PEER-LED TEAM LEARNING
INTRODUCTORY BIOLOGY

MODULE 11: MENDELIAN GENETICS 1

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I. Introduction
In sexually reproducing animals, genetic information is passed from the parents to offspring by means of **haploid gametes** (egg and sperm) which, in most organisms, unite to form a **diploid zygote**. The zygote receives half of its chromosomes from one parent and half from the other. The alleles that the parents pass on determine not only the **genotype** of the offspring, but also its observable traits -- its **phenotype**. For example, a child could have the blood type **A**, **B**, **AB**, or **O** depending on what alleles were inherited from the parents. Understanding the patterns of hereditary transmission is the general objective of this workshop.

Benchmarks. Having completed this workshop, you will be able to:

1. Demonstrate the following skills necessary for genetic problem solving: representing genotypes using the proper symbols, determining the gametes produced by parents in a cross, setting up and completing a Punnett square, and finding the genotypic and phenotypic ratios of offspring from a cross.
2. Relate the genetic makeup of gametes to the process of meiosis.
3. Explain the concept of dominance and solve problems involving monohybrid crosses with simple dominance.
4. Explain the concepts of incomplete and codominance and solve problems involving monohybrid crosses with genes showing these interactions.
5. Solve problems involving the inheritance of genes with multiple alleles.

Prepare for your workshop by reading assignments in your textbook (ex., Audesirk, et al. 6th edition, chapter 12; Campbell, 4th edition, Chapters 13 and 14) and completing the Pre-Workshop activities below. Show your work for review in the workshop.

II. Pre-Workshop

Activity 1. Concept and Relationships

1. For the following terms:
 a. give a brief definition
 b. make diagrams of cellular genetic structure that illustrate the relationships among them

heterozygous	**homozygous**	**genotype**
genome	**diploid**	**haploid**
allele	**gene locus**	**homologous chromosomes**
gene		

2. Define the following terms related to genetic crosses:

phenotype	**dominant allele**	**recessive allele**
trait	**character**	

3. The concepts of **character and trait** are important to review. Consider some observable **character** like eye color. Give some examples of specific expressions (traits or phenotypes) that go with eye color. Give other example for characters and traits in non-human organisms.

4. Name four different traits for the character, blood type.

5. Which traits an individual possesses depend to a large extent on what alleles for a gene were received from the parents. For example, how would the alleles carried by people with blue eyes compare to alleles of people with brown eyes?

6. State how genotype is different from trait (phenotype).

7. Explain how genotype and phenotype are related, and give an example.

Activity 2. The genotype of a cell

1. It is often important to summarize what alleles are present in a cell by noting its **genotype**. This notation will also be the genotype for the multicellular organism to which the cell belongs because all the body (somatic) cells of one individual have the same alleles on their chromosomes. Using Figure 1.2 as an example, we represent the genotype by:
    a) including a **letter** for each allele that is present on the chromosomes. What alleles are present? _____

    b) writing those alleles in alphabetical order: _____

    c) placing the upper case (capital) letter first when two different alleles for a gene are present on homologous chromosomes (ex., **AaBb**).
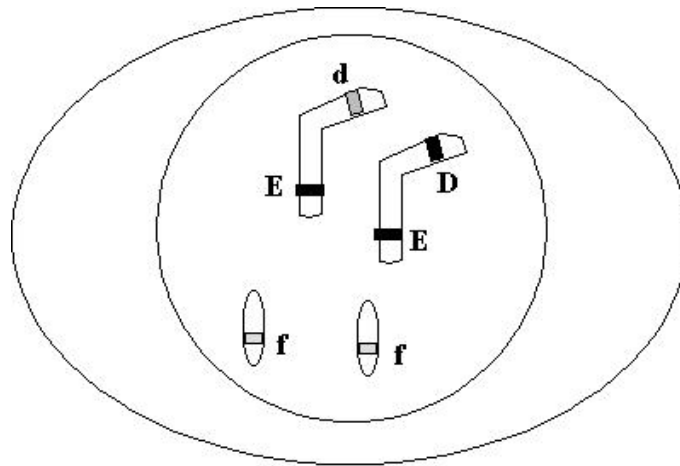
Figure 1.2 Alleles and Genotype

2. Write the correct genotype for the cell in Figure 11.1. _____

3. If the alleles present were **G, a, A, t, T,** and **G**, what would be the correct genotype? _____ .

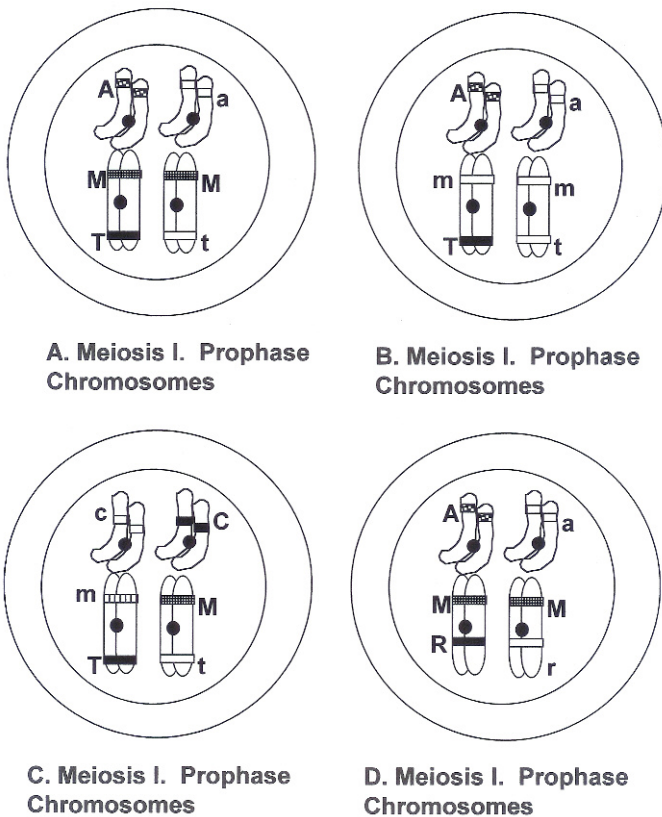4. On Fig. 1.2, add 2 **R** alleles at the top end of the smaller chromosomes. Now write out the genotype.
_____

5. In your own words summarize the procedure and rules for writing the genotype of a cell.
_____
_____

Activity 3. Determining the genetic makeup of gametes

For each of the diploid cells in Fig. 11.2, show the genetic makeup of gametes that could result from meiotic divisions of each cell. Note that the chromosomes can be distributed in different ways, giving rise to different genetic combinations.

A. Meiosis I. Prophase Chromosomes

B. Meiosis I. Prophase Chromosomes

C. Meiosis I. Prophase Chromosomes

D. Meiosis I. Prophase Chromosomes

Fig. 11.2. Cells prepared for meiotic divisions to form gametes.

Activity 4. Skills for genetic problem solving
These exercises will help you learn the skills needed to determine the **patterns of inheritance** from one generation to the next.   These same skills are used by geneticists, livestock breeders, and health counselors in their work. The general question to be answered is: "What are the genotypes and phenotypes of the offspring likely to be if individual **A** mates with individual **B**?" We use a monohybrid cross with dominance to learn the skills.

1. What is a **cross**? What symbol represents a cross? State in words what is meant by "Tall plant x short plant".

2. How many genes are involved in a monohybrid cross?

3. In one type of cross between parents that have different traits (phenotypes) for a character, only one of the traits is expressed in all of the offspring. The relationship revealed from this cross is called _____ .

4. For example when a tall plant is crossed with a short plant, all the offspring (progeny) are tall. Tallness is the _____ trait. Shortness is the _____ trait.

5. The tall plant and short plant are called the **parents**, or **P generation**, in the cross. Usually the parents are represented, not by words (like "tall plant"), but by their genotypes. If **T** is the allele for tallness and **t** is the allele for shortness, what would be the genotypes for the following plants?
     a. a short plant _____
     b. a tall homozygous plant _____
     c. a heterozygous plant _____

6. The offspring of a cross, called **progeny**, are represented the same way—with their genotypes. If the offspring from a cross were all tall, what might their genotype(s) be? _____

7. The offspring of the parents in a cross are members of the **first filial (F$_1$) generation**. To determine the genotypes and phenotypes of the F$_1$ generation involves three important steps:
     Step 1: Write out the cross using the genotypes of the parents.
     Step 2: Determine the possible gametes that can be formed by the parents.
     Step 3: Use a Punnett square to identify the genotypes of all expected   offspring from the cross.

8. Step #1 was reviewed in #5; an example is shown in the first step of Fig 11.3.

9. Step #2 was practiced in Activity 2 above and a sample is shown in Fig. 11.3. Determining gametes is an essential step that often gives students trouble. You will remember that meiosis I sorts the two chromosomes from each homologous pair into different daughter cells. The final result is that each gamete has one of the two homologous chromosomes of the parent cell, and not the other.
     a. For example, if the parent cell had **T** and **t**, what will the gametes have? _____
     b. About how many gametes will have each allele? _____ .Review Activity 2 if this is unclear.

10. Step #3: In setting up a Punnett square, the gametes of 1 parent are represented by symbols for the alleles (like **T** and **t**) placed at the top of each column in the matrix. The gametes of the second parent are represented by allele symbols on the left-hand side of the square next to each row. Study Fig 11.3 to make sure you understand how to do it.
     The gametes from which parent are shown at the top of the table?_____
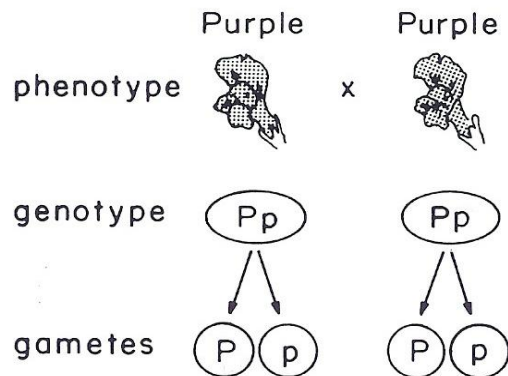   On the left side?_____

Step 1. Set up the cross
            Heterozygous parents Pp x Pp
                P = allele producing purple flowers (dominant)
                p = allele producing white flowers (recessive)
Step 2. Determine the gametes

	Purple		Purple
phenotype	🌸	x	🌸
genotype	(Pp)		(Pp)
gametes	(P)(p)		(P)(p)

Step 3. Complete the Punnett square

♀\♂	P	p
P	PP	Pp
p	Pp	pp

Step 4. Determine the genotypic ratio

        I : 2 : I
        PP   Pp   pp

Step 5. Determine the phenotypic ratio

        3 : I
     purple   white

Fig. 11.3. Setting up a genetics problem

11. In many genetics problems, the final tasks are to determine the **genotypic ratio** and **phenotypic ratio** of the offspring. Ratios represent the relative number of each kind that are present. For example, if a workshop has 10 men and 5 women, the ratio is written 10:5 or 2:1
    a. To obtain the genotypic ratio, you must first determine the number of *different genotypes* that are represented among the progeny. For example PP, Pp, and pp are three different genotypes.
    b. Next count up the number of individuals with each genotype.
    c. Finally express them as a ratio. For example: 1 PP: 2 Pp: 1 pp (Fig 11.3)

d. If there is only one genotype represented among the progeny, no ratio is possible. In this case you would simply summarize the results by saying, for example, "All are genotype Tt."
.   e. If in the cross shown in Fig 11.3, 50% of the offspring were white and 25% were heterozygous purple, what would be the genotypic ratio? _____ . Write the genotypes beneath each number in your ratio.

12. The **phenotypic ratio** is determined by the number of observable traits for the character studied in the cross. For instance if the character is flower color, as in Fig. 11.3, there are two different phenotypes (traits) purple and white.
       a. First, determine how many different phenotypes are represented among the progeny. (Note that some different genotypes may have the same phenotypes.)   _____
       b. Second, count the number of offspring of each phenotype _____
       c. Third, express the numbers as a ratio. For example 3 talls : 1 short _____
       d. Again, if there is only 1 phenotype represented, no ratio is possible. For example, you might simply report, "All are tall."

III. Workshop

Activity 1. Skills in genetic problem solving
Pair problem-solving. Each pair gets one of the following problems and has two minutes to solve it. Each pair presents its solution in jigsaw fashion to the rest of the workshop. Use table 11.1 for genotypes of the parent cell.

Table 11.1. Genotypes for garden pea plants and people.

Organism	*Genotypes*	*Phenotypes (Traits)*
Garden Pea Plants	PP or Pp	Purple flowers
	pp	White flowers
	YY or Yy	Yellow seeds
	yy	Green seeds
	RR or Rr	Smooth seed coat
	rr	Wrinkled seed coat
	TT or Tt	Tall plants
	tt	Short plants
Humans	EE or Ee	Free earlobes
	ee	Attached earlobes
	RR or Rr	Rh positive blood
	rr	Rh negative blood
	FF or Ff	Freckles
	ff	Uniform pigment distribution

1. Represent the parent cell and different gametes that come from that cell by the alleles they carry. (In some problems there may be more than one possibility. List all possibilities.)
       a. A heterozygous pea plant with purple flowers
       b. A short pea plant

c. A pea plant that produces seeds with a smooth coat
d. A heterozygous human with free earlobes
e. A human with Rh positive blood type
f. A pea plant that produces yellow seeds with smooth coats and is heterozygous for both
g. A tall pea plant with white flowers
h. A Rh- person with free earlobes
g. A freckled person with free earlobes

2. . Using the symbols in Table 11.1, represent the following crosses. Include all possible genotypes.   The first is done as an example.
   a. Tall homozygous plant with short (dwarf) plant.   *Answer*:   **TT x tt**
   b. Pea plants with purple flowers (heterozygous) and with white flowers
   c. humans with free earlobes (heterozygous) and with attached earlobes
   d. humans with Rh+ blood (homozygous) and with Rh- blood
   e. Tall pea plants having purple flowers with short pea plants having white flowers
   f. Rh+ person with freckles and Rh- with no freckles

3. Now set up Punnett squares for the six crosses you summarized in #2a-f and fill in the F$_1$ genotypes.

4. Determine the **genotypic ratios** for the six crosses in #2 and express them with the genotypes written below the numbers.

5. Determine the **phenotypic ratios** for the crosses in #2. Indicate the phenotypes next to the numbers.

6. The following are some steps in solving genetics problems.
   a. Organize the steps, in order, using a flow chart.
   b. Briefly explain what each step means in your own words.
   c. Give an example of the step using actual symbols.

   Steps:
▪   Determine the possible gametes that may be formed by each parent.

▪   Write out the cross using genotypes of the parents.

▪   Determine the genotypic ratio of the offspring.

▪   Set up a Punnett Square with the gametes entered along the left side and across the top.

▪   Determine the phenotypic ratio of the offspring.

▪   Fill in the cells of the Punnett square to determine what offspring should be expected from the cross.

▪   Determine the correct symbols for the alleles.

<u>Activity 2. Crosses with simple dominance</u>
Round robin for questions 1-3. Pair problem solving with jigsaw for the rest.

1. An individual pea plant is heterozygous for a gene influencing height (Tt). Only one allele is expressed.
   a. How are genes and allele different?
   b. How are they related?
   c. Which allele is expressed?

d. What is the expressed allele called?
e. What is the non-expressed allele called?
f. What happens to the non-expressed allele?
g. Can the non-expressed allele be expressed again in later generations?
h. What is the only genotype that will permit expression of recessive alleles?

2. By simply looking at the plant or animal (the phenotype), how can you distinguish between a homozygous individual (TT) and a heterozygous one (Tt)?

3. Explain briefly Mendel's Law of Segregation. Give an illustration that helps in your explanation.

Do the following problems in pairs on the board or large sheets of newsprint. Show all the steps and be ready to explain your work to other students.

4. In a given plant, the yellow seed color allele (Y) is dominant to green seed color (y). Give the genotypic and phenotypic ratios for the following crosses:
    a. homozygous yellow x green
    b. heterozygous yellow x green
    c. heterozygous yellow x homozygous yellow
    d. heterozygous yellow x heterozygous yellow
    e. green x green

5. In tigers, there are rare white individuals that lack the normal orange pigment in the fur but still have black stripes. This condition is caused by the expression of a recessive allele, **w**. The dominant allele is **W**. A pair of normally colored parents produces a white cub and a normally pigmented cub.
    a. What are the possible genotypes of the cubs?
    b. What are possible genotypes of the parents that produced the two cubs?
    c. Explain your reasoning by showing a cross that could give the observed results.

6. A guinea pig with black fur was bred to one with brown fur and all offspring had black fur. Breeding two pigs from the F1 generation produced a combination of black and brown individuals in the F2 generation.
    a. What is the dominant allele for coat color? How do you know?
    b. Give symbols to the alleles for coat color in guinea pigs.
    c. Show the genotypes of the parental pair, the alleles in the gametes from each one, and the genotypes of the F1 offspring. Use a Punnett Square to summarize the crosses.
    d. Determine the genotypic and phenotypic ratio for the F1 offspring.
    e. Show the cross between F1 individuals that produced the F2 generation
    f. Suggest what the genotypic and phenotypic ratio would be among the F2 offspring.

7. Pea plant breeders wanted to pick healthy tall plants that were homozygous for the T/t gene. They had a collection of 10 plants that were healthy and tall, but the genotype of these for the height gene was unknown. How might they determine if the 10 tall plants were heterozygous or homozygous for the height gene?
    a. Show all possible genotypes for the 10 tall plants.
    b. What are the possible gametes they could produce if they are heterozygous and homozygous?
    c. Investigate what the outcomes would be if you crossed each individual(TT or Tt) with: a homozygous tall plant, a heterozygous tall plant, or a homozygous short plant.
    d. What cross would be most useful in making the discrimination between heterozygous and homozygous tall plants? Explain using your results.
    e. Explain the concept of a **test cross**.

8. Phenylketonuria is a genetically based disease in which the individual is unable to breakdown an amino acid called phenylalanine which, with its by-product phenylpyruvate, accumulates in the blood stream causing

mental retardation and other side effects. The disease is the result of the expression of a recessive allele. A normal man and woman produce a child with phenylketonuria.

    a. Make up symbols for the alleles in this cross.

    b. Suggest the genotypes of the man, woman and baby and show how normal parents can have a baby with the disease.

    c. If the woman gets pregnant again, what is the probability that she will give birth to a child with the disease? Give the expected ratio of normal offspring to those with the disease.

    d. Can you think of any way these parents can avoid giving birth to a child with this disease?

Activity 3. Incomplete Dominance and Codominance

Team competition. Divide the workshop into two teams. All teams do all the problems, dividing responsibilities among the team members. After a time period for problem solving determined by the peer leader, teams will alternate in giving answers to questions or parts of questions. After an answer is given, the other team has the opportunity to correct or complete the answer given by the other team. Two points per complete answer, one point for corrections or additions. Another way to run the competition is to have one team answer questions in a round robin fashion until it misses. The other team takes over and answers questions until it misses. The peer leader acts as final judge..

1. In **incomplete dominance**, how does the phenotype of the heterozygous individual compare to that of the two homozygous types? Give an example.

2. What is the reason for the phenotypic differences at the molecular level? Explain using the example.

3. To avoid confusion with complete dominance situations, the symbols for the alleles are different than those for complete dominance. For example, in flower color in snapdragons the gene is **C** and the two allelic forms are indicated with superscripts C^R for red pigment, and C^W for the absence of pigment (white).

    a. Give the genotypes of the homozygous and heterozygous individuals

    b. Indicate for each individual what gametes it could produce with the flower color allele identified.

    c. State the relationship between phenotype and genotype for flower color.

4. The so-called "blue" Andalusian variety of chicken is produced by a cross between the black and white varieties. Only a single gene with two alleles is involved. What color offspring and in what ratios would you expect if you crossed:

    a. two blue chickens

    b. a blue and a black chicken

    c. a white and a blue chicken

    The results suggest what relationship between the alleles of the color gene?

5. Two roan colored (red and white hairs mixed) cattle are mated repeatedly and the calves in the F_1 are three different colors, red, white and roan. What are the genotypes of the parents? What is the probability of getting each of these colors (the expected phenotypic ratio)?

Activity 4. Codominance and multiple alleles

Competition as above, or pair problem solving and jigsaw results.

1. Some traits are determined by genes with more than two alleles. Blood type in humans is an example. There are three alleles are involved: I^A is for type A blood, I^B is for type B blood, and **i** is for type O blood. What does each allele code for in the chemistry of blood cells?

2. There are dominance relationships among the three alleles. Based upon the symbols alone what would you predict about the relationships? Explain.

3. Using I^A and I^B explain the concept of **codominance.** What is the relationship of these alleles to **i**?

4. The relationship between genotypes and phenotypes is shown in Table 11.2. Pick two of the examples and state in words the relationship.

Table 11.2. Blood Types and Genotypes in Humans

Blood type (phenotype)	Genotype
0	ii
A	I^AI^A or I^Ai
B	I^BI^B or I^Bi
AB	I^AI^B

5. Determine the genotypic and phenotypic ratios expected in children from the following marriages of people with various blood types.
      a. the man is **AB**, and the woman is heterozygous **B**
      b. the woman is heterozygous **A**, and the man is heterozygous **B**
      c. the man is **O**, and the woman is **AB**
      d. the woman is **AB** and the man is heterozygous **A**
     If there were eight children born to each couple, how many of each blood type would be expected among the offspring?

6. A woman with blood type **B** is heterozygous for the blood type gene. She gives birth to a child who is heterozygous with blood type **A**. In a paternity suit she claims that a certain man is the father and should provide support for the child. Tests show that he is not the father.
      a. what blood types and genotypes could the man have and not be the father?
      b. if he were the father, what blood types and genotypes might he have?

7. Determine which of the following are true and which are false:
      a. A type O child may have two type A parents.
      b. A type O child may have one type AB parent.
      c. A type A child may have two type AB parents.
      d. A type AB child may have one type O parent.

IV. Post-Workshop

<u>Activity 1. Linking concepts</u>
With this vocabulary list make as many mini-concept maps as you can that show important relationships between individual concepts. Follow the rules for concept mapping.

genotype	phenotype	trait
blood type	dominance	dominant
recessive	Law of Segregation	cross
P generation	progeny	sex determination
Punnett square	genotypic ratio	phenotypic ratio codominance
multiple alleles	incomplete dominance	

independent Assortment   first filial generation (F$_1$)   gametes

second filial generation (F$_2$)

Activity 2. Genetics Problems

For each of the problems below:

a. *state the category* of which it is an example (e.g., monohybrid cross with dominance, codominance, incomplete dominance, dominance with multiple alleles).

b. *state what clues* led to your decision.

c. *solve the problem* showing your work, step by step.

1. In a given plant, fruit shape is controlled by a single gene with two alleles. Plants bear fruits that are long, oval or round. Determine the results of the following crosses. Give genotypic and phenotypic ratios. Show your work.

a. plants bearing long fruit x plants bearing oval fruit

b. oval x oval

c. oval x round

d. long x round

e. round x round

2. Two long-winged flies are mated and their offspring include 78 with long wings and 24 with short wings.

a. What are the genotypes of the parents? (You invent the symbols.)

b. Among the F$_1$ generation, what is the expected genotypic ratio?

c. Of the 102 offspring produced, how many of each genotype would you expect?

d. If all short-winged flies among this progeny were allowed to mate among themselves randomly, which phenotypes could be expected in the F$_2$?

3. An F$_1$ female fly from Problem #7 is crossed with a male who is homozygous recessive for wing length. What are the expected genotypic and phenotypic ratios of their offspring? Show your work for all possibilities.

4. In snapdragons both the red allele C^R and the white allele C^W for flower color are expressed in the heterozygous individual giving a pink phenotype.

a. A red parent is crossed with a pink parent and produces 100 offspring. What genotypic and phenotypic ratios would you expect? How many individuals would be in each category?

b. Show the outcome if a representative from each of the different phenotypes above were crossed with a white flowering plant. Give the colors and ratios in each case.

5.   A couple living together has a child with B blood type. The man has blood type AB and the woman has type O blood.

a. What is the genotype of the child?

b. A question of paternity arises when payments for child support are sought by the mother after the couple splits up. The father claims that the woman had been unfaithful and the child was fathered by an acquaintance whose blood type is A. Is this possible?   Explain.

6. What are the possible genotypes and phenotypes for children of a couple that have blood types A and B if both are heterozygous for the blood type gene? If both are homozygous for the blood type gene?

7. Two roan colored (red and white hairs mixed) cattle are mated repeatedly and the calves in the F$_1$ are three different colors, red, white and roan. What are the genotypes of the parents? What is the probability of getting each of these colors (the expected phenotypic ratio)?

8. A spotted rabbit and solid-colored rabbit were crossed. They produced all spotted offspring. When these F_1 rabbits were crossed the F_2 consisted of 32 spotted and 10 solid colored rabbits. Which characteristic is determined by a dominant gene? Give a summary of the crosses using appropriate symbols for the two alleles involved.

9. What proportion of the F_2 spotted rabbits in the prior problem would be heterozygous? Homozygous? How many of the F_2 solid-colored rabbits are expected to be homozygous?

10. What breeding experiment could be used to tell which of the spotted rabbits in the above problem were heterozygous and which, homozygous? Explain using a summary of the crosses.