

Mendelian Genetics

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Description

This lesson explores how genes are passed through families. Students will see why traits sometimes seem to appear in a child when neither parent exhibits the trait. We will also see how statistics and probability relate to these genes and traits. Genetics is of growing importance in modern agriculture, so we will also see some modern agricultural applications of genetics.

Objectives

- Students will be able to apply Mendelian Genetics, sex-linked traits, and codominant traits to various situations.
- Students will know how traits are passed through generations
- Students will relate genetics to chromosomes
- Students will be able to predict the probability of various outcomes in reproduction.

North Dakota State Standards

7.4.3 Identify the characteristics of reproduction (e.g., sexual, asexual)

9-10.4.4 Relate DNA, genes, and chromosomes

9-10.4.6 Compare and contrast the results of mitosis and meiosis

9-10.4.7 Apply the basic concepts of genetics to predict inherited traits

11-12.4.2 Explain how types of DNA technology may impact society now and in the future

11-12.2.4 Formulate and revise explanations based upon scientific knowledge and experimental data

8.2.2 Use evidence to generate descriptions, explanations, predictions, and models

Schedule

9:00	Opening Activity
9:30	Activity 1 – Macaroni Family
10:00	Activity 2 – Mendelian Genetics
10:30	Activity 3 – The Punnett Square (Activity 4 fits in if everything is going quickly)
11:00	Activity 5 – Sex Determination (This one is extremely fast)
11:15	Activity 6 – Sex-linked and Codominant Traits
12:00	Lunch
12:45	Activity 7 – Heredity in Gummy Bears
1:30	Activity 8 – Dihybrid Crosses
2:15	Activity 9 – Modern Genetics (my weakest activity: will be very fast)
2:30	Activity 10 – Dragon Breeding!

Activity 1 – The Macaroni Family

In this activity we will explore how genes are passed through generations. We will see how traits can be hidden for generations and suddenly appear. Children may look a lot like their parents, but have a lot of traits which are like neither parent. By the end of this activity, we will have some taste of how this works.

Our various traits are governed by our *genes*. The genes themselves are stored in the nucleus of the cell on the various *chromosomes*. The chromosomes in turn are actually made of DNA and proteins which have been woven together. It would be more precise to say that our genes are actually coded on the DNA. However, in this activity, we won't look so much at the DNA as we will the chromosomes and the patterns of heredity.

In this activity, we will see how traits are passed down through three generations from grandparents to their grandchildren. In this activity we will ignore the dominant and recessive concept, but we will pick that up in the next activity. We will model a family with 4 different homologous pairs of chromosomes. The grandparents of this family are all homozygous, but we will color code each grandparent. Each macaroni shape represents a different chromosome. Don't attach any meaning to the color other than which grandparent it came from.

Find your family template. Each grandparent gets all macaroni of the same color, but two of each shape to represent the homologous pair. Colors are recorded on the templates for the grandparents.

Now, close your eyes and select one of each shape from Grandmother 1 and one of each shape from Grandfather 1. These are the genes for Mother. Repeat for the Father's family. Record these genes on the template.

Repeat again with the mother and father to select the genes for Child 1. Again, record the results on the template. Return the pasta to the Mother and Father and repeat for all four children. Record the results each time.

We pick one of each chromosome because each parent donates only one chromosome from each homologous pair. We'll study this in the next section.

Reflection Questions

1. How many chromosomes did each child inherit from Mother?
From Father?
2. How many of each chromosome (pasta type) does each child receive?
3. Did any of the four children have exactly the same combination of chromosomes?
4. Did every child get at least one of his/her chromosomes from each grandparent?
5. Would it be possible for a child in this activity to have the following combinations of chromosomes:
 - (a) eight yellow chromosomes?
 - (b) four yellow chromosomes and four red chromosomes?
 - (c) three blue chromosomes, two green chromosomes, and three red chromosomes?
6. Where did the four grandparents get their genes?
7. Scientists estimate that we each have about 80,000 genes (40,000 gene pairs). How many genes did you get from your mother?
From your father?
8. How do your children compare to other group's children?
9. Do you think it would be possible for a mother and father to have four children with the same combination of genes? Why or why not?

Activity 2 – Mendelian Genetics

Gregor Mendel studied these patterns during the nineteenth century, though the value of his work was not recognized until after his death. His work contradicted the accepted science of his day which had concluded that children's traits were an "averaging" of their parents traits. The strength of his work was his record keeping which showed many generations of pea plants and their various traits. His records made it clear that "averaging" was not the way traits are passed on.

We have no time today to analyze his data. Instead, we will look at a small summary of his results taken in a single year.

Parent 1	Parent 2	Offspring
White	White	White
Yellow	Yellow	Yellow
White	White	1/2 yellow, 1/2 white
White	Yellow	All White
White	Yellow	1/2 yellow, 1/2 white
White	Yellow	1/4 yellow, 3/4 white

Table 1: A sample of pea flower color results in one generation.

Reflection Questions

1. When yellow is bred with yellow, do white flowers ever develop?
2. When white is bred with white, do yellow flowers ever develop?
3. When white is bred with yellow, is the yellow ever covered up?
4. When white is bred with yellow, is the white ever covered up?
5. Which trait is the "stronger", the white or the yellow?
6. If a parent is carrying both the yellow gene and the white gene, what color will the parent be?
7. If the parent is carrying both the yellow gene and the white gene, could their children ever be the hidden color?

These simple results illustrate that there are actually two types of genes. The *dominant* gene is the stronger gene. This is the gene that will cover up the weaker, *recessive* gene. However, these results illustrate another important result: some of the pea plants were pure-breeding. Others were not. Let's examine this case by case. You may have noticed that the yellow was always pure-breeding. However, when bred with white flowers, the yellow was sometimes covered up, occasionally completely. The reverse case was never true. Clearly the yellow was the recessive trait and white was the dominant trait.

However, when we bred white flowers, they were not always pure-breeding. Sometimes, the offspring were entirely white. However, at other times, the white flowers bred and created a mix of white and yellow offspring. This suggests that the white flowers must have carried the yellow trait, but it was hidden. The yellow flowers could not carry the white trait because it would have covered up the white trait. So, the flowers carry two traits for color.

Plants which carry genes for two of the same trait are called *homozygous*. Plants which carry genes for two different traits are called *heterozygous*. It is worth noting that each gene is on a different chromosome. Such chromosomes are called *homologous chromosomes* because they govern the same trait, even if they have different genes.

We will now look at how traits can be passed through several generations with a simulation.

Activity 3 – The Punnett Square

Geneticists can predict the probability of various gene combinations in the offspring with a tool called a *Punnett Square*. To use this tool, we need a way to represent the various traits and the homologous pairs of chromosomes.

We represent traits with single letters. For example, the gene for albinism is recessive. The dominant gene is normal coloration. We represent dominant genes with capital letters and recessive traits with lower case letters. Since these are the same trait, we use the same letter. The choice of letter is arbitrary. For this discussion we will use the letter *A* for normal coloration and *a* for albinism.

In our example, two organisms with regular coloration mate. However, these organisms are heterozygous for the trait. That means the father has the genes *Aa* and the mother has *Aa*. Before they mate, they would need to create sex cells. The sex cells would be given only one from the homologous pair. If there are two genes, then there are a total of 4 ways of putting together the sperm and eggs.

The Punnett Square is a handy visual way of organizing the possible combinations. In the case of our example, we would say that

- AA 1/4 or 25% chance of being homozygous dominant
- Aa 1/2 or 50% chance of being heterozygous
- aa 1/4 or 25% chance of being homozygous recessive

We will practice a few of these to get a feeling for heredity.

Albinism is a lack of melanin. Those who exhibit albinism will have no skin or hair (or fur) pigment, and often have red eyes.

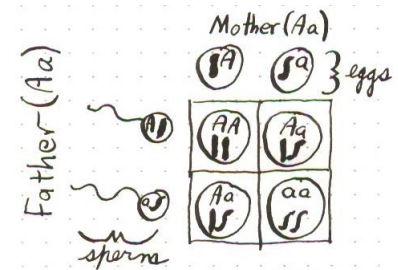


Figure 1: Two ordinary colored animals can breed and produce albinos.

Practice with Heredity

1. In Vulcans, pointy ears are a dominant trait. Spock had a human mother (normal ears) and a Vulcan father and he had pointy ears. Use a Punnett Square to show how his siblings could be entirely pointy-eared.
2. Reread number 1. Use a Punnett Square to show how Spock's siblings could be a mix of pointy and normal ears.
3. Suppose two squirrels with tufted ears reproduce and some of their offspring have plain ears. What is the dominant trait? Write the Punnett Square that shows how this is possible.
4. Albinism is a recessive trait. An albino parent breeds with an ordinary parent. Show how this could occur with NO albino children resulting.
5. Green eggs are a recessive trait in chicken eggs. Brown eggs are dominant. Show how I could get offspring in which 50% of the offspring are brown eggs and 50% are green eggs.

Activity 4 – Probability (Optional)

You may recall that in our example Punnett Square with the albinism, we had percent probabilities. Does this work out in the real world? The author has one sibling. Statistically, one of them should have been female, but they are both male. This next activity will illustrate how this works in a larger group.

You and your lab partner will each be given a penny. In this case we will represent the traits as follows:

Tails albinism *a*

Heads normal coloration *A*

Each penny then represents a homologous pair of chromosomes. Each side of the penny represents a single chromosome. When you flip the coin, this is equivalent to selecting which gene will be given to the sperm or egg.

1. Each of you should flip your coin. Record the resulting combination for your offspring. Repeat 3 more times to find out the genes for your next 3 children. Record these combinations as well.
2. Make 3 more families of four children and repeat the same coin tosses. Record these as well.
3. Calculate totals for each possible combination among all 4 families.
4. Use the totals to make fractions. Then use the fractions to make percents.
5. How closely do your predicted results match the totals that actually happened?
6. How well do each of the families match the predicted results?
7. If I totaled the results from the entire class and compared them to the predicted results, how closely do you think they would match?
8. Why do you think this happens?
9. Do the results of one coin toss affect the results of the next?

The actual choice of which sperm or egg will be “chosen” to make the offspring is entirely random. Thus, one family may have an excessive amount of one trait. It will be balanced out by another family. Punnett Squares predict the possibilities for a large group, not what the individual will do.

Parent 1	Parent 2	Totals
Family 1		
Family 2		
Family 3		
Family 4		

Table 2: Recording chart for the probability activity

	Count	Fraction	Percent
AA			
Aa			
aa			

Table 3: Final totals (all data put together)

Activity 5 – Sex Determination

All around you are males and females. You may have wondered what makes them different. The answer is that males have two different chromosomes: XY and females have two of the same chromosome XX. Essentially, the Y chromosome instructs the sex organs to grow one way and the X chromosome instructs them to grow another way.

When the female splits her chromosomes up to make eggs, each egg contains an X chromosome. When the male splits his chromosomes up to make sperm, half the sperm will contain a Y chromosome, and half will contain an X chromosome.

- Use a Punnett Square to show how sex is determined.
- What percentage of offspring are male? female?
- Which parent determines the gender of the child?
- Can you ever get an offspring that is YY?
- How closely does this match your own family?

In a group of larger families, it would be interesting to look at birth order and gender. What we would find is that there are no real rules. The gender of each child is totally independent of the others.

Activity 6 – Sex-linked Traits and Codominant Traits

Some traits are only seen if a person is of the right gender. For example, baldness is carried on the x-chromosome, but can only be “turned on” if the person carries a y-chromosome. Similarly, calico cats are all female because the gene is only “turned on” if there are 2 x-chromosomes. Typically, sex-linked traits are written as subscripts.

	X_b	X
X_b	X_bX_b	X_bX
Y	X_bY	XY

	X_c	X
X_c	X_cX_c	X_cX
Y	X_cY	XY

Table 4: In the first example, there is a 50-50 chance of having a boy who goes bald (or 25% chance of having a bald child), even though the father is bald. In the second example, two cats carry the calico gene. There is a 25% chance of having a calico kitten (or 50-50 chance of having a calico girl).

Traits which are seen in only one gender or the other are called *sex-limited genes*. Traits such as facial hair are *sex-influenced*. They are far more common in one sex than the other, but not impossible because they are not purely genetic. They are caused by factors such as hormones. For example, testosterone will cause a deeper voice and facial hair in both genders. Estrogen will cause breast growth in both genders.

A few traits will blend. In such cases, both are dominant and we call these *codominant traits*. The classic example is in carnations. They

carry genes for either white or red, but there is a pink phenotype. This comes when a white gene combines with a red gene. If we could see the pink flowers under the microscope, we would see that they have both red pigment and white pigment in their petals. In other words, the traits don't truly blend. Instead, they are both expressed.

	R	R
W	RW	RW
W	RW	RW

	R	W
R	RR	RW
W	RW	WW

The next two questions are a bit more "real world." At one time, there was no DNA testing in cases of questions over parentage. One of the methods used to solve questions of parentage was blood typing. There are four general blood types: A, AB, B, and O. The difference between the blood types is the proteins on the surface of the red blood cells. Types A and B have different proteins. AB is a combination of the two, and O does not have these proteins. This makes O a universal donor. Type AB can take blood from anyone. This makes type AB a universal receiver.

The A and B genes are both equally dominant, and the O gene is recessive.

1. There is a baby in the local hospital with type O blood. Two couples, Fred and Velma, and Daphne and Shaggy are fighting over who gets the baby.
 - (a) Fred and Velma both have type A blood. Write their possible genotypes.
 - (b) Daphne has type O blood. Write her genotype.
 - (c) Shaggy has type AB blood. Write his genotype.
 - (d) Who are the baby's parents? Explain.

2. Use the blood type information from from the previous question for this question. Mr. Flintstone belongs to the blood group A, Mrs. Flintstone belongs to the blood group B, Mr. Rubble belongs to the blood group O, and Mrs. Rubble belongs to the blood group AB. Both couples have fraternal twins but they got mixed up in the hospital, so that no one knows which two babies go to each couple. The hospital finds that there is a child in each of the four basic blood groups.
 - (a) Place the children with the correct parents (each family has two children).
 - (b) Explain where you decided to place each child, and explain your reasoning using Punnett squares.

Table 5: In the first generation, a red carnation RR is bred with a white carnation WW to make all pink carnations RW. In the second generation, two pink carnations are bred to make 25% red carnations, 50% pink carnations, and 25% white carnations.

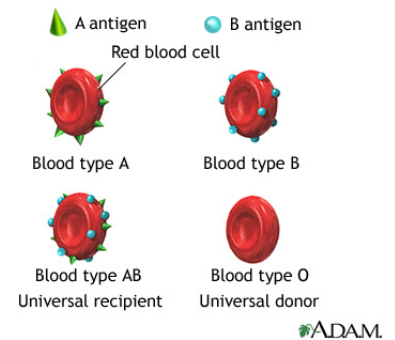


Figure 2: Blood types from <http://health.rush.edu/HealthInformation/graphics/images/en/19450.jpg>

3. Among Hereford cattle, there is a dominant allele called polled; individuals that have this allele lack horns. After you finish high school you become a cattle baron and stock your spread entirely with polled cattle. You personally check each cow to be sure that none possess horns, and none do. Among the calves that year, however, some grow horns. Angrily you turn them into hamburgers and check to be sure that no horned adult has gotten into your pasture. None has, however the next year more horned calves are born. What is the source of your problem? (Show a Punnett square.) What is the best way to remedy your problem? (Hint: What method do local farmers use?)

4. Hemophilia is a sex-linked trait (it is carried on the X chromosome) and results in the inability of the blood to clot. Sex chromosomes are as follows: female XX and male XY. Normal blood clotting is due to the dominant gene H (depicted as X_H), while bleeding is due to the recessive gene X_h . A bleeder male marries a normal female whose father was a bleeder. Show the possible phenotypes and sexes. Show a Punnett square.

Activity 7 – Heredity in Gummy Bears

In this activity we will look at what causes the diverse colors in gummy bears. You will be given a bag of bears that is the result of breeding two gummy bears in captivity. Find the total count of bears in the bag. Empty the bag and sort the bears based on traits you can easily see.

- What traits did you use and why?

Fill in this chart based on your bag of bears.

Characteristic	Alternate Form(s)	Number	Ratio	Genotypes	Mode of Inheritance	Parents

Table 6: Gummy bear recording sheet.

Add your data to the class data on the chalkboard.

When all data are pooled, compare your data to class data. Then answer these questions.

1. Devise appropriate symbols for each of the characteristics you studied. Consider whether they are dominant, recessive, codominant, etc.
2. What are the likely genotypes for the bears you studied?
3. What are the likely phenotypes and genotypes for the parents of the bears you studied?
4. Write the Punnett Square for your bears.
5. Find the ratios for your Punnett Square. How closely do your actual bears match the results from your Punnett Square?
6. If they are not close, repeat your steps until they are.
7. Plot your data on a frequency graph. Your phenotypes should be on the x-axis, and your genotypes should be on the y-axis.

Activity 8 – Dihybrid Crosses

Labradors occur in three popular colors: black labs, yellow labs, and chocolate labs. In addition, there is a fourth variation called a “Dudley.” This involves more than two genes.

Coat color is controlled by two genes on two separate chromosomes.

These are inherited separately. However, these two genes interact. The *B* gene causes the labrador to produce a lot of melanin, resulting in dark skin (and noses). The *e* gene blocks the melanin from getting into the fur¹. A dog with the combination *B_ee* will have dark skin

Gene	Effects
B	Dark Melanin
b	Lighter Melanin (including skin)
E	Allows Melanin
e	Keeps Melanin out of fur

Table 7: The genes of labrador coat color. Note that the *Ee* gene controls whether or not the melanin gets into the fur.

¹ When melanin does not go up the hair shaft, the result is yellow fur. Whiter labs occur because of an additional gene *C*. There is some controversy over whether this gene is really carried by true labs.

but yellow fur. We call these yellow labs. Any combination of $B_E_$ means that the melanin is allowed into the fur. As a result, the lab will have dark skin and dark fur. These are black labs. Chocolate labs have lighter skin bb , but, since the fur is pigmented, the dominant gene must allow pigment to be carried up the hair shaft.

1. Write all possible combinations that will result in a black lab.
2. Write all possible combinations that will result in a yellow lab.
3. Write all possible combinations that will result in a chocolate lab.
4. Write the only possible combination that will result in a “Dudley”: light skin and light fur.
5. Why do you think Dudleys are the most rare combination?
6. Why might dog breeders be interested in the pedigree (family history) of a lab?

Punnett Squares with Labradors²

² For more on labrador coat color, visit <http://www.blueknightlabs.com/color/coatcolor.html>

1. Suppose a “Dudley” breeds with a pure black lab.
 - (a) Write the genotypes of their potential sex cells.
 - (b) Write the genotypes of the potential offspring.
2. Now, suppose a pure black lab breeds with a pure yellow lab.
 - (a) Write the genotypes of their potential sex cells.
 - (b) Write the genotypes of the potential offspring.
 - (c) Explain why the puppies will all be black labs.
3. Suppose two offspring from the previous batch of puppies were accidentally bred.
 - (a) Write the genotypes of their potential sex cells.
 - (b) Write the genotypes of the potential offspring.
4. There is an inherited trait among humans in Norway that causes an individual to have very wavy hair, not unlike that of sheep. The trait, called “wooly”, is very evident when it occurs in families: no children possesses wooly hair unless at least one parent does. Imagine you are a Norwegian judge, and that you have before you a wooly-haired man suing his straight-haired wife for divorce because, although their first child has wooly hair, their second child does not, her hair being quite straight, long and blond. The

husband claims that this information constitutes evidence of infidelity on the part of his wife. Do you accept his claim? Justify your decision, show a Punnett square.

5. A strain of barley (A) has a high yield of seeds but a long stem which is subject to 'lodging' (a flattening of areas of the crop). Another strain (B) has a short, sturdy stem but a lower yield. The genotype of variety A is HHss (high yield, long stem) and the genotype of B is hhSS (low yield, short stem)
 - (a) Show how a plant breeder would cross these varieties to produce a high yielding, short stemmed variety.
 - (b) Explain why this new variety would not breed a new generation with the same traits (high yield and short stem).

Activity 10 – Dragon Genetics

For this simulation, each pair of students will be parents. You will "breed" and make a baby dragon. Your baby dragon will illustrate how your traits are passed on. This lab is different from the previous lab because there are many more traits and there are several kinds of traits. Table 8 on the following page gives the dragon's genome.

Each partner needs to draw 5 chromosome sticks: one of each color of autosome and one sex chromosome stick. Each side of a stick represents a chromosome and the two sides together represent a pair of homologous chromosomes.

For each color autosome and then for the sex chromosomes, each parent should randomly drop the stick on the table. The side that is up represents the chromosome that is passed on to the baby.

Record that alleles from each pair of homologous chromosomes on the data table (provided on a separate sheet of paper). When recording the phenotype, remember that the capital letter represents the dominant trait. There are a few exceptions: codominant traits, sex-influenced traits, or sex-limited traits.

Finally, cut out the traits of the baby (provided separately). Fit them together to make a picture of the baby dragon. Color in the pieces (if appropriate), and glue them. This will be turned in with your data sheet. (One per group). Just like any other parents, the two of you together produce one child (and one grade). This child may also show up in the next chapter.

- How does dropping the stick on the table and transcribing the letters on the sides follows Mendel's Law of Segregation?
- Explain how dropping the colored sticks illustrates Mendel's Law of Independent Assortment.

To compare: the gene for dwarfism is dominant in humans.

Deletions and inversions are mutations. They sometimes produce non-viable offspring (not in our case). If this occurs with your dragon, keep the traits in order and default to the dominant trait if possible. If you're really confused, ask the teacher. (This is new to the activity this year, so I'm not

Chromosome	Dominant Genes		Recessive Genes	
Green Autosome	A	no chin spike	a	chin spike
	B	nose spike	b	no nose spike
	C	3 head flaps	c	4 head flaps
	D	no visible ear hole	d	visible ear hole
	E	[see table 9]		
Red Autosome	F	long neck	f	short neck
	G	no back hump	g	back hump
	H	no back spikes	h	back spikes
	I	long tail	i	short tail
	J	flat feet	j	arched feet
Orange Autosome	K	red eyes	k	yellow eyes
	L	spots on neck	l	no spots on neck
	M	[see table 9]		
	N	no fang	n	fang
	O	spots on back	o	no spots on back
Yellow Autosome	P	no spots on thigh	p	spots on thigh
	Q	green body	q	purple body
	R	small comb on head [see below]	r	large comb on head
	S	[see table 9]		
	T	[see table 9]		
Sex Chromosome	U	regular thigh	u	pointed thigh
	V	four toes	v	three toes
	W	no chest plate	w	chest plate
X Chromosome Only	X	no tail spike	x	tail spike
	Z	long arms	z	short arms
	+	non-fire breather	-	fire breather
Y Chromosome Only	Y	male sex		

Table 8: The dragon genome.

Codominant Traits					
E	eye pointed at each end	e	round eye	Ee	eye round at front only
S	red spots	s	yellow spots	Ss	orange spots
Sex-influenced Traits					
M	wings	m	no wings (dominant in presence of male hormone)		
T	no elbow spike	t	elbow spike (dominant in presence of male hormone)		
Sex-limited Traits					

R or r Only males have the comb on the head

Table 9: "Special" traits for the dragon genome

- Even though the gene for fangs is recessive, most of the dragons have fangs. How might this happen?
- What was the sex of your baby?
- What traits are sex-linked?
- Identify any gene deletions or inversions in the chromosomes you have.
- What traits are more likely to be found in males?
- How might these be an advantage to this sex?
- What traits are more likely to be found in females?
- How might these be an advantage to this sex?

Our Baby !

Names _____

Green Autosomes

GENOTYPES Alleles in
 MOM DAD Egg Sperm TRAIT---Phenotype of Baby

Red Autosomes

GENOTYPES Alleles in
 MOM DAD Egg Sperm TRAIT---Phenotype of Baby

Orange Autosomes

GENOTYPES Alleles in
 MOM DAD Egg Sperm TRAIT---Phenotype of Baby

Yellow Autosomes

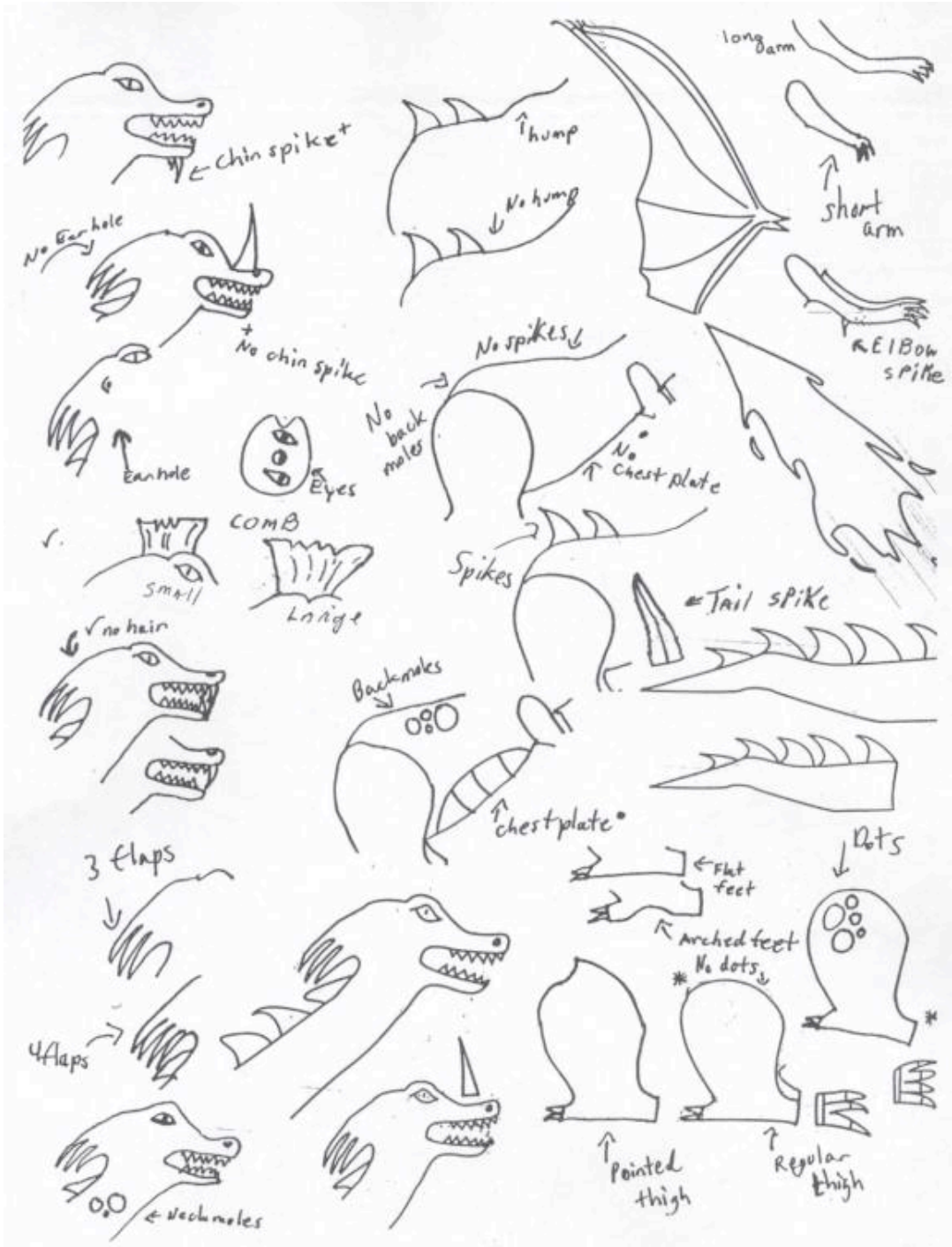
GENOTYPES		Alleles in		TRAIT---Phenotype of Baby
MOM	DAD	Egg	Sperm	

Sex Chromosomes

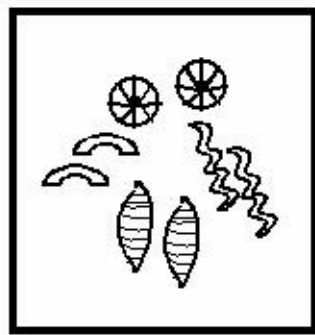
GENOTYPES		Alleles in		TRAIT---Phenotype of Baby
MOM	DAD	Egg	Sperm	

Questions

1. How does dropping the stick on the table and transcribing the letters on the sides facing up follow Mendel’s Law of Segregation? [First state the law.]
2. Explain how dropping the green, orange, and red sticks illustrates Mendel’s Law of ***Independent*** Assortment? [First state the law.]
3. The gene for fangs is recessive, yet most of the dragons have fangs. How can this happen? [Hint. The gene that causes dwarfism (achondroplasia) in humans is dominant.]
4. What is the sex of your baby?
5. What traits are *sex-linked*? [First define “sex-linked”.]
6. Identify any gene deletions or inversions in the chromosomes you have.
- 7a. What traits are *more likely* to be found in males? [Consider sex-linked, sex-influenced and sex-limited traits.]
- 7b. How might these be an advantage to this sex? [Be creative in your answers.]
- 8a. What traits are *more likely* to be found in females?
- 8b. How might these be an advantage to this sex?



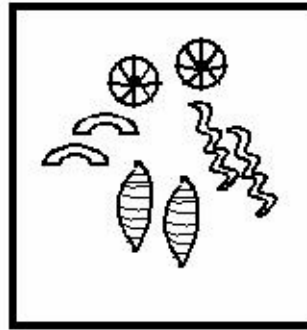
Pasta Genetics



Grandfather 1



Grandmother 1



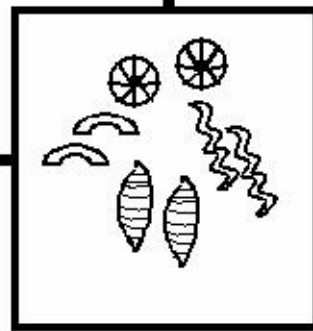
Grandfather 2



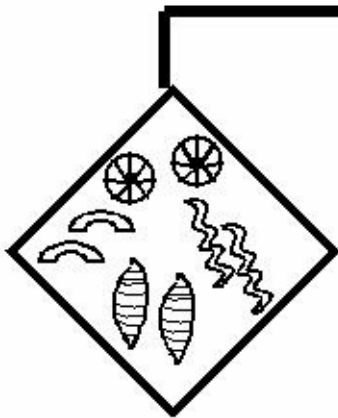
Grandmother 2



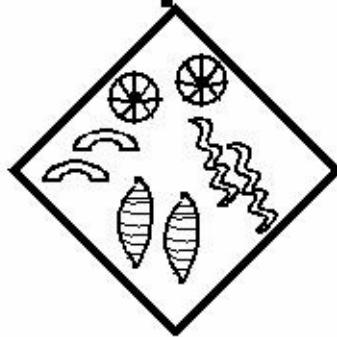
Mother



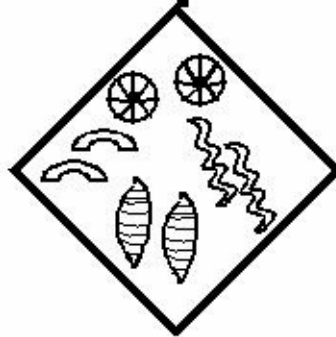
Father



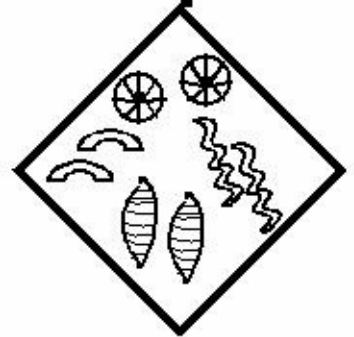
Child 1



Child 2



Child 3



Child 4