BiteScis | STUDENT

Evolution and *E. coli*

Natural Selection in a Stable Environment

Introduction

Sometimes, it's easy to tell organisms apart. Look at any two people and you can usually see obvious differences in appearance. However, when you look at two frogs or two bacterial cells, they may appear identical at first glance. Even if your eyes can't see the differences, nearly every organism within a population is unique. Perhaps two animals have different blood types, or one has the ability to fight off an infection that would kill the other. There are also tons of differences that can only be found if you look at the DNA.

When scientists compare DNA of two individuals, they do not compare the entire sequence of billions and billions of nucleotides. Instead, they focus on particular segments of the DNA that tend to vary from individual to individual. Different versions of a particular region of DNA are called **alleles**. Sometimes it's easy to tell if two organisms have the same allele or different alleles because the allele is associated with a trait we can observe, like fur color or blood type. But other alleles are only observable in the DNA itself. Alleles arise through **mutations,** which are random changes in the DNA sequence. Mutations can happen when there are errors during the DNA copying process or through exposure to certain environmental factors, like sunlight or chemicals. Mutations can be beneficial or harmful for an organism, or they can have no effect on the individual at all.

As populations evolve, certain alleles become more common and others become less common. In fact, **evolution** is defined as a change in the number of individuals that carry particular alleles in a population (**allele frequency**) over generations. All populations of organisms evolve, from humans to bacteria. It's one of the characteristics of all living things.

Evolution can happen in a number of different ways. Mutations could add new alleles randomly. Already existing alleles can become more or less frequent by random chance, like when a fire burns through a forest and kills the unlucky organisms in its path. Allele frequency can also change when organisms migrate into or out of a population, like when a young female gorilla leaves her home to live with a new group of gorillas.

Those methods of evolution are all largely unpredictable. Changes happen at random, regardless of whether or not a particular allele is helpful or harmful. **Natural selection** is different. Through natural selection, alleles tend to become more common when they are associated with a trait that increases fitness, and less common when they are associated with a trait that decreases fitness. Remember that fitness in terms of evolution is not about hitting the gym! Evolutionary **fitness** is a measure of how likely an individual is to survive and reproduce in their environment. A trait that increases fitness in a particular environment is called an **adaptation**.

If every member of a population had equal fitness, natural selection would not occur. Natural selection only occurs when some individuals have higher fitness than others. For example, in some situations, two individuals in a population must directly compete with each other for limited resources such as space, food, or access to mates. Think of two male lions fighting over access to mates. One lion wins the fight and gets to reproduce. The other lion loses, and does not get to reproduce. Obviously, the winning lion in this situation has a higher fitness than the losing lion. But competition can also be indirect, and can occur even when there are plenty of resources because some individuals have advantages that affect fitness, like being able to process food more efficiently (gaining more nutrients), having a better immune system (staying healthier), producing more sperm (having a greater chance to fertilize an egg), or more successfully avoiding predators (staying alive!). In each of these cases, certain individuals within the population are better adapted (have higher fitness), in the particular environment in which they live, compared to others of the same species. Those individuals get to pass on their genes, including all of their beneficial alleles, to more offspring than less fit individuals, who are better fit have a survival advantage and reproduce more than others in that population, passing down their beneficial alleles to more offspring. As a result, the next generation will have more individuals with the traits (visible or not) that helped their parents to succeed. This is evolution by natural selection.

Chances are good that you have explored some examples of evolution by natural selection before now. But today's is a bit different for two major reasons: it involves bacteria and it does *not* involve any change in environmental conditions. Let's get going!

What To Do

Answer the analysis questions below, reading the Bite when instructed.

Analysis Questions

1. Answer the following questions about alleles.

a. Define "allele" in your own words.

b. Describe the relationship between mutations and alleles.

c. A friend claims that if two mice have different alleles, they will look different. Explain **two** reasons why that might not be the case.

2. Explain how evolution by natural selection is different from other ways a population can evolve. Give examples.

3. Explain the role of competition in evolution by natural selection.

4. Why does reproductive success matter in evolution by natural selection?

5. Consider a population of lions.

a. Brainstorm some reasons why some lions might have a higher fitness than other lions. List at least three.

b. Reflect on your examples in part a. Did you have any examples in the first part where the lions were not competing for a limited resource? If so, circle them. If not, try to think of a few now, add them to your list, and circle them.

STOP & read Science Bite:
Evolution in Real Time: Tracking Mutations in *E. coli*

6. Now, consider bacteria. Brainstorm some reasons that among a population of bacteria living in a Petri dish, some might have higher fitness than others. List at least three. (*Hint:* Think about your answers to Question 5.)

7. What are some of the benefits of using bacteria in a study on evolution? Explain your answer, citing specific information from the Bite.

8. In the Bite, the scientists say that the bacterial *mutations* were competing with each other.

a. How is competing in this sense different from the direct competition we often think of in our everyday lives?

b. If it's not direct competition, what do the scientists mean when they say the mutations were competing?

9. Think about your population of lions again from Question 5. A mutation arises that enables the lions to digest a common type of plant that they couldn't digest before (lions usually eat only meat). You read an article in the news that says the lions "got the ability to digest the plants because they needed a new food source." What (if anything) is wrong with this statement? In your response, make a claim about whether mutations arise because they are needed. Explain your reasoning.

10. We often think that evolution happens when an environment changes. In this study, the scientists kept the *E. coli* in a constant, stable environment.

a. How does evolution occur if the environment doesn't change? Remember that evolution is **any** change in allele frequency over generations. (*Hint:* Did the environment change in the situation described in Question 9?)

Let's consider the 60,000th generation from this experiment. What if the scientists took two samples of the bacteria from this generation, sample A and sample B. If you were to compare the genes present in each of these two populations, they'd be identical. But then what if the scientists kept sample A in the same stable environment as usual, and placed the sample B into a different, but still stable, environment. Maybe the temperature was a few degrees cooler, or the humidity a bit higher. They otherwise continue to follow the same experimental procedure that they've been doing for 60,000 generations.

b. A year later, after about 2,000 generations, they compare samples. Would sample A and sample B still be genetically identical? Explain your reasoning.

Now consider two genetically identical samples from the 60,000th generation again. This time, though, both sample A and sample B are kept in the same stable environment as the original population. So you have identical sets of genes in the populations and identical environments.

c. A year later, the scientists compare the two populations and find that they are no longer genetically identical. How can that be? Explain your answer.

11. How is the experiment described in the Bite similar to what actually occurs in nature? How is it different from what occurs in nature?

12. Use **Figure 2** in the Bite to answer the next set of questions.

a. Examine mutations A and B. At what generation did each mutation arise and what was the fate of each mutation?

b. What caused the frequency of mutation A to rise so quickly from generation 0 to 7,000? Refer to reproductive success (fitness) in your answer.

c. Both the C and D mutations are beneficial in this environment. Which mutation arose first?

d. Which mutation, C or D, had a higher frequency at generation 30,000?

e. If both C and D mutations are beneficial, explain the patterns of frequency over the first 30,000 generations.

f. What might have happened with mutation C if mutation D never appeared? Explain your answer.

g. Assume a new mutation arises at generation 30,000 that increases the number of errors that occur when DNA is copied during cell division. What would you expect to happen from generation 30,000 to 60,000? Draw your predictions on the graph.
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13. **Connect to the Big Question**. If you were to compare the bacterial cells in the first generation with the bacterial cells in generation 60,000, you may not be able to see any physical differences. Scientists have many tools they use to observe organisms. What observations did these scientists make that allowed them to see evolution happening in

these bacteria?