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From Wolf to Woof! Artificial Selection via Selective Breeding

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Introduction

Exiled and alone, a young female wolf, soon to be expecting a litter of pups, found herself sitting on her hindquarters along the edge of a rocky cliff overlooking a group of humans. When the humans first arrived, they survived by scavenging kills left behind by her pack. Now, the humans had built a camp and were cooking red deer over a fire. She could see that humans lived in a pack too, not much different from her own. Ever alert yet starving for sustenance and companionship, she cautiously accepted a meat offering left by one of the curious humans. After that, humans regularly brought her food or she would scavenge the scrap piles on the outskirts of camp. Her newborn pups also learned to live along the edge of the human encampment. Winter arrived, and mama and her pups followed the humans as they left for their winter camp in the lowlands. When the pups grew of age, some of them continued to follow the human group while others left in search of their own wolf families. Eventually the wolves that remained by the humans grew to trust them, and even hunt alongside them. Wolves and humans shared the land and the herds together, defended their territory, and embarked on a relationship that would last for the next 30,000 years.[1]

The above narrative is one possible example of how dogs came to be. Every dog we know and love today, from the four pound Chihuahua to the massive two hundred pound Great Dane, shares a common ancestor with the Gray Wolf. Together, you and your students will examine the concepts of natural and artificial selection that led to the practice of domestication. Our focus will be on dogs as we trace their ancestry from ancient wolves to the hundreds of breeds and mixed-breeds that exist today. Topics will include how dogs came to be domesticated to live in our homes, provide companionship, and assist us as helpers and healers in our communities. We will examine how humans have historically manipulated biology through selective breeding to produce desirable traits in our canine companions. We will also consider ethical responsibilities surrounding “negative” traits that inadvertently, or with disregard, seem to be to the detriment of a living creature.

This unit was developed during the summer of 2018 at the innovative Yale National Initiative, where teachers from around the nation collaborate with each other and Yale professors to intensely study a topic and bring it back to the classroom in the form of a published curriculum unit. Yale ecology and evolutionary biology professor Paul Turner led a seminar titled “Manipulating Biology: Costs, Benefits and Controversies,” of which I was an eager participant. I am the STEM lab teacher at a kindergarten to fourth-grade magnet school in urban

New Haven. Each class spends one hour per week with me as they engage in a variety of hands-on science and engineering projects. Our population of 400 students is about 50% Hispanic, 40% African American, and about 10% either White or Asian American. Over 90% of our students receive free or reduced lunch services. Our school is fortunate to have incredibly dedicated teachers and a well-supplied STEM lab, and I am privileged to work with so many remarkable students and their families.

We discussed a variety of topics related to manipulating biology during our seminar work at Yale. Much of that discussion involved an emerging genome editing technology known as CRISPR-Cas9 (Clustered Regularly Interspaced Short Palindromic Repeats). Think Jurassic Park, but with applications in a variety of fields that includes disease control by changing mosquitos so they cannot transmit malaria or dengue virus, or creating designer human babies that have genetic resistances to hereditary ailments. While fascinating and certainly a relevant topic to the future of biological manipulation, this unit will concentrate on past and current practices that do not involve direct gene editing. Instead, third grade students will have this topic brought to their academic level as they create a foundation of understanding about how humans have impacted the evolution of *Canis lupus familiaris*, the dog. Third grade students are expected to study the basics of inherited traits under the current NGSS (Next Generation Science Standards) guidelines. While this unit is designed for third grade, the content and activities within are recommended for any grades third and up.

Before we get to the classroom activities, the following pages will provide a brief overview of natural selection, artificial selection, and domestication. This is essential background information that has been carefully selected based on my studies and research at Yale University and will help you to be a well-informed teacher prior to teaching this unit.

Teaching Strategies

Natural Selection

The concept of natural selection is based on the work of Charles Darwin. In 1859, Darwin wrote “Owing to this struggle for life, any variation, however slight and from whatever cause proceeding, if it be in any degree profitable to an individual of any species, in its infinitely complex relations to other organic beings and to external nature, will tend to the preservation of that individual, and will generally be inherited by its offspring. The offspring, also, will thus have a better chance of surviving, for, of the many individuals of any species which are periodically born, but a small number can survive. I have called this principle, by which each slight variation, if useful, is preserved, by the term of Natural Selection, in order to mark its relation to man's power of selection.”[2] Phenotypes are observable characteristics and traits, including behaviors, which are variations within a species. Eye, hair or skin color, height, shoe size, etc.… are some examples of phenotypes within the human species. The patterns on a zebra, the shape of a bird’s beak, or the sound of a bird’s chirp are just a few examples of observable phenotypes, or physical variations, within animal species. Darwin’s theory of evolution by natural selection was based on the idea that these variations within a species could increase an individual’s ability to survive, compete for resources, and reproduce. More individuals with a favorable phenotype will survive to pass on their traits to future generations, while those with unfavorable traits will become the minority and may eventually be eliminated. Therefore, a species adapts to environmental conditions over time through the power of genetic variation, which is the raw fuel for the process of natural selection. Darwin observed different types of beaks among the finches of the Galapagos Islands. Since there were no other birds to compete with on the islands, the finches had adapted to niches in food availability. Some beaks were best suited for eating seeds and flowers at the top of a cactus, while other bird variants (in this example, species) had beaks favorable for foraging for insects at the base of the cactus.[3]

Another prime example of Darwin's theory of natural selection can be found in the story of the peppered moths of England and Ireland. Peppered moths are predominately white with black speckles. This coloration provides excellent camouflage against bird predation when moths are resting on lichen covered rocks and trees. Some of the moths carry the gene for an almost solid black coloration, but their coloring makes them more visible to predators and their numbers at the time were scarce. In the 19th century, the air pollution from factories and coal burning in homes had a blackening, soot-covered consequence on the environment. During this era, the change in environment promoted a switch in the number of observable black moths. Now the black moths had a genetic advantage as they were better able to blend with their surroundings better than the speckled variety. As a result of their rapid generation times, within a short time period the black moths began to proliferate. "For example, the first black peppered moth was recorded in Manchester in 1848 and by 1895, 98% of peppered moths in the city were black."[4] In the mid-twentieth century, the impact of clean air legislation led to a cleaner environment. Once again, the tree trunks were whiter and growth of lightly-colored lichens increased. This was not favorable for the black moths, but the speckled moths began to flourish again. Both variations of moths still exist today, but the speckled moths are common and the black varieties are rare.

One of the lessons in this unit will include a simulation based on the peppered moth story. Once students have an elementary understanding of natural selection, they will be ready to learn about the closely related concept of artificial selection.

Artificial Selection

Artificial selection, often referred to as selective breeding, relies on similar processes that drive natural selection with one key difference – human intervention in the reproductive process to determine which variants (and hence, traits) dominate the population in future generations. Humans have manipulated biology this way for thousands of years without knowledge of genes or DNA or much of what we understand about biology today. In the introduction to their book on domestic evolution, author/researchers Driscoll and O'Brien write, "It was no more than 12,000 years ago that humankind began to consciously harness the 4-billion-year evolutionary patrimony of life on Earth. Exploiting the genetic diversity of living plants and animals for our own benefit gave humans a leading role in the evolutionary process for the first time."[5] Once humans started artificial selection to develop plants and animals for food, human population size soared from approximately 10 million people to the estimated 7 billion people living on Earth today, all in a span of about 12,000 years.[6] The global impact has been profound. Today, 4.93 billion hectares are used for agricultural practices, which accounts for 70% of all fresh water consumed, and the world's species are going extinct up to 10 times faster than the historic ''background'' rate, primarily contributed to habitat loss due to agriculture.[7]

Artificial selection can occur through a variety of methods. Direct gene editing using CRISPR technology is certainly a direct form of biological manipulation. Another form of artificial selection could be the culling of dandelions growing on a manicured grass lawn, with the goal of reducing the population of one plant species so that another may dominate. One of the first steps in farming is to clear the land, therefore reducing plant competition and modifying the soil to enable selected plants to grow. At some point around 12,000 years ago, humans began to increasingly rely less on hunting and gathering, and more on growing and sustaining food sources of their choice. Agricultural practices led to selecting the right plants to grow, and along the way humans discovered they could cultivate plants that grew and produced food better than other plant types. Trying to pinpoint the first domesticated plants is a challenging task, since agricultural practices developed over millennia in different locations. There is now convincing evidence for at least 10 such "centers of origin," including Africa, southern India, and even New Guinea.[8] Wheat was an early plant to be cultivated and analysis of charred wheat spikelets from a 10,500-year-old archaeological site in Turkey helps tell a story. Upon microscopic examination, domesticated wheat bears a trademark scar from where the spikelet was torn from the stalk during harvesting. It may have needed human help to disperse its seeds. Wild wheat, also collected from the same region, does not have this scarring. Instead, the round and smooth spikelets could easily break free and disperse. The wheat spikelets with the scarring are viewed as evidence of the earliest known domesticated wheat in the world and are a physical sign of the rise of agriculture.[9]

Domestication

Domestication of a species, whether plant or animal, is a form of artificial selection. Dogs, cows, goats, sheep, and pigs are some of the earliest known domesticated animals, just as cereal grains such as wheat were some of the earliest domesticated plants. Animals that provided milk, such as cows and goats, were a valuable source of protein. Other animals were suited for labor intensive plowing, transportation, and as sources for wool, leather (hides), and fertilizer. As people began to raise these animals, they understood that allowing certain individual animals to breed could produce offspring that closely resembled the parents. They could use this knowledge to grow plants and animals with traits beneficial for feeding a growing human population. This population, beginning to thrive, relied less on hunting and gathering and could afford to settle in permanent locations. They would harvest the land for food and resources, and raise animals for food, service, and in some cases, companionship. This change in lifestyle also led to larger communities, where economics, intellect, art, and music would blossom, but would also be ravaged by warfare, famine, disease, and all the intricacies enveloping the human condition.

Domestication is at the heart of how humans arrived where we are today. It is a vast concept with implications that have rattled and elevated the course of human society’s trajectory; and yet as we marvel at the brilliance of human achievement we must not be blinded by the costs of such advancement. This was a resonant theme throughout my seminar work at Yale, and this unit serves to connect our forward thinking about CRISPR with a look at how we have handled the same moral questions in the past.

Domestication is the process by which a wild animal adapts to living with humans through selective breeding by humans over hundreds or thousands of years. Out of all the plants and all the animals that have been domesticated by humans, the dog currently outdates them all. Domesticated dog origins range from a known 14,200 years to an estimated 36,000 years ago. While the question of whether a dog was a dog before it was domesticated remains up for debate, we have been able to genetically show that modern dogs share a common ancestor of the modern grey wolf. The oldest record of a dog buried alongside humans was discovered in a basalt quarry in Bonn-Oberkassel, Germany. The incomplete remains of a dog, plus teeth of a second dog, were found at the beginning of World War I, along with the skeletons of a man and woman. Paleontology analysis shows that the dog appeared to not only have been buried with the humans at the same time, but was also cared for by humans. Carbon dating places the bones to be about 14,200 years old.[10] Where the genetic divergence of dog and wolf took place remains controversial; it is further complicated by proposals that an initial wolf population split into East and West Eurasian groups and were domesticated independently into two distinct dog populations between 14,000 and 6,400 years ago. There is also fossil evidence from 35,000 years ago of a wolf from the Taimyr Peninsula in northern Siberia that diverged from the common ancestor of present-day wolves and dogs. The best knowledge that we have based on fossil evidence is that dogs, classified as *Canis lupus familiaris* and the grey wolf, *Canis lupus* shared a common ancestor, an ancient wolf species known as the Taimyr wolf. The grey wolf is currently the closest living relative to the dog. Dogs evolved from wolves through a centuries-long process of domestication and through this process, a dog's behavior, life cycle and physiology have become permanently altered from that of a wolf, although they can breed and produce viable offspring.[11]

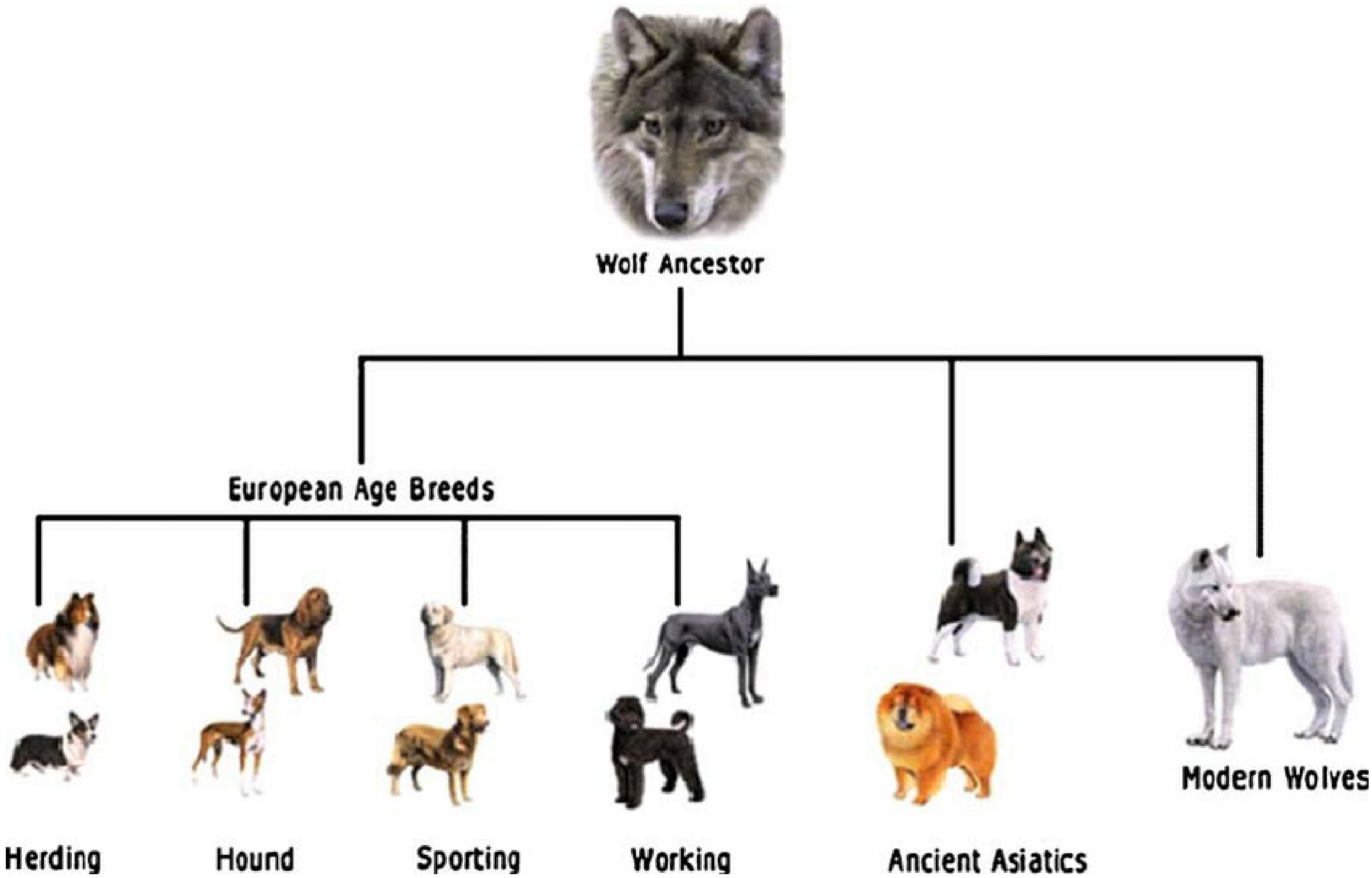

Figure 1 This basic family tree shows how wolves and dogs share a common ancestor. In one of the classroom activities, students will create a similar classification system based on their family tree.

In the 1950's, two researchers in a brutally cold part of Siberia set out to conduct a groundbreaking experiment in domestication. In a span of less than 60 years, they could produce genetically and behaviorally domesticated foxes. Their story is fascinating, and is the subject of both a book and documentary which I will share in the resources section of this unit. This is how they did it:[12]

How to Build a Dog

First, select a species that is dog-like. Russian researchers Belyaev and Trut chose the silver fox. Dogs and foxes, while both from the larger *Canidae* family, cannot interbreed. They are too distantly-related genetically to interbreed, especially because these two species have different numbers of chromosomes.

Second, you need to collect a variety of individuals of that species suitable for breeding. Observe their behavior. Do some foxes seem a bit friendlier than others? Belyeav and Trut found that some variants of the foxes were more docile than others. They separated the most docile from the aggressive wild foxes.

Third, select a behavior trait you want to encourage and play matchmaker. In this case, you want them to be friendly and trusting of you, a human. Belyaev and Trut bred the docile foxes with other foxes, some also docile, some not. The fox pups were hand raised, and as they grew, some developed a docile trait and others became aggressive towards people.

Fourth, keep repeating step three. Foxes were sorted and bred again with other affectionate foxes, with an attempt to insure they still came from a variety of bloodlines. Over several generations, the selected trait of friendliness began to increase. Some individual foxes acted very much like dogs. They wagged their tails, licked the researchers' faces, and behaved quite affectionately. Trut even invited one affectionate fox, Pushinka, to live in her home just like a domesticated dog. Seven generations later, while continuously breeding tame foxes, Belyaev and Trut noticed subtle changes in their foxes. Some of the offspring were retaining juvenile features, both physically and behaviorally, for a longer period. Belyaev realized that development was controlled by hormones, and their fox breeding was beginning to produce a hormonal variance. Belyaev was overjoyed at what he described as the beginning of genetic domestication.[13] After 60 years, the research continues today. Belyaev died in 1985, but Trut still carries on the research program. Their foxes now show even further domesticated features, such as a shorter snout, curly tales, spotted fur, and barking at strangers yet relenting when humans welcome the visitors.[14]

Positive Traits, Negative Consequences

The third activity in this unit is a Design-a-Dog simulation based on the concept of selective breeding of dogs. While we have established that the first dogs genetically diverged from wolves thousands of years ago, that does not explain why we have so many different looking dogs today. Some are so small you can fit them in a shirt pocket, while others are so large that you could understandably confuse them with a small horse. They vary in color, body proportions, speed, smell, and temperament. They can be trained to assist us with rescue operations, to help the disabled, to keep us safe from danger, and to provide a loving and spiritual connection of companionship unrivaled by any of the over 6,495 species of mammals currently known to exist.[15]

One example of a dog bred for its special abilities is the bloodhound. It is one of the best tracking dogs due to the 230 million scent receptors in its nose. This is about the same as the grey wolf, but a human, for comparison, only has about 5 million scent receptors. In addition, the olfactory section of the brain that processes smell is about 40 times in comparative size to the same portion in a human brain. Simply put, this dog's ability to track a scent is incredible. Per an article in Nature magazine, "When a bloodhound sniffs a scent article (a piece of clothing or item touched only by the subject), air rushes through its nasal cavity and chemical vapors — or odors — lodge in the mucus and bombard the dog's scent receptors. Chemical signals are then sent to the olfactory bulb, the part of the brain that analyzes smells, and an 'odor image' is created. For the dog, this image is far more detailed than a photograph is for a human. Using the odor image as a reference, the bloodhound can locate a subject's trail, which is made up of a chemical cocktail of scents including breath, sweat vapor, and skin rafts. Once the bloodhound identifies the trail, it will not divert its attention despite being assailed by a multitude of other odors. Only when the dog finds the source of the scent or reaches the end of the trail will it relent. So potent is the drive to track, bloodhounds have been known to stick to a trail for more than 130 miles."[16]   Other features of the bloodhound also assist it in tracking a scent. Long ears help sweep up scent from the ground, and folds of skin on the face, neck, and chest help trap a scent. The dog is hardy and can tolerate traveling a long distance. These features were retained and enhanced through thousands of years of selective breeding, and the benefit to human society has been impacted. While these traits were probably developed for hunting, bloodhounds can also be used to track a criminal or find a missing person. They can be trained to detect harmful drugs or explosives. They can even be trained to smell low blood sugar or certain types of cancer in humans! Selective breeding has been the key method of developing this trait, and in this case many positive traits were enhanced. Unfortunately, there are many dogs that face a variety of debilitating and potentially lethal health problems that can also be attributed to selective breeding. Many of these problems lead to animal suffering and premature death rates. While the longer process of natural selection may have, over time, produced an animal with all the positive traits retained, the longer process also helps weed out some undesirable traits as well. For example, the German shepherd carries a gene making hip dysplasia, a malformation of the hip joint, a commonly inherited trait. This crippling and painful condition leaves the individual German shepherd prone to a life of hip joint pain and suffering. There are other genetic consequences of selective breeding. Pugs and bulldogs were bred to have a very short snout. As a result, they have a less powerful sense of smell, difficulty in warm weather due to limited panting abilities, and major respiratory problems throughout their lives. Some dog breeds are prone to back and skin problems, cancers, cataracts, and a variety of maladies that are prevalent in a certain breed. Whereas dogs with these problems may not exist today had they evolved naturally, it makes sense that if we want to give human intervention credit for developing positive traits, we have to take credit for the negative consequences as well. This would make an excellent ethical debate topic in a classroom discussion.

Classroom Activities

Lesson 1: Begin the unit with literature. A carefully selected book will help engage students and promote discussion. Two books that I recommend are *From Wolf to Woof* by Hudson Talbott or *Dogs: A Kid's Book of Dog Breeds* by Eve Heidi Bine-Stock. I selected these choices because they are age appropriate for third graders and they also address the history of dog domestication, but in different ways. *From Wolf to Woof* reads much like a modern-day myth and tells a fictional story based on science-based speculation of how wolves may have adapted to living near and with early humans. *Dogs: A Kid's Book of Dog Breeds* is a non-fiction book and dedicates a few pages to a particular dog breed. Included with each passage is a description of that breed's breeding history.

Lesson 2: Continue the unit with a media presentation. There are many age appropriate documentaries about dogs that include the story of their evolutionary divergence from wolves. "A Brief History of Dogs" by Carrot Explains (YouTube channel) is excellent. It is only three minutes long, but is packed with information and even includes the Russian fox researchers mentioned above. Another documentary, called "Dogs!" by Modern Marvels (also on YouTube) clocks in at 45 minutes, but the first 12 minutes are a great introduction to the ancestral link between wolves and dogs. The rest of the documentary focuses on different types of work and services dogs provide to humans. I recommend showing all "A Brief History of Dogs" and the first 12 minutes of "Dogs!" Follow these clips with classroom discussion. Let students develop questions and put them up on chart paper. These questions can serve as talking points later in the unit.

Lesson 3: Online simulations. A computer simulation will help learning about selective breeding in a way that feels like playing a game. A quick google search for "selective breeding simulation" at the time of writing this unit in 2018 brought up many options. I previewed must of them, and the absolute best was by Legends of Learning at https://www.legendsoflearning.com/learning-objectives/artificial-selection-via-selective-breeding/. The game is called Dog Breeding Center and is an excellent way to learn about how dogs are bred for selected traits. You do need to sign up for an account, but the games are free and students can access the game by going to the site and using a class code. You can track their progress in the game once students have logged in. In my opinion, the small investment in time setting up your teacher account was worth it for the value of the activity.

A second choice does not have much to do with dogs, but has everything to do with selective breeding. It uses angelfish and the goal of the game is to increase the value of your aquarium by breeding different types of angelfish with valuable traits. You can find it here: http://www.open.edu/openlearn/science-maths-technology/science/biology/angel-breed#

Lesson 4: Class Simulation. For the final activity of this unit, students will participate in a selective dog breeding simulation game designed by Jennifer Johnson Collins and hosted on the University of California Museum of Paleontology website http://www.ucmp.berkeley.edu/education/lessons/breeding_dogs/. The game challenges students to breed dogs to match certain traits using parent dog cards and a flip of the coin to see if puppies inherit a trait or not. The activity instructions, teacher prompting, downloadable pdfs, and follow up activities are all included.

Notes

1. Darwin, On the Origin of Species by Means of Natural Selection, or, The Preservation of Favored Races in the Struggle for Life.
2. Darwin.
3. “Peppered Moth and Natural Selection.”
4. Driscoll, Macdonald, and O’Brien, “From Wild Animals to Domestic Pets, an Evolutionary View of Domestication.”
5. Driscoll, Macdonald, and O’Brien.
6. Driscoll, Macdonald, and O’Brien.
7. Balter, “Seeking Agriculture’s Ancient Roots.”
8. Balter.
9. Balter.
10. Janssens et al., “A New Look at an Old Dog: Bonn-Oberkassel Reconsidered.”
11. “Wolf-Dog Hybrids | International Wolf Center.”
12. Dugatkin and Trut, How to Tame a Fox (and Build a Dog) : Visionary Scientists and a Siberian Tale of Jump-Started Evolution.
13. Dugatkin and Trut.
14. Dugatkin and Trut.
15. Burgin et al., “How Many Species of Mammals Are There?”
16. "Nature: The Bloodhound's Amazing Sense of Smell."

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Appendix

Implementation of District Standards

This unit is designed for third grade, but can be adapted for higher grades quite easily. It is based on the Next Generation Science Standards, which, as of 2018, is in the final stages of adoption by the New Haven Public Schools district. Under the life science section for third grade, student learning must include:

3-LS1-1. Develop models to describe that organisms have unique and diverse life cycles but all have in common birth, growth, reproduction, and death. [Clarification Statement: Changes organisms go through during their life form a pattern.]

3-LS3-1. Analyze and interpret data to provide evidence that plants and animals have traits inherited from parents and that variation of these traits exists in a group of similar organisms. [Clarification Statement: Patterns are the similarities and differences in traits shared between offspring and their parents, or among siblings. Emphasis is on organisms other than humans.]

3-LS3-2. Use evidence to support the explanation that the environment can influence traits. [Clarification Statement: Examples of the environment affecting a trait could include normally tall plants grown with insufficient water are stunted; and, a pet dog that is given too much food and little exercise may become overweight.]

3-LS4-2. Use evidence to construct an explanation for how the variations in characteristics among individuals of the same species may provide advantages in surviving, finding mates, and reproducing. [Clarification Statement: Examples of cause and effect relationships could be plants that have larger thorns than other plants may be less likely to be eaten by predators; and, animals that have better camouflage coloration than other animals may be more likely to survive and therefore more likely to leave offspring.]

This unit is designed to supplement and enhance the content related to inherited traits found in the Next Generation Science Standards. While selective breeding is indeed connected to these topics, there is still a great deal for students to learn about inherited traits. Inherited traits in humans is not addressed at the third-grade level, so this unit should serve as a valuable and practical application using dogs instead.