Hardy-Weinberg Equilibrium Model

Contributors

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Intended Audience

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<td>K-4</td>
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<td>5-8</td>
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Activity Characteristics

<table>
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<td>Classroom Setting</td>
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<tr>
<td>Requires special equipment</td>
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<td>Uses hands-on manipulatives</td>
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<td>Requires mathematical skills</td>
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<td>Can be performed individually</td>
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<td>Requires group work</td>
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Introduction

Description
In this activity, students explore the Hardy-Weinberg principle and test genotype frequencies across generations under different selective pressures.

Abstract
Students test different individuals’ ability to taste PTC (phenylthiocarbamide) to demonstrate the Hardy-Weinberg principle. Students will also test the genotype frequencies of an ideal population across generations and examine how selection, heterozygote advantage, and genetic drift change the genotype frequencies.

Core Themes Addressed

<table>
<thead>
<tr>
<th>Microbial Cell Biology</th>
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<tbody>
<tr>
<td>Microbial Genetics</td>
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<td>Microorganisms and Humans</td>
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<td>Microorganisms and the Environment</td>
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<td>Microbial Evolution and Diversity</td>
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<td>Other - Evolution and Natural Selection</td>
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</tbody>
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Keywords
allele, gene pool, population, homozygous, heterozygous, genetic drift, selection, heterozygote advantage

Learning Objectives
At completion of this activity, learner will

1. Explain what constitutes evolution
2. Identify seven conditions that are needed for evolution to NOT occur in a population
3. Explain the mechanisms of evolution
4. Be able to use the Hardy-Weinberg equation

National Science Education Standards Addressed

Standard A: Science as Inquiry
- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Standard C: Life Science
- Biological evolution
Teacher Handout

Hardy-Weinberg Equilibrium Model

Student Prior Knowledge

Students should have the following knowledge prior to completing this activity:
1. Capable of solving basic algebraic equations
2. Know the definition for allele, population, and gene pool
3. Be able to distinguish between homozygous-dominant, heterozygous, homozygous-recessive

Teacher Background Information

Evolution is a change in frequencies of alleles in the gene pool of a population. Evolution will NOT occur in a population if seven conditions are met. The Hardy-Weinberg equilibrium equation \((p^2 + 2pq + q^2 = 1)\) can be used to discover the probable genotype frequencies in a population and to track their changes from one generation to another. The \(p^2\) in the equation is the frequency of homozygous dominant (AA) people in a population, \(2pq\) is the frequency of the heterozygous (Aa) people, and \(q^2\) is the frequency of homozygous recessive (aa) ones. Because there are only two alleles in this case, the frequency of one plus the frequency of the other must equal 100%, which means \(p + q = 1\).

Class Time

This activity will require a minimum of one 90 minute class period.

1. It will take students 15-20 minutes to taste the PTC test papers and calculate allele frequencies using the Hardy-Weinberg equation.

2. It will take students 45-60 minutes to test the Hardy-Weinberg Principle of an ideal population, a population subjected to selection, a population with heterozygote advantage, and a population experiencing genetic drift.

Teacher Preparation Time

This lesson will require approximately 10 minutes of preparation time.

1. Divide supplies so that each group will have each necessary component.
Materials and Equipment

Have the following for each student:

PTC paper
Control paper
4 Index cards
1 Coin

Methods

A. Calculating Allele Frequencies Using the Hardy-Weinberg Principle

1. Obtain a piece of PTC test paper.
2. Place it on your tongue and note whether you can detect a taste.
3. Obtain a piece of control paper and place it on your tongue. Comparing the control paper with the PTC paper will help determine whether you detected a taste on the PTC paper.
4. Tally the results for the entire class and enter the results in Table 1.
5. Tally the number of tasters and nontasters, calculate the percentage for each group, and record your results Table 2. Calculate the frequencies for each allele, using the Hardy-Weinberg equation. Be sure to show your work.

B. Testing the Hardy Weinberg Principle

Case 1: Testing an Ideal Population

The entire class will be used as a representative population. The four cards each students uses, two “A” and two “a”, represent haploid chromosomes contributed by parents in a simulated breeding exercise.

1. Obtain four index cards. Label two “A” and two “a”. These will be your haploid chromosomes.
2. Randomly pair off with another student for “breeding”. Choose any other student; gender doesn’t matter in the simulation.
3. Turn your cards upside down and shuffle them. Each partner should turn over the top card in his/her pile. Pair this card with your partner’s card; this will be the genotype of your first offspring.
4. Turn over the next card in your pile. Pair this card with your partner’s card; this will be the genotype of your second offspring.

5. Now you and your partner must take on the genotypes of the two offspring that you produced. For example, if you produced offspring with the genotypes “AA” and “Aa”, one member will begin the next generation with four “A” cards, and the other member will begin the next generation with two “A” cards and two “a” cards. Record the genotype in the Data and Analysis section.

6. Randomly seek out another class member to pair off with for the next generation of “breeding”.

7. Repeat the above procedure for the second generation. Record the genotypes in Data and Analysis section.

8. Repeat Steps 3-7 for three more generations, for a total of five generations. Record the genotypes for each subsequent generation.

9. Combine the genotype of your fifth generation results with the rest of the students’ fifth generation results and enter the totals in the Data and Analysis section.

10. Calculate the allele frequencies after five generations of random mating.

Case 2: Selection

The previous exercise was conducted with ideal parameters. For a more realistic situation, selection must be used. There is 100% selection against homozygous-recessive offspring. If offspring are recessive, they will not survive to reproductive age.

1. Follow the same procedure as the previous exercise, with one difference: If offspring is produced with the genotype “aa”, this offspring will not survive; eliminate the alleles from the population. To maintain population size, you must produce two surviving offspring. If two alleles are eliminated, draw two new alleles from the extra cards.

2. Repeat the procedure for a total of five generations, selecting against homozygous-recessive offspring in each generation. Record the genotypes after every generation in the Data and Analysis section.

3. Combine the genotype of your fifth generation results with the rest of the students’ fifth generation results and enter the totals in the Data and Analysis section.

4. Calculate the allele frequencies after five generations of random mating.

Case 3: Heterozygote Advantage
The previous exercise showed how selection against homozygous-recessive individuals clearly alters the allelic frequencies in a population. Another form of selection that operates within a gene pool is diseases, such as a deadly form of malaria, that affect homozygous-dominant individuals more severely than heterozygous individuals. The heterozygote is therefore favored in a population.

1. Follow the same procedure, eliminating homozygous-recessive individuals as before. In addition, if a homozygous-dominant individual is produced, flip a coin. If the result is heads, the offspring dies; if it is tails, the offspring survives.

2. Repeat the procedure for a total of five generations. Record the genotypes after every generation in the Data and Analysis section.

3. Combine the genotype of your fifth generation results with the rest of the students’ fifth generation results and enter the totals in the Data and Analysis section.

4. Continue the procedure for five more generations, for a total of ten generations, this time starting with the genotypes from the end of the fifth generation. Record the genotypes in the Data and Analysis section.

5. Calculate the allele frequencies after ten generations of random mating.

Case 4: Genetic Drift

Genetic drift is a phenomenon where an allele is lost solely from chance instead of through selection. The most important factor in genetic drift is population size; smaller populations have a much greater potential for genetic drift.

1) Your teacher will divide the class into several smaller populations. Within your smaller population, follow the mating procedure, as in the first exercise, for a total of five generations. Record the genotypes after every generation in the Data and Analysis section.

2) Combine your group's fifth generation results with those of the other small populations and calculate the new allele frequencies.

Tips/Suggestions

- Testing all four cases involving the Hardy-Weinberg Principle might take longer than one 90 minute class period depending how well the students understand the calculations.
- Providing an additional problem worksheet will help students to better understand the Hardy-Weinberg equation.
References

This activity was modified from: “AP Biology Lab 8: Population Genetics and Evolution Lab Activity”. WARD’S Natural Science Establishment. Copyright 2002.

Answers to Student Handouts

1) Provide an example of evolution using the definition you learned from this activity.

*Answer:* Answers will vary but look for examples where a population has allele frequency changes across generations. For example, in a population with a frequency of allele A at 75% and if this frequency is 55% after 10 generations, then evolution has occurred.

2) List seven conditions that are required for evolution to NOT occur in a population. What major assumption(s) were not strictly followed in this simulation?

*Answer:* 1. No mutation, 2. no natural selection, 3. no migration between populations, 4. mating is random, 5. all members of the population breed, 6. everyone produces the same number of offspring, and 7. population is infinitely large. The major assumption that could not be strictly followed in the simulation is assumption 7. This assumption is impossible to simulate in a classroom.

3) Explain one mechanism of evolution and provide an example of how it works.

*Answer:* Answers will vary but look for examples of mutation, genetic drift, natural selection or migration.

4) You have sampled a population in which you know that the percentage of the homozygous recessive genotype (aa) is 36%. Calculate the following:

A. The frequency of the "aa" genotype.
B. The frequency of the "a" allele.
C. The frequency of the "A" allele.
D. The frequencies of the genotypes "AA" and "Aa."
E. The frequencies of the two possible phenotypes if "A" is completely dominant over "a."

*Answer:* A. 36%, B. 60%, C. 40%, D. AA is 16% and Aa is 48%, E. the dominant frequency is 64% and the recessive frequency is 36%.

5) Cystic fibrosis is a recessive condition that affects about 1 in 2,500 babies in the Caucasian population of the United States. Please calculate the following:

A. The frequency of the recessive allele in the population.
B. The frequency of the dominant allele in the population.
C. The percentage of heterozygous individuals (carriers) in the population.
Answer: A. the frequency of the cystic fibrosis (recessive) allele in the population is 0.02 (or 2%), B. the frequency of the dominant (normal) allele in the population is 0.98 (or 98%), C. the frequency of heterozygotes or carriers is 0.04 or 1 in 25

6) Within a population of butterflies, the color brown (B) is dominant over the color white (b). And, 40% of all butterflies are white. Given this simple information, which is something that is very likely to be on an exam, calculate the following:

A. The percentage of butterflies in the population that are heterozygous.
B. The frequency of homozygous dominant individuals.

Answers: A. the frequency heterozygous individuals is 0.47 (47%), B. the frequency of homozygous dominant individuals is 0.14 (14%)
Introduction
Evolution is a change in frequencies of alleles in the gene pool of a population. This definition of evolution was developed by Godfrey Hardy and Wilhelm Weinberg. Hardy, Weinberg, and the population geneticists who followed them came to understand that evolution will NOT occur in a population if seven conditions are met. Think about what those seven conditions are ……….

Hardy and Weinberg went on to develop a simple equation that can be used to discover the probable genotype frequencies in a population and to track their changes from one generation to another. This has become known as the Hardy-Weinberg equilibrium equation. In this equation

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

\( p^2 \) is the frequency of homozygous dominant (AA) people in a population, \( 2pq \) is the frequency of the heterozygous (Aa) people, and \( q^2 \) is the frequency of homozygous recessive (aa) ones.

Because there are only two alleles in this case, the frequency of one plus the frequency of the other must equal 100%, which is to say

\[ p + q = 1 \]

Therefore, \((p + q)^2 = 1^2 \) becomes \((p^2 + 2pq + q^2) = 1\).

Student Background Knowledge
Students should have the following knowledge prior to completing this activity:

1. Capable of solving basic algebraic equations
2. Know the definition for allele, population, and gene pool
3. Be able to distinguish between homozygous-dominant, heterozygous, homozygous-recessive

Vocabulary
**Allele:** alternative version of a gene

**Gene pool:** a complete set of unique alleles in a population

**Population:** a group of individuals of the same species living in the same geographical area

**Homozygous:** having the same alleles for a particular gene
Heterozygous: having two different alleles for a particular gene

Genetic drift: random changes in the gene frequencies of a population across generations

Selection: a process in which some individuals with traits that improve survival or reproduction produce more offspring than other individuals

Heterozygote advantage: a situation in which the heterozygote genotype has a higher relative fitness than either the homozygote dominant or recessive genotype

Materials Checklist

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<thead>
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<th>Item</th>
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<tbody>
<tr>
<td>PTC paper</td>
</tr>
<tr>
<td>control paper</td>
</tr>
<tr>
<td>4 index cards</td>
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<tr>
<td>1 coin</td>
</tr>
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Procedure

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2. Combine your group's fifth generation results with those of the other small populations and calculate the new allele frequencies.
Data and Analysis

Table 1.

<table>
<thead>
<tr>
<th></th>
<th>Taster</th>
<th>Nontaster</th>
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<tbody>
<tr>
<td>PTC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td></td>
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</tbody>
</table>

Table 2.

<table>
<thead>
<tr>
<th>Phenotypes</th>
<th>Allele Frequency Based on the Hardy-Weinberg Equation</th>
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</thead>
<tbody>
<tr>
<td>Tasters ($p^2 + 2pq$)</td>
<td>Nontasters ($q^2$)</td>
</tr>
<tr>
<td>Class Population</td>
<td>#</td>
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</table>

Case 1: Testing an Ideal Population

Initial Class Frequencies: AA: 0.25  Aa: 0.50  aa: 0.25

My Initial Genotype: Aa

$F_1$ Genotype: _____

$F_2$ Genotype: _____

$F_3$ Genotype: _____

$F_4$ Genotype: _____

$F_5$ Genotype: _____

Final Class Frequencies: AA: _____  Aa: _____  aa: _____

$p$: _____  $q$: _____

Number of A alleles present at the fifth generation
Number of offspring with genotype AA _____ X 2 = _____ A alleles
Number of offspring with genotype Aa _____ X 2 = _____ A alleles
    Total = _____ A alleles

\[ p = \frac{\text{TOTAL number of } A \text{ alleles}}{\text{TOTAL number of alleles in the population}} \]
\[ q = \frac{\text{TOTAL number of } a \text{ alleles}}{\text{TOTAL number of alleles in the population}} \]

**Case 2: Selection**

Initial Class Frequencies: AA: 0.25      Aa: 0.50      aa: 0.25

My Initial Genotype: Aa

    F_1 Genotype: _____
    F_2 Genotype: _____
    F_3 Genotype: _____
    F_4 Genotype: _____
    F_5 Genotype: _____

Final Class Frequencies: AA: _____      Aa: _____      aa: _____

    p: _____      q: _____

**Case 3: Heterozygote Advantage**

Initial Class Frequencies: AA: 0.25      Aa: 0.50      aa: 0.25

My Initial Genotype: Aa

    F_1 Genotype: _____
    F_2 Genotype: _____
    F_3 Genotype: _____
    F_4 Genotype: _____
    F_5 Genotype: _____
Final Class Frequencies: AA: _____   Aa: _____   aa: _____
(After five generations)
   p: _____   q: _____
F6 Genotype: _____
F7 Genotype: _____
F8 Genotype: _____
F9 Genotype: _____
F10 Genotype: _____
Final Class Frequencies: AA: _____   Aa: _____   aa: _____
   p: _____   q: _____
Final Class Frequencies: AA: _____   Aa: _____   aa: _____
(After ten generations)
   p: _____   q: _____

Case 4: Genetic Drift

Initial Class Frequencies: AA: 0.25   Aa: 0.50   aa: 0.25

My Initial Genotype: Aa
   F1 Genotype: _____
   F2 Genotype: _____
   F3 Genotype: _____
   F4 Genotype: _____
   F5 Genotype: _____

Final Class Frequencies: AA: _____   Aa: _____   aa: _____
   p: _____   q: _____
Student Worksheet

Hardy-Weinberg Equilibrium Model

Student's name __________________________________________ Date __________________

Questions

1) Provide an example of evolution using the definition you learned from this activity.

2) List seven conditions that are required for evolution to NOT occur in a population. What major assumption(s) were not strictly followed in this simulation?

3) Explain one mechanism of evolution and provide an example of how it works.

4) You have sampled a population in which you know that the percentage of the homozygous recessive genotype (aa) is 36%. Calculate the following:

   A. The frequency of the "aa" genotype.
   B. The frequency of the "a" allele.
   C. The frequency of the "A" allele.
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   E. The frequencies of the two possible phenotypes if "A" is completely dominant over "a."

5) Cystic fibrosis is a recessive condition that affects about 1 in 2,500 babies in the Caucasian population of the United States. Please calculate the following:

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   B. The frequency of the dominant allele in the population.
   C. The percentage of heterozygous individuals (carriers) in the population.

6) Within a population of butterflies, the color brown (B) is dominant over the color white (b). And, 40% of all butterflies are white. Given this simple information, which is something that is very likely to be on an exam, calculate the following:

   A. The percentage of butterflies in the population that are heterozygous.
   B. The frequency of homozygous dominant individuals.