



BEANBAG POPULATIONS GENETICS

How does evolution “work”? This exercise defines basic terms and describes experimental procedures for teachers to use when explaining concepts in evolution. Students work in teams of two, and each team completes two separate experiments demonstrating 1) random genetic drift, and 2) natural selection. Since each team must complete up to ten trials for each experiment, the teacher may want to plan this activity for two class periods.

After all the experiments have been completed, the teams can regroup for a discussion of the experimental outcomes. Under the Reports section of this exercise, guidelines are offered for each group’s written summary of the experiments. Teachers can focus on the following for class discussion: How do the experimental procedures differ? How does the sample size of beans affect the outcome of the experiments? How are the outcomes of the experiments similar? How are they different? How do the two evolutionary forces demonstrated--random genetic drift and natural selection -- change populations differently?

It is difficult to predict the exact outcomes of these experiments, just as it is difficult to predict evolutionary changes. However, the teams can compare their different results, and discuss how the changes in their populations occurred (gradually or suddenly) through the steps of the experiments.

These different results, and the variation in how they are achieved, simulate evolutionary change in the natural world. By the end of the discussion, students should be able to articulate how seemingly minor evolutionary changes can have enormous impact on small populations.

Evolution is normally studied in terms of *populations* instead of *individuals*. In the classroom, it may seem impossible to set up a laboratory procedure that will help students to understand the forces of mutation, migration, random genetic drift, and natural selection -- which all act on populations. However, many of these concepts can be demonstrated in a very basic way. In this activity, beans of two different colors are used to represent two alleles of a single gene that controls a single trait, such as a gene that controls for eye color. The frequency of each color of bean may change from one generation (experimental trial) to the next. (Remember that higher organisms have two copies of each chromosome, one copy originating from each parent. Consequently, the two chromosomes may have different alleles of the same gene depending on what alleles the organism's parents had.) This is a fairly simplistic demonstration that does not take into account dominance, linkage, or other complexities of genetics, but its simplicity will give students an appreciation for how the genetic makeup of a population can be altered over time by seemingly minor forces.

Terminology

Several terms are used to explain differences in populations and how populations change over time. These terms should be used when the students write their reports at the end of the experiments.

- A **gene** is a segment of DNA that contains all of the information necessary for the expression of a protein or structural RNA.
- **Alleles** are variants of a single gene, found in the same position or locus on a chromosome; they represent the possibilities for variation in a population with respect to a particular inherited trait.
- **Locus**: refers to a location on a chromosome occupied by a gene (which may have several alleles).
- **Gene frequency** represents how often an allele occurs in a population. The number of alleles for a particular trait is divided by the total number of genes in the sample of the population you are counting. Gene frequencies are always expressed in decimals, so that if a gene (allele) is present in 50% of a population, the gene frequency is 0.5.
- **Fixation** of an allele occurs when, through evolutionary processes, the gene frequency of one allele at a locus becomes 1.0 (everyone in the population has that allele) or has disappeared from the population entirely (gene frequency = 0.0).
- **Evolution** is a change in a population's gene frequencies over time. Evolutionary forces are processes that can change gene frequencies.
- **Breeding population** describes the part of the population likely to interbreed. An entire species can be considered a breeding population because, theoretically, all members of a species can interbreed. In the real world, however, many individuals do not breed in their own group for some physiological reason (such as age), or between groups (for behavioral or geographic reasons). In population genetics, the breeding population consists only of the individuals that can potentially mate and produce viable offspring. Only breeding individuals have the potential to contribute genes to the next generation.
- **Population genetics** is the study of the behavior of genes and their alleles in populations.
- **Selection** describes a force that determines which genes are passed on to the next generation.
- **Natural selection** is the effect of the environment's interaction with each individual; it acts directly on the individual's phenotype and therefore, indirectly, on the genotype. It is directional because the environment will "favor" the survival of some individuals over other individuals; for instance, if there is a gene that allows certain individuals to store fluids better, these individuals would have an advantage during times of drought. The term "fitness" describes the relative reproductive success of different individuals in a particular environment. Those who survive to

produce offspring, which then survive to reproduce, are more fit than those who do not meet both requirements. The “fittest” are those that leave the highest number of viable offspring. Natural selection acts on individuals, but individuals do not evolve.

- **Artificial selection** occurs when a conscious effort is made to change the genetic makeup of a population, as when humans choose “attractive” or economical traits in animal breeding.

- **Phenotype** is the description of visible traits that characterize an individual or members of a population. Phenotype can reflect both an individual’s genetic makeup and the effects of the environment on an individual.

- **Genotype** is the hereditary makeup of an individual.

- **Mutations** are changes in the genetic material. Not all mutations are “bad”--without mutations there would not be variability (in genetic terms, alleles). Because mutations occur very infrequently, they are very slow to change gene frequencies in a population--unless it is a very small population.

- **Random genetic drift** refers to a change in gene frequencies that is completely random, i.e., there is no necessary selection for or against a particular allele. The allele simply occurs, by chance alone, more or less often in a generation than in the previous generation. This drift has no particular direction -- it can go back and forth. In order for this drifting to influence the entire population’s genotype frequency, it is necessary to have a small population. It is possible for a small population to continue to drift toward or away from a particular gene frequency, in which case it can reach fixation (all or none).

- **Migration** refers to the flow of genes into or out of an isolated population through inbreeding. A small amount of **gene flow** often occurs between populations that normally do not interbreed. As with mutation and random genetic drift, migrants carrying different alleles into or out of a population have a much better chance of changing the population’s gene frequencies if the population is small. Migration is a way to “un-fix” a particular allele in a population.

- **Founder effect** occurs when a small group of individuals forms a new population, which is isolated from the original population. The gene frequencies of subsequent generations may be very different from the original population simply because the small number of individuals who are founders probably do not carry all the allelic forms found in the original population.

Bean Bag Population Genetics Activity

In this activity, beans of two different colors demonstrate evolutionary forces, plus the effects of population size on these forces. Use red and white beans of similar size. In these experiments, the beans represent two different alleles for a gene controlling a single trait. To approximate the possible distribution of genes in populations, nine different “populations” of beans must be prepared. In small containers, such as shallow bowls or jars, create populations of 100 beans. In the first container there will be 10 red beans and 90 white beans (10R/90W; gene frequency of

the red beans is 0.1); in the second there will be 20 red and 80 white (20R/80W; gene frequency of the red beans is 0.2); in the third there will be 30 red and 70 white (30R/70W; 0.3); and so on until you have 90 red and 10 white beans (90R/10W; 0.9) in the last container. The containers should be carefully labeled with both the number of beans and the gene frequency, so that it is easy to determine their contents.

Students work in pairs. Each team requires two small empty containers; a pair of tweezers; a paper plate, with a few random openings large enough for some beans to drop through; a large coffee can; and two recording sheets (see below).

Procedures

Experiment 1: This experiment demonstrates **random genetic drift** in different sized populations by showing the effects of sampling a small number of genes from a population in order to form the next generation. When populations are so small that not many individuals are reproducing, the effect of random genetic drift is greater. The differences in sample size will demonstrate how change can occur more quickly when populations are small.

a) Using the tweezers, and without looking at the beans, one student draws 5 beans from the 50R/50W container, where the gene frequency of the red beans is 0.5. The 5 beans are placed in the student's empty container. Count the number of red beans in the container, thereby determining the gene frequency of this new "population," record this new gene frequency on the sheets, and return the beans to their original container. For instance, if there are 2 red beans and 3 white beans in the student's container, the gene frequency is determined by dividing 2 (the number of red "alleles") by 5 (the total number of "genes"); the gene frequency is 0.4. Find the container that has the same gene frequency as the new population (in this case, 40R/60W), and draw 5 beans from that container. Again, count the number of red beans, determine the gene frequency, record your findings, and return the beans to their container. The experiment is repeated until 10 generations (trials) are simulated, or until the gene frequency reaches **fixation** (all red or all white beans).

b) The second member of the team repeats the procedure, starting again with the 50R/50W container, and recording all of the trials.

c) The first student collects data in a similar fashion to the original experiment, but draws populations of 10 beans in each trial instead of 5. All data are recorded on the data sheet.

d) The second student repeats the procedure with populations of 10.

e) The procedure is repeated by each student, drawing populations of 20 beans in each trial.

Experiment 2: This experiment is designed to demonstrate **natural selection** by using a "screen," in this case, a paper plate with holes randomly poked through it, as a selective agent. Selection is the only directed evolutionary process, where an external or environmental factor influences the survival and reproductive success of particular genes. The "screen" in this experiment acts the same way as a change in the environment might act. Since the beans are not

uniform in size, the screen (the external factor) will “select” the desirable beans. Changing the sample size (5, 10, then 20) will demonstrate how the size of the population can determine how rapidly evolution occurs. The paper plate is laid on top of the coffee can and pushed in a little to stabilize it.

a) Start again with the 50R/50W container and a population of 5. Pour beans slowly directly from the 50/50 container until the correct population (in this case, 5) falls through. If the can and screen are shaken to “help” the beans through, they must be shaken for every trial. If too many beans drop into the coffee can, the trial must be repeated.

b) Repeat as in Experiment 1, so that there are two experiments each for the population sizes of 5, 10 and 20, with each experiment running to fixation or 10 trials. Record the frequency of red beans on the table for each experiment.

Reports

Using the data collected, each team writes up a few paragraphs about each experiment. The following information should be included:

a) a description of the purpose of the experiment, and the procedures, in the students’ own words;

b) a discussion on how sample size affects the outcome of each experiment;

c) a comparison of the outcomes of the two experiments (how the results of the experiments are similar, and how they are different) and;

d) an analysis of how the forces of evolution demonstrated in these experiments—random genetic drift and natural selection—affect population change differently.

Recording sheet:

TRIALS

Sample Size↓	1	2	3	4	5	6	7	8	9	10
5 (student 1)										
5 (student 2)										
10 (student 1)										
10 (student 2)										
20 (student 1)										
20 (student 2)										

Student names _____ Experiment _____

Make two copies of the table for each team. Record the data for each experiment on a separate table, and label the tables clearly. The data (frequencies) may also be recorded on graph paper, if desired.

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