Activity: Modeling Evolution
Model natural selection in a population of bacteria.

Practice(s): Analyzing and Interpreting Data
Crosscutting Concept(s): Cause and Effect, Patterns
Disciplinary Core Idea(s): LS4.B Natural Selection, LS4.C Adaptation

The Modeling Evolution activity uses paperclips to represent bacteria. There are as many as a billion kinds of bacteria and archaea in the ocean. They have important roles in the ocean including decomposition, photosynthesis, and nutrient cycling, especially nitrogen.

Modeling Evolution allows students to experience how the process of natural selection is the result of:

1) the potential for a individuals with a mutation to increase in number,
2) the heritable genetic variation (mutation) of individuals, and
3) the proliferation of those organisms that are better able to survive and reproduce in the environment.

Common Misconceptions

T-NS Table 1.4. Evolution by Natural Selection Misconceptions

Misconception	Explanation
Genetic Variation Organisms can produce new adaptations "at will" to fit into their environment	Genetic variation is ultimately caused by changes (mutation) to DNA. Mutations arise through errors in transcription or translation of DNA. Most mutations are neutral or harmful. Although large groups of genes can be turned off or on by mutations to regulatory genes, the original evolution of advanced structures takes a very long time.
Natural Selection Natural selection is perfect and aiming to create the "best" organism possible	Natural selection works on variations that exist in a population. Natural selection does not have a goal, and it is not perfect. Individuals with imperfections (e.g. susceptible to disease, low drought tolerance, slow swimmer, etc.) can reproduce and pass on their traits to future generations.
Bad Genes Natural selection will get rid of all bad, or harmful, genes	There are a number of reasons that "bad genes" remain in populations. For example: the bad genes might not affect reproductive ability, the bad genes might keep recurring in the population by mutation (especially if the mutation is a simple one), the bad genes might have a benefit in some situations, or the bad genes might be linked to another trait with a benefit. It is also possible that natural selection has not had time to weed out a particular type of bad gene yet.

Adaptation Everything about an organism is perfect for its environment	Many features of organisms are the result of chance. Some genetic mutations are neutral and stay in a population because they do no harm. Some genetic traits were historically beneficial but are retained in modern times. Some traits may have evolved in a different environment and had a different use than they currently do. Some traits are a byproduct of another trait.
Theories Theories are tentative.	The word *theory* is often used colloquially to mean guess or idea. A scientific theory is not the best guess of an individual; rather it is the current best cohesive explanation of a natural phenomenon, which is well supported by a variety of types of evidence.

Additional misconceptions and confusions:

- Traits developed within an organism's lifetime can be passed down genetically to its offspring.
- Nature consciously chooses traits (nature gives organisms what they need)
- Organisms try to evolve.
- Body parts that look the same on different organisms mean the organisms are closely related.
- Evolution is only possible with small organisms or only causes small changes
- Evolution always take a long time.
- Natural selection acts on individuals.
- Organisms do not change over time.
- The kinds of organisms that are living on earth (or in the ocean) today have always lived on earth (or in the ocean) in the past.
- Organisms can choose to go or live anywhere (in any habitat) in the ocean.
- Organisms don't affect their habitats, and their habitats don't affect them.
- The environment does not affect genotype expression.
- Organisms can produce new adaptations "at will" to fit into their environment.
- Natural selection is perfect and aiming to create the "best" organism possible.
- Natural selection will get rid of all bad, or harmful, genes.
- Everything about an organism is perfect for its environment.

Activity: Modeling Evolution

T-NS Table 1.7. Suggested activity progression, if adhering closely to activity as written with no major modifications, assuming class periods of 40 minutes.

Day	Task
1	Introduction to activity
	Activity
2	Class discussion

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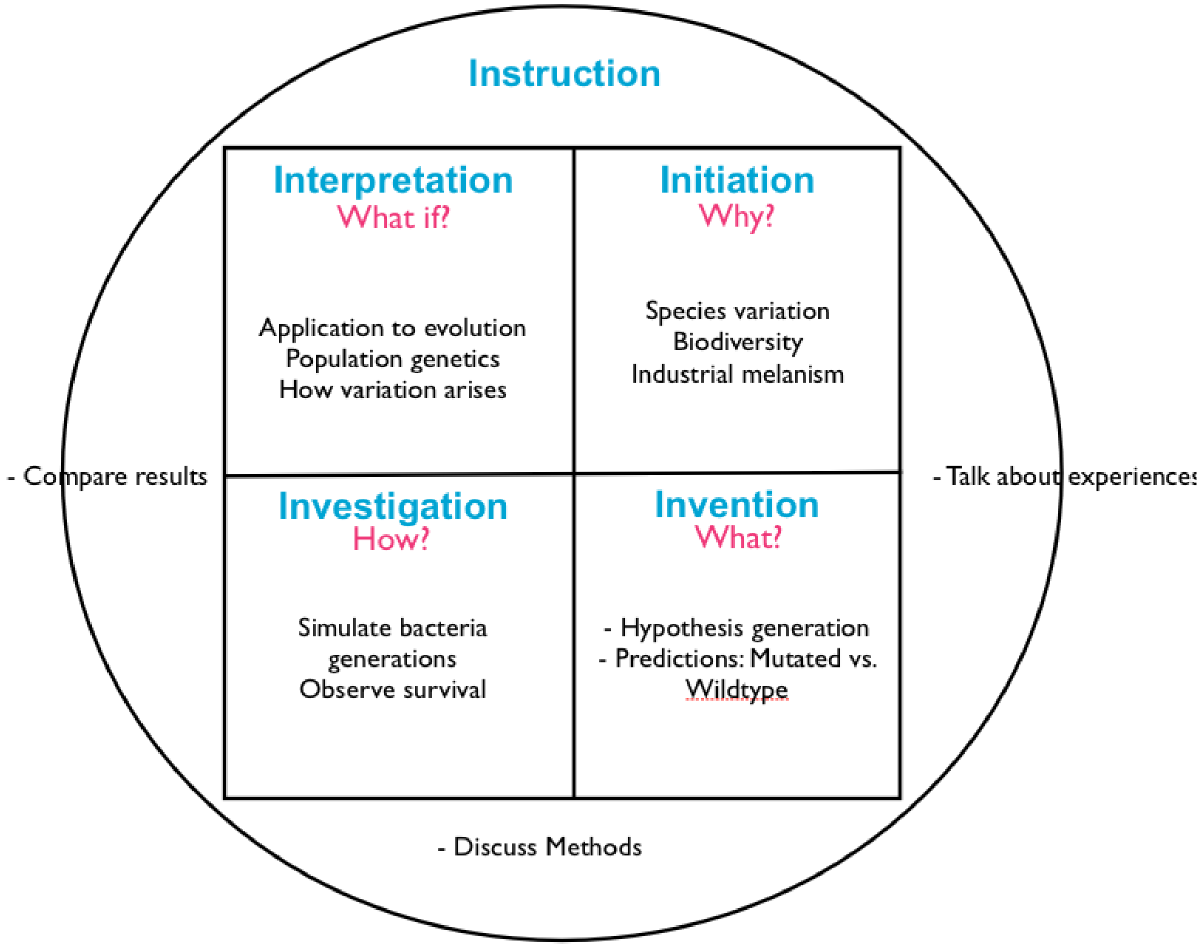
NS Table 1.8. Materials, if adhering closely to activity as written with no major modifications, assuming class of 32 students divided into groups of two (16 groups).

Materials	Quantity	Per	Class Total	Notes on Material Number or Material Modification
Paper clips plastic-coated	50	Group	800	Although the materials list includes 50 plastic-coated paper clips, it is highly unlikely that students will required more than ~20 of this type of paper clip due to structure of activity. However, starting with an equal number of both mutant and typical bacteria avoids giving students clues as to how the activity will turn out.
Paper clips regular silver	50	Group	800	
Six-sided die	1	Group	16	Die with numbers 1 through 6
Pens or pencils (2 colors)	1 of each color	Group	16 of each color	

Activity Inquiry Prompts

1. Why do your number of bacteria in each generation differ from another groups numbers?
2. What conditions are necessary for their to be change over time?
3. How does this model accurate? Where does this model break down?

Planning with TSI



T-NS Fig. 1.7. Planning Modeling Evolution through TSI phases

Focus Modes(s):

- Replication
    - Replication and comparison of activity across groups, optional replication of activity within group.

Procedure

**NOTE* Figures and tables in this section refer to figures and tables in EOFE unless otherwise noted.*

Stress that:

- *Bacteria usually die when exposed to an antibiotic.*
- *In our model, mutated bacteria lose their coating – and now have resistance to the antibiotic.*
- *Bacteria must reproduce to pass on their DNA.*
- *Bacteria must live to reproduce.*

1. Start with a population of 20 bacteria, 18 typical and 2 mutated bacteria. Record the starting bacteria population for both typical and mutated bacteria in Table 1.2 in the column labeled “At start of generation”.

   It is important that students understand why one type of bacteria is different than another (there was a mutation that caused the bacteria to have antibiotic resistance, which we see as a loss of color).

   If students do not have much background on genetics, you may choose to leave your explanation simply in terms of a mutation, or change, in the bacteria. If students understand some genetics, this would be an appropriate place to review the structure of DNA, how changes arise and how they are expressed.

2. The entire population of bacteria will be exposed to an antibiotic. You will simulate this event by rolling the die for *each* individual bacterium (paperclip) to see if the bacterium survives antibiotic treatment.
   a. For typical bacteria, survival and reproduction happen only when a 1 is rolled; any other roll will lead to death (see Table 1.1).
   b. For mutated bacteria, survival occurs in rolls of 1-5, and death only occurs when a 6 is rolled (see Table 1.1).

Table 1.1. Dice roll determining bacteria survival

Bacteria	**Dice Roll**					
	1	**2**	**3**	**4**	**5**	**6**
Typical (Coated Paperclip)	Survives	Dies	Dies	Dies	Dies	Dies
Mutated (Silver Paperclip)	Survives	Survives	Survives	Survives	Survives	Dies

Students may be a bit confused at this stage, but once they start rolling the die in step 4, it becomes clear how to determine if an individual lives or dies.

3. Predict the number of typical and mutated bacteria that constitute your population of bacteria at the end of five generations.

   You may chose to share student predictions on a board.

4. For each individual bacterium, roll the die.
   a. Determine if the bacterium survive by consulting Table 1.1.
   b. When a bacterium dies, remove it from the population by setting it aside.
   c. Record the number of bacteria that died after antibiotic treatment in the “Dead” column in Table 1.2.
   d. Record the number of bacteria that survived after antibiotic treatment in the “Survivors” column in Table 1.2.

   You may choose to model how to fill out the table for one generation of bacteria if you students are confused. Circulating through the groups and asking students what the paperclips represent and how they are determining which ones die will help students connect the simulation to real life.

5. The surviving bacteria reproduce. Bacteria divide in half when they reproduce, in a process called **binary fission**. Each surviving bacteria becomes two bacteria. In Table 1.2, use the number of survivors from generation 1 to calculate and record the number of bacteria after reproduction in the “Reproduction” column in Table 1.2.

   Advise students to first determine which bacteria survive and then work with the survivors to determine the starting population for the next generation.

   Students may need help understanding why each of the surviving bacteria turn into two bacteria. This is because bacteria reproduce by dividing in half to create an identical daughter cell (like mitosis in eukaryotic cells). In order to simulate multiple generations, the bacteria in the simulation need to reproduce. It might be more accurate if the antibiotic resistant bacteria reproduced at a different rate than the typical bacteria, but for this simulation it works well, and keeps the procedure simpler, to have both types of bacteria reproduce once each generation (if they survive).

6. Write the number of bacteria in your “Reproduction” column at the end of one generation in the column “At start of generation” for generation 2.

7. Repeat steps 2-4, filling in Table 1.2 for another four generations.

   Depending on the roll of the dice, students may find that their population dies in the first or second generation. You can advise them to do an additional trial and to keep both sets of results.

   A typical set of values for one group for this activity is shown in the table below.

Table 1.2 Bacteria survival over generations

Generation	Bacteria	Number of Bacteria: At start of generation	Dead (end of generation)	Survivors (end of generation)	Reproduction (multiply surviving bacteria by 2)
1	Typical (coated paperclip)	*18*	*10*	*8*	*16*
	Mutated (silver paperclip)	*2*	*0*	*2*	*4*
2	Typical	*16*	*12*	*5*	*8*
	Mutated	*4*	*0*	*4*	*8*
3	Typical	*8*	*6*	*2*	*4*
	Mutated	*8*	*1*	*7*	*14*
4	Typical	*4*	*3*	*1*	*2*
	Mutated	*14*	*1*	*13*	*26*
5	Typical	*2*	*2*	*0*	*0*
	Mutated	*26*	*4*	*22*	*44*
6	Typical	*0*			
	Mutated	*44*			

8. Graph your results for both typical and mutated bacteria in Figure 1.1. Use the numbers in the “At start of generation” column. Use a different color for each type of bacteria.

   If students graph their results on clear plastic sheets, you can overlay them on top of each other to show class results. Results can also be graphed on big chart paper or by using a computer program.

9. *Optional Part A.* If there is time, run the experiment again.

10. *Optional Part B*: If there is time, continue to model the experiment through another five generations. Before you start, predict the number of typical and mutated bacteria that will be present at the end of ten generations.

    Additional options: Vary the numbers needed to each type of bacteria to "live" or "die", vary the number of starting bacteria, vary the environment so mutated bacteria do not always have the advantage. Once your students run and understand the basics of this activity, the possibilities are endless!

Answers to Activity Questions

1. Compare your final typical and mutant bacteria numbers with your class. How are your findings similar or different? Why?

   Answers will vary. Random chance plays a factor, but generally students will see that, over time (generations), there populations will tend toward all antibiotic-resistant bacteria. Some students, however, just by chance, may kill off the antibiotic resistant strains early on. This is normal and happens in nature. Not all mutations survive, even if they are beneficial. Some students may kill off their entire population (especially if they killed off the antibiotic resistant bacteria early on). Again, this is normal in nature, especially in small populations under extreme environmental pressure (in this case, the antibiotic).

   It is very important to compare individual groups results graphically (as in Procedure Step 8) and/or by numbers. Students will be better able to understand the concepts of the activity and answer activity questions if they can see the similarities and differences and importance of replication by comparing their results with others and speculating as to why groups results varied.

2. Did your prediction match your observations? Why or why not?

   Answers will vary.

3. On average, how do the proportions of typical and mutated bacteria change in the population over time?

   Answers will vary. Random chance plays a factor, but generally students will see that, over time (generations), there populations will tend toward all antibiotic-resistant bacteria while the typical bacteria die off.

4. What would have happened if your mutated bacteria happened to die during the first generation?

   You will have no more mutated bacteria, and it is likely that your whole population will die off because the typical bacteria have a low rate of survival when they are in the environment with antibiotics. Your students may have observed this in their trials, just by chance. This is normal and happens in nature. Not all mutations survive, even if they are beneficial.

5. What was necessary to model evolution? (Hint: Think about how the game would work if all the paper clip bacteria looked the same.)

   In order for natural selection to act on the population, there had to be variation. Variation is caused by differences in DNA. In this case, the difference in the mutated bacteria's DNA makes it resistant to antibiotics.

   There also had to be selective pressure. Antibiotic resistance is a trait that is subject to selection. If the bacteria are living in an environment without antibiotics, there is no advantage to having antibiotic resistance. However, if the environment changes and the bacteria are exposed to an antibiotic, bacteria that are resistant to antibiotics have a greater chance of surviving and reproducing. The antibiotic in the environment selects for antibiotic resistance traits.

6. This activity simulated a selective process that resulted in a shift of gene variation within a population over a short time scale. How do you think a shift in the proportion of genes in a population could lead to the evolution of a new species?

   Answers will vary, but in speciation the proportion of genes shifts enough to change the population (or a subset of a population) into a new species.

7. Explain why genetic evolution happens to a whole population rather than to a single individual.

   In every day speech, we use the term evolution to mean change over time in personal ways (i.e. "my view on that subject has evolved" or "his art shows the evolution of his training"). However, in terms of genetic evolution, the only change that remains in the population is from those individuals that have reproduced. Thus, an individual can have a mutation, but only the population can perpetuate the mutation over time.

8. Animals can develop illnesses from bacterial infections. Antibiotic medications are sometimes prescribed to treat these infections What do you think might happen to a population of bacteria that is exposed frequently to such antibiotics?

   Answers will vary. If there was a mutation for antibiotic resistance in the population, then you would expect the antibiotic resistant bacteria percentage of the population to increase and the percentage of the population that was not resistant to decrease. If none of the bacteria in the population had a mutation for resistance, then the population would probably get smaller because the drugs will kill them.

9. Before the widespread use of antibiotics, there were only low levels of antibacterial resistance. As antibiotic use has grown, so has the number of antibiotic resistant bacteria. Why do you think this has occurred?

There is selective pressure against bacteria without antibiotic resistance, so the bacteria that are resistant persist. And, if any bacteria develop antibiotic resistance, they have an advantage, so their population is increasing.

10. During a bacterial infection, exposure to antibiotics helps kill off bacteria. However, the antibiotic must be administered for a relatively long period of time. What might happen if someone were to be prescribed antibiotics, but did not complete their full course?

    Answers will vary. The person might be fine, and all of the bacteria might die. On the other hand, some of the bacteria might live, and the bacteria that do live will have a higher probability of being antibiotic resistant. This is a real problem in modern medicine.

11. If you did Procedure 10, optional part B, how did the first five generations of the model compare to the second five generations of the model?

    Answers will vary. You may also have students answer questions pertaining to other optional model extensions.