Artificial Selection and the Evolution of Wolves and Dogs

Purpose

This lesson explores how scientists use data to draw inferences about evolutionary relationships and how humans engage in artificial selection, even without consciously meaning to! In this lesson, students will learn about dog domestication and a new study that provides insights and evidence into how and why domestic dogs and wolves have diverged.

Audience

This lesson was designed for use in an introductory high school biology course.

Lesson Objectives

Upon completion of this lesson, students will be able to:

- analyze data and observations to draw inferences about domestic dog evolution.
- explain one theory for how dog domestication could have occurred.

Key Words

artificial selection, breed, domestication, mutation, natural selection, phenotypic plasticity, phylogenetic tree, speciation, whole-genome sequencing

Big Question

This lesson plan addresses the Big Question: "*What does it mean to observe?*"

Standard Alignments

- **Science and Engineering Practices**
  - **SP4**. Analyzing and interpreting data
  - **SP6**. Constructing explanations (for science) and designing solutions (for engineering)
- **MA Science and Technology/Engineering Standards (2016)**
  - **HS-LS3-4(MA).** Use scientific information to illustrate that many traits of individuals, and the presence of specific alleles in a population, are due to interactions of genetic factors and environmental factors.
  - **HS-LS4-1.** Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence, including molecular, anatomical, and developmental similarities inherited from a common ancestor (homologies), seen through fossils and laboratory and field observations.

- **NGSS Standards (2013)**

  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.

- **Common Core Math/Language Arts Standards**

  CCSS.ELA-LITERACY.RST.9-10.7. Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words.

Misconceptions Addressed

- This lesson addresses many common misconceptions about evolution, including the following:
  - Evolution acts only on traits you can see. (Questions 3, 8)
  - Evolution acts directly on genes. (Question 5)
  - Mutations arise and evolution occurs because organisms need something. (Question 6)
  - Organisms close together on a phylogenetic tree are always most closely related. (Question 2b)
  - Organisms at the top, or to the right in a phylogenetic tree are the most evolved. (Question 2c)
- Further information about student misconceptions on this topic can be found here as well as on the Understanding Evolution website. They also have a terrific site devoted to tree-thinking and misconceptions related to phylogenetic trees.

Bite and Primary Sources

- **Bite** "A Bark Stronger than a (Science) Bite" *based on:*

Axelsson, Erik *et al.* 2013. "The genomic signature of dog domestication reveals adaptation to a starch-rich diet." *Nature* 495:360–364.

- **Companion pieces about the article**

Lacapra, Veronica. 2013. "In Order To Live With People, Canines Evolved To Love Carbs." NPR Podcast, January 24, 2013. (NB: Title is teleological, Question 6 addresses that.)

Callaway, Ewen. 2013. "Dog's Dinner was Key to Domestication" *Nature News,* January 13, 2013.

Materials

Copies of the Student Handout and Science Bite for each student

Time

This activity should take approximately one 50-minute class period.

Student Prior Knowledge

It would be helpful for students to have an understanding of natural and artificial selection, and a familiarity with reading phylogenetic trees. It would be helpful if students were familiar with genomes and how comparing genomes is one way to infer evolutionary relationships.

Instructions and Teacher Tips

General Procedure

- This lesson can be run as an independent or small-group activity.
- Have students read through the worksheet and answer the questions as they go, reading the Science Bite when instructed.
- Check in after most students have completed Table 1 and make sure that there aren't any issues understanding natural selection and evolution that need to be addressed before proceeding to the Bite. Consider asking for predictions about the types of genes that might be involved in dog domestication before passing out the Bite.
- You could read the Bite as an entire class or have individual students read it at their own pace.
- After students have completed the lesson, consider bringing them together as a class or break into small groups to compare answers and to discuss any remaining questions.

Tips, Variations, and Extensions

- Be sure to distinguish for your students the difference between natural selection and artificial selection. Natural selection differs from artificial selection only in that it is driven by naturally occurring processes, rather than purposeful breeding and selection of desirable traits by an outside party (usually humans).
- Consider a warm-up that engages students in thinking about their pets. What parts of the pets' lives do the students control? What benefit do the students get from having pets? What benefits do the pets get from living with the students?
- Question 6 discusses teleology, the misconception that traits evolve for a particular purpose. This is among the most common misconceptions about evolution. Spend time on this question and make sure that students truly understand that variations, such as the ability to digest starch, are in place in a population already, they do not arise out of need or because they'd be helpful in a certain environment. Mutation is random. Selection, however, is not random. That is why we can make predictions about how the distribution of various traits will shift in a given environment.
- This lesson is a great opportunity to talk about speciation and what it is (and isn't). Wolves and dogs are the same species, they have not speciated, and yet they are still

distinct and have some distinct characteristics. Question 7 gets into this a bit, but you can expand it in discussion.

- After they have completed the lesson and read the Bite, wrap up this lesson by bringing it back to the original discussion. How did humans artificially select dogs? How did dogs undergo natural selection to better be domesticated by humans?

Background Information and Research Details

- Dogs have supposedly been around humans for about 11,000 years, which matches up nicely with the fact that agriculture was established 10,000 years ago. However, there is some controversy surrounding the origin of dog domestication; remains of dogs and humans together have been found as far back as 33,000 years.

- In this study, the researchers also identified many other genes besides those linked to behavior and digestion that differed among wolves and dogs, 36 regions containing 122 genes total. One group of genes was related to behavior and brain development that differ between wolves and dogs. This is unsurprising given the behavioral differences among these animals. The researchers focused on the digestive genes because these represented the most novel finding, and supported the 11,000-year domestication timeline in the dog domestication controversy.

- Your students might be interested to know more about how researchers "read" genomes. The specifics vary, but in general, they look for patterns in the nucleotide sequences. For example, in this study, they looked for regions of the dog genome with "reduced pooled heterozygosity" and/ or "increased genetic distance to wolf." Reduced heterozygosity means a stretch of the genome that tends to be similar across individuals. These regions are evidence of a recent shared ancestry (since there hasn't been a lot of time for mutations to accumulate). Increased genetic distance to the wolf means that they are looking for places where dogs and wolves tend to differ. Once regions are identified, researchers can try to figure out what it does. If the region is part of or adjacent to (i.e., linked) a gene, then you can make inferences about a connection between evolution and the function of the gene. These sorts of details aren't as important as the underlying message: It's a lot of work to "read" a genome and it's not like reading a book. It takes computing and analysis of millions of base pairs!

- Amylase was one of the main genes found to be different in dogs and wolves. However, the differences were not in the coding sequence. The amylase gene found in dogs vs. wolves isn't different, but the *number of copies of the gene* is. The genetic changes were in the copy number: dogs have 2–15 times as many copies of amylase in their genome, meaning they have a larger arsenal of this enzyme to digest starch. As a result, dogs have higher levels of amylase enzyme expression and activity than do wolves.

- Another difference was found in MGAM, which codes for maltase. Dogs produce a longer version of maltase that looks more like the maltase found in plant-eating animals. This "long" maltase seems to be better at digesting starch than the short wolf maltase.

- Finally, the researchers found mutations in SGLT1, a sodium/glucose cotransporter that sits on the surface of cells and helps them take up glucose after it has been consumed.

Dog SGLT1 is structurally different from wolf SGLT1 and may be more efficient at taking up glucose. This is in keeping with what we've learned so far: if dogs are better at breaking down glucose from their starchy diet, their cells should have evolved to become more efficient at taking it up from the environment as an energy source.

Big Question Discussion

This lesson should get students thinking about the Big Question "*What does it mean to observe?*" In particular, how do scientists use observations in different domains (physical structure, behavior, diet, genes) to infer evolutionary relationships? If you choose to delve into the Big Question, consider the following ideas:

- At the beginning of class, review the similarities and differences between natural and artificial selection. What observations can be made about domestic dogs and wolves that might suggest which mechanism was primarily responsible for their divergence?
- Domestic dog breeds provide a great example of how comparing physical differences only can be misleading. We observe tremendous differences among breeds, and yet they are all, at the species level, the same. Are there other examples students can think of where comparisons of outward physical characteristics might be misleading? Do they think that means those traits are always meaningless? How do students think that scientists help to guard against making bad inferences? Try to get students to suggest that they do so by looking at more than one set of observations. By looking not just at physical traits, but also behaviors, diets, genes, etc., and by constantly re-evaluating their hypotheses when presented with new data.
- After students have read the Bite, ask them what they picture when they read about differences among genes. How do they think we know that a change from a G to a C at a particular place is important or not? Try to get them to make connections between genotypes and phenotypes, and to appreciate that not every difference is significant, only those that are consistent and correlated with a difference in phenotype.

Answers

*Sample completed **Table 1:***

	Similarities	Differences
Physical Appearance	• They all have the same basic body structure: four legs and a tail. • They all have fur.	• The wolf has a longer snout. • Dog breeds are all different sizes and have different body proportions, coat types, and ear shapes.

Diet	• There is meat in both.	• Wolves eat only meat and eat it directly from the animal. • Domestic dog food is made by humans and contains grains and processed ingredients.
Habitat	• Dogs and wolves both like to be outside • Both habitats provide shelter, food, water, and other basic needs.	• Wolves live in the "wild," while dogs are domesticated and are provided their needs by humans. • Wolves live outside only and don't live by humans.

1. After learning about how domestic dogs evolved from gray wolves, a friend says, "Like how humans evolved from chimpanzees!" Is that a good comparison? If not, how could you correct this student's misconception?

No, it is not a good comparison. Humans did not evolve from chimpanzees. Humans and chimpanzees diverged from a common ancestor. Domestic dogs did, however, evolve from wolves. This happened much more recently and in fact, the two animals are not fully speciated (unlike chimpanzees and humans).

2. Use **Figure 1** to answer the following questions:

a. A node, an important part of the phylogenetic tree, is circled in red on the image. What do you think a node represents?

Nodes represent divergence points of two lineages/common ancestors.

b. The side-striped jackal is much more closely related to the black-backed jackal than it is to the African wild dog. Describe how you can use the diagram as evidence to support that claim.

By following the lineages on the diagram, the side-striped jackal and the black-backed jackal meet at a node before the side-striped jackal and African wild dog do. This means that the black-backed jackal and side-striped jackal share a more recent common ancestor than the side-striped jackal and African wild dog.

c. You read in a book that coyotes are more closely related to gray wolves than they are to domestic dogs. Do you agree with that claim? Justify your answer using the phylogenetic tree.

No, I do not agree with the claim. Looking at the diagram, the common ancestor of the coyote and the domestic dog is the same common ancestor as the one shared by the coyote and Gray wolf. Therefore, they are equally related.

3. In the Science Bite, we learned that scientists looked for categories of genes that differed between wolves and dogs. Which two groups stood out?

Nervous system development and digestion

4. Dogs were domesticated by humans. Why do you think it was advantageous for a domesticated dog to have the ability to digest starch?

As dogs began to live with humans, it was probably advantageous to be able to eat starch because they could no longer hunt for themselves. Starch is probably what humans had available to feed them, and if they could not digest starch, they would not be able to survive and reproduce as well.

5. Why do you think the ability to digest starch is not a common trait among wolves? Use concepts of natural selection in your answer.

Because it doesn't offer an advantage to wolves, who have a carnivorous diet. Without a selection pressure in favor of starch digestion, a mutation for the trait would not spread throughout the population when it does arise.

6. A news article about this research had the title, "In Order to Live With Humans, Canines Evolved to Love Carbs." This is an example of teleology, the most common misconception about evolution that suggests traits evolve for a particular purpose. "Birds evolved wings so that they could fly," is a classic example of teleology.

    a. Explain why thinking traits evolve for a purpose is a misconception. ***Hint:*** How do variations like the ability to digest starch originate?

Mutations are the source of genetic variations upon which natural selection and other mechanisms of evolution act. Mutations arise randomly, therefore traits arise randomly. Once they are present in a population, they can become more or less common depending on selection pressures. A particular mutation does not arise in response to an environmental change or for a particular purpose.

    b. Suggest a better, misconception-free title for the news story.

Sample: answer: "Loving Carbs Became Common Once Canines Started Living with Humans"

7. Do you think wolves and domestic dogs will ever completely speciate? Why or why not?

Sample answer: No, I don't because there is not likely to be a cut-off to gene flow as long as there are some domestic dogs that end up in the wild. Also, there has already been a lot of artificial selection and yet they can still easily interbreed. If reproductive isolation hasn't happened yet, why would it?

8. A company offering 100% raw meat dog food makes the claim that the food is healthier and more natural and will, "Bring out the wild in your dog." Do you agree or disagree with the claim based on your understanding of the research described in the Science Bite?

Sample answer: I disagree. It is true that "wild dogs," or wolves, have a raw meat diet, but that does not mean it's healthier for domestic dogs. Domestic dogs have the ability to digest starches, so it's not reasonable to think that a pure meat diet is somehow more natural. In fact, since there have been changes to digestion genes, it could make domestic dogs sick.

9. **Connect to the Big Question**. Think about how the researchers came to their conclusions as you answer the following questions.

    a. Like scientists, you used observation skills to look at the physical appearances, diets, and genetic differences between dogs and wolves. How did these observations help you better understand the evolution of domestic dogs and wolves?

Sample answer: It helped me understand the key differences, such as diet and habitat, and to appreciate how similar some dogs are in appearance to wolves.

    b. How were scientists able to draw conclusions about the genetic differences among wolves and domesticated dogs? Refer back to the Bite for details on how they used observation and data analysis to come to conclusions.

Scientists compared the genomes of wolves and domesticated dogs and looked to see in what types of genes there tended to be differences. That helped them to infer which traits (the ones coded for by the genes) were likely key to the domestication process.