Mendel's Laws: Their Application to Solving Genetics Problem

Objectives

This lab activity is designed to teach students how to solve classic genetics problems using Mendel's genetic laws and the Punnett square.

This activity is further designed to meet the following **core objectives**:

- **Critical thinking skills** – Students will make inquiries into inheritance of traits and then evaluate and analyze genetics problems.
- **Communication skills** – Students will communicate team solutions both orally and visually to the class as they teach their classmates how to solve an assigned team problem.
- **Empirical and Quantitative skills** – Students will apply the Mendelian genetics laws and the Punnett square to quantify the outcome of their assigned genetic problem.
- **Teamwork** – Students will work in teams of 2 to 4 to solve an assigned genetics problem.

Furthermore, this activity enables students to demonstrate the following **student learning outcomes.**

- Describe the reasoning processes applied to scientific investigations and thinking.
- Identify the principles of inheritance and solve classical genetic problems.
- Describe modern evolutionary synthesis, natural selection, Mendelian inheritance, micro and macroevolution, and speciation.
- Be able to apply scientific reasoning to investigate questions, and utilize scientific tools such as microscopes and laboratory equipment to collect and analyze data.
- Communicate effectively the results of investigations.
- Use critical thinking and scientific problem-solving to make informed decisions in the laboratory.

Instructors will demonstrate how to apply Mendelian genetics laws and the Punnett square to solve genetics problems. Afterward, students will work in teams of 2 - 4 students and be assigned a genetics problem to solve. After all student teams have solved their problems, they will teach the class how to solve the problem. Their classmates will write down the steps to solution of each problem in their lab handouts.

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Mendel's Genetic Laws

1. **Alleles** control an inherited characteristic & exist in individuals in pairs (You inherit one member of the pair from your father & one member of the pair from your mother). The two alleles of a pair are the same in **homozygous** individuals. The two alleles of the pair differ in **heterozygous** individuals. The **genotype** is the allele combination that produces a character state. The **phenotype** is the visible, physical trait.

2. **LAW OF DOMINANCE**: Whenever the two alleles of a pair in a given individual differ, only one, the dominant one will be expressed. The **dominant allele** indicates the appearance of heterozygotes. One allele is said to be dominant over another if a heterozygous individual for that allele has the same appearance as an individual homozygous for it. The **recessive allele's** phenotype effects are masked in heterozygotes by the presence of a dominant allele.

3. **LAW OF SEGREGATION OF ALLELES**: When the gametes (egg & sperm) are formed by an individual, only one member of each allele pair is included in a gamete. Recall that gametes are **haploid**. When the parent generation produces gametes (eggs or sperm), each gamete will receive only one allele for a given trait. When the egg and sperm unite during **fertilization**, the resulting embryo receives one allele for the trait from the egg and one allele for the trait from the sperm, restoring the allele pair and the **diploid** condition.

4. **LAW OF INDEPENDENT ASSORTMENT**: All of the possible kinds of gametes that can be formed, will be formed in equal proportions. Alleles for different traits are inherited independently of each other so long as they are located on different homologous gene pairs.

Steps to Solving Genetics Problems

1. READ the problem
2. Write down what you know
    a. Record the possible phenotypic outcomes
3. Assign letters for the alleles
    a. Use a capital letter for the dominant trait
    b. Use a lower case letter for the recessive trait
4. Determine the genotypes involved
5. Make gametes (sex cells – each gamete will carry only ONE allele for a trait, not both)
6. Solve using a Punnett Square
7. Reread the question & make sure that you have answered it

Single Trait Problems (Monohybrid Crosses)

Red pigeon is in front of the more commonly-colored brown pigeon.

Photo source: naturetales.blogspot.com

SAMPLE PROBLEM: The allele for red feather color in pigeons, *R*, is dominant to the allele for brown feathers, *r*. A red pigeon who had a red parent and a brown parent is mated with a brown pigeon.

a. What are the genotypes of the two pigeons being mated?
b. Identify the gametes produced by each of the pigeons being mated.
c. What proportion of the F_1 progeny would be expected to have brown feathers?

STEPS TO THE SOLUTION:

1. **Write down what you know**

Possible phenotypes: *RR* = red feathers; *Rr* = red feathers; *rr* = brown feathers

Grandparent Pigeons – Red X Brown
(Genotypes) *R* __ *r r*

Parent Pigeons - Red X Brown
(Genotypes) *R* __ *r r*

F_1 (first filial or offspring or babies) --

2. **Determine the genotypes involved**

We know that the brown parent must be homozygous, or *rr.* Otherwise, it would appear red in color. The red parent is a little trickier. That parent could be either homozygous or heterozygous. Rereading the problem, we see that this parent was produced from the crossing of a red and a brown pigeon. In other words we are at the very least crossing *R*_ X *rr* to get the red parent. In order for the offspring of this cross to be red it must have one dominant allele that it will inherit from its red parent. We know that the brown pigeon must give all of its offspring the recessive allele. Thus, the red parent pigeon in this problem must have a heterozygous genotype for color, or *Rr*.

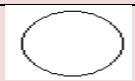
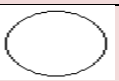
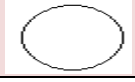
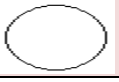
Now we can record the parent's genotypes.

Grandparent Pigeons – Red X Brown
(Genotypes) *R* __ *rr*

Parent Pigeons - Red X Brown
(Genotypes) *Rr* *rr*

F_1 (first filial or offspring or babies) --

3. **Make gametes** (sex cells – each gamete will carry only ONE allele for a trait, not both)
The brown pigeon has a genotype of *rr*. Thus all of the gametes it will produce will have the *r* allele.
The red pigeon has a genotype of *Rr*. Thus it will produce gametes with *R* alleles and gametes r alleles in equal proportions.

Parent Pigeons	Red X	Brown
(Parent Genotypes)	*Rr*	*rr*
Gametes Produced		
		

4. Solve using a Punnett Square

Gametes	*R*	*r*
r		
r		

Genotypic ratio of the F_1 generation = 2 *Rr* : 2 *rr*.
Phenotypic ratio of the F_1 generation = 2 red : 2 brown.

6. Reread the question & make sure that you have answered it

a. The red parent's genotype is *Rr*. The brown parent's genotype is *rr.*
b. The red parent produces 2 types of gametes. Half carry the allele of red & half carry the allele for brown.
The brown parent produces only one type of gamete. All of its gametes carry the allele for brown.
c. We would expect half of the offspring to have brown feathers.

Two Trait Problems (Dihybrid Crosses)

SAMPLE PROBLEM: In humans, brown eyes are dominant to blue eyes. Also brown hair (brunette) is dominant to red hair. Imagine that a man who is heterozygous for both traits marries a woman who is heterozygous for both traits.

a. What are the genotypes of the parents?
b. What would be the phenotypic ratio of their potential children?

1. **Write down what you know**

Parents -	MAN	X	WOMAN
	heterozygous brown eyes		heterozygous brown eyes
	heterozygous brunette		heterozygous brunette

2. **Assign letters for the alleles**:

Brown eyes are dominant to blue eyes. We will use the letter b for these alleles. Brown is dominant, so it should be *B*. Blue is recessive, so it should be *b*.

We know that brunette hair color is dominant to red hair. We've already used the letter b, so we will use the letter r for these alleles. Brunette is dominant, so it should be *R*. Red hair is recessive, so it should be *r*.

3. Determine the genotypes involved

Remember that the parents are heterozygous for both traits.

Parents -	MAN	X	WOMAN
	heterozygous brown eyes		heterozygous brown eyes
	heterozygous brunette		heterozygous brunette
(Genotypes)	*B b R r*		*B b R r*

4. **Make gametes** (Sex cells – Remember that each gamete will carry only ONE allele for a trait, not both. However, since this is a two-trait or dihybrid problem, the gametes will carry ONE allele for eye color and ONE allele for hair color.)

HINT: Do an allele cross to make sure you get one of every possible type of gamete! (Remember FOIL)

	F(irst)	O(uter)	I(nner)	L(ast)
Parents' Genotypes	*BbRr*	*BbRr*	*BbRr*	*BbRr*
Gametes	*BR*	*Br*	*bR*	*br*

5. **Solve using a Punnett Square**

Gametes				

You have just written all of the genotypes possible for their children! Let's figure out what their phenotypes will be.

a) To have the ***brown eyes, brown hair*** phenotype, a child must have at least B__ R__. There are four ways to satisfy this minimum. Locate each of the following genotypes in the Punnett square and record the number of each type:

BBRR _____ ; BbRR _____ ; BBRr _____ ; BbRr_____ ; Total _____

b) To have the ***brown eyes, red hair*** phenotype, a child must have at least B_rr. Locate and record again:

BBrr _____ ; Bbrr _____ ; Total _____

c) To have the ***blue eyes, brown hair*** phenotype, a child must have at least bbR_. Locate and record again:

bbRR _____ ; bbRr _____ ; Total _____

d) To have the ***blue eyes, red hair*** phenotype, a child must have at least bbrr. Locate and record again:

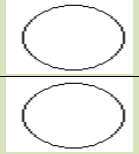
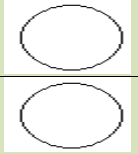
bbrr _____ ; Total _____

THUS, the phenotypic ratio of the man and woman's potential children is:

_____ brown eyes, brown hair : _____ brown eyes, red hair :
_____ blue eyes, brown hair : _____ blue eyes, red hair

Incomplete Dominance Problems

SAMPLE PROBLEM: In humans, inheritance of hair texture shows incomplete dominance. If a person inherits two alleles for curly hair, they have very curly hair (*CC*). If a person inherits two alleles for straight hair, they have very straight hair (*C'C'*). A heterozygous person (*CC'*), on the other hand, shows an intermediate condition, wavy hair. If a wavy-haired man married a wavy-haired woman, what percentage of their children would you expect to have curly hair?

Parents	Man X Wavy-Haired	Woman Wavy-Haired
(Parent Genotypes)	*CC'*	*CC'*
Gametes Produced		

Because the couple are heterozygotes, they will produce two types of gametes; *C* and *C'*. We can use this information to complete a Punnett square.

Gametes	*C*	*C'*
C		
C'		

What percent of their offspring should have curly hair? _____

Sex-Linked Trait Problems

SAMPLE PROBLEM: In humans, red-green color blindness is a sex-linked trait. Normal color vision is due to allele *B* & color blindness is due to allele *b*. The heterozygous condition results in a carrier condition in females (they see red-green normally, but can pass the trait on to their offspring). What would be the phenotypic ratio of offspring produced by a color blind male and a carrier female?

For this problem, we have 3 possible character states:		
$X^B X^b$ = carrier female	$X^b X^b$ = color blind female $X^b Y$ = color blind male	$X^B X^B$= normal female $X^B Y$ = normal male

The color blind male in this case will have genotype $X^b Y$. He will produce 2 types of gametes: X^b & Y. The carrier female will have genotype $X^B X^b$. She will produce 2 types of gametes: X^B & X^b. We can use this information to complete a Punnett square.

Gametes	X^B	X^b
X^b		
Y		

What will be the phenotypic ratio of this couple's children? _____

Let's Practice: Students will work in teams of 2 - 4 and be assigned a genetics problem to solve. After solving their problems, the student teams will teach the class how to solve their assigned problem. Classmates will write down the steps to solution of each problem in their lab handouts.

MONOHYBRID PROBLEMS

1. Several plants with purple flowers were crossed to plants with white flowers. The seeds from the cross produced plants on which only purple flowers appeared. These purple-flower plants were then crossed to each other & the seeds from the cross produced 346 purple flowered plants & 128 white flowered plants. Illustrate the crosses involved & determine the phenotypic & genotypic ratios of the last generation of plants.

Gametes		

2. In peas, long-stem (*L*) is dominant over short-stem (*l*). Give the expected phenotypic ratios for the following four crosses:

a. homozygous long X short

Gametes		

Phenotypic ratio:

c. heterozygous long X homozygous long

Gametes		

Phenotypic ratio:

b. heterozygous long X short

Gametes		

Phenotypic ratio:

d. heterozygous long X heterozygous long

Gametes		

Phenotypic ratio:

3. In humans, dimples (*D*) are dominant to nondimples (*d*). A couple who both have dimples, have a child without dimples. What must be the genotypes of the two parents? What is the probability that their next child will have dimples?

Gametes		

DIHYBRID PROBLEMS

White, sphere-shaped squash

Photo source: http://www.thenibble.com/

Yellow, disk-shaped squash

Photo source: http://www.photographsofaustralia.com/

4. In the summer squash, white fruit (*W*) is dominant over yellow (*w*), & disk-fruit shape (*D*) is dominant over sphere-shaped (*d*).

a. What are the phenotypes of the following squashes?

1) *WWdd* _____

2) *wwDD* _____

3) *WwDd* _____

4) *wwdd* _____

5) *WwDD* _____

b. What would be the phenotypic ratio of the offspring produced from the following cross?

WwDd X *wwdd*

Gametes produced by *WwDd*:	F(irst)	O(uter)	I(nner)	L(ast)
Gametes				

Gametes produced by *wwdd*:	F(irst)	O(uter)	I(nner)	L(ast)
Gametes				

Genotypes of offspring (F_1 generation):

Gametes				

Phenotypic Ratio of F_1 generation:

_____ White, Disk: _____ White, Sphere: _____ Yellow, Disk: _____ Yellow, Sphere

Black, long-haired rabbit

Photo source: http://upload.wikimedia.org/

5. In rabbits, black fur is due to a dominant allele *B*, and brown fur is due to its recessive allele *b*. Short hair is due to the dominant allele *S*, & long hair is due to the recessive allele *s*. A cross is done between a homozygous black, long-haired rabbit & a homozygous brown, short-haired rabbit.

a. What would be the genotype(s) & phenotype(s) of the F_1 generation?

b. When the F_1 offspring are allowed to breed, what will be the phenotypic ratio of the F_2 generation?

Brown, short-haired rabbit

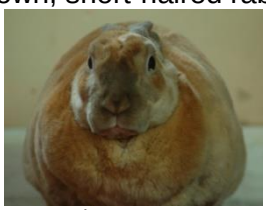


Photo source: http://farm3.static.flickr.com

Parent Rabbits			Offspring (F_1 generation) We will cross two F_1 babies next	
Phenotypes	Genotypes	Gametes Produced	Genotype	Phenotype
Homozygous black, long-haired				
Homozygous brown, short-haired				

Gametes produced by F_1 generation:

F_1s' Genotype	F(irst)	O(uter)	I(nner)	L(ast)
Gametes				

Genotypes of F_2 generation:

Gametes				

Phenotypic Ratio of F_2 generation:

_____ Black, Short: _____ Black, Long: _____ Brown, Short: _____ Brown, Long

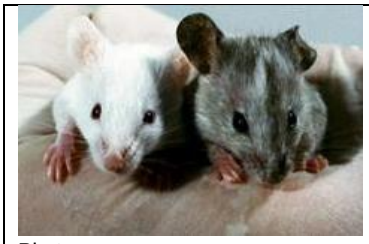


Photo source:
http://media.knoxnews.com/

6. In mice the gene for coat color has two forms. The allele for colored coat (*C*) is dominant to the allele for albino (*c*). There are two forms for the gene controlling whiskers, as well, straight (*S*) is dominant to bent (*s*). Imagine that we had a female mouse whose mother was homozygous colored with bent whiskers and whose father was an albino that was homozygous for straight whiskers. We are going to cross this female on a male mouse that is albino and has bent whiskers.

a. What percent of their offspring will be albino?
b. What percent of their offspring will have straight whiskers?
c. What would be the phenotypic ratio of their offspring?

Female Mouse's Parents			Female Mouse	
Phenotypes	Genotypes	Gametes Produced	Genotype	Phenotype
Homozygous colored, bent				
Homozygous albino, straight				

Gametes produced by Female Mouse:

Female Mouse's Genotype	F(irst)	O(uter)	I(nner)	L(ast)
Gametes				

Gametes produced by Male Mouse (albino with bent whiskers):

Male Mouse's Genotype	F(irst)	O(uter)	I(nner)	L(ast)
Gametes				

Genotypes of F_1 generation:

Gametes				

Phenotypic Ratio of F_1 generation:

_____ Colored, Straight: _____ Colored, Bent: _____ Albino, Straight: _____ Albino, Bent

7. In rabbit coats, spotted (*S*) is dominant to solid color (*s*) and black (*B*) is dominant to brown (*b*). A brown, spotted rabbit is mated with a solid, black one and all the offspring (the F_1 generation) are black and spotted.
a. What are the genotypes of the parents?
b. What are the genotypes of the offspring (the F_1 generation)?
b. What would be the phenotypic ratio of the F_2 generation if two of these F_1 black, spotted rabbits were mated?

Parent Rabbits			Offspring (F_1 generation) We will cross two F_1 babies next	
Phenotypes	Genotypes	Gametes Produced	Genotype	Phenotype
Brown, spotted				100% Black, spotted
Black, solid				

Gametes produced by F_1 generation:

F_1s' Genotype	F(irst)	O(uter)	I(nner)	L(ast)
Gametes				

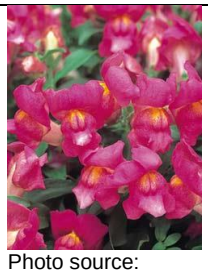
Genotypes of F_2 generation:

Gametes				

Phenotypic Ratio of F_2 generation:

_____ Black, Spotted: _____ Black, Solid: _____ Brown, Spotted: _____ Brown, Solid

INCOMPLETE DOMINANCE PROBLEMS

 Photo source: http://www.greenearthgrowers.net/	 Photo source: http://www.jparkers.co.uk/	 Photo source: http://www.weststarfarm.com/	**8**. In snapdragons, red flower color (W) is not completely dominant over white (W'); the heterozygous condition produces pink flowers. What will be the result of a cross between two pink-flowered snapdragons? Between a pink and a white one?

Parent Flowers	Pink X	Pink
(Parent Genotypes)		
Gametes Produced		

Genotypes of F_1 generation (offspring of pink X pink):

Gametes		

Phenotypic Ratio of F_1 generation (offspring of pink X pink):

_____

Parent Flowers	Pink X	White
(Parent Genotypes)		
Gametes Produced		

Genotypes of F_1 generation (offspring of pink X white):

Gametes		

Phenotypic Ratio of F_1 generation (offspring of pink X white):

_____

9. Two parents have wavy hair & dimples. They have a child with curly hair & no dimples. Identify the genotypes of the two parents and then determine all of the possible phenotypes that their children could have for the dimple & hair trait. (Remember that dimples is dominant to nondimples. Also the heterozygous condition in which a person inherits an allele for straight hair & an allele for curly hair results in an intermediate condition, wavy hair.)

Parents			Child	
Phenotypes	Genotypes	Gametes Produced	Genotype	Phenotype
Wavy hair, dimples				Curly hair, no dimples
Wavy hair, dimples				

Parents' Genotypes (wavy hair, dimples): _____

Gametes produced by Parents:

	F(irst)	O(uter)	I(nner)	L(ast)
Gametes				

Genotypes of their offspring:

Gametes				

Phenotypic Ratio of F_2 generation:

_____ Curly hair, Dimples: _____ Wavy hair, dimples: _____ Straight hair, dimples:
_____ Curly hair, no dimples: _____ Wavy hair, no dimples: _____ Straight hair, no dimples

10. In shorthorn cattle, the polled (hornless) condition (P) is dominant over the horned condition (p), also the heterozygous condition of red coat (W) and white coat (W') is roan. If a homozygous polled red animal is bred to a white horned one, what will the F_1 be like? If two F_1 were crossed, what would be the phenotypic ratio of the F_2 generation?

Red Polled

Photo source: http://www.rarebreeds.co.nz/

Roan

Photo source: http://www.midcontinentfarms.com/

White Horned

Photo source: http://www.glcattleco.com/

Parent Cattle			Offspring (F_1 generation) We will cross two F_1 babies next	
Phenotypes	Genotypes	Gametes Produced	Genotype	Phenotype
Homozygous red, polled				
White, horned				

Gametes produced by F_1 generation:

F_1s' Genotype	F(irst)	O(uter)	I(nner)	L(ast)
Gametes				

Genotypes of F_2 generation:

Gametes				

Phenotypic Ratio of F_2 generation:

_____ Red Polled: _____ Roan Polled: _____ White Polled:
_____ Red Horned: _____ Roan Horned: _____ White Horned

SEX-LINKED TRAIT PROBLEMS:

SOME PRACTICE SEX-LINKED TRAIT PROBLEMS

Calico Cat

Photo source: http://www.hanne-mugaas.com/

Tortoise Shell Cat

Photo source: http://www.catsarewonderful.com/

11. In cats, orange color is due to allele B' & black color is due to allele B. The heterozygous condition (B'B) results in a color known as calico (calico is a coat pattern that is mottled in tones of black, orange, and white) in females. These alleles are known to be sex-linked. What coat color types would be expected from a cross between a black male & a calico female?

For this problem, we have 3 possible character states:		
$X^{B'} X^{B}$= calico female	$X^{B'} X^{B'}$ = orange female $X^{B'} Y$ = orange male	$X^{B} X^{B}$ = black female $X^{B} Y$ = black male

Genotype of black male: _____

Gametes produced by black male: _____

Genotype of calico female: _____

Gametes produced by calico female: _____

Gametes		

What will be the phenotypic ratio of their kittens? _____