Modeling Natural Selection

SC Academic Standards: 7.L.4A; 8.E.6B; H.B.4C; H.B.5A.

NGSS DCI: MS-LS3.B; MS-LS4.B-C; HS-LS3.A-B; HS-LS4.B-C.

Science and Engineering Practices: S.1A.1; S.1A.2; S.1A.4; S.1A.5; S.1A.7

Crosscutting Concepts: Patterns; Cause and Effect: Mechanism and Explanation; Systems and Systems Models; and Stability and Change.

Focus Question(s): How does evolution by natural selection occur? What causes an allele or phenotype to be advantageous? Disadvantageous?

Conceptual Understanding: Inheritance is the key process causing similarities between parental organisms and their offspring. Organisms that reproduce sexually transfer genetic information (DNA) to their offspring. This transfer of genetic information through inheritance leads to greater similarity among individuals within a population than between populations.

Adaptation by natural selection acting over generations is one important process by which species change in response to changes in environmental conditions. The resources of biological communities can be used within sustainable limits, but if the ecosystem becomes unbalanced in ways that prevent the sustainable use of resources, then ecosystem degradation and species extinction can occur.

Biological evolution occurs primarily when natural selection acts on the genetic variation in a population and changes the distribution of traits in that population over multiple generations.

According to the theory of biological evolution, natural selection results in populations that are adapted to a particular environment at a particular time. Changes in the physical environment have contributed to the expansion, emergence, or extinction of the Earth's species. Biodiversity is increased by the formation of new species (speciation) and decreased by the loss of species (extinction). Modern classification of Earth's biodiversity is based on the relationships of organisms to one another.

Background: There is extensive evidence that organisms tend to change very slowly over long periods of time. This change is called evolution; evolution is the process that leads to the change in prevalence of traits or alleles, the process of adaptation, and even the formation of new species.

There are three main things that are necessary for evolution to occur:

1. **Variability.** There must be variability in what traits or alleles of a gene are in a population. If there is no variability (as in a population of clones, where everyone is genetically identical), there will be no chance for evolution to occur. Variability can be maintained many ways, including through random mating or because there is a benefit to carrying heterozygous alleles; for example, in some humans it is advantageous to have one allele for sickle cell anemia and one for normal blood at the sickle cell gene because heterozygotes are resistant to malaria. One of the most common ways variability is maintained is through mutations. Mutations are random changes in DNA. Many mutations don't alter gene expression or what proteins are made, and have no apparent effect on the organism. Most mutations that do have significant effects are bad for the organism. Very occasionally, there are mutations that produce a new or altered trait that is advantageous for an organism.

2. **Heritability.** Evolution works by changing which traits are more prevalent in succeeding generations, and this only works if the trait of interest is heritable. Traits that are not heritable can't evolve. For example, if you get a tattoo, you've changed your skin coloration, but since tattooing isn't heritable, your offspring will not have tattoos when they are born – and if you work out and get bigger muscles, these, too are not something you can pass to your offspring. Your natural hair color, on the other hand, is based on genetics and may be passed on to your children. Learned behaviors are non-heritable as well; just because your father learned how to dance the polka doesn't mean you knew how to polka when you were born.

3. **Differential Reproduction.** Some organisms in a population leave more offspring than others, and thus the heritable traits of some organisms are passed on at a higher frequency. Over time, this differential reproduction will lead to some traits or alleles being more frequent in the population, while others are less frequent or even disappear. Just because a trait is found more frequently doesn't imply that it is "better" or "dominant". If every organism in each generation reproduces at the same rate within a population, there will be no difference in which traits or alleles are more frequent, and therefore no evolution.

Evolution is change in allele frequencies, which occurs in every generation. However, noticeable changes in phenotype may take a long time to evolve. For example, there are 14 species of finches that live on the Galapagos, each of which differs in beak shape, beak size, and diet. All 14 species came from a common ancestor, and it took up to five million years for the 14 species to evolve. Evolution cannot occur within an individual, only within a population or species.

Evolution is not directed or predetermined. Just like you can't spontaneously grow a tail because you think it would be cool, an organism can't spontaneously obtain a trait they "want" through mutation. Mutations are random, not directed, and they don't occur because they are "needed."

The evolution of a trait can occur through two main ways: random chance (called genetic drift) or natural selection.

GENETIC DRIFT: The frequency of specific alleles in a population can change drastically due to simple chance, leading to random shifts in a population's traits. The effect of random chance on the frequency of alleles or traits in a population is called genetic drift. "Random chance" events can include everything from random mating patterns that lead to an allele being accidently removed from the population to unpredictable environmental events, such as a flood that accidently kills most or all individuals with one allele.

Genetic drift is often almost negligible in a large population. However, as population size gets smaller and smaller, genetic drift can have more and more drastic effects on allele frequencies. For example, think of flipping a quarter with a 50:50 chance of landing heads or tails up. The "heads" side can represent one allele, and the "tails" a second allele. Imagine flipping that quarter 100 times. In this case, you would expect to end your 100 flips with close to a 50:50 ratio of heads to tails tosses; it is extremely unlikely that the ratio will change much, and it's almost impossible to get all heads or all tails (without a rigged coin). If you only flip that same quarter 4 times, however, you have a much higher probability of randomly getting all four heads or all four tails. These same rules of probability apply to alleles in a population.

Population bottlenecks and founder effects are special cases of genetic drift. A **population bottleneck** occurs when a population experiences a catastrophic event that either kills almost all individuals or prevents almost all individuals from reproducing. Often, this is due to disease or natural disasters, such as volcanic eruptions, floods, ice ages, etc. In bottlenecks, even if a population began as a large population, that population will suddenly be very small. Since it is random which individuals survive a bottleneck, genetic drift will play a strong role in what alleles are present in the new, bottlenecked population.

Founder effects are another special form of genetic drift. In this case, a few random individuals from a large population leave to found a new population in a new environment. Again, since only a random subset of the larger population will make up the new population, genetic drift will play a strong role in which alleles and what proportion of alleles will be in the new population.

NATURAL SELECTION: Not all effects on allele frequencies are random or due to random events. Sometimes there are traits that give an organism a reproductive **advantage**, either through increasing survival rate or increasing fecundity. These traits will be more likely to be passed on to the next generation through natural selection, the process by which genetic traits that provide an advantage to an organism are passed on to offspring at a higher rate than non-advantageous traits. Natural selection is all about reproduction; if an organism can reproduce more or has a higher chance of survival until reproduction, their traits will be selected for.

Over many generations, an advantageous trait may become more prevalent in a population or in a species. These advantageous traits are considered adaptive, and the process of selecting for adaptive traits over many generations is termed adaptation.

There is one specific kind of natural selection that is worth mentioning: sexual selection. Sexual selection is the selection of a trait by one sex in a mating pair. Often the trait being selected for is something showy. The most commonly-cited example is in peacocks: peahens prefer to mate with males that have bigger, brighter, showier tails. Even though large tails can also attract predators and get in the way, larger tails lead to increased reproduction because the females, when given the choice, will select the male with the largest showiest tail. Males who have their tails cut shorter, or have the eyespots cut out, show reduced mating success.

Evolution has also led to the survival of predators that select the "right" food items – and the co-evolution of prey that can avoid the predators. Some predators employ a **generalist** strategy, and tend to have broad diets; they chase and eat many of the prey/food items with which they come into contact. There are also those with a more **specialist** strategy, having a narrow diet and ignoring many of the prey items they come across, instead searching preferentially for a few specific types of food. Usually, animals exhibit strategies ranging across a continuum between these two extremes.

In this lab we will investigate how predators and prey have **co-evolved** (one evolving in response to the other) strategies for survival. Prey (different colored macaroni) shows variability in color and prey that are camouflaged tend to survive better and so have greater reproductive success, leading to greater numbers of prey with camouflage coloration in successive generations. Likewise, predators that can find more prey tend to survive better and so have greater reproductive success, leading to larger numbers of predators with certain prey-finding strategies (to overcome the camouflage) in the next generation.

Materials: Three bags of small marshmallows, three bags of popcorn kernels, three bags of dried beans (medium size, like a pinto bean), three bags of elbow macaroni, Large bucket (5 gallon), broom, two packs of Solo plastic cups (16 oz), two boxes of plastic forks, two boxes of plastic knives, two boxes of plastic spoons, one box of toothpicks, chalkboard or poster paper.

Previous Knowledge: (genetics): The terms **dominant** and **recessive** describe the inheritance patterns of certain traits. That is, they describe how likely it is for a certain **phenotype** (not genotype) to pass from parent offspring. Sexually reproducing species, including people and other animals, have two copies of each gene. The two copies, called alleles, can be slightly different from each other. The differences can cause variations in the protein that's produced, or they can change protein expression: when, where, and how much protein is made. Proteins affect traits, so variations in protein activity or expression can produce different phenotypes.

A dominant allele produces a dominant phenotype in individuals who have one copy of the allele, which can come from just one parent. For a recessive allele to produce a recessive phenotype, the individual must have two copies, one from each parent. An individual with one dominant and one recessive allele for a gene will have the dominant phenotype. They are generally considered "carriers" of the recessive allele: the recessive allele is there, but the recessive phenotype is not. A dominant allele is not necessarily "better" nor more common. It just masks the recessive if both alleles are present.

Dominant and recessive inheritance are useful concepts when it comes to predicting the probability of an individual inheriting certain phenotypes, especially genetic disorders. But the terms can be confusing when it comes to understanding how a gene specifies a trait. This confusion comes about in part because people observed dominant and recessive inheritance patterns before anyone knew anything about DNA and genes, or how genes code for proteins that specify traits. Though it may seem contradictory, recessive alleles can be present in a population higher frequencies than dominant alleles. Consider eye color. Eye color is influenced mainly by two genes, with smaller contributions from several others. People with light eyes tend to carry recessive alleles of the major genes; people with dark eyes tend to carry dominant alleles. In Scandinavia, most people have light eyes—the recessive alleles of these genes are much more common here than the dominant ones.

Further**,** mode of inheritance has nothing to do with whether an allele benefits an individual or not. Take rock pocket mice, where fur color is controlled mainly by a single gene. The gene codes for a protein that makes dark pigment. Some rock pocket mice have dark fur, and some have light fur. The dark-fur allele is dominant, and the light-fur allele is recessive. When mice live in a habitat filled with dark rocks, dark fur is "better" because it makes the mice less visible to predators. But when mice live in a habitat filled with light rocks and sand, light fur is "better." It's the **environment** that matters, not whether the allele is dominant or recessive.

<u>Procedure:</u>

Populations of sexually reproducing species are not identical, and often within a population you can see a variety of phenotypes (Think eye color and skin color as visible, or morphological, phenotypes in humans, or think allergy to bee stings or lactose intolerance as invisible (physiological) phenotype in humans. Or, think rack size in deer, color in petunia flowers, or wing color in peppered moths). There are 4 variants our (one) predator *Wegonna getu*, and 16 individual predators in our population. The 4 morphological variants relate to the morphology of the feeding appendage, or "hand": one is scoop shaped (spoon); one is thin and pointed (toothpick); one is flat (knife); and one has several points (fork). Different students can rotate in and out of the predator population, but 16 will forage in each bout.

At the start of the simulation you will want 16 predators, 4 that hold a toothpick in their hand, 4 that hold fork, 4 that hold a spoon, and 4 that hold a knife.

There is also one prey species (*Leavus aloneus*), which also has 4 morphological variants. The 4 morphologies of the prey are: 1) puffy (small marshmallow); 2) small and hard (popcorn kernel); 3) large and hard (dried bean); and 4) curvy and hard (elbow macaroni). The initial population size of prey is 400 (100 of each morphological variant, or 25% of each phenotype. It is helpful to have Ziploc bags with the 100 items counted out before class begins.

Teacher: At the start of the simulation, the teacher will spread the 400 prey individuals randomly on the floor at the beginning of the foraging bout. ***Tip: Put all morphs into the 5 gallon bucket. Place them in an empty open area on the floor or it can be done outside. Keep the prey covered with the bucket until the foraging actually begins, so no one steps on them or kicks them around.***

Foraging Rules:

1. You can only use your appendage to put food into your mouth (a cup). Do not use your other hand, which should be holding the cup stationary and upright. You cannot push or scrape prey items into your cup (your mouth).
2. Your "mouth," if you are the predator is a plastic cup. At the start of each foraging bout, the 16 predators will kneel in a circle around the prey population. The cup should be set upright on the floor and held upright and stationary.
3. When the teacher tells you to begin, you will have 30 seconds to find and eat prey. When the teacher says "stop", you must stop "eating".
4. You can only eat one prey at a time. You must place each item into the cup. You can be a "sneaky" predator such as being aggressive, steal, or cheat other predators, but once a prey item is in the stomach (cup) you have to leave it alone. No stealing from cups. No using marshmallows to "trap" prey items.

At the end of each foraging bout:

1. Push (with broom) all prey back to center of circle and cover with bucket.
2. Group yourselves by predator morphology. Count the number and type of prey individuals eaten by each predator type. For example, spoons ate ***w*** marshmallows, ***x*** popcorn kernels, ***y*** dried beans, and ***z*** macaroni; knives ate ***w*** marshmallows…etc.
3. Record the data in the format on the data table provided, and on blackboard or poster paper.

4. Dump or put the prey into a "morgue." This can be a large beaker. (you can have non-players sort and replace the 100 initial items back in bags for the next lab).
5. Count the number of prey survivors of each type (original number - number eaten). ***Tip: Students that were not predators during generation 1 can assist in counting in steps 1 and 2.***
6. Finally, reproduction takes place. *Leavus aloneus* reproduces by binary fission. For each surviving prey individual, add one identical individual to the population.
7. To determine prey reproduction by *Wegonna getu*, remember that there are only 16 predators total in each generation – but the percentage of each morphology may change (originally there were 25% of each morphonology, with 4 of each type). After feeding bout 1, calculate the number of individuals of each predator morph for generation 2 as

(#prey captured by morph 'a'/ total # prey captured by all morphs) x 100

This number equals the percent of morph 'a' (out of 16) in the next generation. Do the same with morph 'b', 'c', and 'd'.

Round this number to the nearest whole number. ***Tip: Remember there are no more than 16 predators total that are allowed.***

7. **Repeat** the predation bouts for 4 generations. You may want to let different students take a turn as a predator. Record the number of surviving predators and prey at the end of each bout in the data tables:

8. Plot the number of prey and the number of predators over time in the provided graphs. Each graph should have four lines for each morph.