HEREDITY AND VARIATION

OVERVIEW

Students often do not understand the critical role of variation to evolutionary processes. In fact, ***variation is the only fundamental requirement for evolution to occur***. Natural selection is often erroneously perceived to have this role; however, natural selection is a mechanism of evolution (one of several), while **variation is a <u>prerequisite</u> for evolution**. In other words, there can be evolution without natural selection, but there cannot be evolution without variation.

In this section, the fundamental principles of heredity and variation that are necessary before a complete understanding of evolution is possible are described. A basic understanding of genetics is assumed.

INDIVIDUALS AND HEREDITY

Like begets like. Every individual organism looks more similar to its parents than it does to a non-related individual. The reason for this is heredity: *offspring inherit their genes from their parents.* Each individual in a sexually-reproducing species obtains half of its genes from its mother and half from its father. The passing down of genes from parent to offspring creates a link between the generations; a link that goes back in time to the very first organism (the ancestor of all living things).

However, organisms do not look exactly like their parents; offspring can be quite different from their parents. Why is this? What causes an individual to look the way it does? In other words, ***what influences the phenotype of an individual?*** The phenotype of an individual (i.e. what it looks like) is influenced by several factors, and is represented in the following equation:

$$\mathbf{P = G + E + (G*E)}$$

P = phenotype of individual
G= genotype of individual

E = environment of individual
G*E = interaction of genotype and environment

The phenotype of an individual is determined by the ***genotype*** *of the individual* (or the specific alleles and allele combinations it has inherited from its two parents), *the* ***environment*** *that the individual was raised in, and an interaction between the individual's genes and its environment*. For example, an individual's height is determined by: his genes (are his parents relatively tall or short?), his environment (was he adequately nourished growing up or deprived of appropriate nutrition?), and the interaction between his genes and environment (how are his height-determining genes influenced by his environment?).

This G*E interaction can be most easily understood with an example. What does it mean if you inherit alleles that make you susceptible to alcoholism (or cancer, or cardiovascular disease, etc.)? It does not mean that you are destined to become an alcoholic. However, it does mean that you are *more likely* to become an alcoholic than somebody who does not have the same genotype. In other words, some people have an inherited predisposition to become alcoholics. Whether you actually get the disease (i.e. display the disease phenotype) will be influenced by your particular lifestyle (i.e. your environment). If you never drink alcohol, you will not become an alcoholic, regardless of any genetic predisposition. However, if you do drink, even if you drink exactly the same amount as your friends who do not have this predisposition, you may be more likely to become an alcoholic than they will. This is due to the interaction between your particular genotype with your particular environment.

To summarize, the phenotypic trait of an individual organism are influenced by both the genes it inherits from its parents, and the environment in which it was raised. When the individuals within a population differ in a phenotypic trait, the population is said to exhibit variation for that trait.

POPULATIONS AND VARIATION

Variation is a property of a population[1]. Variation occurs when individuals within a population differ in their characteristics. There are two general categories of variation: discrete and continuous.

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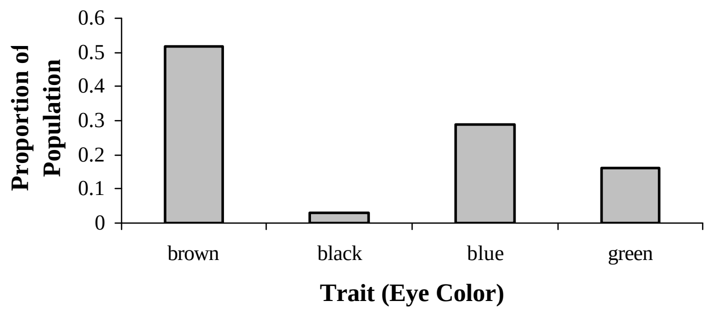
[1] ***A population is defined here as a group of individuals of one species living in a specific geographic region***

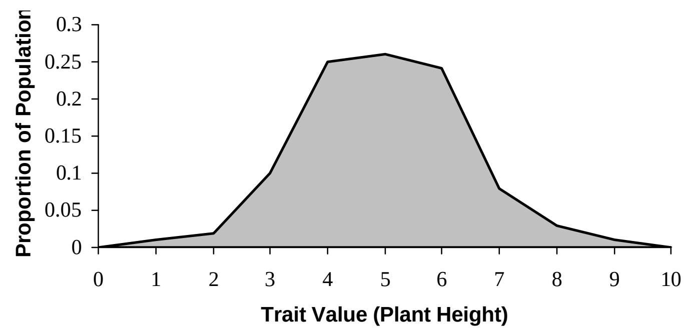
Discretely varying traits are traits that can be put into categories, like eye color (see Figure 1). Mendel's garden peas displayed discrete variation in seed color and texture. Seeds were either yellow or green, smooth or wrinkled. Discretely varying traits are usually influenced by only one or a few genes. They can also be influenced by environment, although usually not significantly.

Figure 1: Discretely Varying Character



Continuously varying traits cannot easily be put into categories. Instead, variation in these types of traits is best represented in a frequency distribution or histogram, since ***continuous traits vary along a continuum***. Height (in humans or plants, etc.) is an example (see Figure 2). This type of trait is usually measured with some sort of numerical unit (e.g. centimeters for height or kilograms for weight). Continuous traits, which comprise most morphological characters, are usually influenced by many different genes as well as environment.

Figure 2: Continuously Varying Trait



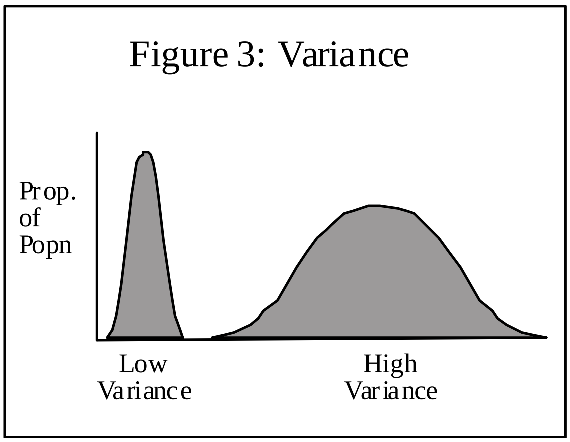
When only one or a few genes determine a phenotypic trait, it is a simple matter to determine how much genetic variation there is in a population (e.g. Mendel's peas). However, for continuous (or quantitative) traits, it becomes more complicated. This is because phenotypic variation within a population is caused by differences in the genes among individuals, as well as the differences in the environment among individuals. This can be represented in the following equation:

$$\mathbf{V_P = V_G + V_E}$$

V_P = Phenotypic variance within a population

V_G = Variance due to genotypic effects
V_E = Variance due to environmental effects

Variance is a statistical measure of the dispersion in a frequency distribution. In other words, how "spread out" is the distribution (see Figure 3). Mathematically, the variance is the average of the squared deviation of observations from the arithmetic mean. It is also the square of the standard deviation. For our purposes, variance is a measure of how much variation is in a population.



Variation in a population due to genetic differences among individuals (V_G) is what is important to evolution. For example, if natural selection is imposed on a variable trait in a population, the extent that the population can respond to the selection (i.e. evolve) depends on how much of the phenotypic variation in the trait is determined by genes. If the trait is heavily influenced by genes, then you should see a change in the variation in the trait in the next generation (i.e. it will evolve). If it is heavily influenced by environment, you will not see a difference in the variation in the trait in the next generation (it will not evolve).

Going back to our example of height, we have seen that an individual's height is influenced by both genotype and environment, and that populations display a lot of variation in height. Variation in height that is due to individual differences in the environment in which they were raised cannot evolve. Only variation in height that is due to differences in alleles among individuals can evolve. For example, say that tallness is favored by natural selection, and that height is completely determined by the environment. Tall individuals will produce more offspring than short individuals; therefore, most of the kids in the next generation will have come from tall individuals. However, since the genes of tall individuals are not necessarily different from the genes of shorter individuals, height will not evolve. The height of the kids in the next generation will solely depend on the environment of that generation (not on their genes). On the other hand, if height has a strong genetic influence, then the population will evolve. Tall individuals will produce more offspring than shorter individuals, and those offspring will inherit the tall genes. Since most of the kids in the next generation will have come from tall individuals, and they have inherited the tall genes, there will be more tall individuals in the next generation (regardless of environment); height has evolved.

To summarize, genes and environment influence how individuals look (i.e. phenotypes), and this in turn contributes to variation, a property of populations. Only variation that is caused by different genes among individuals can evolve. What then, causes genetic variation?

THE CAUSES OF GENETIC VARIATION

The ultimate source of all genetic variation is mutation**—**changes to the DNA itself. This is the only way new alleles (varieties of a gene) are produced. If mutations occur in a germ (reproductive) cell, then it can be transmitted to the next generation. If they occur in somatic (non-reproductive) cells, they are not passed on to the next generation.

Mutations are rare events: the average rate of mutation is about one per 100,000 genes. Thus it would take on average 100,000 generations for a mutation to occur at any one specific gene. However, each individual has many, many functional genes. Thus, at the level of the whole individual, mutations actually occur quite often. It is estimated that each human gamete (egg or sperm cell) has on average one mutation.

Mutations can be harmful, they can be beneficial, or they can be neutral (neither harmful or beneficial). *The effect of the mutation will often depend on the current environment of the organism.* For example, a mutation that confers resistance to DDT in mosquitoes is harmful to the mosquito possessing it, unless that mosquito happens to be in an environment where DDT is being used. Note that "harmful" does not necessarily mean "deadly." Some harmful mutations are lethal to the organism, but other harmful mutations are just "not as good" as the other alleles in the population (e.g. they may cause the individual to grow slower than those without the mutation). These mutations are selected against, but the selection is not as strong as it is for a lethal mutation.

Another cause of genetic variation in sexual organisms is recombination. Recombination (the two processes of independent assortment and crossing over) produces gametes with chromosomes with unique sequences. ***Recombination produces new combinations of alleles at different genes*** (i.e. combinations that are different from the parent). As a result of recombination, each gamete produced by a single sexually reproducing individual is uniquely different from all other gametes. As an exercise, calculate how many possible types of gametes can be produced by an individual that is variable at 10 genes (i.e. the individual is heterozygous at 10 genes). Answer[2] [[put link to footnote]]

Another cause of genetic variation within a population is gene flow. When an individual organism moves into a new population, it brings its alleles into the new population. Some of these alleles may be different from the alleles that are currently in the population. When new alleles are brought into a population through gene flow, the genetic variation within the population has increased.

Note that recombination and gene flow work by re-organizing and re-arranging existing alleles. Mutation is the only source of completely new alleles.

RESOUCE LIST

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[2] If the individual is heterozygous at 10 different genes, then there will be 2^{10} different gamete possibilities (or 1024).

LESSONS ABOUT HEREDITY AND VARIATION

HEREDITY

Access excellence has a couple of activities that investigate inheritance: "A Mix-up at the Hospital" [[www.accessexcellence.org/AE/AEPC/ASM/25.html]] and "A Paternity Case." [[www.accessexcellence.org/AE/AEPC/ASM/26.html]] Both of these activities use DNA typing to match babies with parents, and to determine potential paternity, respectively.

For something a little different, check out "'Chips' off the Old Block?" [[www.accessexcellence.org/AE/AEC/AEF/1994/johnson_chips.html]] This activity has students bake cookies from the same recipe, with some students using recipes with a "mutation." They then try to identify from the cookies' "phenotypes" which recipes (genotypes) had the mutations. You could also bring up potential differences in phenotypes due to differences in their "environment" (i.e. different students baking).

VARIATION

The simplest way to get across the idea that there is an abundance of variation in natural populations is to have students measure the same trait in 50 – 100 individuals. This can be something really easy, like beans from a grocery store, or something a little more complicated (but potentially much more interesting), like wild collected plants or animals. Collect individual plants or animals from a single species (either as a class field trip or by yourself) and bring them to the classroom to measure. *Be sure to collect actual individuals, and not just different parts from one individual* (such as 100 leaves from one tree). Have the students choose a trait to measure (or have them all measure one trait you choose), collect data and graph it (frequency histogram). [[Link to variation worksheet—separate file]]

"Sampling Variation in a Natural Population" at the Access Excellence sit [[www.accessexcellence.org/AE/AEC/AEF/1996/macphee_population.html]] has a nice description of a student project in which they go out on their own and find a species with which they collect their own data.

Throughout the semester, **have them keep in mind (by continuously pointing out) that, in order for evolution to occur, there has to be variation**. When you talk about mutations, tell them that when a new mutation occurs in a population, this mutation has brought variation into the population. Natural selection (or other causes of evolution) can now act on that variation—is this new mutation beneficial or harmful? Also, when doing other activities, for example on natural selection, point out variation within the population. If you do a natural selection simulation exercise, point out that there is variation in the population (red chips, yellow chips, blue chips and white chips), and that this variation is a prerequisite for selection to occur.