Hardy-Weinberg Extension for the Whirling Allele (W)
Student Material

Directions/Procedure
1. The black cards (Clubs & Spades) have been separated from the red cards (Diamonds & Hearts) to make a pool of 60 red and 40 black cards, respectively. These 100 cards make up the "gene pool" for the whirling condition. This gene pool contains 40 black (w) cards, which represents the recessive allele, or gene, for the "whirling" condition and 60 red (W) cards, which represents the dominate allele, or gene for the "whirling condition.
Calculate the frequency of the w (black) allele and that of the W (red) allele in this population.

2. The 40 w alleles (black cards) can be paired to form 20 homozygous genotypes (ww) for the non-twirling condition. The 60 W alleles (red cards) can be paired to form 30 homozygous genotypes (WW) for the whirling condition. Calculate the frequencies of the diploid genotypes WW, Ww, and Ww. If helpful, use the Punnett square below.

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Card Exchange
1. You will be given two or more cards. Do not show these cards to anyone.
2. Exchange one card with another person as directed by the teacher.
3. Set aside each new pair of cards as it is formed. Repeat the process until all the cards (alleles) have been exchanged and all new allele pairs have been formed.
4. Using the data collected by all the class, calculate the frequency of the W and w alleles (red and black cards). How does this frequency compare with the initial frequency of the alleles (red and black cards)? Explain.

5. Calculate the number and percentage of each of the WW, Ww, and ww genotypes.

6. Is the frequency of these genotypes different from the frequency in the
original population? Explain.

Second round of mating
1. Use the data from the 1st round of mating to predict the frequencies of W and w alleles and the different genotypes expected in the next generation.

2. As directed by your teacher, complete the 2nd round exchange and the analysis of the data. Record the class data.

Hardy-Weinberg Equilibrium: Brief Background Information

In a system in equilibrium, a “steady state” exists until external forces or factors are introduced to disturb the equilibrium. Thus, in a system in equilibrium there is no change in gene pool. To maintain equilibrium in a system no new genes must enter the gene pool, mating must be random, mutations must not occur, natural selection must not be operating, and the population must be very large. In the model used in this activity, these conditions were maintained. However, the population might not have been large enough to prevent sampling errors. However, these ideal conditions are unlikely to exist in a natural population. Also, if the frequencies do not approximate those expected by the Hardy-Weinberg Equilibrium, one or more of these conditions do not exist in the population and it is changing. Thus, the continued analysis of a population on the basis of Hardy-Weinberg Equilibrium has the potential to be useful in quantifying the evolutionary change in a population.

Major concept: In a population where mating is random, the death rate equals the birth rate, and there is no migration in or out there will be no change in the population unless mutations and natural selection are occurring.
**Expected frequencies on the basis of the Hardy-Weinberg Equilibrium**

The gene frequency of a population in Hardy-Weinberg Equilibrium is represented as follows:

\[ p = \text{the frequency of the dominant allele } W \text{ (gene for whirling)} \]
\[ q = \text{the frequency of the recessive allele } w \text{ (gene for non-whirling)} \]
\[ p + q = 100\% \]

\[ q^2 = \text{the frequency of the recessive genotype (ww)} \]
\[ p^2 = \text{the frequency of the dominant genotype (WW)} \]
\[ 2pq = \text{the frequency of the Ww genotype} \]

\[ p^2 + 2pq + q^2 = 1 \]

Complete the calculations for the frequencies of each of the following in the round 1 mating:

1. **Recessive trait (w)**
   \[ q = \]

2. **Non-whirling genotype (ww)**
   \[ q^2 = \]

3. **Dominant trait (W)**
   \[ p = 1 - q = \]

4. **Heterozygous genotype (Ww)**
   \[ 2pq = \]

5. **Homozygous WW genotype**
   \[ p^2 = \]

6. **Thus the population is composed of three genotypes at the calculated frequencies of**

   - **Homozygous (ww) for the non-whirling gene** =
   - **Heterozygous carriers (Ww) of the whirling gene** =
   - **Homozygous (WW) for the whirling gene** =

   Does your total for the genotypes equal 1?
7. Using probability and the Punnett Square
The genotypes formed during the 1st round of mating were WW, Ww, and ww. Because 60 of the 100 original alleles were W (red cards) and 40 of 100 were w (black cards), .6 of the alleles were W and .4 were w. Complete the following Punnett square. To depict this more clearly, a Punnett square can be set up. Because of the population size the frequencies that resulted probably varied from these values.

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<tr>
<td>W</td>
<td>f = .6</td>
<td>f = .4</td>
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<tr>
<td>W</td>
<td>f = .6</td>
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<td>w</td>
<td>f = .4</td>
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Are your results the same as those from your calculations using the Hardy Weinberg Equilibrium formula?

**Comparison of the data collected in 1st and 2nd round**
1. Analyze the results and, if present, the variation between the 1st and 2nd round data.

2. Compare the variation between the 1st and 2nd round data and the frequencies predicted by the Hardy-Weinberg Equilibrium.

3. Why is the word equilibrium is used in labeling, or stating, the Hardy-Weinberg Equilibrium concept?
4. Analyze how the frequency of alleles would change if the individuals who were homozygous recessive (ww) never mated.
Hardy-Weinberg Extension for the Whirling Allele (W)
Teacher Material

Overview
This activity is designed to model the theoretical distribution of two alleles in the gene pool during the mating process in a large population that over an extended period of time has no gain or loss of genes, the genes are not subject to mutation, and natural selection is not occurring. The Hardy-Weinberg Equilibrium is explained and applied in this activity.

TEKS-Biology
7 The students knows the theory of biological evolution
C3E evaluate models according to their adequacy in representing biological objects or events
7B illustrates the results of natural selection in speciation, diversity, phylogeny, adaptation, behavior, and extinction

Materials
- Two decks of playing cards (3" x 5" labeled cards are also workable).
- A song from a Rolling Stones album (optional) to play during the introduction of this activity.
- No student worksheets have been prepared.

Preparation
- Separate the black (Clubs & Spades) from the red (Diamonds & Hearts) cards from the 2 decks to make a pool of 60 red and 40 black cards, respectively. These 100 cards make up the "gene pool" for the whirling condition. This gene pool contains 40 black cards and 60 red cards, so the frequency of the w (black) allele is 40/100 = 0.4, and the frequency of the W (red) allele is 60/100 = 0.6.
- Create 20 homozygous genotypes (ww) for the non-twirling allele by pairing the black cards by color only. Create 30 homozygous genotypes (WW) with the whirling allele by pairing red cards. The frequencies of the diploid genotypes are 0.6 for WW (30/50), 0.4 for ww (20/50) and 0 for Ww.

Procedure
1. Review the genetics of the whirling condition as emphasized in the earlier phase of this activity. Emphasize that all the genotype pairs are homozygous.
2. Ask the class to calculate the frequency of each gene and the frequency of each diploid genotype.
3. Distribute the cards to the students. Depending on class size, the number of allele pairs a student will hold will vary. In a class of 25, each student
would have 2 allele pairs (4 cards). In a class of 20, give 10 students 2 allele pairs (4 cards) and 10 students 3 allele pairs (6 cards). For other class sizes, adjust accordingly, but maintain a gene pool of 100 alleles (cards).

4. It is essential in this process that mating be random and without regard to genotype. Thus, students should move around the room with their cards. To model the necessary randomness, each student should move around to greet in sequence three other students. In meeting a 4th student, each should exchange one card without indicating whether the card being passed on is red or black. (To avoid confusion, this phase of the activity may need to be orchestrated so that the students are prompted so as to move in unison from the sequence of these meetings).

5. Each student should set aside each new pair as it is formed. The process is repeated until all the cards (alleles) have been exchanged and all new allele pairs have been formed.

6. Calculate the frequency by number and percentage of the genes and genotypes. (Make sure that each student keeps his or her set of cards separate for use in the 2nd round of this activity).

7. Because no W and w alleles (red and black cards) have either entered or left the gene pool, the frequencies of W and w will still be 0.6, and 0.4, respectively.

8. Work with the students to determine the number and percentage of each of the WW, Ww, and ww genotypes.

9. Discuss why the frequency of these genotypes is not the same as in the original set of genotypes.

Second round of mating

1. Ask the students to predict the frequencies of genes and genotypes expected in the next generation.

2. As noted previously the frequency of the W (red cards) and w (black cards) alleles remains constant as cards have not been added or deleted. Because of this factor and the random pairing, the frequency of the three genotypes should be similar to the 1st round frequencies. However, because of the limited population, sampling errors could impact the results significantly.

3. Repeat the 2nd round exchange and the analysis of the data.

4. Compare the results of the two rounds and discuss why the results are similar or possibly different.

Hardy-Weinberg Equilibrium: Brief Background Information

In a system in equilibrium, a “steady state” exists until external forces or factors are introduced to disturb the equilibrium. Thus, in a system in equilibrium there is no change in gene pool. To maintain equilibrium in a system no new genes must enter the gene pool, mating must be random, mutations must not occur, natural selection must not be operating, and the population must be very large. In the
model used in this activity, these conditions were maintained. However, the population might not have been large enough to prevent sampling errors. However, these ideal conditions are unlikely to exist in a natural population. Also, if the frequencies do not approximate those expected by the Hardy-Weinberg Equilibrium, one or more of these conditions do not exist in the population and it is changing. Thus, the continued analysis of a population on the basis of Hardy-Weinberg Equilibrium has the potential to be useful in quantifying the evolutionary change in a population.

Major concept: In a population where mating is random, the death rate equals the birth rate, and there is no migration in or out there will be no change in the population unless mutations and natural selection are occurring.

**Expected frequencies on the basis of the Hardy-Weinberg Equilibrium**
The gene frequency of a population in Hardy-Weinberg Equilibrium is represented as follows:

\[ p = \text{the frequency of the dominant allele } W \text{ (gene for whirling)} \]
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\[ p + q = 100\% \]

\[ q^2 = \text{the frequency of the recessive genotype (ww)} \]
\[ p^2 = \text{the frequency of the dominant genotype (WW)} \]
\[ 2pq = \text{the frequency of the Ww genotype} \]
\[ p^2 + 2pq + q^2 = 1 \]

**Calculations**

1. **Recessive trait (w)**
   40 of the 100 alleles were w (non-whirling) thus the frequency for this recessive trait is
   \[ q = \frac{40}{100} = .40 \]

2. **Non-whirling genotype (ww)**
   The square of the frequency of recessive allele (w) is equal to the allele frequency of the non-whirling genotype (ww).
   \[ q^2 = (.40)^2 = 0.16 = 16/100 \]

3. **Dominant trait (W)**
   The frequency of the normal (whirling) allele (W) is equal to 1 - the frequency of the non-whirling allele (w) (60 of the 100 alleles were W (whirling)).
   \[ p = 1 - q = 1 - 0.40 = 0.60 \]
4. Heterozygous genotype (Ww)
The frequency of the Ww genotype is
\[ 2pq = 2 \times (0.6 \times 0.4) = 0.48 \text{ or } 48/100 \]

5. Homozygous WW genotype
The frequency of the WW for the normal allele (W) is
\[ p^2 = WW = 0.6^2 = 0.36 \text{ or } 36/100 \]

6. Thus the population is composed of three genotypes at the calculated frequencies of
- Homozygous (ww) for the non-whirling gene = 0.16 = 16/100
- Heterozygous carriers (Ww) of the whirling gene = 0.48 = 48/100
- Homozygous (WW) for the whirling gene = 0.36 = 36/100

7. Using probability and the Punnett Square
The genotypes formed during the 1st round of mating were WW, Ww, and ww. Because 60 of the 100 original alleles were W (red cards) and 40 of 100 were w (black cards), on the basis of probability the predicted frequency of the genotypes would be .36 WW (.6 x .6), .24 Ww (.6 x .4), .24 wW (.4 x .6) and .16 ww (.4 x .4). To depict this more clearly, a Punnett square can be set up. Because of the population size the frequencies that resulted probably varied from these values.

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**Comparison of the data collected in 1st round**
1. Analyze the results and, if present, the variation between the 1st and 2nd round data. *Because the frequencies of the W and w alleles have not changed (cards were neither added or taken out of the sets), the frequencies of the genotypes should be similar. However, the small sample size will result in some variation in the frequencies.*
2. Analyze the variation between the 1st and 2nd round data and the frequencies predicted by the Hardy-Weinberg Equilibrium. Because the frequencies of the W and w alleles have not changed (cards were neither added or taken out of the sets), the frequencies of the genotypes should be similar. However, the small sample size will result in some variation in the frequencies.

3. Why is the word equilibrium is used in labeling, or stating, the Hardy-Weinberg Equilibrium concept? Because the gene pool is not changed, the percentage of alleles present in the population does not change. Be sure to emphasize the difference between the alleles, which stay constant, and the genotypes, which vary due to the randomness of mating.

4. Analyze how the frequency of alleles would change if the individuals who were homozygous recessive (ww) never mated. If 16 of the 40 w alleles would be removed from the gene pool and now 60/84 of the alleles are W and 24/84 are w. If the homozygous recessive population never mated, there would be no equilibrium as the frequency of the w allele would continue to decrease. As a result, the population would change and there would be more “whirlers” and less “whirlers.”

Another round?
If time and interest permits, conduct a 3rd round using a new ratio of W alleles (red cards) to w alleles (black cards). For example, 70 red cards and 30 black cards could be used to make up the gene pool.

Predicted results on the basis of the Hardy-Weinberg Equilibrium

\[
p = .70 \text{ (the frequency of the dominant allele } W)\\
q = .30 \text{ (the frequency of the recessive allele } w)\\
p + q = .7 + .3 = 1\\
\]

\[
q^2 = \text{ the frequency of the recessive genotype (ww)}\\
p^2 = \text{ the frequency of the dominant genotype (WW)}\\
2pq = \text{ the frequency of the Ww genotype}\\
\]

\[
p^2 + 2pq + q^2 = 1\\
.7^2 + 2(.7 \times .3) + .3^2 = 1\\
.49 + .42 + .9 = 1.00\\
\]

49\% = the frequency of the WW genotype
42\% = the frequency of the Ww genotype
9\% = the frequency of the ww genotype
Notice that the removal of 10 w alleles (black cards) and the addition of 10 red cards (W) resulted in predicted decrease of 7% and 6% in the ww and Ww genotypes, respectively, and a 13% increase in the WW genotype. These results show the significance of the flow of genes in or out of a population.

Analysis of the model
The overall activity (cards used, format of the activity, and Hardy-Weinberg Equilibrium) represents an effort to model how the distribution of gene frequencies in a population may be determined. Discuss with the students how the strengths and the limitations of this model in helping them understand the phenomena involved.

Reference
This activity has been adapted from Cronkite, Donald. "Hardy-Weinberg Equilibrium According to Hoyle: OR, Population Genetics of Platypapyrus foursuitii OR, Using playing cards to model basic population genetics." Access Excellence Woodrow Wilson Collection.

To view a video that shows a classroom where the Hardy-Weinberg Equilibrium is being emphasized go to the following site:
http://www.pbs.org/wgbh/evolution/educators/teachstuds/tvideos.html

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