Spork and Beans
(Natural Selection, Microevolution, and Adaptation)

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NGSS High School Performance Expectations

HS-LS4-2. Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment.

HS-LS4-3. Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait.

HS-LS4-4. Construct an explanation based on evidence for how natural selection leads to adaptation of populations.

Objectives
Upon completion of this lesson students will be able to:
1. Describe how particular traits increase the success of an organism in its environment.
2. Explain how the process of natural selection operates.
3. Define adaptation.
4. Describe the role that variation in traits, caused by genetic mutation and sexual recombination, plays in natural selection.
5. Define and recognize microevolution in a population.
6. Explain how natural selection can cause microevolution.
7. Contrast the effect that natural selection has on individuals and populations.
8. Explain how evolution is the result of organisms interacting with their environments, but is not goal-oriented.

Materials and Setup
<u>Engage</u>:
For each pair of students, the following materials should be organized in small paper bags. They should be ready to quickly distribute but should not be visible to the students until you are ready to begin the activity.
- one plastic spoon
- one plastic spork (Taco Bell or Kentucky Fried Chicken)
- one paper or plastic party cup
- 50 small marshmallows (25 per student)

Explore:
The materials for this activity are essentially the same as for the Engage activity, with the exception that half of the sporks need to be replaced with spoons so that the entire population of utensils is approximately 75% spoons and 25% sporks.

- one coin (penny, nickel, or quarter, etc.) for every pair of students
- extra sporks and forks to accommodate a population shift

Explain:
No additional materials are needed for the Explain activity.

Elaborate:
The materials for this activity are the same as for the Explore activity, with the exception that lima beans are used instead of marshmallows. The beginning population for this activity is the ending population from the Explore.

- 25 lima beans per student combined into one large prey population (beans should approximate the marshmallows in color and size as much as possible)
- extra spoons to accommodate a population shift

Safety
This lesson poses no specific safety hazards. Students should be reminded to be careful not to accidentally stab other students in the heat of competition. It is also a good idea to instruct students that you do not want to see marshmallows or beans flying through the air—they belong in their habitat.

Requisite Knowledge/Skills for Students
Students should already have a working knowledge of simple. Mendelian genetics and be able to use Punnett squares to determine the offspring probabilities of various crosses.

Procedure
Engage:
20-30 minutes. In addition to engaging students, this activity will introduce the predator-prey simulation and serve to give the students practice using utensils as predators.

1. Introduce the spoon as a member of a predator population. Then introduce the spork as a different member of the same population, that recently arose due to a genetic mutation which causes the fork-like appearance. Ask students which form of the species they think is the better predator. If students quickly respond, have them justify their answer. If not, ask them what other information they need to answer the question. Lead them to consider the type of prey the utensils feed on, relating the prey to solid or liquid, soft or hard food, etc.
2. Hold up a marshmallow and indicate that it is the prey for the utensil species in its current environment. Repeat the question, asking students whether they think the spoon or the spork is the better predator. Be sure to have students justify their answers. Playfully encourage students to advocate for their position; play devil's advocate if there is no difference of opinion among students.

3. Have students work with a partner and ask them to test which utensil is the better predator. There are a number of possibilities. You can let students design and conduct their own test, reporting what they did and what they found. Or to keep the whole class on a similar timeline, you can dictate the method. The most straight forward approach is to have a head-to-head competition between the spoon and spork. With either utensil, the object of the competition is to place as many prey items as possible in the cup in the allotted 30 seconds. Instruct each student to test both utensils and average the results with their partner's performance for each type of predator. Instruct the students to hold their cup flat on the edge of the table or desk immediately in front of them. About 50 marshmallows should be randomly distributed on the surface in front of them. They can only acquire one prey item at a time, and may only do so using the utensil. If two or more prey are acquired at one time, they must be discarded before another prey item may be taken. The hand holding the cup may be positioned and used in any fashion to facilitate the unloading of a prey item from the utensil into the cup. This is the only part of a student's body that may contact the prey, and it must remain in contact with the cup at all times and the cup must not move from its designated position in front of the student. If students use a scooping action with the spoon or spork, marshmallows are readily unloaded into the cup. Marshmallows stuck on the tines of a spork require extra effort to place in the cup, however. One strategy is to place the marshmallow between two fingers of the hand holding the cup, directly over the opening, and close the fingers while pulling the utensil upward.
4. Again, ask students which is the better predator. Most students should report the spork as the better predator when a stabbing motion is used. Regardless of the outcome, it is important to emphasize that their conclusions about whichever utensil is the better predator are based on evidence. This is also an excellent opportunity to ask what makes a test fair, discussing controls, replication, and other issues, such as different feeding behaviors (some students scoop with the spork, some stab), etc. Ask students what feeding behavior they used and why. Point out to students that, much like our utensils, organisms in nature have traits that increase their success in the environment. Ask students to give examples.
5. *Evaluate:* Students will view photos in PowerPoint or on paper to describe how particular traits increase the success of an organism its environment.

   For instance:
   (1) Show a dolphin, shark, and tuna and ask what traits they share for aquatic life. Ask students how these traits are useful in an aquatic environment.
   (2) Show a Northern shoveler, point out the spatula-shaped beak, and ask how its structure might be used in foraging.

<u>Explore</u>:
40-50 minutes. This activity will allow students to make their experiment more realistic, by competing with other individuals in a population. It will provide students an opportunity to make and test predictions, based on their previous findings. Students will also begin to form an understanding of relevant concepts and connect their findings to scientific explanations.

1. Tell the students that their experiment may not be fair. In nature, predators are competing with other organisms for their prey. Inform students that they will now simulate a

population of utensils, all competing for the same prey. Instruct them to form one large group, either on several tables pushed together, or on the floor in a tight circle. If the floor is carpeted, provide a solid surface on which to place the marshmallows, such as a large piece of cardboard. They should bring their utensils and cups with them and combine their marshmallows into one large pool, evenly distributed in front of the group, to simulate the prey population. Replace half of the sporks with spoons, making the population of predators consist of approximately 75% spoons and 25% sporks. Explain to students, that since the spork condition is caused by a relatively recent mutation, the spork is not as common in the utensil population. Before you begin, have students predict which predator will do better, the spoon or spork. Make sure they base their answer on their evidence from the Engage activity. Allow 30 seconds for predation and then ask students who got the most prey items. Inform students that the half of the class that got the most marshmallows survived, while the other half died after not being able to find enough resources. Explain to students that the utensils just experienced a selection event. Emphasize the death and survival of the two groups so the students understand that survival is a key component of natural selection and that it was the environment that "selected" who survived and who did not.

2. Inform students that the experiment is still not as realistic as it could be. Reproduction is also a key component of natural selection, since that is how individuals pass on their genes to the next generation. Inform students that the half of the population that survived will now get to reproduce. Instruct the students who get to reproduce to locate the nearest potential mate and produce four offspring. Surviving members of the population will immediately die following reproduction, but first the entire population must be replaced for the next round of predation (a new utensil for each student). To reproduce, remind them that first they will need to determine their genotypes, and then they can use a Punnett square to determine the possible genotypes of their offspring. The gene that is responsible for utensil shape (U) comes in two different versions, or alleles. The U^S allele is responsible for the spoon-like appearance of both the spoon and spork, while the U^F allele (caused by a genetic mutation) is responsible for the fork-like appearance of the spork. The two alleles show incomplete dominance; thus, the genotype of the spoon is U^SU^S and the genotype of the spork is U^SU^F. Each parent randomly contributes one U allele to each offspring, and they can use a coin flip to determine which allele (U^S or U^F) they will pass on to each of their four offspring. Since each spoon only possesses the U^S allele, that is all they will pass on, and four spoon offspring will be produced (no need to flip a coin). See the Punnett square on the left in the diagram below to visualize

	U^S	U^F
U^S	U^SU^S	U^SU^F
U^S	U^SU^S	U^SU^F

Spoon x Spork

	U^S	U^F
U^S	U^SU^S	U^SU^F
U^F	U^SU^F	U^FU^F

Spork x Spork

the possible offspring from a cross between a spoon and a spork. It is also possible that two sporks will mate (Punnett square on the right). Notice that there is the potential to produce an individual with the genotype, U^FU^F—a fork! Don't point this out to your students. Let them discover it for themselves. Usually the first time two sporks mate, students notice the possible gentoype and suspect that it produces a fork. Instruct students who do not get to reproduce to help those who do by constructing Punnett squares and flipping coins. At the end of reproduction, the population of utensils will be the same size as before, although the proportion of spoons, sporks and forks may differ.

3. Continue for several rounds of predation and reproduction. Suggest to students that they attempt to use a different utensil each round (if possible) and rotate to a new location at the table, to make the experiment fair. Throughout the rounds of predation, record the results on the board for everyone to see. Record data in a table similar to the one below, which assumes a class size of 24. Add a column for forks once one arises in the population. *More than four rounds may be required for a fork to arise in the population.* It may take even more rounds for spoons to disappear. As the number of rounds increases, a shift toward sporks and forks should become more pronounced. Before you begin, have students predict what they expect to happen to the population in terms of numbers of spoons and sporks, based on their conclusions made in the Engage. Those who think the spork is a better predator should predict an increase in their numbers in the population, etc. When a fork does arise in the population, it will most likely do as well as the spork and begin to establish itself in the population after a number of rounds of predation and reproduction. After enough rounds of predation, it is possible for the spoon to disappear from the population. If this occurs, ask students if it can reappear in the next generation (as long as two sporks survive to reproduce, they can produce another spoon). If another spoon is produced, ask students if they expect it to do any better in the next round of predation. Ask students why the spork and fork were superior predators. *Note: If a fork does not arise naturally in the population in the time you have allotted for the activity, you can introduce some (although this is less desirable). Indicate that it was possible for two sporks to mate and produce a fork, and that you are curious about how it will do.*

generation	# spoons	# sporks
1	18	6
2		
3		
4		

4. *Evaluate:* On a notecard to be returned to teacher, have students explain how the process of natural selection operates. Ask students to specifically address the results in the data table, explaining what happened to the utensil population.

Explain:
10-15 minutes. This activity will allow students to continue to connect their findings to scientific explanations, as well as articulate their understanding of relevant concepts and formalize definitions.

1. Lead a discussion to establish a class definition of adaptation as a trait that increases the success of an organism in a given environment, including survival and reproduction.
2. Ask students to describe the role that variation in traits, caused by genetic mutation and sexual recombination, plays in natural selection. It is possible to begin by asking students how things would have gone differently if the utensil population consisted entirely of spoons.
3. *Evaluate:* Students' understanding of the two points above is informally assessed by the teacher during the class discussion, based on student responses.

Elaborate:
30-40 minutes. This activity will allow students to modify and improve their conceptual understanding and apply it to a new situation.

1. Announce that the environment has undergone a dramatic change and that the marshmallow prey has gone extinct. Lima beans have replaced marshmallows as prey for the utensil population. Hold up a lima bean, showing students how hard it is by banging it on the table. Ask them what they predict will happen if they continue the experiment with the current number of spoons, sporks and forks in the population (the number of utensils following the last round of reproduction in the Explore). Encourage them to provide an explanation that is connected to their understanding of variation and its role in natural selection.
2. *Evaluate:* Have students record their prediction and explanation on a notecard and turn it into the teacher.
3. Repeat several rounds of predation and reproduction as in the Explore section. Record the data in a table on the board again. As the number of rounds increases, a shift toward spoons, and away from forks, should become apparent (the fork is very inefficient with the bean prey). Almost certainly, no forks will survive a round of predation to reproduce. Ask students to explain why the spoon and spork are doing well now, and the fork is not. Make sure students understand that natural selection in the changed environment (bean instead of marshmallow prey) has dictated the change. If enough rounds of predation take place, it is almost certain that the fork will be eliminated from the population. When this happens, ask students if the fork could ever reappear in the population. Have them explain how (as long as two sporks survive to reproduce, there is the possibility of producing a fork).
4. Announce to students that although the numbers of spoons, sporks and forks may change from one generation to the next, what is more interesting is what happens to the frequencies of the U^S and U^F alleles in the population. Point out to students that to calculate allele frequencies, they need to know the number of each allele in the population each generation. Add the columns, seen in the diagram on the next page, to the table on the board. The correct number of alleles and allele frequencies is provided

for a fictitious population in the table below, as an example. Note that your starting population may be very different. See if the students can fill in the rest of the table from the number of spoons, sporks, and forks.

gen.	# spoons	# sporks	# forks	# U^S alleles	# U^F alleles	freq. U^S alleles	freq. U^F alleles
1	1	13	10	15	33	0.313	0.688
2							
3							
4							

5. Once the table is completed on the board, point out to students that the population has experienced microevolution and define it for them as a change in allele frequencies in a population from one generation to the next. Ask students to explain what caused the population to evolve. Encourage them to use scientific terminology and connect their explanation to the concepts of variation among individuals in a population, natural selection and microevolution. Ask students to describe how individuals are subjected to natural selection, but it is populations that evolve (individuals either do or do not survive and reproduce, but changing allele frequencies is a phenomenon that happens at the population level). Finally, remind students that the utensil population shifted toward forks in the marshmallow environment and toward spoons in the bean environment, completely reversing directions. Point out that this illustrates how evolution should not be viewed as goal-oriented, that there is not one pre-determined, best endpoint. Make sure they understand that evolution is the result of organisms interacting with their current environment, that the environment selects those individuals which are best suited, and that natural selection can only work with the existing genetic variation in a population.

6. *Evaluate:* Give the students a quiz to formally assess their understanding of natural selection and microevolution (attached).

Evaluate:

After the Engage (Photo Questions): Students describe how particular traits increase the success of an organism in its environment (Objective 1). They should be able to explain how specific traits help a number of different organisms in their particular environments.

After the Explore (Notecard Responses): Students explain how the process of natural selection operates (Objective 2), specifically addressing the data table for their utensil population. They should understand that the environment "selects" those individuals that are best suited by determining who survives and who does not. They should also understand that reproduction is a key component in natural selection, as that is how individuals pass on their genes to the next generation. They should be able to explain that this is what caused spoons to decrease, and sporks and forks to increase in the population from one generation to the next.

During the Explain (Discussion Questions): Students construct a definition of adaptation as a trait that increases the success of an organism in a given environment, including survival and reproduction (Objective 3). Their understanding of this concept should be based on the results of the Explore activity, specifically addressing the finding that individuals in the utensil population experienced differential survival and reproduction. Students also describe the role that variation in traits, caused by genetic mutation and sexual recombination, plays in natural selection (Objective 4). They should understand that variation in the traits among the individuals of a population is the raw material for natural selection. The environment selects those traits that are best suited to current environmental conditions. Students should understand that mutation is the ultimate source of this variation, since it is responsible for the production of different alleles. They should also understand that sexual recombination shuffles the alleles of surviving individuals that are able to reproduce, resulting in variation among the offspring of the future population.

During the Elaborate (Notecard Responses): Students make and explain predictions about the effect the new environment will have on the utensil population. They should predict that the spoon-like appearance of the spoon and spork will make these utensils more successful in scooping lima beans than the fork (Objective 1). The beans are too hard to stab, and the fork is restricted to a relatively inefficient form of scooping.Thus, they should predict that natural selection will cause the population to shift toward spoons and sporks (Objective 2).

After the Elaborate (Quiz): The quiz assesses students' understanding of microevolution as a change in the allele frequencies of a population from one generation to the next (Objective 5) and how natural selection can cause microevolution (Objective 6). They should also understand that individuals are subjected to natural selection, but it is populations that evolve (Objective 7), and that evolution is the result of organisms interacting with their environments, but is not goal-oriented (Objective 8). Student mastery of Objectives 1-4 is indirectly assessed as it is required to answer quiz questions successfully.

Scientific Background for the Teacher

Adaptations are traits that increase the success of individual organisms in a given environment. These traits can include anatomical structures, coloring, internal physiology, or even behaviors. Populations become adapted to their particular environments over time through the process of natural selection. Natural selection is based on differential survival and success in reproduction. In general, individuals with traits that are well suited to the current environment survive and produce more offspring than other members of the population. These individuals pass on their particular genes for these traits (alleles) to their offspring. Thus, the particular allele frequencies can change from one generation to the next, but serve to keep the population adapted to current environmental conditions. Microevolution is defined as a change in the allele frequencies of a population from one generation to the next.

The variation among traits in a population is the result of genetic mutation, sexual recombination, and migration. This genetic variation is the raw material for the process of natural selection. Natural selection can only work with the existing variation in a population, and in this way, is *not* goal-oriented. Rather, evolution is the result of the interaction between organisms and their environment. The environment essentially "selects" (as in natural selection) those individuals that are best suited under the current conditions by eliminating those individuals less suited. A change in the environment often precipitates changes in the population—*never* in individuals, however. It is the population that "evolves," not the individual, although the individual is the entity that is subjected to natural selection. Only at the population level can the required change in allele "frequencies" occur to meet the definition of microevolution.

Misconceptions

This lesson requires students to reconcile their explanations of concepts with actual observations, testing their developing understanding and preconceptions of evolution (Jensen and Finley 1996 and Crow 2004). In particular, we use *Spork & Beans* to address the following misconceptions identified in the literature.

- Mutations are detrimental to fitness (Alters and Nelson 2002). This activity illustrates that a mutation (U^S to U^F) may result in a more adaptive trait under certain environmental conditions.

- Changes in traits are a result of need/use/disuse (Mayr 1982, Brumby 1984, and Bishop and Anderson 1990). Students can see that the spoon is capable of capturing prey and that the U^F allele is unnecessary.

- Acquired characteristics are heritable (Mayr 1982 and Alters and Nelson 2002). We point out to students that individuals who become adept at a particular feeding behavior do not pass on this skill to offspring.

- Students do not recognize the importance of genetic variation (Mayr 1982 and Rutledge and Warden 2000). We confront this misconception by suggesting that students simulate a round of predation with an all-spoon population!

- Environmental conditions are not considered important in causing selective pressures (Rutledge and Warden 2000). This activity clearly demonstrates how the environment (marshmallow or bean prey) can drive the evolution of a population.

- Students do not recognize the role of reproductive success in evolution (Rutledge and Warden 2000). A few rounds of predation emphasize that survival is not enough; they must pass on their genes to offspring to affect change in the population.

- Evolutionary change is based on gradual modifications in traits, not the changing proportion of individuals with particular alleles (Mayr 1982, Bishop and Anderson 1990, and Rutledge and Warden 2000). By counting the number of individuals in the population, students see that the proportion of three distinct phenotypes varies from generation to generation. In the marshmallow environment, this lesson illustrates an increase in the frequency of the U^F allele as more individuals with that allele survive and reproduce.

- Evolution is deterministic (Lord and Marino 1993, Bishop and Anderson 1990, and Alters and Nelson 2002). By altering the environment (replacing marshmallow prey with beans), we help students to evaluate the idea that evolution is working toward some predetermined endpoint. Students come to realize that evolution is the result of organisms interacting with current environmental conditions, and is not goal-oriented.

Integration within Science Discipline
This lesson integrates different content areas within the discipline of biology by requiring students to apply previously learned knowledge of Mendelian genetics in the new context of evolution. Understanding of genetic mutation and sexual recombination is essential for students to comprehend how the environment, through the process of natural selection, determines the future traits of a population.

Interdisciplinary Components
This lesson also requires the integration of math skills learned in grades 6-8 with an understanding of genetic crosses and population dynamics. Students must determine the probabilities of predicted offspring from various matings, and calculate the allele frequencies of populations from one generation to the next.

References

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Quiz Questions:

(1) The number of individuals in successive generations, of three different utensil populations, is presented below. Determine which populations underwent microevolution and explain how you know.

	Population 1			Population 2			Population 3		
gen.	spoons	sporks	forks	spoons	sporks	forks	spoons	sporks	forks
1	1	13	10	5	14	5	10	12	2
2	2	12	10	7	10	7	5	7	12
3	2	13	9	2	20	2	10	12	2

Answer: Populations 1 and 3 underwent microevolution since there was a change in the allele frequencies from one generation to the next. To answer the question, students need to first determine the frequencies of the U^S and U^F alleles in each population. Students may have the misconception that because the starting and ending allele frequencies for Population 3 are identical, the population did not undergo microevolution.

(2) How did natural selection cause microevolution in our utensil population?

Answer: There was variation among individuals in the utensil population (spoon, spork, and fork), caused by three combinations of the U^S and U^F alleles (U^SU^S, U^SU^F, and U^FU^F). The environment selected those individuals that were best suited to current environmental conditions (marshmallow or bean). These individuals survived long enough to reproduce and pass on their genes to the next generation. Over successive generations there was a change in the allele frequencies of the population, resulting in an increase in the frequency of the U^F allele in the marshmallow environment and of the U^S allele in the bean environment.

(3) Explain the statement that individuals are subjected to natural selection, but it is populations that evolve.

Answer: Through natural selection, individuals either do or do not survive and reproduce. The alleles of reproducing individuals are passed to future generations. From one generation to the next, allele frequencies may or may not change in the population. Since "frequency" is a characteristic of a population, and not an individual, evolution is a phenomenon that occurs at the population level. Individuals do not evolve.

(4) Using our utensil population as an example, explain the statement that evolution is NOT goal-oriented.

Answer: The utensil population shifted toward individuals with a fork-like appearance in the marshmallow environment. It shifted back toward spoon-like individuals in the bean environment. The environment determined which form of the predator was best suited to current conditions (bean or marshmallow). However, natural selection could only work with the existing variation in the population (U^S and U^F alleles). It could not fashion a new, more efficient, form of the predator from non-existing genetic variation. Thus, evolution is the result of organisms interacting with their ever-changing environments.