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; Energy and Matter: Flows, Cycles, and Conservation; 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.

<u>Background</u>: 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, 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. 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.

In this lab we will investigate how natural selection works to select phenotypes that aid survival of prey. Prey (macaroni) shows variability in color / size 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.

<u>Materials</u>: A couple bags of wacky mac brand noodles (these have 4 shapes/colors – purple wheels, yellow shells, orange rotini, and green penne), a nice grassy area outside, data recording instruments (paper, pencil, clipboard), Ziploc bags.

<u>Previous Knowledge:</u> (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 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.

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.

Procedure:

1. Explain that in this simulation, the noodles (wacky mac) represent one species of prey - just one species – that happens to have some variation in color and shape (morphology). The students will play the predator on the macaroni species. The grass is the prey's habitat.
2. Per group: Take 40 noodles, 10 of each type and place them a Ziploc bag. This bag is labeled 'hunted'. Give each group another bag filled with wacky mac (label this bag 'reproduction').
3. Divide the students into groups of 4 (one timer, one data recorder, one to distribute noodles, one hunter)
4. Each group selects are area about 2m x 2m square, and one student distributes the 40 'hunted' noodles throughout that area (make sure the hunter is far enough away he/she can't see the noodles on ground).
5. For 10 seconds only, let the student 'hunter' pick up noodles in the designated area.
6. Count the number of each type of noodles "eaten"
7. All noodles remaining in the hunting area now reproduce (for every one noodle, add one more of the same type/color (because the genes for color / morphology are inherited from parents)). Take noodles from your "reproduction" Ziploc.
8. Record Data: How many noodles of each type/color were eaten? How many remain? How many were added through reproduction? How many are in the hunting area now? Graph the changing numbers of each phenotype.

generation		yellow	purple	orange	green
1	Starting population	10	10	10	10
2	After hunt (# surviving) After Reproduction				
3	After hunt (# surviving) After Reproduction				
4	After hunt (# surviving) After Reproduction				
5	After hunt (# surviving) After Reproduction				

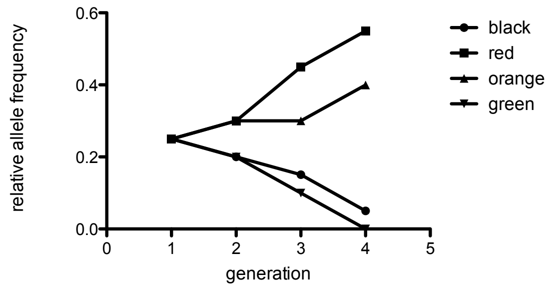
Table 1. Data on # of each morph of macaroni species each generation.

Data Analysis: Students graph the numbers in columns 3-6 onto one graph, using a key to show which line is which morph. # of individuals on Y, Generation on X. You should graph the number of individuals after reproduction each generation.

Extensions: 1. Use real data at http://bguile.northwestern.edu to look at Galapagos finches.

2. Modeling natural selection with jelly beans: Take 4 colors (phenotypes) and thus flavors (genotypes) of jelly beans. Try to use at least one flavor that is usually considered "yucky". Ex: Buttered popcorn flavor versus cherry and lime and orange. Or black licorice versus mint versus berry versus orange. Put 15 of each color in the center of the table. Each student takes one jellybean to eat. The remaining jelly beans reproduce (double the number of remaining beans of each color). Repeat for at least 4 trials (generations). Graph the change in relative frequency of the 4 colors under predation pressure. For the first generation, you have 15 of each of 4 colors (25% each; relative frequency = 0.25).

changes in relative allele frequency of 4 colors (phenoptypes) of jelly beans



3. Explore insect foraging behavior with a lab from http://www.esa.org/tiee/vol/v4/experiments/insect_predation/description.html It uses different "appendages" (forks, knives, etc) to capture prey (m&m's, candy corn, skittles), including scenarios where one prey is toxic.

4. You can also do the Project Learning Tree "Birds and Worms" exercise, which shows how camouflage has been naturally selected for to help prey avoid predation (good for younger kids, involves an outside (preferably) race).

<u>Reflection Questions:</u>

- **Which prey morphology increased in phenotype frequency over the generations?** (Usually the green because they blend in so well with the green grass that they are harder to see).

- **Which prey morphology decreased in phenotype frequency over the generations? (**Usually the orange – easiest to see. Numbers for yellow and purple may vary, yellow is easier to see but smaller in size and sometimes falls to the soil level and the grass may cover them).

- **How does this simulate what happens in nature? How does each part of the simulation link with something in nature?** (the colors and sizes represent variation in a population. Picking up noodles represents predation and adding noodles represents reproduction. Snakes with colors similar to the environment can avoid predation with their camouflage, so the numbers of snakes that blend in increases – favorable traits tend to increase over successive generations).

- **What conditions are necessary for natural selection to occur?** (there must be at least two heritable phenotypes (variation within a population and heritability).

- **What other constraints on a population, besides predation, may keep members from surviving, maturing, and dying of old age?** (natural disasters like hard winter, drought, wildfires, or perhaps disease. Some organisms will survive and reproduce, and some will not (differential reproduction).

- **What things in our simulation were NOT like you would find in nature?** (populations are generally larger than 40 individuals, physical color isn't the only trait to be selected against / for, physical traits often have more than 4 variations, some organisms may die of natural causes, or environmental causes (not just predation reducing numbers), hunting and reproduction do not always occur one right after the other, reproduction rates vary (ours just doubled each time), and the time frame – often 5 generations isn't enough time to see phenotype rations shift.

Models and Explanations: In this lab we explored natural selection of macaroni prey. **A student who demonstrates understanding** of these concepts can explain the graph of the simulation's results – that the prey was all one species with variation in phenotype (different colored morphs). The variants who were successful in avoiding detection by predators survived, reproduced, and had offspring that, because of heritability of traits, had the same phenotype as the parent – and that phenotype increased in number / proportion over generations. Thus, evolution occurred, using the definition of evolution as the change in allele frequency over generations of time (i.e., individuals do not evolve, species do). The graph shows this as the number of the green morph / variant increased over time.

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<u>**Student Worksheet**</u>

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.

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3	**After hunt (# surviving)** **After Reproduction**				
4	**After hunt (# surviving)** **After Reproduction**				
5	**After hunt (# surviving)** **After Reproduction**				

Table 1. Data on # of each phenotype morphology over the generations

__Reflection Questions:__

- **Which prey morphology increased in phenotype frequency over the generations?**

- **Which prey morphology decreased in phenotype frequency over the generations?**

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