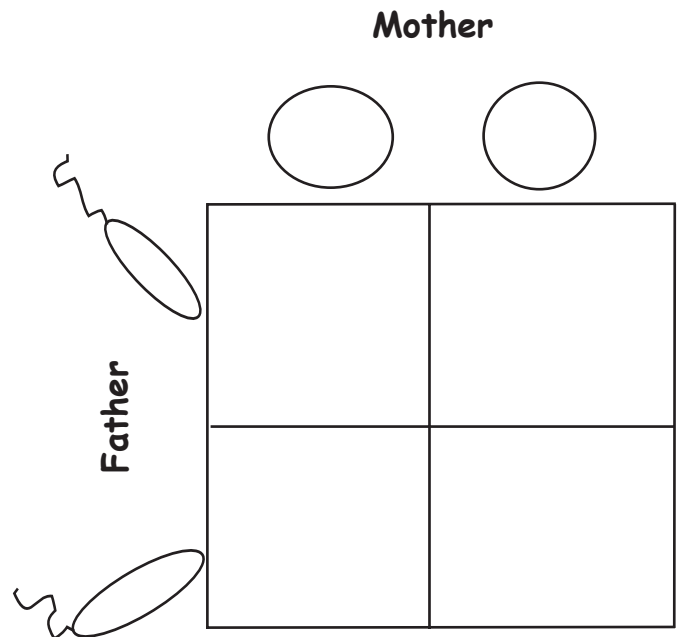
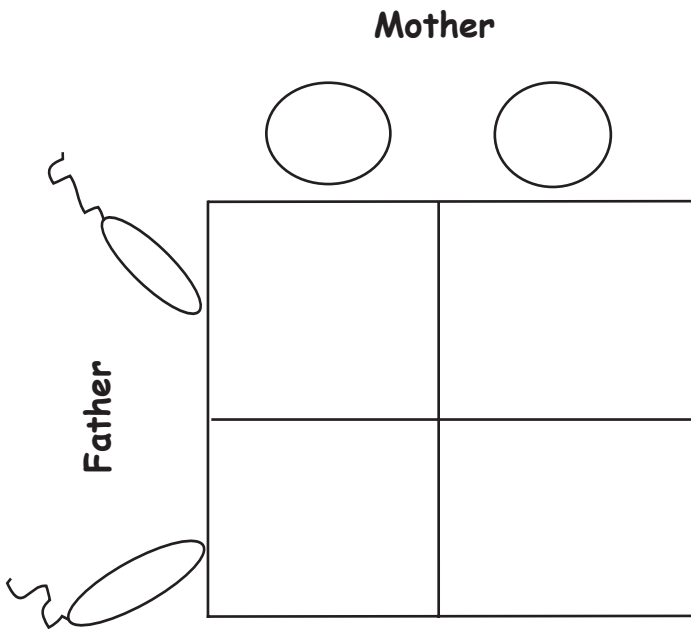
# Mendelian Inheritance

Using Punnett Squares to Explore How Genes are Inherited

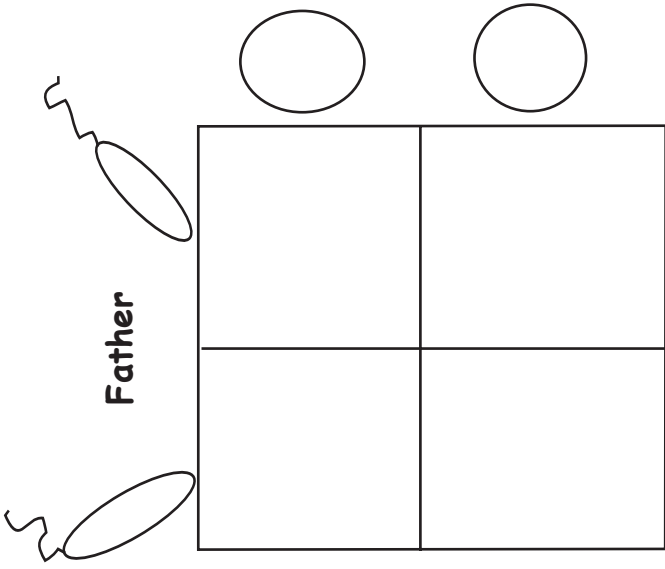


T - Tongue Roller  
† - Unable to Roll Tongue

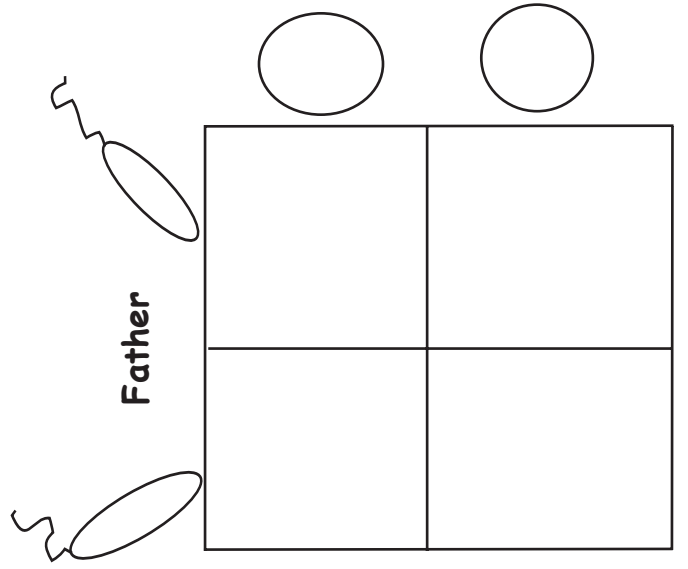
Will the children of these people be able to roll their tongues?



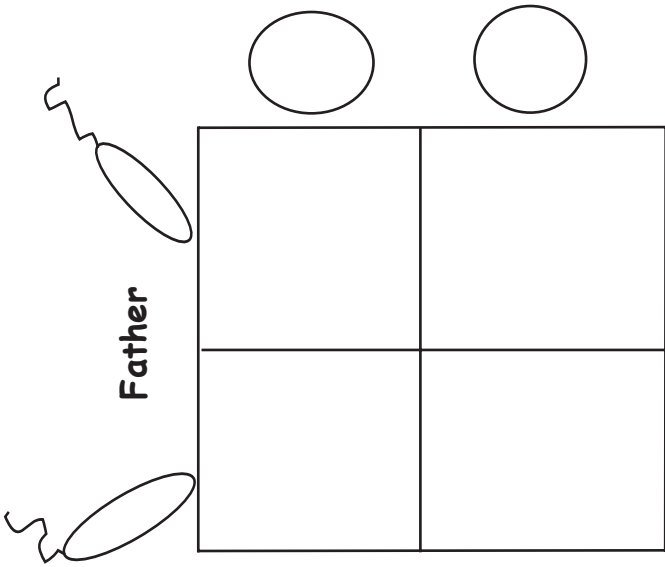
Mother



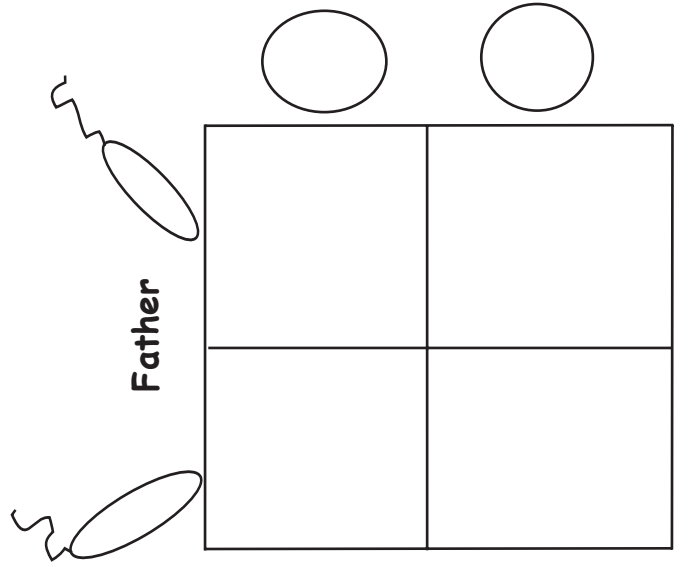
Mother



Mother



Mother



# Human Traits Checklist

For each example circle whether you have the dominant or recessive trait.

Dominant Trait

Recessive Trait

Tongue Roller

or

Can't Roll Tongue

Widow's Peak

or

No Widow's Peak

Free Earlobe

or

Attached Earlobe

Taste PTC Paper

or

Can't Taste PTC

Straight Thumb

or

Hitchhiker's Thumb

Bent Little Finger

or

Straight Little Finger

Mid-Digital Hair

or

No Mid-Digital Hair

Dimples

or

No Dimples



# Human Traits Wheel

Look at the trait in the middle of the wheel, if you have it, color in the **YES** section, if you don't have it color in the **NO** section. Working from the middle out, do the same for each trait, until you reach the outermost circle. Did any two people in the group get the same number?

