Gametes, Alleles, Heredity, Probability

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Georgetown High School is a grade 10 - 12 high school located in Georgetown, Texas. Biology is a graduation requirement that most students take as 9th graders at a different campus. Many of the 10th – 12th graders taking biology at this campus are struggling or reluctant learners. Some of these students are limited English learners and special education students and many are below-grade level readers. Classes are arranged in a 90 minute block that meets every other day.

Misconceptions

Our purpose was to address three misconceptions in genetics.

- Primarily, we knew that many high school students could go through the motions of a Punnett Square and predict the possibilities of a genetic cross, but could not relate the Punnett Square to the products of independent assortment.
- In addition students often fully understood the variety that exists in human genetics, knowing that each person is unique but did not recognize that genetic variety is evident in all living things.
- Furthermore, students had difficulty interpreting the probability with the genotypic and phenotypic ratios associated with genetic crosses.

Addressing the misconceptions

In addressing these misconceptions we designed the following lessons as a part of an inheritance unit:

- Meiosis and independent assortment lesson (1 class period). See document "Meiosis and independent assortment" and "Meiosis and independent assortment student handout" pages 3-7
- Engagement – genetic variety observed in a sampling of organisms (1 class period). See "Heredity Engagement" and "Heredity Engagement Student Worksheet" pages 8-13
- Punnett Squares and predicting genotypic and phenotypic ratios (2 class periods). See "Punnett squares" and "Punnett squares student worksheet" pages 14-18
- Probability lesson (1 class period) See "Probability" and "Probability Student Worksheet" pages 19-27

Curriculum Standards

These lessons were designed to meet the curriculum standards as outlined in the Texas Essential Knowledge and Skills (TEKS):

6. Science Concepts: The student knows the structures and functions of nucleic acids in the mechanisms of genetics. The student is expected to:
   (D) compare genetic variations observed in plants and animals
   (E) compare the processes of mitosis and meiosis and their significance to sexual and asexual reproduction

In addition the lessons meet the curriculum standards as outlined in Project 2061-

> American Association for the Advancement of Science
> "The sorting and recombination of genes in sexual reproduction results in a great variety of possible gene combinations from the offspring of any two parents."

Assessment

The following methods of assessment were made:

- Informal assessments including teacher observation
- Daily "Ticket Out the Door": Students are given a slip of paper in which to answer a question posed by the teacher. The question is asked during the last 5 minutes of class and must be handed in as they leave class. Teacher does not formally grade answers but looks over to determine what, if any, misconceptions remain.
- Answers to heredity and probability student handouts
- 2 Punnett square quizzes
- Genetics test (multiple choice/short answer/matching)

Additional Note:

In an effort to encourage student interest in college and improve the ratio of students to teacher, we involved students currently enrolled in a genetics class at Southwestern University. Dr. Pierce designed and led the lesson on probability while each group of 3 students participated with the help of a college student. In addition, college students aided students in groups during the engagement exercise. An extra training session was provided by both Benjamin Pierce and Grace Lisenby guiding the college students in what to expect and how to interact with the high school students. See "College Student/High School student interaction tips" handout, page 28.

Meiosis and Independent Assortment

Prior knowledge – chromosome structure, steps in mitosis

Materials needed – popsicle sticks (8 per pair of student) , yarn: 2 dark colors (example purple and green) and 2 light colors (example white and yellow), double sided tape, Velcro tabs, map pencils, large pieces of paper (the back of a book cover works well and is about the right size!)

Objective: Each student will be able to use a model of a set of chromosomes to demonstrate segregation of alleles, gamete formation and independent assortment. They will be able to evaluate the efficacy of the model they created.

Setup: Approx. 20 minutes: Prior to class attach Velcro tabs to all popsicle sticks at the center, cut yarn into short (about 10cm) pieces.

Procedure:

1. Divide class into pairs. Distribute one popsicle stick per student and give half of the class a short length of a dark piece of yarn (ex: purple). The other half of the class gets a short length of a light piece of yarn (ex: white)

2. Explain that the yarn represents a gene. Have students fill in working definition of gene on Student Handout. Also explain that the purple represents one form (allele) of that gene, like purple flowers. The white represents the other form (allele) of that gene, like white flowers.

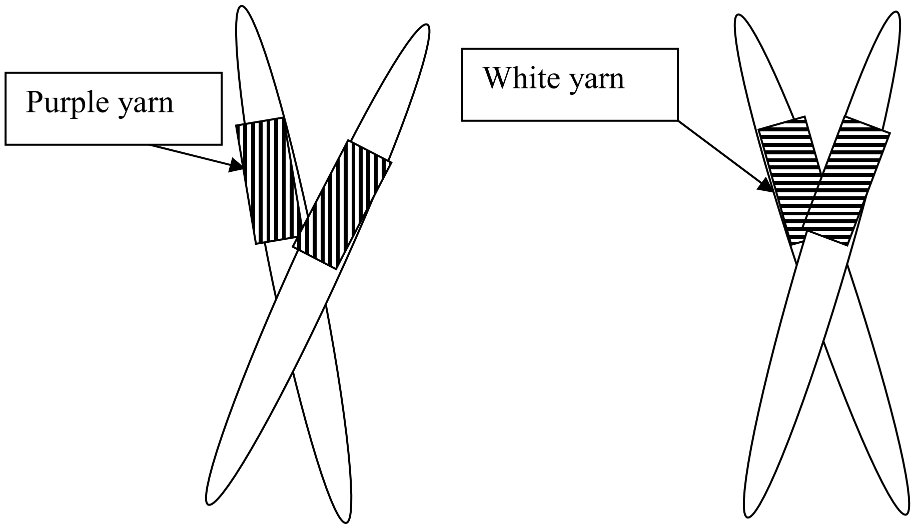
3. Give time for students to discuss with a partner the answer to question 2 and 3. Discuss as a class.

4. Using double sided tape students should place a strip on both sides of the popsicle stick being careful to not cover the Velcro tab. Then they should take their yarn and tightly wrap it around the stick pressing it to the stick. As they wrap it explain how this models the way DNA coils up to make a chromosome.

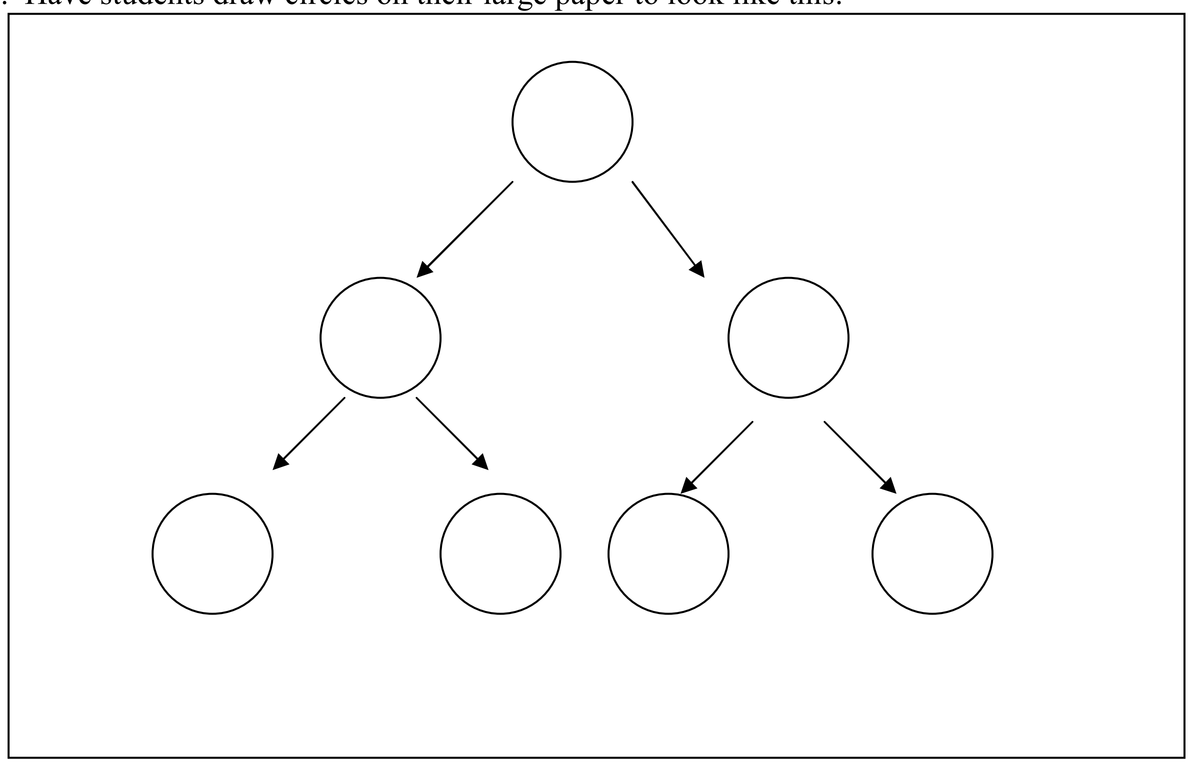
5. Simulate replication: Distribute another piece of yarn giving each student whatever color they previously had. They can follow the procedure above using a new popsicle stick to make a duplicate chromatid. Review students about when this occurs in the cell cycle and why. They can attach the two chromatids using the Velcro patch. Allow students time to answer questions 4 and 5 on the handout.

6. Distribute another 2 pieces of yarn to each student. Distribute white yarn to students who have chromosomes with purple and purple yarn to students who have chromosomes with white

7. Have students repeat step #4 using 2 new popsicle sticks. Have them place their two pairs of sticks side by side on their desk. Explain that this represents a homologous pair. Their product will look something like this:



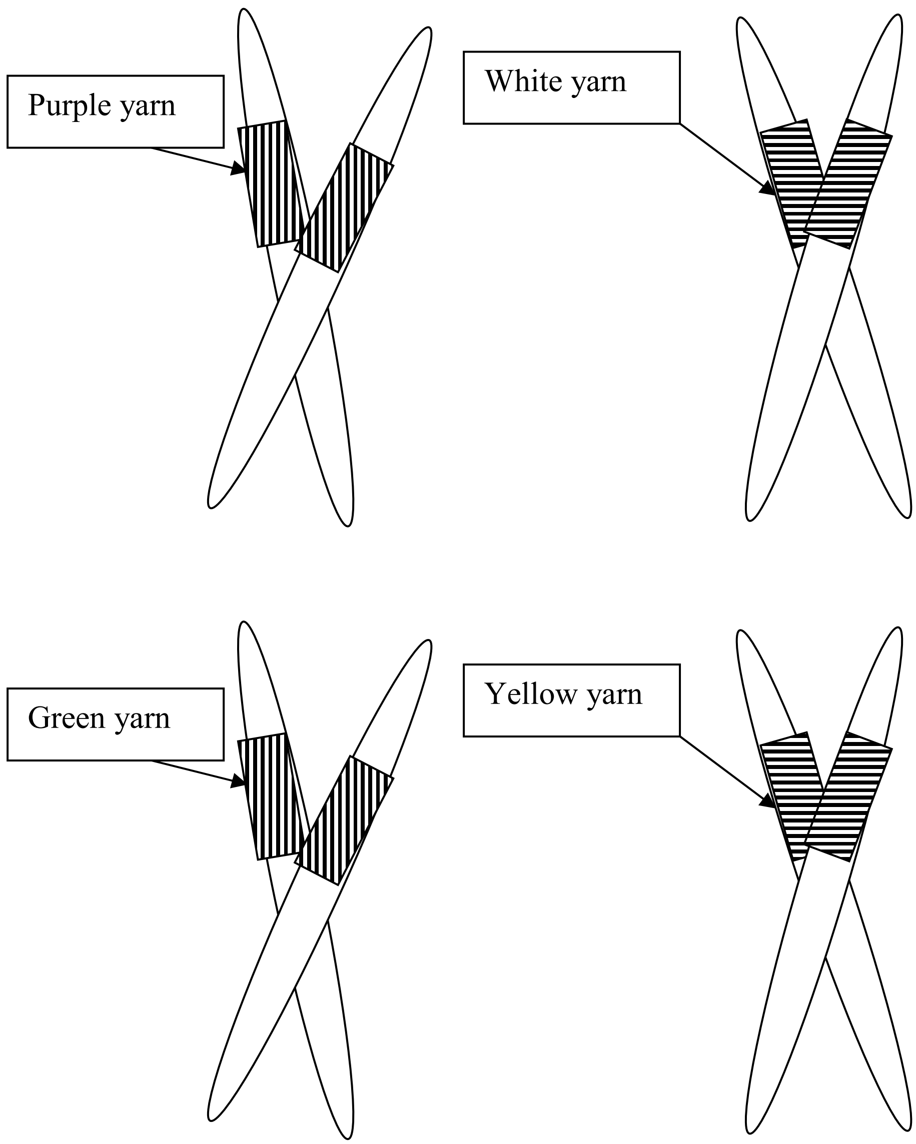
8. Have students draw circles on their large paper to look like this:



9. Guide them to place the tetrad (all 4 chromatids) in the top circle and then separate the tetrad moving one pair to the left and one to the right. Demonstrate that at this point the direction they move is completely random and use that to illustrate segregation.

10. Guide students to separate the chromosome pairs placing one of each pair in the bottom circle. Allow time to for them to answer question 6 and 10-12.

11. Repeat procedure making another set of popsicle 4 sticks but this time use different colors of yarn (for example green and yellow). Their 8 popsicle sticks should look something like this:



12. Once they have assembled their new tetrad, point out that this is a different chromosome with a different gene. Discuss how many chromosomes we have and that each chromosome has more than one gene. Allow time to answer questions 7 – 9.

13. Guide the students in placing their two tetrads in the circle at the top and then separating the tetrads to place chromosomes in the left and right circles followed by splitting up the chromatids to make the gametes. Here it's important to go to each pair of

students and point out that the tetrads sort independent of each other. Help students answer question 13 on the student handout and discuss as a class

14. Have students place all 8 of their popsicle sticks into a baggie labeled with their name. You can use them again when you teach Punnett squares

Meiosis and Independent Assortment – Student Handout

1. What is a gene?

2. How is this popsicle stick a good model for a chromosome? How is it not?

3. What is an allele?

4. When and why does a chromosome make a copy of itself?

5. What is a homologous pair? Draw your homologous pair below and use map pencils to color your drawing.

6. What four gametes can be formed from your set of chromosomes?

7. What does your new tetrad look like? Draw and color it in the space below.

8. How many chromosomes do humans have?

9. Are they all the same size (length?)

10. How many cells are formed at the end of meiosis?

11. Compared to the amount of DNA you had at the beginning of meiosis, how much do you have at the end?

12. Why is it necessary for the amount of DNA to divide when making gametes?

13. Draw the possible gametes that could be formed by this individual.

Heredity Engagement Activity

The purpose of this engagement activity is to stimulate student interest in genetics and to help students explore some basic concepts and terminology in genetics. Students are divided into small groups of three to four students. Each group visits one of five stations where they observe mice, fruit flies, corn kernels, corn seedlings, and pictures of dogs. The students examine the organisms at each station and attempt to answer questions on the student worksheet. We had a college student or teacher at each station, who helped guide the student engagement by asking the questions such as those below. We emphasized that we were not looking for specific answers to the questions. After filling in the worksheet, each group moved to the next station.

I. Station 1 – Mice

Materials to Observe: Different colored mice. Parents and several litters of baby mice, preferably at least one with a recessive trait in which the parents differ from some of the offspring.

Information to Give to Students: These mice are called house mice because they often occur in and around houses and other buildings. Their scientific name is *Mus musculus*. House mice are used a lot in science and in the study of heredity. In some cages we have two parents and the babies they produced.

Objectives:
(1) Genes code for traits but are distinct from the traits.
(2) Some genes are recessive; two parents may give rise to offspring that are different from both parents.
(3) Importance of genetic models.

Questions
1. What differences do you see among the mice?
2. Why do the mice differ in color? Why is one mouse white and another mouse black?
Possible Answer: Color is a genetically determined trait. The different colored mice have different genes for color.
3. Can you think of any genetic traits in humans that differ among people like the color differences that occur in the mice?
Possible Answer: hair color, eye color, skin color (although skin color varies continuously)
4. What do you think would happen if you mated two white mice?
5. What do you think would happen if you mated two black mice?
6. Here we have a litter of mice in which both parents are black and yet some of the baby mice are white. How can that happen?
Possible Answer: Some of the genes that code for traits are recessive. This means a mouse might carry the gene for a recessive trait, such as white, even though the appearance of the mouse is black.

7. What do you think we would get if we mated a black mouse with a white mouse?
8. Mice are often used in scientific and medical research. What are some of the advantages of using mice in science?
Possible Answer: Small size, reproduce rapidly, have large litters of offspring, easy to rear in the laboratory, not the same ethical problems that occur with using humans in research.

II. Station II - Fruit Flies

Information to Give to Students: Fruit flies are small insects that are often found around fruit. Have any of you every seen a fruit fly hovering around a banana or other fruit? Do you know the scientific name of the fruit fly. It's *Drosophila melanogaster*. Fruit flies have been used a lot in genetics research and teaching because they are small, easy to rear in the laboratory, and have lots of offspring. Look at the fruit flies through the microscope. The files in one dish are called wild-type, because they are the flies that one usually finds in the wild. They have the usual or normal traits. Now look at the flies in the other three dishes.

Objectives:
(1) Look for traits that vary.
(2) Mutations. Difference between wild-type traits and mutants.
(3) Definition of a gene.
(4) Some of the advantages of using fruit flies for genetic research.
(5) What geneticists do.

Questions
1. How do the flies in the other three dishes differ from the wild-type flies?
Answer:
   a. has white eyes instead of red
   b. lacks wings
   c. hairs on its back looked singed
2. What causes one fly to have white eyes and another to have red eyes?
Possible Answer: The traits are determined by genes and fruit flies with different colored eyes have different genes.
3. What is a gene?
Possible Answer: A gene is defined in different ways. How a gene is defined often depends on the question that is being asked. One definition is an inherited factor that determines a trait.
4. The flies with white eyes, no wings, and singed hairs are called mutants. What is a mutant? What is a mutation?
Possible Answer: A mutation is an altered gene.
5. What do you think would happen if we mated two flies with white eyes?
6. What do you think would happen if we mated two flies with red eyes?
7. What do you think would happen if we mated a fly with red eyes with a fly with white eyes?

8. People who study heredity and genes are called geneticists. Geneticists often study fruit flies. Why do you think they study flies instead of dogs or cats or horses or humans?

III. Green and Albino Corn

Information: These are corn seedlings. The corn seeds were produced by crossing two green corn plants and the seeds are the offspring from this cross. The offspring (the seeds) were placed in soil and watered. New corn plants sprouted from the seeds. You can see that some of the seedlings are green and some are white.

Objectives;
(1) Developing hypotheses and experiments to test hypotheses.
(2) Examining ratios of offspring from a cross.

Questions

1. Why do you think some of the seedlings are green and some are white? Can you come up with several different hypotheses to explain the fact that some are green and some are white?
2. How might you go about testing these hypotheses?
3. Assume that the differences in color (green vs white) is determined by genes. The two parent corn plants were green. Some of the offspring from this cross are white. How can you get white offspring from two green parents?
3. Count the number of green and white seedlings. Which color is more common?
4. Calculate the percentage of green and white seedlings.
   green/total
   white/total
5. What percentage of green to white do you get? Any ideas why this ratio occurs?
6. What do you think will happen to the white seedlings?
7. What is a gene? Do plants have genes

IV. Ears of Corn

Information: An ear of corn contains a number of corn kernels. Each kernel is a seed, the offspring of a cross between two corn plants. Farmers take pollen from one corn plant and place it on the flower of another corn plant. The ear of corn is family of offspring from a cross. So, the kernels in an ear of corn are all brothers and sisters.

Objectives:
(1) Recognizing differences in more than one trait.
(2) Examining ratios in the offspring from a cross.

Questions:

1. What are some of the differences you see in the kernels of corn?
2. What causes these differences?
3. Why are the kernels of one ear not always all the same?
4. Count the number of types of kernels in one ear (purple vs yellow; full vs shrunken)? How many of each type do you find?
5. Calculate the percentage of each type. What are the percentages?

V. Variation in Dogs

Information: Look at all the pictures of different types of dogs. Some of the pictures show different dog breeds and others show different colors of dogs within the same breed.

Objectives:
(1) Understanding that artificial selection can produce genetic differences.
(2) Results of genetic crosses.

Questions:
1. Why do dogs come in some many different colors, shapes, and sizes?
2. Where did dogs originally come from?
Possible Answer: from wolves
3. Why do breeds of dogs differ in things like color, size, shape, and behavior?
Possible Answer: Breeders have favored different traits in different breeds. Over time, the breeders selected for traits that were desirable. In response to this artificial selection, the different breeds evolved different sizes, shapes, colors, and behaviors.
4 Great Danes are large and Chihuahuas are small. If you breed two Chihuahuas, will you ever get a Chihuahua as big as a Great Dane? Or, if you breed two Great Danes, will you get a dog that looks like a Chihuahua. Why?
5. What would happen if you mated a Great Dane with a Chihuahua?
6. Some breeds come in different colors. For example, Labrador Retrievers come in three colors, brown, black, and yellow. What causes some Labs to be black and others to be brown?
7. What do you think would happen if two black Labs are mated? Will you always get black puppies?
8. What about mating two yellow Labs?
9. What if we mated a black Lab with a yellow Lab?

Heredity Engagement Activity
Student Worksheet

I. Station 1 – Mice

1. What differences do you see among the mice?

2. What do you think causes these differences?

3. What do you think would happen if you mated two white mice?

4. List any traits in humans that you think are due to genetic differences?

II. Station II - Fruit Flies

1. How do the flies in the four dishes differ?

2. What might cause one fly to have white eyes and another to have red eyes?

3. What is a gene?

4. What is a mutation?

III. Green and Albino Corn

1. Remember that a hypothesis is an educated guess that can be tested. Take a look at these plants and note the difference in color. Why are they different colors? Propose at least two different hypotheses to explain the fact that some of the corn plants are green and some are white. Write your hypotheses below.
   a.

   b.

2. Assume that the differences in color (green vs white) is determined by genes. The two parent corn plants were green. Some of the offspring from this cross are white. How can you get white offspring from two green parents?

3. Count the number of green and white seedlings. Which color is more common?

IV. Ears of Corn

1. What are some of the differences you see in the kernels of corn?

2. What might cause the differences that you see among the kernels?

3. Count the number of types of kernels in two rows (purple vs yellow; full vs shrunken)? How many of each type do you find?
   Calculate the percentage of each type.
   Formula: $\frac{\#\ kernels}{total\ kernels} \times 100$

Kernel Color			Kernel shape		
	Number	%		Number	%
Purple			Full		
Yellow			Shrunken		
Total		100%	Total		100%

V. Variation in Dogs

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2. Where did dogs originally come from?

3 Great Danes are large and Chihuahuas are small. If you breed two Chihuahuas, will you ever get a Chihuahua as big as a Great Dane? Or, if you breed two Great Danes, will you get a dog that looks like a Chihuahua. Why?

4. What would happen if you mated a Great Dane with a Chihuahua?

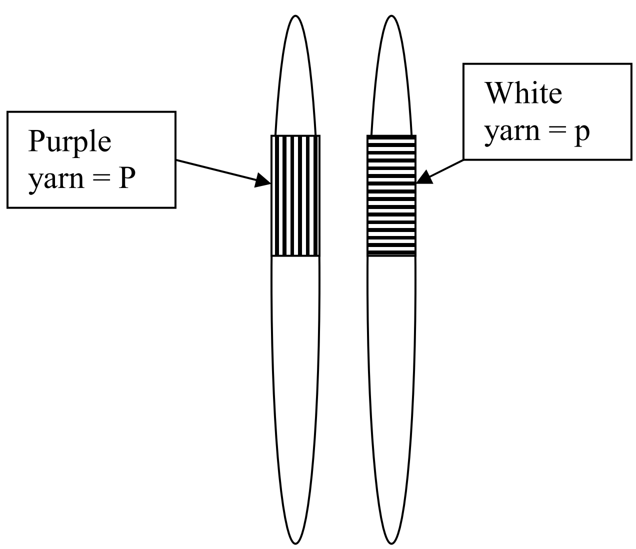
Punnett Squares

Prior knowledge – basic genetics terms (genotype, phenotype, homozygous, heterozygous, dominant, recessive), chromosome structure, steps in mitosis and meiosis

Materials needed –baggie with 8 chromosomes made during meiosis activity (see "Meiosis and Independent Assortment" activity, map pencils, large pieces of paper (the back of a book cover works well and is about the right size!)

Objective: Each student will be able to use a model of a set of chromosomes to demonstrate segregation of alleles, gamete formation and independent assortment. They will be able to evaluate the efficacy of the model they created.

Procedure:
1. Hand out materials to student and have student take out a pair of homologous chromosomes and leave the other 6 sticks in the baggie. They can set these aside. Here is an example of what they will have:

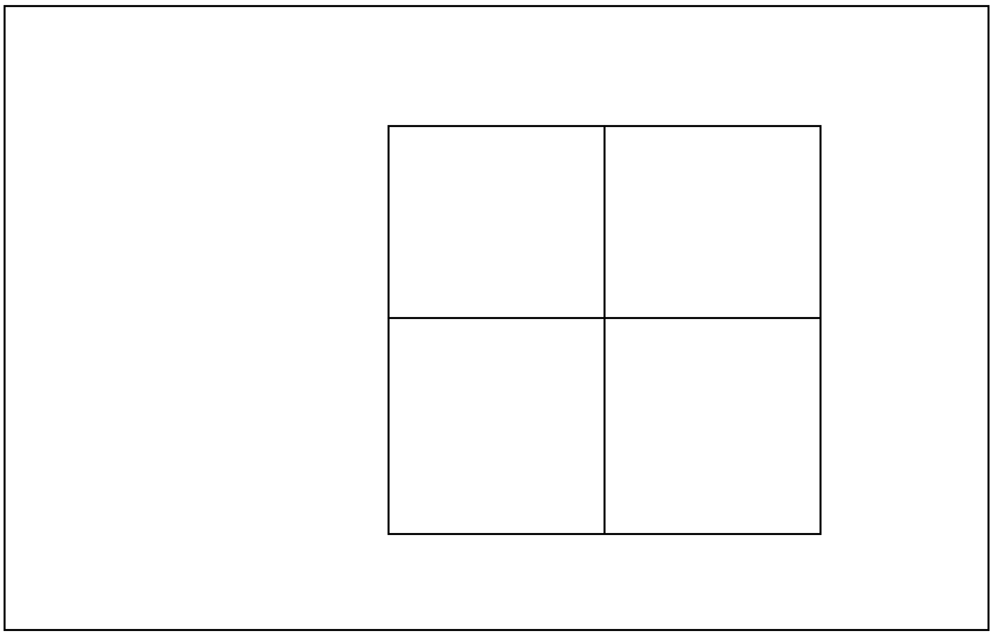


2. Establish letters for the various colors on the popsicle sticks. If you used Purple and white, you can have *P* = Purple and *p* = white. Have them represent a real genetic trait. For instance, purple can be the flower color of a pea plant and white could represent the allele for white flower color.

3. Guide your students to answer questions 2,3, and 4. #2 should be *Pp* and the other possibilities are *PP* and *pp*. #3 is purple, and the other possibility is white. The answer to #4 is that both *PP* and *Pp* will result in a purple individual

4. Briefly revisit meiosis and point out that the two chromosomes separate to make gametes. Have students answer #5 on their handout.

5. Have student pairs find another pair of students and move next to them. They are now working in groups of 4. One group of 4 should obtain a large piece of paper and draw a punnett square on it. It should look like this



5. Have one pair move the gametes to the top of the Punnett square and the other pair move their gametes (chromosomes) to the side of the Punnett square. Have them move the chromosomes around to determine the contents of each box. Have students answer number 6-10 on their handout

6. As an extension, you could have students try out different combinations (*Pp* X *pp*, *PP* X *pp*, *Pp* X *PP*, etc)

7. Distribute Punnett square practice page and allow students to work on it.

Punnett Squares – Student Handout

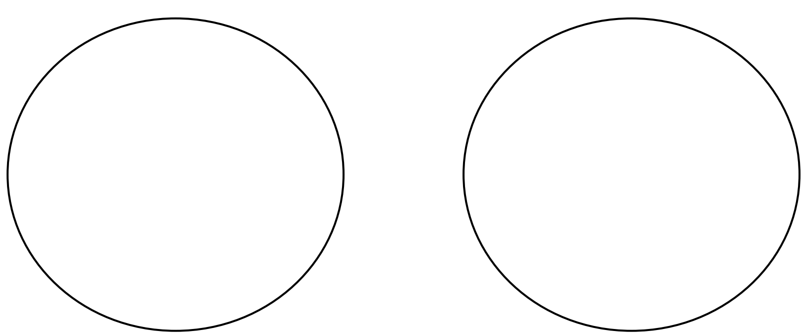
1. Draw and color your 2 chromosomes in the space below.

2. What letters represent your individual's alleles? ______________ This is called genotype. What other genotypes are possible?

3. How would an individual look if they have had the combination of chromosomes you have on your desk? ________________ This is called phenotype. What other phenotype(s) is/are possible?

4. Why are there three possible genotypes and only 2 possible phenotypes?

5. Draw the 2 gametes that this individual will make:



6. What are the letters that represent each parent in your cross: ________ X_________

7. Draw your Punnett square and indicate the chromosomes both by drawing them and by using a letter to represent the chromosome:

8. a. What is the genotype of the offspring in the upper left corner of your Punnett square:______
What is the phenotype of that individual?
b. What is the genotype of the offspring in the upper right corner of your Punnett square:______
What is the phenotype of that individual?
c. What is the genotype of the offspring in the lower left corner of your Punnett square:______
What is the phenotype of that individual?
d. What is the genotype of the offspring in the lower right corner of your Punnett square:______
What is the phenotype of that individual?

9. What is the genotypic ratio of all the offspring? ______________________

10. What is the phenotypic ratio of all the offspring? _____________________

11. How do the gametes of each individual contribute to the offspring?

12. Why do you use a Punnett square?

Punnett Review

Trait	Dominant	Recessive	**Trait**	Dominant	Recessive
Plant height	Tall (*T*)	Short (*t*)	**Fur/hair color**	Black (*B*)	White (*b*)
Eye color	Hazel (*H*)	Blue (*h*)	**Earlobes**	Unattached(*U*)	Attached (*u*)
mid-digit hair	Present (*P*)	Missing (*p*)	**Dimples**	Dimple (*D*)	No dimples (*d*)

1. What letters do you use to represent an individual that is
    a. homozygous recessive for fur color? __________
    b. heterozygous for dimples?
    c. hazel eyed? _____________ or _______________
    d. blue eyed? __________
    e. lacking mid digit hair? _________________
    f. heterozygous for eye color and earlobes? _______________
    g. homozyogous tall, heterozygous black hair? ______________
    h. Homozygous unattached earlobes, heterozygous dimpled? _____________

2. What is the genotype and phenotype of the offspring when two heterozygous tall plants cross?

3. What is the genotype and phenotype of the offspring when a person who is heterozygous for dimples crosses with someone who is homozygous for no dimples?

4. What are the parents' genotype if 1 out of every 4 offspring has white hair and the other 3 have black fur?

5. What are the chances that 2 individuals that are both heterozygous dominant for black fur will have an offspring with black fur? _____________

6. What are the chances that the child of a heterozygous hazel eyed father and a blue-eyed mom will be hazel eyed?

7. What are the chances that the child of a homozygous hazel eyed father and a blue-eyed mom will be hazel eyed?

8. What are the chances that the child of a homozygous hazel eyed, heterozygous dimpled father and a heterozygous hazel eyed, homozygous dimpled mom will have blue eyes and no dimples?

Probability Exercise

Engagement

Each student attempts as best they can to answer each of the following questions.

1. What is probability?
2. When you flip a coin, how likely are you to get heads to come up on top? How likely are you to get a tails on top? How do you know?
3. If you flip a coin 10 times will you get exactly 5 head and 5 tails? Why or why not?
4. If you flip a coin 10 times, could you ever get all 10 heads, just by chance?
5. A couple has had 3 girls in a row. They desperately want a boy. If they have one more child, what is the chance that their fourth child will be a boy?
6. Assume that a gene for red (*r*) is recessive to a gene for white (*R*). Two parents who are both heterozygotes (*Rr* x *Rr*) have four offspring. How many of the four offspring will be red (*rr*)? Will all the offspring from such a cross ever be all white?

Explore and Explain

1. What is probability?

Explanation - Probability is the likelihood of an event, expressed as a mathematical ratio. For example, you might want to know how likely it is that you will win the Reader's Digest $10,000,000 Sweepstakes. If you read the small print on the back of the sweepstakes ticket, you will find that they gave away 243,000,000 tickets and there is only one winner. The probability this therefore 1/243,000,000.

Probability is usually expressed as a fraction (e.g. the probability of being born male is $^1/_2$), a decimal number (e.g. the chance of a mutation occurring is 0.000001), or a percent (e.g. the chance of rain is 20%). Probability always ranges from 0 to 1, and refers to the number of times a specific event will occur in a large group of events. For example, when we say that the probability of being born male is $^1/_2$, what we really mean is that in an infinitely large group of births, $^1/_2$ of the babies will be male. Since $^1/_2$ of the babies in this large group are male, the probability of any single baby being male is also $^1/_2$. The larger group on which the probability is based is called the **population**. Probability refers to the frequency of the event within the population.

Question: The local weather forecaster says that there is a 75% chance of rain today. What does "75% chance of rain mean?

Explanation **-** It means that on a large number of days with weather conditions similar to those that are present today, it rains 75% of the time.

Question: Can you have a 150% chance of rain?

Explanation **-** It is impossible to have a 150% chance of rain. Probability can range from 0-100%. It cannot be over 100%.

2. <u>When you flip a coin, how likely are you to get heads to come up on top? How likely are you to get a tails on top? How do you know?</u>

Explore

During the engagement period, you were asked what is the probability of flipping a coin and having a heads come up on top. What did you answer? How do you know?

So you have made a hypothesis that if you flip a coin, you have a 50% chance of of heads and a 50% chance of tails. How could you go about testing this hypothesis?

Each student flips a coin 10 times. Record the number of heads and number of tails. Tabulate the entire class data on the board. Calculate the probability of heads and the probability of tails.

Discuss how the data may differ from expected. Why don't we see exactly 50% heads and 50% tails. Due to chance factors. Chance important in many things in science. Also occurs in genetic crosses. You may expect 50% green and 50% white, but just by chance, you may get something different. For example, you might get 12 green and 8 white.

3. <u>If you flip a coin 10 times will you get exactly 5 head and 5 tails? Why or why not?</u>

What did you answer? Let's see what happens when we flip a coin 10 times.

Each student flips a coin 10 times. Do this three times (30 flips in all).
Look at number of times a student obtained:
10 heads
9 heads
8 heads
7 heads
6 heads
5 heads
4 heads
3 heads
2 heads
1 head
0 heads

Only a few times did we get exactly 5 heads and 5 tails

4. <u>If you flip a coin 10 times, could you ever get all 10 heads, just by chance?</u>

Explanation - Did we ever get 10 heads in a row? Even though the probability of this event is low, if you flip a coin enough times, you will eventually get 10 heads in a row.

How often would you expect it to occur? (½ x ½ x ½ x ½ x ½ x ½ x ½ x ½ x ½ x ½) = 1/1024)

5. A couple has had 3 girls in a row. They desperately want a boy. If they have one more child, what is the chance that their fourth child will be a boy?

Explore – Let the flip of a coin represent the birth of a baby. Heads will represent a girl, tails will represent a boy.

Flip a coin until you get three heads (girls) in a row. Then flip the coin one more time. Record whether the sex of baby (whether the flip is a heads or tails) after the three girls in a row. Do this four times.

Trial	Sex of baby after three girls in a row
1	_____
2	_____
3	_____
4	_____

Combine data on the board. Calculate the probability of a boy after three girls in a row and the probability of a girl after three girls in a row.

Number of Girls	Number of Boys	Total	Prob. of Girl (number of girls/total	Prob. of Boy (number of boys/total)

Explanation – What was the probability of a having a girl after three girls in a row? What was the probability of having a boy after three girls in a row? Why were they the same?

The probability of having girl is ½, regardless of how many girls have been born previously. This is because the probability is ½ in every conception and prior conceptions do not alter this probability. The probability is determined by the sex chromosomes and does not change based on how many boys and girls have already been born.

6. Assume that a gene for red (*r*) is recessive to a gene for white (*R*). Two parents who are both heterozygotes (*Rr* x *Rr*) have four offspring. How many of the four offspring will be red (*rr*)? Will all the offspring from such a cross ever be all white?

Explore – When two heterozygous parents are crossed (*Rr* x *Rr*) the offspring are expected to be ¾ red and ¼ white (a 3:1 ratio).You will be given a bag containing red and white beans in a 3:1 ratio. These represent the potential progeny of a cross in which we expect a ratio of 3 red to 1 white in the offspring.

Close your eyes and pick out 4 beans one at a time, to assure random selection. Record the bean's phenotype (red or white) and replace it in the bag. Repeat. Be sure to replace each bean in the bag after you have taken it out and recorded its phenotype. Shake the bag frequently.

The four beans you select represent the four offspring from a cross between the two heterozygous parents. Record the number of red and white beans you selected below. Do this five times.

	Number of Red Beans	Number of White Beans
Family 1	_______	_______
Family 2	_______	_______
Family 3	_______	_______
Family 4	_______	_______
Total Number	_______	_______

Along with the other students in the class, record your results on the board.

4 Red 0 White	3 Red 1 White	2 Red 2 White	1 Red 3 White	0 Red 4 White
_____	_____	_____	_____	_____

Explanation – Did you always get exactly 3 white and 1 red offspring in your crosses? Why not? In a cross between two heterozygous parents, we expect ¾ of the offspring to be red and ¼ to be white, but chance often produces deviations from these expected results. Clearly we do not always get exactly ¾ red and ¼ white. In fact, sometimes we get all white and no red and occasionally we get 0 white and all red.

What did you see when you added all the offspring together? Calculate the percent white and percent red for all the crosses. When we combine the results from all the crosses, we see that the numbers are very close to ¾ red and ¼ white. This illustrates the importance of having a large number of offspring in a genetic cross. When the number of offspring is small, we may not see the ratio expected from a genetic cross, but when the number of offspring is large, the ratio becomes apparent.

Probability Questions

1. What is probability?

2. When you flip a coin, how likely are you to get heads to come up on top? How likely are you to get a tails on top? How do you know?

3. If you flip a coin 10 times will you get exactly 5 head and 5 tails? Why or why not?

4. If you flip a coin 10 times, could you ever get all 10 heads, just by chance?

5. A couple has had 3 girls in a row. They desperately want a boy. If they have one more child, what is the chance that their fourth child will be a boy?

6. Assume that a gene for red (*r*) is recessive to a gene for white (*R*). Two parents who are both heterozygotes (*Rr* x *Rr*) have four offspring. How many of the four offspring will be red (*rr*)? Will all the offspring from such a cross ever be all white?

Probability Worksheet

I. Flip a coin 10 times. Record the number of heads and tails.

Your 10 Flips

___ Number of Heads

___ Number of Heads

For the Entire Class

___ Number of Heads

___ Number of Heads

___ Probability of Heads (number of heads/total flips)

___ Probability of Tails (number of tails/total flips)

II. Flip a coin 10 times. Do this three times (30 flips in all).

Your 30 flips

	Number of Heads	Number of Tails
Trial 1 (10 flips)	___	___
Trial 2 (10 flips)	___	___
Trial 3 (10 flips)	___	___

For the entire class

Number of Times in 10 Flips

10 heads	____	4 heads	____
9 heads	____	3 heads	____
8 heads	____	2 heads	____
7 heads	____	1 heads	____
6 heads	____	0 heads	____
5 heads	____		

III. Assume that heads equals girls and tails equals boys. Each flip of the coin is a baby. Flip a coin until you get three heads (girls) in a row. Then flip the coin one more time. Record whether the sex of baby (whether the flip is a heads or tails) after the three girls in a row.

Your Data
Sex of baby after three girls (three heads) in a row: ____

Sex of baby after three girls (three heads) in a row: ____

Sex of baby after three girls (three heads) in a row: ____

Sex of baby after three girls (three heads) in a row: ____

Class Data
Number of girl babies after three girls in a row: ____

Number of boy babies after three girls in a row: ____

Total ____

Probability of a girl baby after three girls in a row (number of girls/total): ____

Probability of a boy baby after three girls in a row (number of boys/total): ____

IV. When two heterozygous parents are crossed (*Rr* x *Rr*) the offspring are expected to be ¾ white and ¼ red (a 3:1 ratio).You will be given a bag containing red and white beans in a 3:1 ratio. These represent the potential progeny of a cross in which we expect a ratio of 3 red to 1 white in the offspring.

Close your eyes and pick out 4 beans one at a time, to assure random selection. Record the bean's phenotype (red or white) and replace it in the bag. Repeat. <u>Be sure to replace each bean in the bag after you have taken it out and recorded its phenotype.</u> Shake the bag frequently.

The four beans you select represent the four offspring from a cross between the two heterozygous parents (one family). Record the number of red and white beans you selected below. Do this five times.

Your Data	Number of White Beans	Number of Red Beans
Family 1	_______	_______
Family 2	_______	_______
Family 3	_______	_______
Family 4	_______	_______
Family 5	_______	_______
Total Number	_______	_______

Class Data

Along with the other students in the class, record your results on the board.

4 White 0 Red	3 White 1 Red	2 White 2 Red	1 White 3 Red	0 White 4 Red
_____	_____	_____	_____	_____

GENA project – Guidelines to College Students for Working With High School Biology Students

1. Start by introducing yourself. Try to learn their first names or call them by name. I'll have them write it at the top of their papers and they should be wearing an ID.

2. Read over the questions the kids will be answering so you're familiar with the questions and possible answers.

Also recognize that for many of the questions a variety of answers are possible and while some answers are better than others, try to find a way to honor all the ways a kid can answer the question. Even if it's flat out wrong, remember that they've had very little instruction in genetics and we're trying to get them to explore the topic. Right answers aren't the goal and many of the questions have multiple "right" answers.

3. Keep them focused. They will be excited (especially by the flies and mice) and will probably lose focus a few times. Keep drawing them back to the questions. Ex: "Okay, guys, let's get back to these questions. Julia, what do you think a gene is?"

4. They will want to stand there and wait for your answer. They'll view you as an expert and they are reluctant to provide an answer if they think you have a better one you'll give them. Avoid giving them answers outright. Keep reinforcing that I'm not grading their papers for right/wrong. The attempt is what I'm looking for.

5. If you finish your questions and can't go on to another station and they begin to ask you questions about college, I'm okay with you talking to them about it. Only a few of these kids would define themselves as college-bound and we're always looking for ways to change that. However, watch out for the slippery slope of personal questions. Don't allow them to pull you into the "do you drink, do you smoke" series of questions. They think college is one big continuous frat party and will probably want to explore that aspect of college life with you. Don't go there.

Also note:

Station III – the questions are really "thinking" kind of questions. You'll have to really help guide the discussion to arrive at some answers. Remember that they know nothing about alleles and so "kind of soil" or other environmental condition is, to me, a perfectly acceptable hypothesis that would account for seedling color. Try to guide them to at least one hypothesis that is related to genetics rather than environment.

Station IV – you will have to help them with the data collection and math. You might divide it up and combine the data. Have some count kernel color and others count shape and then combine data to complete the table. Some of them really struggle with math, so help them with the math even though it's just calculating percentages.

Lisenby and Pierce
GENA Lesson on Genetics
Assessment of Student Performance

A genetics assessment was given to three separate groups at the conclusion of the unit of study.

- Group A – Control Group. Biology students *not* enrolled in Lisenby's class (had a different biology teacher). The teacher presented meiosis, independent assortment, segregation and probability using curriculum that had been previously developed and used at Georgetown High School.
- Group B – Control Group. Students enrolled in one of Lisenby's biology sections, but not in the class receiving the heredity engagement and probability lesson. They did receive the Punnett Square and Meiosis lessons.
- Group C – Treatment Group. Students taught in Lisenby's biology section that participated in all four parts of the GENA designed unit.

Group B and C had two questions on their test that were open-ended and required a written explanation on the part of the student. These two questions were intended to gauge students understanding of the probability unit that was part of the GENA designed lesson. For both questions they had to provide an explanation to receive credit. The questions were:

Question #17 - According to this Punnett Square, the chance of being a male is 50%

	X	Y
X	XX	XY
X	XX	XY

If there is a family with 5 kids and all of them are girls, what is the chance that the next child will be a girl? Explain your answer.

Question #25 - Cystic fibrosis is a genetic disorder that is recessive. We can use the letters *H* = healthy and *h* = cystic fibrosis. A couple you know are both heterozygous (*Hh*) for the condition. They have one child who has the disorder. They have no other children but have told you they want to have more. They believe that they have had their sick child and are planning on having 3 more children believing that they will all be healthy. Is that right? Explain your answer.

Data Analysis of Test Scores and Probability Questions

The overall scores on the genetics assessment of three groups are given in Table 1.

Table 1 – Average Scores of Students in Experimental and Treatment Groups on Genetics Assessment

Group	Experimental/Treatment	Mean Test Score	Standard Error
A	Control (other teacher)	67.43	2.37
B	Control (Lisenby)	68.96	2.49
C	Treatment (Lisenby)	74.35	3.51

The scores of the two control groups (taught by another teacher and by Lisenby) were very similar. The treatment group (group that received the GENA-designed lesson) scored on average 5 points higher on the assessment. However average scores among the three groups were not significantly different (F = 1.24, df = 2, 101, P = 0.29). There was also no significant difference between both control groups combined and the treatment group (F = 2.27, d.f. = 1, 101, P = 0.13).

The number of students correctly answering questions 17 and 25 on probability in treatment and control groups are given in Table 2.

Table 2 - Percent of Students in Experimental and Treatment Groups That Answered Probability Questions Correctly

Question	Control/Treatment	Percent Correct	Total Number
17	Control	46.0	50
17	Treatment	76.5	17
25	Control	20.0	50
25	Treatment	35.3	17

Students in the treatment group who received the GENA designed lesson on probability generally did better on the probability questions than students in the control group. Among students in the treatment group, 76% answered question 17 correctly, compared with only 46% in the control group. A chi-square test indicates that these differences are significant (one-tailed Fisher's Exact Test, P = 0.027). More students in the treatment group also answered correctly question 25 (35% for the treatment group vs. 20% for the control group), but these differences were not significantly different (one-tailed Fisher's Exact Test, P = 0.17)

In summary, the GENA designed curriculum did appear to positively affect student performance on the genetics assessment. Students that received the curriculum scored on average 5 points higher overall on the assessment, although the difference was not statistically significant. The lack of statistical significance is partly a function of the small size of the treatment group (17 students) and the high variance in test scores among groups.

Students who received the curriculum were also more likely to correctly answer questions on probability, particularly question 17, for which the differences were statistically significant. Question 17 focused on a major misconception about probability (that outcomes of prior events alter the probability of future events). Our lesson plan directly addressed this misconception by having students generate empirical data to test whether prior events (number of girls in a family) affects future probability (probability of having a girl in the future). Our data suggests that hands-on analysis of probability can be effective in correcting this misconception.