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TEACHER'S RESOURCE BOOK  
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## TABLE OF CONTENTS

Introduction	1
Learning Objectives	2
Program Summary	3
<u>STUDENT ACTIVITIES</u>	
1: Practice Problems (Set 1)	7
Answers to Set 1	8
2: Practice Problems (Set 2)	10
Answers to Set 2	11
3: Practice Problems (Set 3)	13
Answers to Set 3	14
4: Discussion Questions	16
Answers to Discussion Questions	17
5: Simple Probability	18
Answers to Simple Probability	19
6: Probability in Hybrid Crosses	20
Answers to Probability in Hybrid Crosses	22
7: Independent Assortment	23
Answers to Independent Assortment	25
8: Corn Exploration	26
Answers to Corn Exploration	27
9: Human Traits	28
10: Science Biographies	29
<u>FACT SHEETS</u>	
1: Glossary	30
2: Bibliography	32
Other Biology Programs	33

From the time of the early Greeks and Romans, people were aware that offspring tended to resemble their parents. It was obvious that cats had kittens and dogs had puppies. Likewise, it was known that good offspring could be bred from superior parents.

What was not known was the mechanism for passing information from one generation to the next. For a long time it was thought that the blood was responsible for this process. We still hear of such expressions as *blood line*, *royal blood*, *blue blood*, and even *bad blood*.

In the 1850's, when Gregor Mendel began his work, we did not even know the agent of genetic information, let alone its mechanism for transfer.

Gregor Mendel's hard work, perseverance, and insight serve as a model for all science investigators. He knew nothing of DNA, genes, mitosis, or meiosis. The ideas he formulated were based entirely on his observations and his experiments. Essentially, he used good science technique to arrive at his conclusions. Gregor Mendel's most important and powerful research tool was his mind. His work resulted in an entire new branch of science and it is fitting that he has earned the title, "Father of Genetics."

This program introduces students to Mendel's ground-breaking work using his original pea experiments as examples. It then moves on to show how later scientific developments have modified or expanded on some of his original concepts.

## LEARNING OBJECTIVES

After watching the video *Exploring Inheritance and Genetics* and participating in the activities in this Teacher's Resource Book, your students will be able to:

- understand the role of genes and chromosomes in the patterns of inheritance of living things
- state Mendel's laws of heredity
- explain the relationship of genes, chromosomes, and chromosome pairs
- distinguish between dominant and recessive genes
- understand the use of Punnett squares
- state the difference in expected and observed results and how each is determined
- identify some mechanisms of heredity that do not follow the principles of Mendel's three laws

This program deals with Mendel's observations and research that led up to the formulation of his classic laws of heredity.

## PART I: MENDEL'S PRINCIPLES

Gregor Mendel, an Austrian monk, experimented with common garden pea plants. These were convenient organisms to work with because they are grown easily and produce large numbers of offspring. The fact that they self-pollinate allowed him to control the genetic crosses.

Mendel observed that visible characteristics, such as height or seed color, were inherited. He saw that many traits existed in either of two possible forms. A pea plant was either tall or short; its seeds were either yellow or green. Mendel studied seven different traits that appeared in the pea plants.

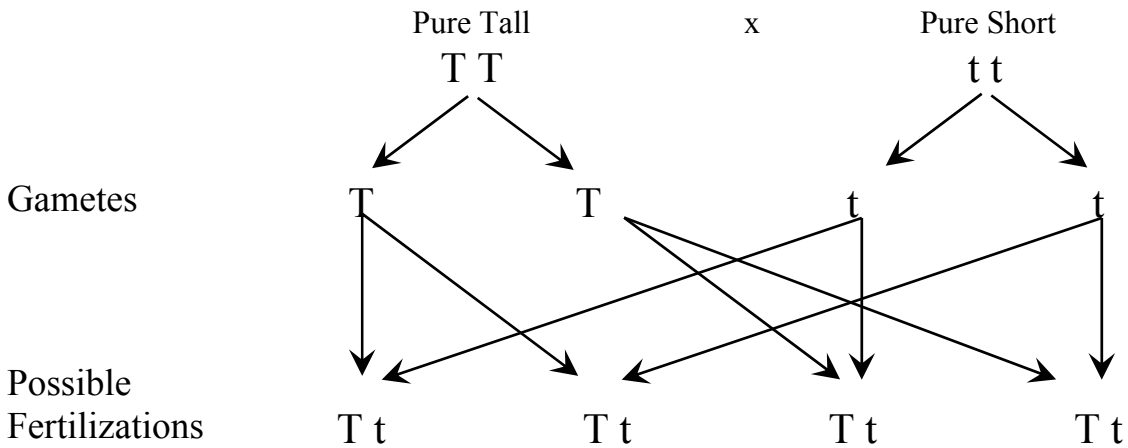
Obviously, Mendel knew nothing of genes, chromosomes, or the processes of mitosis and meiosis. These areas had not even been explored yet. By using good scientific technique, he was able to establish the foundation for what we today call the science of *genetics*.

It was known that pea plants reproduce sexually. Mendel started with purebred strains to perform his experiments. Unlike many other plants, peas self-pollinate. Mendel removed the pollen-bearing anthers from each plant so it couldn't pollinate itself. Then he fertilized it with pollen from another plant.

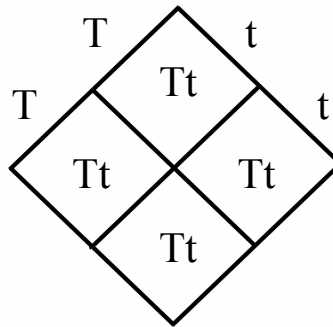
Mendel observed that in his first series of crosses dealing with two pure, but contrasting, traits (e.g., tall and short), only one of these traits (tall, in this case) showed up in the next generation. He called the trait that showed up the *dominant* trait, and the one not seen, the *recessive* trait. The fact that this occurred with all seven characteristics he studied led him to formulate his *law of dominance*.

Mendel next went on to cross-pollinate the first-generation plants with other first-generation plants. To his surprise, the recessive characteristics reappeared in some of the new offspring. Careful statistical analysis of his data showed that the ratio of dominant to recessive traits in the second generation was always approximately 3:1.

In order to explain these results, Mendel had to make certain assumptions. Each pea plant is produced by the union of a pollen (sperm) and an egg. Every trait, therefore, must be controlled by two characters—one from the male and one from the female. Today we call these characters *genes*. He represented a dominant gene with a capital letter and a recessive gene with a lower case letter. It is conventional to use the first letter of the dominant trait. He illustrated a cross between a pure tall plant with a pure short plant as follows:

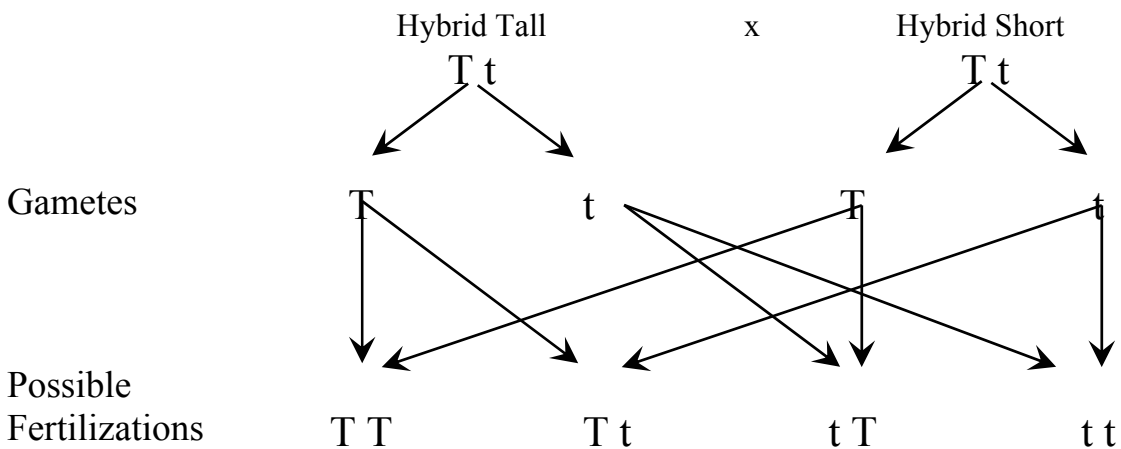


This was later simplified by using the Punnett square method.

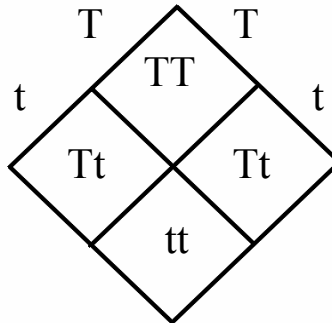


Note that the results come out the same with either method. They show that only dominant characteristics may appear and that all the offspring are hybrids.

Mendel went on to explain the results of the second cross in this way.



or



The results show that three-quarters (75 percent) of the offspring will show the dominant trait and one-quarter (25 percent) will show the recessive trait. Mendel realized his data only approximated these ideal ratios because his samples were of a limited size.

This explanation led to the principle of *segregation*, which in modern terms would be stated this way: when gametes are formed, the genes in a pair segregate so that each gamete has only one gene, rather than the normal two. The gametes later unite to produce offspring in predicted ratios.

Mendel also looked at the results of crossing two traits at a time—for example, the condition of height and the condition of the seed color. He observed that one characteristic had no bearing on how the other was expressed. His third law of inheritance is called the principle of *independent assortment*. Today, we know that the genes controlling these traits must be on separate chromosomes so that their expression is not linked in any way.

## PART II: MODIFYING MENDEL

After Mendel's work was rediscovered in the year 1900, scientists did studies to confirm his laws. A number of exceptions surfaced and modifications of Mendel's principles of inheritance were needed.

Snapdragon plants provide an example of one exception. When a plant with red flowers is crossed with a plant with white flowers, the flowers on the offspring do not conform to Mendel's principle of dominance: they are pink. This is called *incomplete dominance*.

Our modern understanding that thousands of individual genes are located on a single chromosome leads to the modification of another of Mendel's principles, the principle of *independent assortment*. Only genes lying on different chromosomes will be assorted independently unless crossing over takes place.

In spite of these modern developments, our current understanding of genetics rests firmly on the foundation laid by Gregor Mendel, working alone with pea plants in the garden of his monastery.

# STUDENT ACTIVITIES

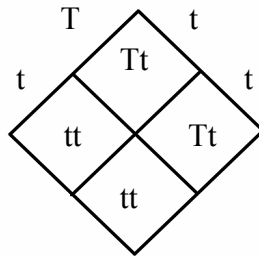
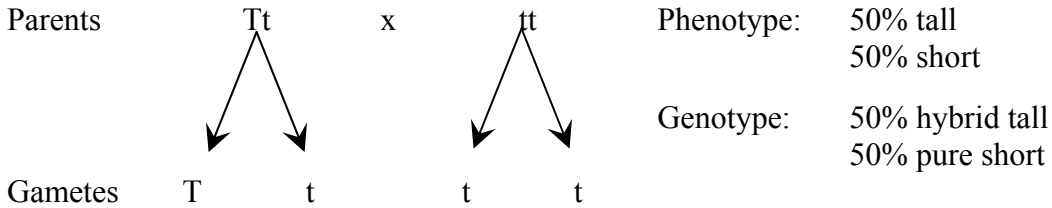
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On a separate sheet of paper, use keyed and labeled diagrams to show the following genetic crosses. These are all based on traits that Gregor Mendel saw in his pea plants.

**Example:**

Tallness is dominant over shortness. Cross: Hybrid tall x Pure short

Let **T** = gene for tallness. Let **t** = gene for shortness.



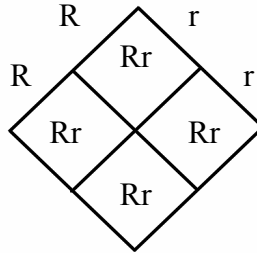
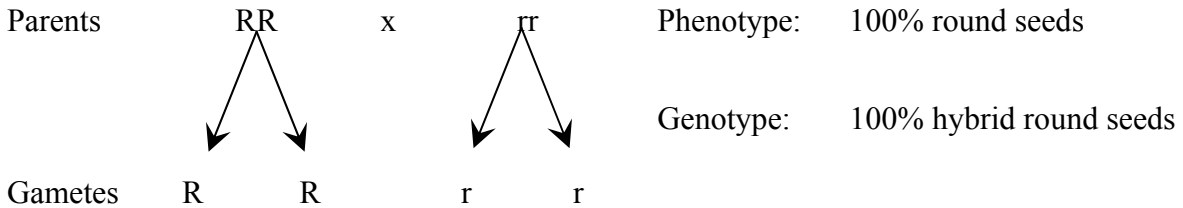
1. Round seeds are dominant over wrinkled seeds.  
Cross: Pure round seeds x Pure wrinkled seeds
2. Green pods are dominant over yellow pods.  
Cross: Hybrid green pods x Hybrid green pods
3. Axial flowers are dominant over terminal flowers.  
Cross: Hybrid axial flowers x Pure axial flowers
4. Colored seed coats are dominant over white seed coats.  
Cross: Hybrid colored seeds x Hybrid colored seeds

Name: \_\_\_\_\_

**Answers:**

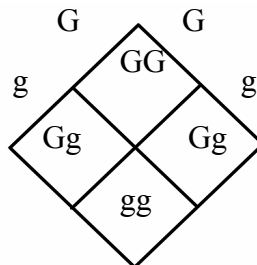
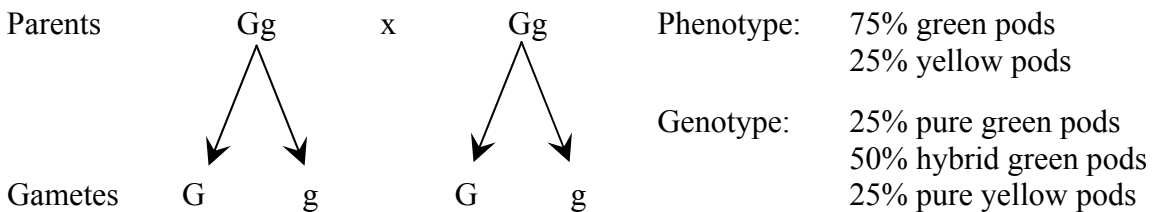
1. Round seeds are dominant over wrinkled seeds.  
Cross: Pure round seeds x Pure wrinkled seeds

**Let  $R$  = gene for round seeds. Let  $r$  = gene for wrinkled seeds.**



2. Green pods are dominant over yellow pods.  
Cross: Hybrid green pods x Hybrid green pods

**Let  $G$  = gene for green pods. Let  $g$  = gene for yellow pods.**





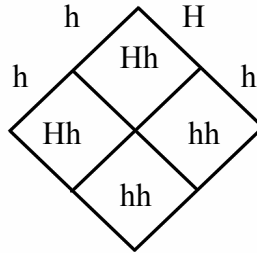
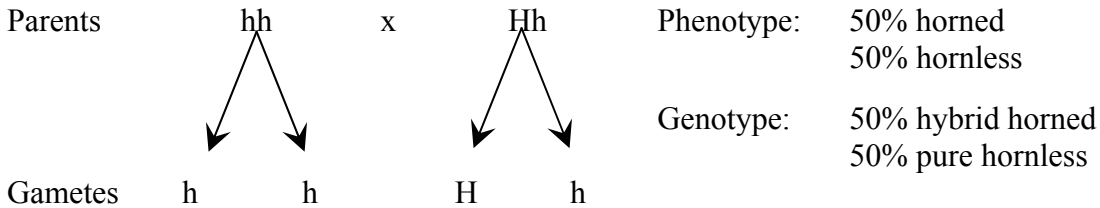


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**Answers:**

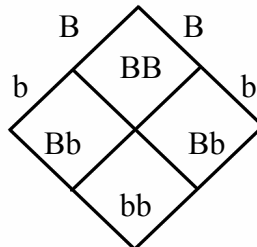
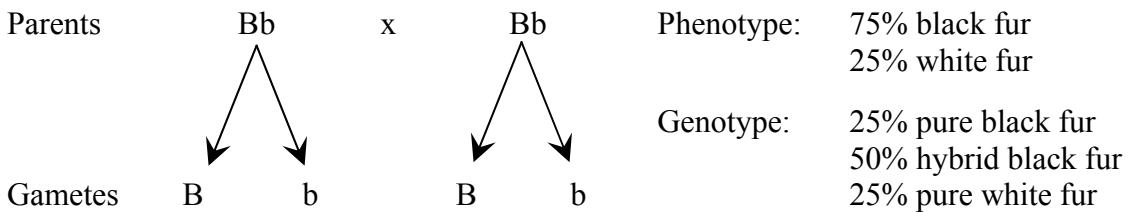
1. The horned condition in cattle is dominant over the hornless condition.  
Cross: Pure hornless x Hybrid horned

**Let  $H$  = gene for horned condition. Let  $h$  = gene for hornless condition.**



2. Black fur is dominant over white fur in guinea pigs.  
Cross: Hybrid black x Hybrid black

**Let  $B$  = gene for black fur. Let  $b$  = gene for white fur.**



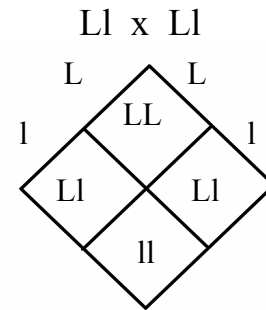
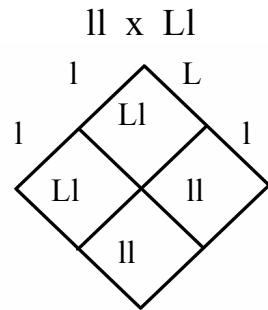
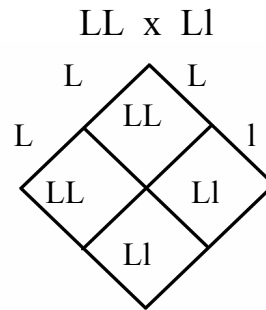
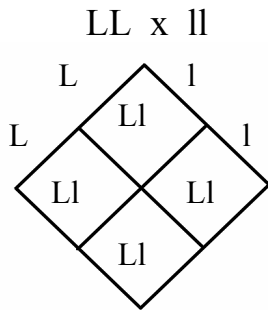
Name: \_\_\_\_\_

**Answers (continued):**

3. Long wings are dominant over curly wings in fruit flies. Show all the different crosses that can produce hybrid long wing individuals.

**Let  $L$  = gene for long wings. Let  $l$  = gene for curly wings.**

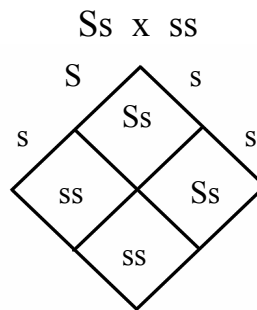
Crosses that can produce hybrid long wing individuals:



4. Short beaks are dominant over long beaks in a particular species of birds. Show all the different crosses that result in 50% of the offspring having long beaks.

**Let  $S$  = gene for short beaks. Let  $s$  = gene for long beaks.**

Crosses that result in 50% of the offspring having long beaks:



Name: \_\_\_\_\_

On a separate sheet of paper, use keyed and labeled diagrams to show the following genetic crosses. These problems represent exceptions to Mendel's laws of heredity because they deal with situations where neither gene is dominant to the other.

1. If a black Andalusian fowl is crossed with a white Andalusian fowl, all the offspring come out blue (really a combination of black and white feathers).

Cross: White Andalusian hen x Blue Andalusian rooster

2. In radishes, we find some radishes with long roots and some with round roots. The offspring of a cross between a pure round rooted radish and a pure long rooted radish show all oval shaped roots.

Cross: Oval rooted x Oval rooted

3. A brown bird was crossed with a white one and all the offspring produced were tan. If these offspring were crossed and produced 20 new individuals, what colors and ratios would be expected?

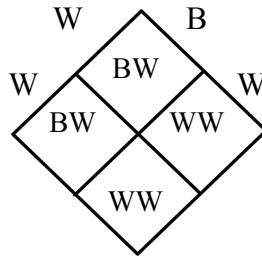
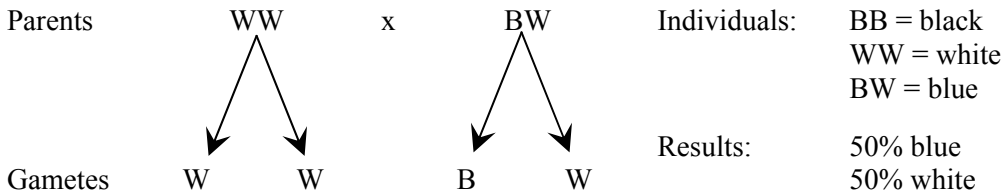
Name: \_\_\_\_\_

**Answers:**

1. If a black Andalusian fowl is crossed with a white Andalusian fowl, all the offspring come out blue (really a combination of black and white feathers).

Cross: White Andalusian hen x Blue Andalusian rooster

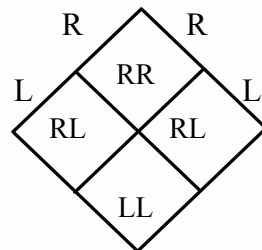
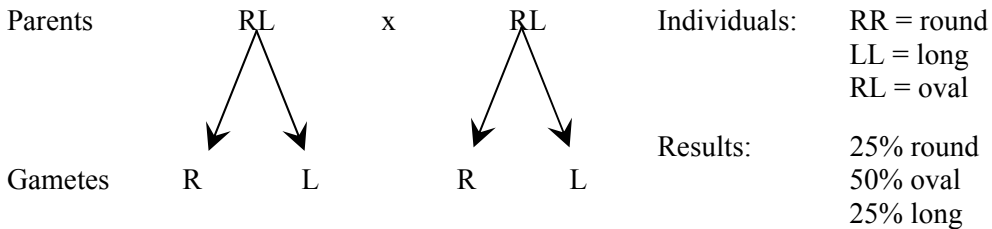
Let *B* = gene for black. Let *W* = gene for white.



2. In radishes, we find some radishes with long roots and some with round roots. The offspring of a cross between a pure round rooted radish and a pure long rooted radish show all oval shaped roots.

Cross: Oval rooted x Oval rooted

Let *R* = gene for round. Let *L* = gene for long.



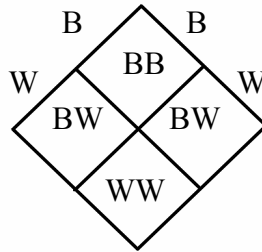
Name: \_\_\_\_\_

**Answers (continued):**

3. A brown bird was crossed with a white one and all the offspring produced were tan. If these offspring were crossed and produced 20 new individuals, what colors and ratios would be expected?

Let *B* = gene for brown. Let *W* = gene for white.

Parents	BW	x	BW	Individuals:	BB = brown
					WW = white
					BW = tan
				Results:	25% brown x 20 = 5
					50% tan x 20 = 10
Gametes	B W		B W		25% white x 20 = 5



Name: \_\_\_\_\_

DISCUSSION QUESTIONS

1. Why was Mendel's work considered revolutionary?

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2. How did Mendel's explanation differ from prevailing ideas of that time?

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3. What assumptions did Mendel make in coming up with his theory of inheritance?

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4. Explain how Mendel's background in mathematics served him well in his research.

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5. Mendel has been criticized for only using the part of his data that he could explain clearly, using his newly established laws of heredity. If he did ignore his other data, is this a fair criticism?

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6. Mendel's work was rediscovered 16 years after his death. Why was it not appreciated during his lifetime?

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1. Why was Mendel's work considered revolutionary?  
*Mendel explained the mechanism for heredity. This was something people had thought about, but could not explain, for thousands of years. His work established an entire new field of science.*
2. How did Mendel's explanation differ from prevailing ideas of that time?  
*Mendel came up with a specific mechanism to explain how characteristics could be transmitted from parents to their offspring. Earlier theories included blood as the hereditary agent and preformation, where it was thought that miniature individuals were contained in eggs or sperm.*
3. What assumptions did Mendel make in coming up with his theory of inheritance?  
*Mendel did not know about meiosis. He assumed that genes, which he called "unit characters," occurred in pairs which separated from each other into two types when gametes were formed.*
4. Explain how Mendel's background in mathematics served him well in his research.  
*Mendel was aware that large samples were significant statistically. He also showed how an understanding of probability was necessary to draw conclusions from his data.*
5. Mendel has been criticized for only using the part of his data that he could explain clearly, using his newly established laws of heredity. If he did ignore his other data, is this a fair criticism?  
*Mendel was the first person to work in this area of research. He had no reference books to turn to. It is probable that he tried to make sense of whatever he could and decided to leave the rest for others to attempt to decipher.*
6. Mendel's work was rediscovered 16 years after his death. Why was it not appreciated during his lifetime?  
*The mathematical explanations were confusing to many biologists of that period. They simply did not see the significance of his work and chose to ignore it. Some people speculate that even Charles Darwin had seen Mendel's work, but did not grasp its importance.*

Name: \_\_\_\_\_

In tossing a coin, you have an equal chance of getting *heads* or *tails*. In terms of probability, these odds can be expressed as:

**1 heads : 1 tails**

Working in pairs, you and a classmate should toss a single coin 30 times. Record your results in the space below. Turn each set of results into a ratio of *heads* : *tails*.

_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____

Next, total the entire class's results and establish an overall ratio.

**Questions:**

1. Which results come closer to the expected ratio, the individual team results or the class average?

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

2. Why are large samples necessary in order to establish reliable results?

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

Name: \_\_\_\_\_

**Answers:**

1. Which results come closer to the expected ratio, the individual team results or the class average?  
*Generally, the class average will more closely approximate an expected 1:1 ratio.*
2. Why are large samples necessary in order to establish reliable results?  
*The larger the sample, the less likely random chance will upset the expected ratios.*

Name: \_\_\_\_\_

We can simulate a hybrid x hybrid cross by tossing two coins at a time. If we use Tt x Tt, we find that each parent can produce gametes of either T or t. We see that there is an equal chance of getting T or t, just like the two-sided coin gives us an equal chance of getting a *heads* or a *tails*. Mathematically both of these situations can be expressed as follows:

Results of tossing two coins at a time.

	$\frac{1}{2}$ H	+	$\frac{1}{2}$ T	
X	$\frac{1}{2}$ H	+	$\frac{1}{2}$ T	
	$\frac{1}{4}$ HH	+	$\frac{1}{4}$ HT	
			$\frac{1}{4}$ HT	+
				$\frac{1}{4}$ TT
	$\frac{1}{4}$ HH	+	$\frac{1}{2}$ HT	+
				$\frac{1}{4}$ TT

Results of a hybrid tall (Tt) x hybrid tall (Tt)

	$\frac{1}{2}$ T	+	$\frac{1}{2}$ t	
X	$\frac{1}{2}$ T	+	$\frac{1}{2}$ t	
	$\frac{1}{4}$ TT	+	$\frac{1}{4}$ Tt	
			$\frac{1}{4}$ Tt	+
				$\frac{1}{4}$ tt
	$\frac{1}{4}$ TT	+	$\frac{1}{2}$ Tt	+
				$\frac{1}{4}$ tt

How would this look using the Punnett square method?

Working in pairs, you and a classmate should carry out 20 trials of tossing two coins at a time. Log your results on the back of this page, or on a separate sheet of paper.

Name: \_\_\_\_\_

**Questions:**

1. What are the expected ratios for this activity?

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2. Which of Mendel's laws of heredity does this illustrate?

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3. Which numbers come closer to the expected ratios, the individual pairs of results or the class average?

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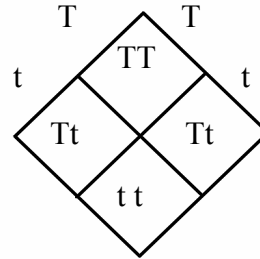
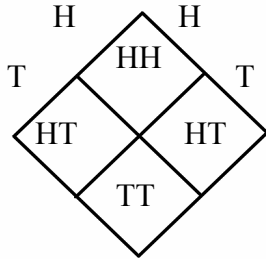
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Name: \_\_\_\_\_

**Answers:**

How would this look using the Punnett square method?



1. What are the expected ratios for this activity?  
*two heads - 25%*  
*one heads and one tails - 50%*  
*two tails - 25%*  
*This can be expressed as 1:2:1.*
2. Which of Mendel's laws of heredity does this illustrate?  
*Law of Segregation.*
3. Which numbers come closer to the expected ratios, the individual pairs of results or the class average?  
*If the sample is large enough, the class average will more closely approximate the 1:2:1 expected ratios.*

Name: \_\_\_\_\_

The following activity is very helpful in understanding Mendel's Law of Independent Assortment. We will simulate a cross between two dihybrid individuals. They are both hybrid tall and hybrid yellow seeded, which we will represent as TtYy.

1. Four sets of colored beads are needed to represent the gene makeup of the two dihybrid parents. This color guide might be used as a typical key for this exercise.

KEY:

Red = gene for tallness (dominant trait)  
Blue = gene for shortness (recessive trait)  
Yellow = gene for yellow seeds (dominant trait)  
Green = gene for green seeds (recessive trait)

2. Each parent needs two containers to represent its genetic makeup. In the first container, place an equal number of red and blue beads (approximately 50 of each). In the second container, do the same using the yellow and green beads. Repeat this procedure to represent the gene makeup of the second parent.
3. To simulate gamete formation, choose one bead from each container of the first parent. Repeat the procedure for the second parent.
4. To simulate fertilization, bring together the gametes from each parent. The following is illustrative of what might occur:

	<u>Parent 1</u>		<u>Parent 2</u>		<u>Offspring</u>
First Pick	Red, Green	+	Red, Yellow	>	RRYG

This individual would be pure tall and hybrid yellow.

Second Pick	Blue, Green	+	Red, Green	>	RBGG
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This individual would be hybrid red and pure green.

5. Replace the beads in the containers and draw again. (It is important to replace the beads so the odds will be the same on each draw.)
6. List the results based on phenotypes (physical appearance) as follows:

Tall and Yellow  
Tall and Green  
Short and Yellow  
Short and Green

Name: \_\_\_\_\_

**Questions:**

1. What are your ratios for these four categories?

Tall and Yellow \_\_\_\_\_

Tall and Green \_\_\_\_\_

Short and Yellow \_\_\_\_\_

Short and Green \_\_\_\_\_

2. Which of Mendel's laws of heredity does this exercise illustrate?

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3. Show the Punnett square that illustrates this cross.

Let T = gene for tallness

Let t = gene for shortness

Let Y = gene for yellow seeds

Let y = gene for green seeds

4. What are the results of your Punnett square for each category?

Tall and Yellow \_\_\_\_\_

Tall and Green \_\_\_\_\_

Short and Yellow \_\_\_\_\_

Short and Green \_\_\_\_\_

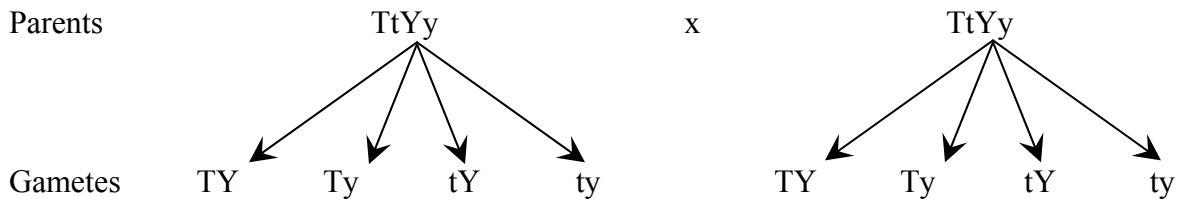
## ANSWERS TO INDEPENDENT ASSORTMENT

**Answers:**

- What are your ratios for these four categories?  
*The expected ratios are 9:3:3:1.*
- Which of Mendel's laws of heredity does this exercise illustrate?  
*Law of Independent Assortment*
- Show the Punnett square that illustrates this cross.  
*It might be best to follow normal convention of using the letters of the traits involved as follows:*

**KEY:**

Let T = gene for tallness  
 Let t = gene for shortness  
 Let Y = gene for yellow seeds  
 Let y = gene for green seeds

**PUNNETT SQUARE:**

	TY	Ty	tY	ty
TY	TTYYY	TTYy	TtYY	TtYy
Ty	TTYy	TTyy	TtYy	Ttyy
tY	TtYY	TtYy	ttYY	TtYy
ty	TtYy	Ttyy	ttYy	ttyy

**Results:**

Tall and Yellow 9  
 Tall and Green 3  
 Short and Yellow 3  
 Short and Green 1

Name: \_\_\_\_\_

Specially bred ears of genetic corn can be purchased from biological supply houses. Your teacher will provide each pair of students with a set of ears of corn that are the result of a hybrid x hybrid cross.

As you work on this activity, remember that each kernel is the result of a fertilization. The color of a kernel is a trait controlled by a gene. Establish which color is the dominant trait (*e.g.* dark purple) and which is the recessive trait (*e.g.* yellow).

Students should count every kernel on the ear of corn for the two colors. When you are finished, your class should establish a ratio for your numbers and put all the class data on the chalkboard.

**Questions:**

1. If all the individual ratios are rounded off to the nearest whole number, what is the most common ratio?

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2. Which of Mendel's laws of heredity does this exercise illustrate?

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3. Which ratios are closer to the expected ratios, those of the individual ears of corn or the class average?

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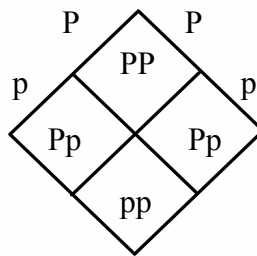
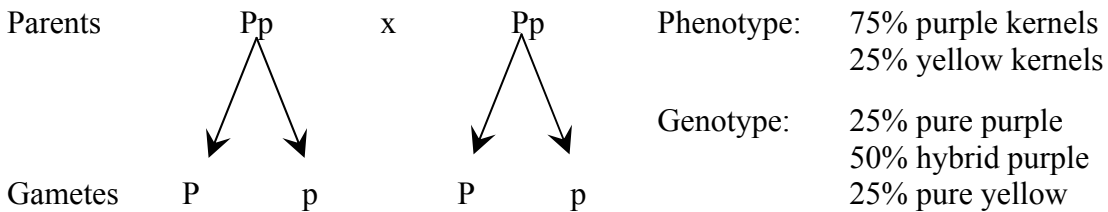
4. Use a Punnett square to illustrate the results of this cross.

**Let  $P$  = gene for purple kernels. Let  $p$  = gene for yellow kernels.**

**Answers:**

- If all the individual ratios are rounded off to the nearest whole number, what is the most common ratio?  
*3:1*
- Which of Mendel's laws of heredity does this exercise illustrate?  
*Law of Segregation*
- Which ratios are closer to the expected ratios, those of the individual ears of corn or the class average?  
*If the sample is large enough, the class average should more closely approximate the expected results.*
- Use a Punnett square to illustrate the results of this cross.

**Let  $P$  = gene for purple kernels. Let  $p$  = gene for yellow kernels.**



Name: \_\_\_\_\_

Make a list of several traits exhibited in humans that follow Mendelian patterns of inheritance. Examples include: handedness, where right is dominant over left; ability to roll the tongue, where the ability to roll is dominant over the inability to roll; or PTC tasting. PTC paper contains a harmless chemical which can be tasted by some people, but not others. The ability to taste the chemical is the dominant trait. The PTC paper can be purchased through most biological supply houses.

If you and your classmates perform a little research and brainstorming, you will turn up a host of other traits that can be studied. When you have developed a list of traits, you should check your family to determine how many people have the traits. If possible, construct a “family pedigree.”

Once all students have investigated their family traits, take a survey to see how your classroom population conforms to the expected ratios for these traits.

List of traits that I want to investigate:

_____	_____
_____	_____
_____	_____
_____	_____

Construct your family pedigree in the space below. Use additional paper if you need more room.

Name: \_\_\_\_\_

Since the time of Gregor Mendel, many scientists have made important contributions to our understanding of genetics. For this assignment, you will do research on the background of a modern-day scientist.

After you have researched your scientist, create your own newspaper article about him or her. You might want to include such things as a copy of the scientist's birth certificate, obituary or even a page from his or her diary. Obviously, you will be inventing some of the details, but your article should be based on actual facts about the scientist's life.

Here are a few researchers to consider as a starting point for such a project.

James Watson  
Barbara McClintock  
Francis Jacob  
Frederick Griffith  
Francis Crick  
George Beadle

Jacques Monod  
Herman Muller  
Thomas Morgan  
Edward Tatum  
Oswald Avery  
Robert Feulgen

# FACT SHEETS

Name: \_\_\_\_\_

**Allele:** One of the two or more forms of a gene for a specific trait.

**Anther:** The saclike structure of a stamen in which pollen grains are produced.

**Codominance:** The expression of both alleles of a heterozygous pair; a condition in which neither allele of a pair is dominant over the other.

**Cross:** The mating of two organisms with contrasting traits.

**Dihybrid:** An individual that has two pairs of contrasting traits.

**Dominance:** The principle of genetics stating that when contrasting alleles are crossed, only one will be expressed.

**Dominant gene:** An allele that is always expressed when it is present.

**Gamete:** A monoploid sex cell; a sperm cell or egg cell.

**Gene:** A distinct unit of hereditary material found in chromosomes; a sequence of nucleotides in DNA that codes for a particular polypeptide.

**Independent assortment:** The principle of genetics stating that different traits are inherited independently of one another.

**Linked genes:** Genes located on the same chromosome; they are not independently assorted, but instead are distributed together during meiosis.

**Monohybrid:** An individual that is heterozygous for a trait.

**Pistil:** The female reproductive organ of flowering plants.

**Pleiotropy:** The condition in which genes have more than one phenotypic effect.

**Pollen grain:** The small, spore-like structure containing the male monoploid gamete produced by the anther of a flowering plant.

**Pollination:** The transfer of pollen from an anther to a stigma of a flower.

**Polygenic inheritance (also called multiple gene inheritance):** The type of inheritance in which two or more pairs of genes affect the same characteristic.

Name: \_\_\_\_\_

**Punnett square:** A diagram that is used in genetics to show the results of a cross.

**Recessive gene:** An allele whose physical trait does not show up when the contrasting dominant allele is present.

**Segregation:** The separation of alleles during meiosis resulting in the presence of only one allele for a particular trait in each gamete.

**Stigma:** An enlarged sticky knob on the top of a pistil that receives pollen.

**Trait:** A characteristic exhibited in an organism due to its genetic makeup.

Name: \_\_\_\_\_

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