

Mechanisms of Evolution: Genetic Drift and Natural Selection

Introduction

A population is a group of individuals of the same species living in the same geographical area that interbreeds freely. The sum of all the alleles of all the members of the population is its gene pool. For each gene, every individual has only two alleles, but there may be more than two alleles in the gene pool, each with its own frequency. Evolution is frequently defined genetically as a change in the frequency of one or more alleles in the gene pool from one generation to the next. As the frequency of an allele refers to its frequency in the population, evolution occurs in the population as a whole, and not in individuals. The conditions that cause a change in allele frequencies are:

1. mutations,
2. gene flow,
3. nonrandom mating,
4. genetic drift, and
5. natural selection.

This exercise focuses on genetic drift and natural selection.

Genetic drift refers to changes in allele frequencies due to random chance alone. The founder effect occurs when a few individuals start a new colony and only a fraction of the genetic diversity of the original gene pool is present in these individuals. The new population is likely to have much different allele frequencies than the parental population.

Natural selection occurs when a new phenotype appears in a few members of a population that allows them to better utilize the available resources. These individuals are more likely to survive and have more offspring than those individuals that lack the new phenotype. In subsequent generations, more members of the population will have the new phenotype, and eventually, many members of the population will have the phenotype and be better adapted to the environment.

A. The Hardy-Weinberg Law

The Hardy-Weinberg law, which is used to calculate the frequencies of alleles in a gene pool, provides a baseline by which to judge if evolution has occurred or not. Hardy and Weinberg independently demonstrated that sexual reproduction alone will do nothing to change the frequencies of alleles in a gene pool provided that certain conditions are met. These conditions are:

1. There must be no mutations of the alleles.

2. There must be random mating between individuals, regardless of genotype.
3. The population must be large enough so that the laws of probability operate.
4. The population must be isolated, with no immigration or emigration.
5. There must be no natural selection.

Provided these conditions are perfectly met, the population will not evolve and the allele frequency will not change from one generation to the next. However, if an outside evolutionary agent, such as genetic drift, natural selection, nonrandom mating, mutation, or gene flow is operating, allele frequencies will change and the population will evolve.

The frequency of the recessive and dominant alleles, the three genotypes (homozygous dominant, heterozygous, and homozygous recessive), and the two phenotypes (dominant and recessive) can be calculated using the Hardy-Weinberg law, which is outlined below.

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

where p^2 = % homozygous dominant individuals
 p = frequency of the dominant allele
 q^2 = % homozygous recessive individuals
 q = frequency of the recessive allele
 $2pq$ = % heterozygous individuals

Also, $p + q = 1$ (there are only two alleles for a particular gene in an individual), and

$$p^2 + 2pq + q^2 = 1 \text{ (these are the only genotypes).}$$

Establishing a Baseline

In this exercise, the class constitutes a population and we will be following the allelic and genotypic frequencies for PTC tasting and a type of earlobe.

PTC (phenylthiocarbamide) is an antithyroid drug that prevents the incorporation of iodine by the thyroid gland into thyroid hormone. The ability to taste PTC is an autosomal trait; tasting (T) is dominant to nontasting (t). Whether earlobes are attached or free is also an autosomal trait. Unattached (E) is dominant to attached (e) earlobes.

To get the baseline (control) values for the class follow the steps below and enter the appropriate values in table 1.

1. Taste a piece of PTC paper. Can you taste it? _____
What is your genotype? _____
2. Have a class member examine your earlobes and determine whether they are attached or unattached. Do you have attached or unattached earlobes? _____
What is your genotype? _____
3. Determination of **homozygous recessive frequency (q^2)**:
 - a. $\frac{\text{Number of students who cannot taste PTC}}{\text{Number of students in the class}} = \frac{\quad}{\quad} = q^2$
 - b. What percentage of the class has attached earlobes?
 $\frac{\text{Number of students with attached earlobes}}{\text{Number of students in the class}} = \frac{\quad}{\quad} = q^2$
4. Fill in the first column of table 1.
5. Determine the **frequency of the recessive allele (q)** by calculating the square root of q^2 . Fill in the second column of table 1.
6. Determine the **frequency of the dominant allele (p)** using the formula $p + q = 1$, that is, $p = 1 - q$ and fill in the third column of table 1.
7. Determine the **frequency of the homozygous dominant genotype (p^2)** by multiplying p times p and fill in the fourth column of table 1.
8. Determine the frequency **of the heterozygous genotype ($2pq$)** by multiplying 2 times p times q and complete column five of table 1.

Table 1.

Trait	q^2	q	p	p^2	$2pq$
PTC tasting					
Earlobes					

9. Complete table 2 by filling in the “Genetic Frequencies” column with the numbers calculated in steps 3, 7 and 8. Then complete the “Number of Students” columns by first filling in the number of students who have the recessive phenotype (q^2) from step 3. Then calculate the number of students with the homozygous dominant genotype by multiplying p^2 times the number of students in the class, and the number of students with the heterozygous genotype by multiplying $2pq$ times the number of students in the class.

Table 2. Present Generation

Genotypes	Genotypic Frequencies		Number of Students	
	PTC Tasting	Earlobes	PTC Tasting	Earlobes
Homozygous Recessive (q^2)				
Homozygous Dominant (p^2)				
Heterozygous ($2pq$)				

Testing the Hardy-Weinberg Law

Your instructor will select one of the two traits for further testing. Given the data in table 1, predict the genotypic frequencies in the next generation if the Hardy-Weinberg law applies.

$$q^2 = \underline{\hspace{2cm}} \qquad q = \underline{\hspace{2cm}}$$

$$p^2 = \underline{\hspace{2cm}} \qquad p = \underline{\hspace{2cm}}$$

$$2pq = \underline{\hspace{2cm}}$$

- Using the frequencies from table 2 as a guide, your instructor will assign you a genotype for the trait being followed. (Students who know their phenotype should use their own genotype.)
- Write down your initial parental genotype. _____

- To ensure random mating you must behave completely uninhibitedly and choose anyone in your class (male or female) as a mate. This person cannot refuse you.
- Each couple will have two offspring. Each member contributes one allele to each offspring and is determined by flipping a coin. If the coin comes up heads, the left allele is passed on, and tails means the right allele is passed on. Now fill in Table 3.

Table 3. F₁ Generation

Offspring	Your Contribution	Partner's Contribution
1		
2		

- Select one of the two offspring; its genotype now becomes yours (the parent's have died). Record your new F₁ genotype. _____
- Find a new partner and repeat the procedure outlined above, recording your new genotype each time, until you have completed five generations:

F₂_____ F₃_____ F₄_____ F₅_____

- Now fill in table 4, using the F₅ genotype information. You will need to complete the number of students column first and the genotypic frequencies column second.

Table 4. F₅ Generation

Genotypes	Genotypic Frequencies	Number of Students
Homozygous recessive (q ²)		
Homozygous dominant (p ²)		
Heterozygous (2pq)		

- Compare the results in table 2 and table 4. Do these results match the predictions you made earlier? Why or why not.

B. Genetic Drift

Genetic drift refers to chance, or random, changes in the allele frequency of a gene pool. These changes cannot be predicted nor can organisms adapted to prevent these random changes. Examples of events that cause genetic drift are natural disasters like fires and floods that randomly eliminate members of a population that are “in the wrong place at the wrong time”. The remaining members of the population reproduce more prolifically than they normally would (less competition for resources and mates) and the alleles they carry will be present in the gene pool of subsequent generations at frequencies greater than those of the individuals who were eliminated.

Founder Effect

The founder effect occurs when a small number of individuals from a large population colonize a new habitat. The smaller the founding population, the less likely the founding gene pool will reflect the gene pool of the original population. Consequently, the allele frequencies in the subsequent generations of the new colony will be much different from those of the original population.

1. To model the founder effect, the instructor will divide the class (the original population) into two smaller populations. How many individuals in each new population? _____ Each member begins with their F_5 genotype from the previous section.
2. Calculate the genotypic and allele frequencies for your new population and complete table 5.

Table 5. Parental Generation

Genotypes	Genotypic Frequencies	Number of Students
Homozygous recessive (q^2)		
Homozygous dominant (p^2)		
Heterozygous ($2pq$)		

3. Follow the same mating procedure as before, but within your small population, until you have completed five generations.

Initial (P) generation _____ F₁_____ F₂_____

F₃_____ F₄_____ F₅_____

Fill in Table 6 using the F₅ generation data for your population.

Table 6. F₅ Generation

Genotypes	Genotypic Frequencies	Number of Students
Homozygous recessive (q ²)		
Homozygous dominant (p ²)		
Heterozygous (2pq)		

Compare Table 5 and Table 6. Do the results suggest that genetic drift has occurred? Explain.

C. Natural Selection

Populations contain varied individuals. These differences affect their ability to successfully leave behind offspring. The differential success in reproduction was described by Darwin as natural selection. Natural selection results in alleles being passed on to the subsequent generation at frequencies disproportionate to their occurrence in the parental generation. Mutation contributes to natural selection as it gives rise to new alleles that may better adapt individuals containing them to their environment, and contribute to the adaptation of the population as a whole.

Antibiotic Selection of Bacteria

Most bacteria that are grown in the presence of small amounts of antibiotics die, although some survive. Those bacteria that survive contain mutations that neutralize the effect of the antibiotics and confer antibiotic resistance to the bacterium. Each surviving bacterium then gives rise to a colony of bacterial cells, each containing the mutant gene that gives resistance to the antibiotic.

1. Working in pairs, obtain two culture plates that have been pre-inoculated with *Escherichia coli*. **CAUTION: While these bacteria are normal inhabitants of the human lower GI tract, ingestion of these bacteria can cause mild to severe food poisoning (and in some cases, death). Use caution when handling the plates and wash your hands thoroughly after handling the plates.**
2. Carefully place a blank sterile disk and disks impregnated with different antibiotics on the surface of each plate. Record the names of the antibiotics and their locations on the plates in the diagrams below.
3. On the bottom of one disk write a large letter C (for control) and the first letter of the name of each antibiotic (adjacent to its disk). Tape the lid shut and label it with your name and lab section.
4. Before closing the second plate, expose it to UV radiation for 10 seconds to cause mutations. **CAUTION: Direct UV exposure can damage your eyes.** Tape the lid shut, label each antibiotic disk as described above, and label the lid with your name and lab section.
5. Each plate will be placed at 37°C for 24 hours then kept in a refrigerator until the next lab session.
6. Measure the clear zones around each antibiotic disk and record your data in the table 7 below.

Table 7.

	Measurement of Clear Zone				Conclusions
	Control Disk	Antibiotic A	Antibiotic B	Antibiotic C	
Plate (not exposed)					
Plate (exposed to UV)					

7. Do your results suggest that mutations resulting in antibiotic resistance occurred before or after exposure to antibiotics? Explain.

8. Has a change in the gene pool frequency occurred? Explain.

9. What would you expect to happen if bacteria growing in the presence of the antibiotics were used in a repeat experiment, that is, would the growth around the antibiotic disks be greater or not? Explain.

Laboratory Questions

1. List the conditions that must exist for the Hardy-Weinberg law to apply.

2. What evidence would you look for to indicate that a population is evolving?

3. Assume Hardy-Weinberg equilibrium.
 - a. If $p = 0.8$ for a population, calculate the values of q , p^2 , q^2 , and $2pq$. Show all your working.

- b. What would be the gene pool frequencies in the next generation if evolution does not occur?

- 4. Natural selection results in organisms adapting to their environment.
 - a. What was the environment provided for the bacteria in this exercise?

 - b. How did you know that natural selection had occurred?

 - c. The next generation would have a change in gene pool frequency for what trait?

- 5. a. How does genetic drift differ from natural selection?

 - b. How does the end result of genetic drift differ from the end result of natural selection?

- 6. If 49% of a population showing Hardy-Weinberg equilibrium has a recessive phenotype for a trait, what is the value of p ?