Name: ______________________________________ Date: ________________________

Student Exploration: Hardy-Weinberg Equilibrium

Vocabulary: allele, genotype, Hardy-Weinberg equation, Hardy-Weinberg principle, heterozygous, homozygous, incompletely dominant, Punnett square

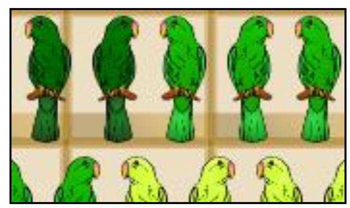
Prior Knowledge Questions (Do these BEFORE using the Gizmo.)

	D	*d*
D		
d		

1. A bird's feather color is controlled by two **alleles**, *D* (dark feathers) and *d* (lighter feathers). Suppose two *Dd* birds mate. What percentages of *DD*, *Dd*, and *dd* offspring would you predict? Use the **Punnett square** at right to help determine your answer.

   DD __________ *Dd* __________ *dd* __________

2. In this situation, what ratio of **heterozygous** (*Dd*) to **homozygous** (*DD* and *dd*) offspring would you expect to find? ____



Gizmo Warm-up
Many factors—immigration, natural selection, hunting, etc—can influence the composition of a population. To determine if one of these factors is affecting a population, it is useful to know what a population looks like when *none* of these factors is present.

In 1908, Godfrey Hardy and Wilhelm Weinberg independently discovered the laws that govern such populations. These laws can be explored in the *Hardy-Weinberg Equilibrium* Gizmo.

1. The parrots you see represent a population of 500 parrots. For these parrots, the *D* allele is **incompletely dominant** over *d*, which means that *Dd* parrots are intermediate between *DD* and *dd* parrots. In the Gizmo, select the TABLE tab. How many parrots of each **genotype** are in the initial population?

   DD __________ *Dd* __________ *dd* __________

2. Return to the DESCRIPTION tab. Click **Begin**, and then click **Breed**. What happens?

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3. Click **Hatch**, and look on the TABLE tab. What are the parrot populations now?

   DD __________ *Dd* __________ *dd* __________

Activity A: Alleles and genotypes	Get the Gizmo ready: • On the DESCRIPTION tab, click **Reset**. • Check that ***DD*** is 50% and ***dd*** is 30%.	

Question: How will the proportion of genotypes and alleles change over time when mating is random and no natural selection is occurring?

1. Predict: How do you expect the proportions of *D* and *d* alleles to change over time?

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2. Gather data: Run a generation in the Gizmo. After clicking **Hatch**, fill in the allele and genotype percentages for generation 1. Repeat this process for 5 generations.

	Initial values	**Generation**				
		1	**2**	**3**	**4**	**5**
% *D* alleles	60					
% *d* alleles	40					
% of *DD* genotype	50					
% of *Dd* genotype	20					
% of *dd* genotype	30					

3. Analyze: What patterns do you see in your data? ___________________________________

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4. Interpret: Select the ALLELE GRAPH tab. What does this graph show? _________________

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5. Interpret: Select the GENOTYPE GRAPH tab. What does this graph show? ______________

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(Activity A continued on next page)

Activity A (continued from previous page)

6. Gather data: On the DESCRIPTION tab, click **Reset**. Set ***DD*** and ***dd*** to any values you like. Fill in the initial values in the table below, and then run the Gizmo for five generations. Record the allele and genotype percentages for each generation in the table below.

	Initial values	**Generation**				
		1	**2**	**3**	**4**	**5**
% *D* alleles						
% *d* alleles						
% of *DD* genotype						
% of *Dd* genotype						
% of *dd* genotype						

7. Analyze: Do the patterns you noticed in the first experiment appear in the second? Explain.

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8. Draw conclusions: The **Hardy-Weinberg principle** states that the proportions of alleles and genotypes in a population will remain stable as long as the following criteria are satisfied:

- Mating is random.
- There is no immigration or emigration.
- No natural or artificial selection is occurring.
- There is no mutation.
- The population is relatively large.

How well does the Hardy-Weinberg principle describe this population of parrots?

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9. Think and discuss: Would you say that this parrot population is evolving? Explain.

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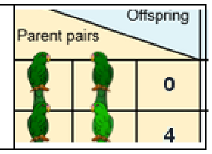
Activity B: **Genotype ratios**	<u>Get the Gizmo ready</u>: • Click **Reset**. • Set ***DD*** to 30% and ***dd*** to 70%.	

Question: How do genotype percentages relate to allele percentages?

1. <u>Calculate</u>: You can use the laws of probability to predict how many *DD*, *Dd*, and *dd* offspring will result from this parent population.

   A. What is the current percentage of *D* alleles in the population? ___________________

   B. What is the current percentage of *d* alleles in the population? ___________________

   C. What is the probability of inheriting a *D* allele from a parent? (Hint: Convert the percentage of *D* alleles to a decimal.) _________________ Call this value *p*.

   D. What is the probability of inheriting a *d* allele? _________________ Call this value *q*.

2. <u>Explain</u>: If a trait is determined by two alleles, the sum of *p* and *q* is 1. Why is this true?

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3. <u>Calculate</u>: Fill in the current *p* and *q* values next to the *D* and *d* alleles around the Punnett square at right. Then calculate the probability of each offspring genotype. Write these values into the individual squares.

   For example, the upper left box in the square represents the probability of a *DD* offspring. The probability of inheriting a *D* allele from each parent is *p*, so the probability of *DD* is p^2.

	D: ___	*d*: ___
D: ___		
d: ___		

   What is the sum of the probabilities in the four squares? ______________________________

4. <u>Manipulate</u>: Now determine an algebraic expression for the probability of each genotype in terms of *p* (the probability of inheriting *D*) and *q* (the probability of inheriting *d*). Use the Punnett square above as a guide.

   A. In terms of *p* and *q*, what is the probability of a *DD* offspring? ___________________

   B. In terms of *p* and *q*, what is the probability of a *dd* offspring? ___________________

   C. In terms of *p* and *q*, what is the probability of a *Dd* offspring? ___________________

(Activity B continued on next page)

Activity B (continued from previous page)

5. Calculate: The **Hardy-Weinberg equation** states that the sum of the probabilities of each genotype is equal to 1:

   probability of *DD* + probability of *Dd* + probability of *dd* = 1

   $$p^2 + 2pq + q^2 = 1$$

   Why is the probability of *Dd* equal to 2*pq*? ____

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6. Predict: Check that ***DD*** is still set to 30% and ***dd*** is still set to 70%. With $p = 0.3$ and $q = 0.7$, what are the predicted percentages of *DD*, *Dd*, and *dd* offspring?

   Predicted percentages: *DD* __________ *Dd* __________ *dd* __________

7. Test: Click **Begin**, **Breed**, and **Hatch**. What are the resulting genotype percentages?

   Actual percentages: *DD* __________ *Dd* __________ *dd* __________

   How close are these to the predicted values? ______________________________________

8. Apply: For a dominant/recessive gene, it is often difficult to determine the percentages of dominant and recessive alleles in a population because individuals that express the dominant trait may be either homozygous (*DD*) or heterozygous (*Dd*). The only thing that is known for certain is the percentage of individuals that are homozygous recessive (*dd*).

   A. Suppose that 16% of a population is homozygous recessive (*dd*). According to the Hardy-Weinberg equation, what is the value of q^2? ____________________

   B. If you know q^2, you can calculate *q*. What is the value of *q*? ____________________

   C. Recall that $p + q$ is equal to 1. What is the value of *p*? ____________________

   D. Based on the values of *p* and *q*, calculate the percentages of the *DD* and *Dd* genotypes: *DD* _______________ *Dd* _______________

9. Check: If a population is in Hardy-Weinberg equilibrium, genotype percentages will remain stable over time. Set ***DD*** to the value given in part D above and ***dd*** to 16%. Run several generations in the Gizmo. Do the genotype percentages remain relatively constant? Explain.

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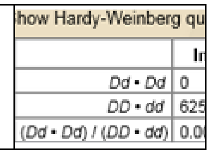
Activity C: **A useful Hardy-Weinberg ratio**	Get the Gizmo ready: • Click **Reset**. Set ***DD*** to 50% and ***dd*** to 50%. • Turn on **Show Hardy-Weinberg quantities**.	

Question: How can you determine if a population is in Hardy-Weinberg equilibrium?

1. Manipulate: The Hardy-Weinberg equation is $p^2 + 2pq + q^2 = 1$, where p = probability of *D*, q = probability of *d*, p^2 = probability of *DD*, $2pq$ = probability of *Dd*, and q^2 = probability of *dd*.

   A. Look under **Show Hardy-Weinberg quantities**. Notice there are two terms: *Dd•Dd* and *DD•dd*. Rewrite each of these in terms of the variables *p* and *q*.

   Dd•Dd: ____________ *DD•dd*: ____________

   B. The third line of the table is the ratio (*Dd•Dd*) / (*DD•dd*). Rewrite this ratio in terms of *p* and *q*, and then simplify the expression. Show your work.

   C. If a population is in Hardy-Weinberg equilibrium, what would you expect to be the ratio of *Dd•Dd* / *DD•dd*? ____________

   Because this ratio is usually close to 4 when a population is in Hardy-Weinberg equilibrium, finding the ratio can be used as a quick test to see if a population is in equilibrium or not. (Note: In most populations, the ratio will range from about 2 to 8.)

2. Experiment: With *Dd* set to 0%, the initial value of *Dd•Dd* / *DD•dd* is 0. Click **Begin**, **Breed**, and **Hatch**. Record the percentage of *DD*, *Dd*, *dd*, and *Dd•Dd* / *DD•dd* for 5 generations in the table below.

	Initial values	Generation				
		1	2	3	4	5
% *DD* genotype	50					
% *Dd* genotype	0					
% *dd* genotype	50					
Dd•Dd / *DD•dd*	0					

3. Calculate: What is the mean value of *Dd•Dd* / *DD•dd*? __________

   While the value of *Dd•Dd* / *DD•dd* may vary a bit, it will tend to stay fairly close to the expected value of 4 as long as a population is in Hardy-Weinberg equilibrium. If the value of *Dd•Dd* / *DD•dd* differs significantly from 4 (for example, below 2 or above 8), it is a sign that the population is not in equilibrium and selection may be taking place.