NAME: __________________________
Pretest: How much do you know about Genetics?
The purpose of this tool is to determine the extent to which some basic genetic principles and concepts are understood. Please answer each of the following statements with either a true or false response.

1. Certain acquired characteristics, such as mechanical or mathematical skill, may be inherited.
2. Identical twins are always of the same sex.
3. Fraternal twins are more closely related to each other than to other children in the family.
4. The father determines the sex of the child.
5. Each parent contributes half of a child’s genetic makeup.
6. Certain thoughts or experiences of a mother may mark or alter the hereditary makeup of an unborn child.
7. Color-blindness is more common in males than in females.
8. A person may transmit characteristics to offspring which he himself, does not show.
9. Certain hereditary characteristics are influenced by the blood.
10. Identical twins are more closely related than fraternal twins.
11. Certain inherited traits may be altered by the stars, moon, or planets early in development.
12. Males are biologically stronger than females.
13. The tendency to produce twins may run in families.
14. A craving for a food such as strawberries may cause a birthmark on an unborn child.
15. Many of a person’s inherited traits do not appear.
16. The parent with the stronger will contributes more to a child’s inheritance than the other parent.
17. If a person loses a limb in an accident, it is likely that he or she will have a child with a missing limb.
18. The attitude of parents toward each other influences the emotional makeup of an unborn child.
19. Children born to older parents usually lack the vitality of those born to younger parents.
20. The total number of male births exceeds female births each year.
Acquired Traits and Inherited Traits
The “nature versus nurture” debate has raged for a long time. Exactly which traits are inherited, and to what degree they are inherited is still not clear in the case of certain traits. For example, there have been efforts to find a gene for criminality or addictive personalities, but none have been proven to date.

Sometimes we blame genetics for something that in reality has nothing to do with genes. Parents sometimes want to take credit for passing on good qualities or talents to their children, when in reality the talent is the result of a nurturing and supportive environment as opposed to genetic endowment. Think about the following questions:

- If someone is considered “accident prone,” is this characteristic inherited or is it something the person acquires?
- If both parents have brown eyes, what colour of eyes do you think the children will inherit?
- If one parent had an accident and lost a finger (has only nine fingers), how many fingers will that person’s children inherit?
- If one parent decides to get into shape by lifting weights and develops large muscles, will the children inherit large muscles without having to lift weights?
- A child has a wonderful musical ability but neither parent even plays an instrument. Is this an inherited or acquired trait?

The following lists do not represent all possible traits, but they will give you an idea of which traits are inherited and which are acquired.

**Inherited Traits**
-eye colour, general height, hair colour, blood type, earlobe attachment, tongue rolling, freckles, dimples, hair (straight or curly), hair colour, length of eyelashes, skin colour, shape of face, eye shape, hemophilia, colour blindness, shape of thumb, shape of hairline.

**Acquired Traits**
-musculature, missing limbs or digits, most behaviours, most fears, conditions that result from disease or injury, being good at Biology.

Answer the following questions about acquired and inherited traits (in the space provided):

1. If both parents have brown eyes, what colour of eyes will the children inherit? Explain.

2. If one parent had an accident and lost a finger (has only nine fingers), how many fingers will the children inherit? Explain.

3. If one parent loves the outdoors, will all of the children be “outdoors types?” Explain.

4. If a blue-eyed man and a brown-eyed woman have four children with brown eyes, will their fifth child also have brown eyes? Explain.

5. Is it possible for a person to have one brown eye and one blue eye (glass eyes or coloured contacts notwithstanding)? Explain.
Review of Senior 1 Science

Solve the following:

1. In dogs, short hair is dominant over long hair. Two dogs heterozygous for short hair produce a litter of eight pups. Predict the appearance of the pups. Show your results through the use of a Punnett Square, and place in the space below.

2. In humans, long eyelashes are dominant; short eyelashes are recessive. A woman with long eyelashes and a man with long eyelashes have 4 children. One child has short eyelashes; the others have long eyelashes.
   a) List the probable genotypes of the parents.
   b) List the probable genotypes and phenotypes of the children.

3. Peas may have yellow or green seeds. A cross between a green seed plant and a yellow seed plant produced all yellow seeds. Crosses between two of the F₁ Generation produced 58 yellow and 19 green seeds.
   a) Identify the genotypes of the P generation.
   b) What would the phenotype ratio of yellow seeds to green seeds be if one plant from the F₁ was crossed with the yellow seed plant from the P₁ generation?
4. In cattle, polled (hornless) is dominant to horned. If a breeder of purebred cattle, all of which are polled, suspects that her recently purchased prize bull is heterozygous for the horned allele, how might she determine if her suspicion is correct?

5. Cystic fibrosis is a recessive genetic disorder affecting 1 in every 2500 children born in Canada. A child with the disorder is born to a couple who show no symptoms of the disease.
   a) List the genotypes of the parents and the child.
   b) What is the chance the next child the couple has will be a carrier of the disease?

6. In rabbits, black colour is due to a dominant gene B, and brown colour to a recessive gene b. Short hair is due to the dominant gene S, and long hair to its recessive allele s. A homozygous black, long-haired rabbit, and a brown, homozygous short-haired one are crossed.
   a) What would be the genotype of the F₁ generation?
   b) What would be the phenotype of the F₁ generation?
   c) If one of the F₁ rabbits was mated with a brown, long-haired rabbit, predict the phenotype and genotype ratio of the offspring.
HUMAN GENETICS LAB

Purpose:

1. To examine some dominant and recessive traits in humans.
2. To determine our own phenotypes and genotypes.
3. To determine the presence of dominant and recessive alleles in a population.

Procedure:

1. You will examine eight observable traits in human beings. Record your results in the data Table 1.
   a. Tongue rolling ability: The ability to roll is dominant (R), while non rolling is recessive (r).
   b. Hand clasping: Clasp your hands together quickly so that the fingers interlock. Crossing the left thumb over the right is dominant.
   c. Lips: Broad lips are dominant (L) over thin lips (l)
   d. Eye pigmentation: A dark iris pigment (black/brown/green) is dominant (D) over the recessive (d) light pigment (blue/gray).
   e. Hitchhiker’s thumb: A straight thumb is dominant (S) over the ability to bend the last joint backward at an angle of 60 or more.
f. Bent little finger: The dominant condition is for the last joints of the little fingers to bend away from each other (B), while straight little fingers are recessive.

g. Widow’s peak: The widow’s peak trait is dominant (W) over a straight hairline (w).

h. Earlobe attachment: The trait for “free” earlobes is dominant (E) over “attached” earlobes (e).
### Table 1: Data collected of Observable Traits

<table>
<thead>
<tr>
<th>Trait</th>
<th>Your Phenotype</th>
<th>Possible Genotype</th>
<th># of Classmates with Dominant Phenotype</th>
<th># of Classmates with Recessive Phenotype</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tongue Rolling</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hand Clasping</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lips</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eye Pigmentation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hitchhiker’s Thumb</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bent Little Finger</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Widow’s Peak</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Earlobes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Questions:**

1. What is the minimum and maximum number of recessive alleles in the class population?
   - Minimum: _______
   - Maximum: _______

2. What is the minimum and maximum number of dominant alleles in the class population?
   - Minimum: _______
   - Maximum: _______
Early Genetics - Gregor Mendel (Notes)

Mendel's Principles of Inheritance (Notes)
Reasons for Mendel’s Success (Notes)

Characteristics of Pea Plants (Notes)
Early Genetics - Reginald Punnett (Notes)

Use of the Punnett Square (Notes)
Probabilities of Genotypes and Phenotypes

Gregor Mendel used pea plants to show how simple traits are passed from one generation to the next. He used purebred plants (where the offspring have all the same traits as their parents). He controlled pollination so that no other plants could introduce new genotypes. We can apply Mendel's laws to human traits, too. There are many human traits that are controlled by a single pair of alleles.

Let's use the ability to roll the tongue as an example of a trait that can be inherited. If you can roll your tongue, you have the gene on at least one chromosome that controls for this characteristic. There are two genes that control this trait, one from each parent. This pair of genes is shown by using letters of the alphabet and is called the genotype. The trait you express is the phenotype, that is whether or not you can roll your tongue. This inherited trait can be passed on to your children.

In fact, the ability to roll the tongue is a dominant trait, whereas if you cannot roll your tongue you have the recessive trait. An upper case letter shows the dominant gene, whereas a lower case letter depicts the recessive trait. The concept of dominant and recessive really only applies to phenotypes or observable characteristics. We are not able to observe the genotype of an organism directly. We infer it based on offspring phenotypes. Also, dominant in this context does not mean stronger or more important.

In our example of tongue rolling, we can use the letter "T" to represent the gene that causes you to roll your tongue. The letter "t" can be used to show the recessive gene. T and t are alternate forms of a gene for one trait; these alternate versions are called alleles. Depending on the genes that you inherited from your parents, you can be one of the following:

<table>
<thead>
<tr>
<th>Genotype</th>
<th>Phenotype</th>
</tr>
</thead>
<tbody>
<tr>
<td>TT</td>
<td>Can roll the tongue</td>
</tr>
<tr>
<td>Tt</td>
<td>Can roll the tongue</td>
</tr>
<tr>
<td>tt</td>
<td>Cannot roll the tongue</td>
</tr>
</tbody>
</table>

Note that the only genotype where both alleles are recessive results in the inability to roll the tongue.
When chromosomes separate during meiosis, some gametes will have the dominant gene and other gametes will have the recessive gene. Gametes will not have both, as described by Mendel's Law of Segregation.

After fertilization, as the Punnett square shows, you can have four possible genotypes. In this example, all children will have the ability to roll the tongue because the "T" gene masks or hides the "t" gene. When the genotype shows one dominant and one recessive gene, we say that the genotype is heterozygous (Tt). If the genotype has both dominant alleles or both recessive, we say that it is homozygous dominant (TT) or homozygous recessive (tt).

Let's examine a cross of Tt and Tt, that is, a situation in which both parents can roll their tongues. Because they have both the dominant and recessive form of the gene, they are said to be heterozygous. Another way to describe this genotype is to say that the parents are "carriers" of the recessive trait.

Fill in the Punnett Square with the correct genotypes. Note that the probability (chance) of having children that can roll their tongues is three out of four. The three tongue rollers all have the dominant T gene. The one non-rolling combination of genes is tt, and has a one in four chance of occurring. We can also express these phenotypic probabilities as 75% rolling to 25% non-rolling.

It is important to notice the difference between the probabilities in genotypes compared to phenotypes. There are several versions of gene combinations, but there are only two expressions of the genes. The probabilities of the genotypes are:

\[ \frac{1}{4} \text{ is homozygous dominant, TT} \]
\[ \frac{1}{2} \text{ is heterozygous, Tt} \]
\[ \frac{1}{4} \text{ is homozygous recessive, tt} \]

The probabilities of the phenotypes are:

\[ \frac{3}{4} \text{ are rollers} \]
\[ \frac{1}{4} \text{ are non-rollers} \]
Probabilities with Two Traits (A Dihybrid Cross)

From the experiment with pea plants, Mendel inferred that there are two factors (genes) controlling for a given trait, and each has an equal chance of inclusion in a gamete. A given trait has no effect on the inheritance of any other trait. Mendel called this the Law of Independent Assortment. This law also applies to humans, as in the examples of tongue rolling and eye colour.

A **dihybrid cross** involves parents that are hybrids or heterozygous for two different traits. If brown eyes are dominant over blue eyes, the letters "B" and "b" can be used. Keep in mind that eye colour is not as simple as shown.

If both parents are heterozygous for both traits, the genotype is TtBb. After meiosis, the possible gametes are TB, Tb, tB, and tb. Complete the following Punnett square to show the offspring of these parents.

<table>
<thead>
<tr>
<th></th>
<th>TB</th>
<th>Tb</th>
<th>tB</th>
<th>tb</th>
</tr>
</thead>
<tbody>
<tr>
<td>TB</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tt</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bb</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>tB</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>bB</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>tB</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>bB</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

After analyzing the 16 possibilities:

9 out of 16 (9/16) can roll their tongue and will have brown eyes because of the following genotypes:

TTBB, TtBB, TtBb, TtBb

3/16 can roll their tongue and will have blue eyes because of the following genotypes:

TTbb, Ttbb

3/16 cannot roll their tongue and will have brown eyes because of the following genotypes:

ttBb, ttBB

1/16 cannot roll their tongue and will have blue eyes because of the following genotype:

ttbb
Problems

Solve the following:

1. In humans, brown eyes are dominant over blue eyes and cleft chins are dominant over smooth chins. If a brown-eyed cleft chinched heterozygote and a blue eyed smooth chinned recessive have a child:
   a) What is the probability the child will have brown eyes and a smooth chin?
   b) What is the probability that the child will have blue eyes and a smooth chin?

2. In humans, cystic fibrosis is carried by a recessive gene. What is the probability the children of carriers of the disease will also be carriers? (note: a carrier is heterozygous for the condition thus can pass on the disease but does not show it)

3. Pea plants that are heterozygous for both height and pod shape are crossed.
   a) What four possible phenotypes can appear in the offspring?
   b) What is the probability of each type?

4. In guinea pigs, black fur is dominant over white fur and short hair is dominant over long hair. If both the male and female parents are heterozygous for both traits, what proportion of their offspring should have long black hair?
5. Which of Mendel’s Laws of Heredity is best illustrated by each of the following:
a) Our inheritance for eye color is not affected by our inheritance of left or right handedness.
b) Two red flowered garden peas have some offspring with white flowers.
c) When striped silk moths are bred to non-striped silk moths (both pure breads), all of their offspring are striped.

6. Some people are anosmic, which is the inability to smell the odor of musk. Children of two anosmic are also anosmic. Children of normal parents are usually normal, but a few of them are anosmic. Is the gene described above dominant or recessive? Explain your reasoning.

7. In humans, long eyelashes are dominant to short eyelashes, and dark hair is dominant to red hair. A man with long eyelashes and red hair marries a woman with short eyelashes and dark hair. They have a child with long eyelashes and red hair, and another with short eyelashes and dark hair.
a) Give the genotypes of the parents and show why.
b) Give the genotypes of the children and show why.

8. In hogs, a gene that produces a white belt around the animal’s body is dominant over its allele for a uniformly colored body. Another gene produces a fusion of the two hoofs on each foot, a conditioned know as syndactyly; this gene is dominant over its allele, which produces normal hoofs. Supposedly a uniformly colored hog homozygous for syndactyly is mated with a normal-footed hog homozygous for the belted character.
a) What would be the genotype and phenotype for the F₁?
b) If the F₁ generation are allowed to bread freely among themselves what genotype and phenotype ratios would you predict for the F₂?
Starting a Family Using Mendelian Genetics

**Purpose:** To investigate the concepts of alleles, dominant and recessive traits, and genetic inheritance.

**Materials:** Poster paper, pencil crayons

**Procedure:**
1. Use the following list of phenotypes below to create yourself. Use a random process to determine which alleles you use to create your genotype. Record your genotype in the space provided and draw a picture of yourself. Hint: Use hair length and small accessories to make your picture look like the appropriate gender.

2. Find someone of the opposite gender in the class that “suits your fancy” and get married. Draw a picture of your new spouse using their genotype.

3. After several years of marriage you decide to have a baby. Use a random process to determine to which allele you will each contribute to the baby. Record the baby’s genotype in the space provided.

4. Draw a picture of your new baby!

**Question**

a) Does your baby look more like the mother or the father, or a combination of both? Explain why making reference specific reference to Mendelian Genetics?

5. Repeat the procedure with your spouse and have a second child.

**Question**

b) Do you expect the second child to look exactly the same as the first child? Why or why not? Explain making specific reference to Mendelian Genetics.
<table>
<thead>
<tr>
<th>Trait</th>
<th>Genotype of Father</th>
<th>Genotype of Mother</th>
<th>Genotype of 1st Baby</th>
<th>Genotype of 2nd Baby</th>
</tr>
</thead>
<tbody>
<tr>
<td>Face Shape (R,r)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chin Size (V,v)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chin Shape (S,s)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cleft Chin (L,l)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hair Color (B,b)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hair Body (C,c)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Widows Peak (W,w)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eyebrow color (H,h)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eyebrow size (T,t)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eyebrow link (N,n)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eye color (E,e)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eye Size (Z,z)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eye Shape (A,a)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eye lashes (Y,y)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mouth Size (M,m)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lip Size (Q,q)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dimples (P,p)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nose Size (N,n)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nose Shape (F,f)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Earlobe (J,j)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hairy Ears (O,o)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Freckles (Q,q)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
GENOTYPE OF FATHER ________________________________
GENOTYPE OF MOTHER __________________________________________
GENOTYPE OF CHILD #1
GENOTYPE OF CHILD #2

Build a Baby “Rebop” Activity

Purpose
- To experience the genetic principles of inheritance, dominance, and recessive trait expression while making a creature known as a “Rebop.”
- To provide an example and template for continued projects involving rebops and more complicated principles of inheritance.

Materials
pipe cleaners, play dough, push pins, paper clips, push pins,

Procedure
1. Flip a coin to determine the genotype of your Rebop. Use the letters A through K to represent the specific alleles for every trait, and fill in the Tables below. In the case of dominant traits, flip a coin a second time to determine whether heterozygous or homozygous. In these Tables, the first trait (uppercase) is considered dominant and the second trait (lowercase) considered recessive.

<table>
<thead>
<tr>
<th>Trait</th>
<th>Genotype</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body Segments</td>
<td></td>
</tr>
<tr>
<td>Square - A</td>
<td></td>
</tr>
<tr>
<td>round - a</td>
<td></td>
</tr>
<tr>
<td>No. of Body Segments</td>
<td></td>
</tr>
<tr>
<td>(not including head)</td>
<td></td>
</tr>
<tr>
<td>Two - B</td>
<td></td>
</tr>
<tr>
<td>three - b</td>
<td></td>
</tr>
<tr>
<td>Color of Eyes</td>
<td></td>
</tr>
<tr>
<td>Pink - C</td>
<td></td>
</tr>
<tr>
<td>black - c</td>
<td></td>
</tr>
<tr>
<td>Color of Feet</td>
<td></td>
</tr>
<tr>
<td>Blue - D</td>
<td></td>
</tr>
<tr>
<td>green - d</td>
<td></td>
</tr>
<tr>
<td>No. of Feet per Segment</td>
<td></td>
</tr>
<tr>
<td>2 pairs - E</td>
<td></td>
</tr>
<tr>
<td>1 pair - e</td>
<td></td>
</tr>
<tr>
<td>Length of Tail</td>
<td></td>
</tr>
<tr>
<td>Long - F</td>
<td></td>
</tr>
<tr>
<td>short - f</td>
<td></td>
</tr>
<tr>
<td>Shape of Tail</td>
<td></td>
</tr>
<tr>
<td>Curly - G</td>
<td></td>
</tr>
<tr>
<td>straight - g</td>
<td></td>
</tr>
<tr>
<td>Shape of Antennae</td>
<td></td>
</tr>
<tr>
<td>Curly - H</td>
<td></td>
</tr>
<tr>
<td>straight - h</td>
<td></td>
</tr>
<tr>
<td>Size of Wings</td>
<td></td>
</tr>
<tr>
<td>(on front segment)</td>
<td></td>
</tr>
<tr>
<td>Large - I</td>
<td></td>
</tr>
<tr>
<td>small - i</td>
<td></td>
</tr>
<tr>
<td>Color of Wings</td>
<td></td>
</tr>
<tr>
<td>Green - J</td>
<td></td>
</tr>
<tr>
<td>blue - j</td>
<td></td>
</tr>
<tr>
<td>Body Color</td>
<td></td>
</tr>
<tr>
<td>Orange - K</td>
<td></td>
</tr>
<tr>
<td>blue - k</td>
<td></td>
</tr>
</tbody>
</table>

2. Use the genotype to build your parent Rebop according to the principle of inheritance of dominant and recessive alleles. Draw a picture of your Parent Rebop in the space below.

PARENT #1 REBOP

1. Flip a coin to select which allele will be contributed to your offspring. Place each of the alleles in the boxes below.

4. Find an attractive Rebop to act as the other parent for your offspring. Copy the alleles that they determined (through coin flip) would be contributed to their offspring. Place each of these alleles in the boxes below.
5. Use the genotype above to draw the Rebop #2 according to the principle of inheritance of dominant and recessive alleles. Place your drawing in the space below.

**PARENT #2 REBOP**

---

6. Complete the following Table, which will show the complete genotype for your “Baby” Rebop. Then, build a “Rebop” baby according to the principle of inheritance of dominant and recessive alleles. Draw this Rebop in the space below. Also, list the phenotypes for your baby Rebop.

<p>| | | | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
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**BABY REBOP**

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**Phenotype of Baby REBOP**

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7. Prepare your 3 Rebops for a family picture! Place a label (with your group members’ names) next to the three to better identify which is yours. Once provided, attach the family picture in the space below:

Conclusion
Mendel's Laws and discoveries did and continue to do a great job explaining the inheritance of traits in pea plants and Rebops. However, if you look around at humans, animals, and some other plants you realize that phenotypic expression does not always follow such a simple dominant-recessive pattern of inheritance. In the next section, we will examine these important exceptions to simple Mendelian Genetics.
Exceptions to Mendel's Principles

As remarkable as Mendel's work was for his time, it was limited to the study of pea plants that had a limited number of traits carried on different chromosomes. Mendel didn't know anything about genes and chromosomes. A great deal more has been learned about exceptions to Mendel's principles. In this section we will look at exceptions to Mendel's principles, in order to provide a more accurate sense of the complexity of genetics.

We have been working with traits carried on separate chromosomes. Traits that are found on the same chromosome are said to be linked. In this case, the Law of Independent Assortment does not apply. To make things more complicated, sometimes during meiosis portions of chromosomes can be exchanged between chromosomes. The result of this crossing over is the formation of new linkages, and the breaking apart of genes that were once on the same chromosome. Crossing over also means that the chromosomes children inherit are not exact copies of their parents' chromosomes.

The latest estimates from the Human Genome Project work is that a human has about 30 to 35 thousand genes (as recently as 1999 it was thought that humans had at least 100 000 genes). Given the sheer number of genes and the behaviour of chromosomes, predicting genotypes and phenotypes gets complicated indeed. Geneticists actually use the probabilities of crossing over and linkage to create a map of most of the genes in the human genome.

Here is a sampling of some of the exceptions to Mendel's Principles, including a common name for the exception.

1. **INCOMPLETE DOMINANCE**
   In some cases, an intermediate phenotype is shown if neither allele is dominant. In snapdragons, flower color can be red, pink, or white. The heterozygous condition results in pink flowers (or an intermediate trait). A white snapdragon crossed with a red snapdragon produces all pink offspring. Two pinks crossed together produce 1/4 white, 2/4 pink, and 1/4 red flowers.

2. **CODOMINANCE**
   Both alleles can be expressed. For example, red cows crossed with white will generate roan cows. Roan refers to cows that have red coats with white blotches. This phenotype might seem to support the blending theory. The blending theory predicts pink F1 progeny. The F2 progeny, however, demonstrate Mendelian genetics. When the F1 roan individuals self-fertilize, the F2 progeny have a phenotypic ratio of 1 red:2 roan:1 white.

3. **MULTIPLE ALLELES**
   Labrador Retriever- more than one set of alleles interact to result in black, brown, or gold Labrador retrievers.

4. **LETHAL ALLELES**
   Some genes are lethal when both alleles are present. Lethality can occur before or after birth. An example is the "creeper" allele in chickens, which causes the legs to be short and stunted. Creeper is a dominant gene, heterozygous chickens display the creeper phenotype. If two creeper chickens are crossed, one would expect to have (from mendelian genetics) 3/4 of the offspring to be creeper and 1/4 to be normal. Instead the ratio obtained is 2/3 creeper and 1/3 normal. This occurs because homozygous creeper chickens die.

5. **PLEIOTROPY**
   Some single alleles have more than one distinguishable phenotypic effect. An example is the coloration pattern and crossed eyes of Siamese cats, which are both caused by the same allele. Another example is
the gene that causes pigment color in rats. White rats also have very sensitive eyes and often become blind.

 Exceptions Project

You have been presented with several ways that phenotypic expression does not follow a simple dominant-recessive pattern of inheritance. Now, utilizing your Rebop activity as a template, you will demonstrate one of these exceptions. Your goal is to create a short 3-5 minute presentation to the class that illustrates one of these exceptions using Rebops. You will research a specific exception of the genetics inheritance of traits using notes, textbooks, and the internet. After completing your research you will create a Rebop presentation (PowerPoint presentation, lab activity) to teach and demonstrate the topic to your classmates. It is also the group’s responsibility to gather the necessary supplies. Due date is ________________.

Multiple Alleles and Codominance

In some traits, there are more than two alleles for its expression. Usually, the two alleles can be either dominant or recessive. Because of mutations, there can be a third form of a gene on the same location of the chromosome.

Since only two alleles can be present at a time, the third form can sometimes show itself, depending on what has been inherited from parents.

Blood type is an example of multiple alleles. There are three alleles for blood type: A, B, and O. A person can only have two of these. The following chart shows all the possible genotypes and phenotypes for blood type.

In the Type AB, neither allele is dominant over the other. In this heterozygous condition, an individual has both types of proteins in their blood. This condition is known as codominance.

Incomplete Dominance

Another condition exists where neither allele is dominant. This is called incomplete dominance, when the phenotype is somewhere in between the expression of the trait. For example, if red is usually dominant over white in a type of plant, incomplete dominance means that the effects of the two genes seem to blend and produce a pink colour. Here, all heterozygous plants are pink.

We see a more complicated form of incomplete dominance in humans when we examine skin colour or height. In these traits and others, there are many genes responsible for one trait. There are many degrees of skin colour just like there are many variations of intelligence. These are examples of polygenic inheritance.

Epistasis is condition where a gene on a different chromosome can hide or mask the effect of the other genes. Genes that interfere with the operation of other genes are said to be epistatic.

Let us use the colour of dogs as an example. Imagine that the dominant gene B produces black colour and the recessive gene b produces brown. There are other genes on another chromosome that also affect coat colour. These genes can be called W and w. If the dominant W gene is present, it prevents the colour from showing up. The recessive gene w does not prevent colour.
The genotype \(wwBb\) could be black and the genotype \(WwBb\) would be white. The \(W\) allele interferes with the effect of the \(B\) allele, and therefore the dog will be albino.

**Mutations**

A change, even slight, to the chemical structure of a gene is called a mutation. The rate at which a given gene mutates is normally very low. But the number of genes that an individual carries is large and when including a whole species, the total number of genes is vast. For these reasons, mutations are constantly occurring. Pure chance dictates which gene in which individual mutates.

A mutation can cause a very subtle phenotypic effect or it can be dramatic. When a mutation causes the death of an organism, it is said to be lethal. Many mutations are recessive and are not expressed unless the individual is homozygous. Natural selection pressure will quickly eliminate a harmful mutation from a natural population. Natural selection operates on the phenotype and only indirectly on the genotype. If a mutation is recessive, it can persist in a population masked by a dominant gene.

Natural selection will not eliminate the mutation quickly if there is no harmful phenotype. Inbreeding increases homozygosity and can greatly increase the likelihood of recessive genes being expressed.

In certain situations the harmful effect of the gene can help the individual. People homozygous for sickle-cell anemia (a condition where red blood cells are improperly shaped) have a reduced life expectancy. People with the heterozygous genotype have a mild form of the disease, but they also have an increased resistance to malaria and therefore there is natural selection pressure to maintain the gene in the population. In this case, the benefit outweighs the cost to the individual. In regions where malaria is not a threat, selection pressure operates against the mutation. For example, the descendants of African blacks living in the United States show a steady decrease in the incidence of sickle-cell anemia.

Only rarely is a mutation beneficial to an organism resulting in natural selection propagating the gene.

**Problems involving Mendelian Exceptions** (complete on separate sheets of paper)

1. Earlier in this lesson there was an example of what is known as an epistatic effect of genes. In the example, dog colour was described as dependent on dominant \((B = \text{black})\) and recessive \((b = \text{brown})\) genes. However, a second pair of genes interacts with the genes for coat colour. This gene also has a dominant form \((W = \text{inhibit colour})\) and a recessive form \((w = \text{no effect on colour})\). Show the genotypes and phenotypes of a cross between a heterozygous albino dog and a heterozygous black dog. The cross is: \(WwBb \times wwBb\).
2. A classic experiment that illustrates gene interactions was done with chickens. Chickens have different shapes of combs (the thick, red, fleshy crest on top of the heads). Use your favourite web search engine and do a search on “chicken comb types.” The list of hits will probably include a link to the description of the experiment. What do a rose comb, a pea comb, a walnut comb and a single comb look like? Describe each with a written description or a diagram.
3. With the knowledge about chickens’ combs, determine the phenotypes if you cross a chicken with a rose comb, \(RRpp\) with a chicken with a pea comb, \(rrPP\). Show the F1 generation and the F2 generation. What type of gene interaction does this represent?
4. Shortly after the births of three babies in the same hospital, it was feared that the name tags of the babies had been mixed up. The easiest way to determine if errors had been made was to take a blood sample from all the parents and babies and then see if the puzzle could be sorted out. The blood test result are as follows:
   a. Mr Jones: type A; Mrs. Jones: type O
   b. Mr. Livingstone: type O; Mrs. Livingstone: type O
c. Mr. Peters: type A; Mrs. Peters: type B
   d. Baby X: type A; Baby Y: type O; Baby Z: type AB
   e. Match the babies with the parents.

5. When a plant with red flowers was crossed with a plant with white flowers, all of the offspring had pink flowers. What is the name for this type of inheritance? Show the resulting progeny of a cross between two pink parents. What is the phenotypic ratio?

6. A gene mutation can be caused by environmental factors. Provide two examples and explain the concept of a mutation.

7. A man whose blood group is A and a woman whose blood group is B have a child whose blood group is O.
   a. What are the genotypes of the three individuals?
   b. What is the probability of the couple's next child having blood group AB?

8. In radish plants, the shape of the radish produced may be long, round or oval. Crosses among plants that produced oval radishes yielded 121 plants that produced long radishes, 243 that produced oval radishes and 119 that produced round radishes.
   a. What type of inheritance appears to be involved? Explain your logic.
   b. What results would you expect from a long with long cross?
   c. What results would you expect from a round with round cross?

9. In crosses between two crested ducks, only about $\frac{3}{4}$ of the eggs hatch. The embryos in the remaining $\frac{1}{4}$ of the eggs develop nearly to hatching and then die. Of the ducks that do hatch, about $\frac{2}{3}$ are crested and $\frac{1}{3}$ have no crest.
   a. What type of inheritance pattern appears to be involved? Explain.
   b. If a crested and non-crested duck are crossed, what phenotypic ratio would you expect in the ducklings? What genotypic ratio would you expect?

10. In certain cattle, the hair colour can be red (homozygous RR), white (homozygous R'R') or roan, a mix of red and white hairs (heterozygous RR').
    a. When a red bull is mated with a white cow, what genotypes and phenotypes of offspring could be obtained?
    b. If one of these offspring is mated to a white cow, what genotypes and phenotypes of offspring could be produced? In what proportion?

11. How do we account for the variations of skin colour in humans?

12. Create a comprehensive Table that compares and contrasts these three ways that phenotypic traits do not follow a dominant-recessive pattern: codominance, incomplete dominance, mutations.