Variations in Plants and Animals and Variation in Traits
Content Background Document

1. Introduction

The Variations in Plants and Animals and the Variation in Traits units help students understand the roles that trait variation, the environment, inheritance, and natural selection play in the ways populations change over time. These ideas set the stage for learning about heredity and evolution, the word *evolution* isn't used in either unit.

The content that follows will challenge you to broaden and deepen your understanding of changes that take place in populations over time and in traits among living things of the same kind. Developing a strong conceptual understanding of traits and trait variation will also equip you to more effectively teach your students these concepts.

This document was written with you, the teacher, in mind. The subject matter is tied to the science lessons you'll be teaching, but the concepts are presented at a level higher to equip you with the tools and background you'll need to guide student learning. After all, teachers should know more about the science content than their students!

We'll focus first on the idea of traits and then consider how trait variation, the environment, and natural selection contribute to changes in populations.

2. Defining Traits

Traits are features or characteristics of an organism that may be visible or hidden. Think of a dog. How do you know that the organism you have in mind is a dog? You might say that a dog has four legs, two ears, fur, and a tail that wags. These and many other features are the traits of a dog. All species, or organisms of the same kind, have a unique set of traits that set them apart from other species and help us recognize them.

In the units on variation in traits, we focus on the traits that describe how living things of the same kind look or act, such as the length of carrots and sunflowers and the number of spots on ladybugs. However, organisms have many other kinds of traits. *Physical traits* include such characteristics as hair or fur color, eye color, the presence or absence of wings, and many other observable characteristics. *Behavioral traits* include mating rituals or methods of caring for young. For example, bees do a waggle dance to point other bees to food or water.

Another kind of trait involves DNA, a complex molecule called *deoxyribonucleic acid* that is found in most body cells. All of the biological information for an organism is found in its DNA. Genes, the functional units of DNA, carry genetic information that determines the traits of an organism. The specific sequence of DNA that an organism inherits is called a *molecular trait*. In addition to studying physical traits, scientists explore the molecular basis for a trait, or the molecular traits themselves.

A series of chemical reactions in an organism, or a *chemical pathway*, is also considered a trait. One example is the series of chemical reactions that break down sugars in the body to release energy. *Developmental pathways* are yet another category of trait. Tissue specialization in

various parts of the body, such as heart tissue and other muscle tissue, is an example of a developmental pathway.

The sum and interaction of individual traits are what make an organism unique. All organisms of the same kind have similar traits. These shared traits help us identify a species. But not all individuals of the same species are exactly the same. In other words, some traits vary among individuals within a species.

STOP AND THINK

List at least six traits of cats.
For three of those traits, list a few possible variations.

3. Variation in Traits

Charles Darwin lived in the nineteenth century and is best known for his theory of evolution. In his work, Darwin recognized that all living things have trait differences or variations. Today we know that individual members of all species exhibit trait variations. In some species, such as humans or dogs, variations are easy to see. In other species, such as bees or types of beans, it's much harder to identify the differences between individuals. But the variations are still there even though they aren't visible to the naked eye! If you measure the lengths of many individual beans, for example, you'll discover variations. The same is true of bees. Although some traits show little variation, such as the number of legs a bee has, more variation exists in other traits, such as the bees' coloring. In every population of organisms that scientists have studied, they have found some form of variation.

Many of the variations seen in organisms of the same kind can be inherited and passed on to the next generation. Today, scientists perform tests to determine whether a specific variation can be inherited. In an increasing number of cases, they can pinpoint specific genetic changes that lead to trait variation. It's important to realize, however, that if variations appear during an individual's lifetime, they can't be inherited or passed to the next generation.

4. Variation in Traits and the Environment

All organisms live and develop in a particular environment. For an organism to survive and thrive, an environment must meet certain needs. Sometimes certain trait variations can make it easier for individual organisms to live in a specific environment. For example, before the Industrial Revolution, light-colored and dark-colored variations of the peppered moth inhabited London, England. But with the rise of industrialization, pollution filled the city, and as the bark on trees darkened, birds found it easier to see—and catch—the light-colored moths. Over time, as the light-colored moths were eaten up, more and more dark-colored moths appeared, and their inherited trait enabled them to survive. Inherited features that help an organism survive in its environment are called *adaptations*.

STOP AND THINK

What are some other adaptations that make a particular organism well suited for its environment?

In the 1800s, scientists thought that organisms could change their traits simply by choosing to do so. Giraffes with shorter necks, for example, could decide that they needed longer necks and then make their necks grow. Some people today may embrace this idea as a common-sense theory of how adaptations arise. After all, don't we as human beings frequently choose to change characteristics we don't like? If we don't like our weight, for instance, we can choose to change it through exercise and eating healthful foods.

Students may think that adaptation is about making a "perfect" organism, but it actually means that an organism is well suited for the current conditions in its environment. As conditions in the environment change, entire populations of organisms must adapt further, or they may not survive.

An example of this can be seen with several species of finches that live on the Galapagos Islands. In general, the islands don't receive much rainfall, but in 1977, there was a severe drought with almost no rainfall. Scientists were interested in the effect this would have on the finch population, so they measured a number of traits in one species, including weight and beak depth. They also recorded the number of seeds, insects, and cacti on the island. As the drought progressed, all of the organisms, including the finches, struggled to get the food and water they needed to live, and as a result, their numbers decreased.

Many of the finch species on the island could eat small, soft seeds. Because of the drought, however, these seeds were quickly eaten, depleting the food supply. The finches were then forced to eat harder seeds that were difficult to open. As time went on, this had a severe impact on one particular species of finch—the medium ground finch. Since the beaks of these finches weren't large enough to crack open the hard seeds, they had to peel back the shell layers to reach the seeds. Many of the medium ground finches died that year, and of those that survived, none mated.

By the time the drought ended in 1978, only 20 percent of the medium ground finches were still alive. When scientists measured the surviving finches, they made an interesting discovery: These finches were different from the finches at the start of the drought (see table 1).

Table 1. Beak depth of medium ground finches before and after drought

	Number of Birds	Average Beak Depth (in mm)
Original Population	642	9.42
Drought Survivors	85	9.96

STOP AND THINK

According to table 1, what changes took place in the finch population after the drought?

Scientists measured each medium ground finch before and after the drought and observed that although the finches lost weight during the drought, beak depth remained the same. So the finches' beaks didn't grow larger *during* the drought. Rather, some of the finches survived because they had larger beaks. This refutes the theory that individuals of a species can choose to change based upon desired characteristics.

The medium ground finches are an example of how organisms that are best suited for an environment are able to survive. Finches with larger beaks were able to survive longer when environmental conditions changed. This is the accepted view of adaptations today.

In the finch example, drought caused environmental changes, but environmental conditions can change in other ways. An environment may experience sudden changes, such as volcanic eruptions or floods, or more gradual changes, such as temperature increases over many years. Since it's impossible to predict how an environment might change, it's difficult to know which trait variations will give an organism a survival advantage in new conditions.

5. Inherited Traits

Scientists studying the medium ground finches discovered through measurement and analysis that beak depth is an *inherited* trait. So when they compared the beak depth of the surviving parents with the beak depth of their offspring, they found that larger beaks were passed on to the next generation of medium ground finches.

STOP AND THINK

Sketch a graph showing what you think it would look like to compare the average height of parents with their children's heights.

How does trait inheritance work? As mentioned previously, DNA contains all of the biological instructions for an organism. As the functional units of DNA, genes carry this information, as do the regions that control genes. In organisms that reproduce sexually, sperm and egg cells each contain half of the complete set of genetic information. So when a sperm cell unites with an egg, the resulting embryo has the whole complement of genetic information. Each sperm and egg cell

gets one copy of each gene, but random chance determines which of the two copies each cell receives from each parent. This accounts for most of the variation in organisms.

Variation can also occur because of mutations, or changes, in the DNA sequence that occur randomly in cells. In some cases, a change happens within a gene sequence. Since genes contain the instructions for the production of proteins in the body, this change affects the specific proteins that are made, which can have a positive or negative effect on the organism, or no effect at all.

How did the genetic process affect the medium ground finches? The surviving birds all had large beaks, so when they reproduced, they could only pass on the genetic information for large beaks to their offspring. As a result, all of the babies had large beaks. This caused a long-term change in the finch population, since the surviving birds no longer carried the genetic information for small beaks and therefore couldn't pass it on to future generations.

6. Natural Selection

In 1858, Charles Darwin and Alfred Russel Wallace made a joint presentation in which they shared their views on how organisms change over time. Working independently, each scientist came up with the same ideas about how these changes occur. Rather than following the commonly held theory that organisms choose which traits to change, they based their ideas on the following key observations:

1. More offspring are born than survive.
2. Individual organisms within a population exhibit variations in particular characteristics.
3. Some variations among individuals can be passed to offspring, which means that these traits are inherited.

These observations led Darwin and Wallace to the conclusion that individuals will produce more offspring if they have inherited traits that help them survive and reproduce. They also argued that the frequency of these inherited traits will increase in future generations. In other words, the population will change, or adapt, over time.

The process that Darwin and Wallace described explains how adaptations occur in organisms. They called this process *natural selection*. Let's use natural selection to explain what happened with the finches on the Galapagos Islands.

1. More finch offspring were born than survived. An important factor that limited the size of the finch population was the food supply. In this case, soft-shelled seeds were the finches' primary food supply.
2. Within the finch population were individuals with variations in beak depth. Individuals with greater beak depth had larger beaks, and those with less beak depth had smaller beaks.
3. Beak depth can be passed from parents to their offspring.
4. During the drought, soft-shelled seeds were quickly eaten, and the food supply was depleted. The only remaining food source for the finches consisted of hard, difficult-to-open seeds.

5. The finches with smaller beaks had more trouble opening the harder seeds than the finches with larger beaks.
6. When the drought ended, the individuals with greater beak depth (larger beaks) survived.
7. These individuals, in turn, produced offspring with larger beaks, or greater beak depth.
8. After the drought, the whole finch population changed because, on average, more individuals in the next generation had larger beaks.

A few important facts about natural selection need to be highlighted at this point. First, natural selection describes how *populations*, not individuals, change over time. In other words, *individual organisms* don't evolve. Second, the process of natural selection isn't random. Although chance is involved in environmental conditions and the variations present in a population, the characteristics that appear more frequently are the ones that help individuals survive long enough to reproduce. In this respect, natural selection isn't random.

STOP AND THINK

Imagine a species of beetles that lives in a forested area. The population includes black, white, brown, yellow, and green individuals. A drought has caused the beetles' environment to become desert-like. What do you predict the *population* will look like after 15 generations? What do you think the *individuals* will look like after that time?

7. Natural Selection and Evolution

Darwin described evolution as "descent with modification." So far we've described the "modification" part. Natural selection explains how subtle changes happen in *populations* over time. But individuals are connected through inheritance. And because individuals and populations are connected, all species are connected to other species in the tree of life through common ancestors. This is what Darwin meant by "descent." Common ancestry explains why organisms have many shared features. For example, dogs and wolves share many traits, and DNA evidence indicates that the ancestry of domestic dogs can be traced back to wolves. This means that dogs are descendants of wolves.

Natural selection doesn't always lead to changes in all of the traits of a population, however. Think again of the finches. Most of their characteristics remained the same; only their beak depth changed. They still had two wings, two eyes, feathers, cellular processes for breaking down sugar, and so on. In the same way, many traits of a common ancestor still exist among organisms, and the only trait variations are those that affect an organism's survival in certain environmental conditions.

Because of these gradual changes in populations, we can begin to see that natural selection is one of the ways evolution works. But natural selection and evolution aren't synonymous. *Evolution* refers to changes in genetic information and the traits this information encodes across generations of a population or species due to the processes of mutation, natural selection, or

genetic drift. Each of these processes is a *mechanism* of evolution. One of the most powerful and well-documented mechanisms of evolution is natural selection. However, the process of natural selection can exist apart from evolution if the next generation doesn't inherit the selected traits.

How do we know that evolution has occurred? Several lines of evidence contribute to our understanding of evolution. One line of evidence is the *fossil record*. Scientists know that fossils found in deeper layers of Earth are older, and fossils found in shallower layers are younger. There is a clear succession and progression in the fossils they find. Some changes have occurred over time, but the general trend is that the fossils provide evidence of evolution.

Structural similarities among organisms offer another line of evidence for evolution. The limb bones of vertebrates (animals with backbones) that are alive today all exhibit a basic pattern of structural similarity. This includes fish, amphibians, reptiles, birds, and mammals. This pattern suggests that all vertebrates had a common ancestor.

Biogeography, which deals with the geographical distribution of plants and animals, represents another line of evidence for evolution. This branch of biology dates back to Darwin, who found that when he visited different areas of the world, the birds were very similar. Based on these observations, he concluded that the birds had a common ancestor. At some point, some of the birds flew or were blown to other islands or areas and adapted to their new conditions. Even so, they shared enough similarities to indicate a common ancestor.

Other lines of evidence for evolution include similarities among different types of embryos, similarities among DNA sequences of different organisms, and observations of evolutionary changes in the laboratory and in the wild.

8. Summary

In these units on trait variation, students begin exploring concepts that set the stage for learning about heredity and evolution. They discover that variation exists among the same kind of organism, and that scientists can perform tests to determine whether these differences are inherited. Most of the variation in traits among organisms is due to DNA inherited from parents.

Students also learn that some organisms are better suited for their environments and are therefore able to survive longer. If the environment changes, however, these organisms must adapt or they'll die. Individual organisms that are able to survive longer and reproduce pass on their traits to the next generation. Through this process, called *natural selection*, the traits in a population can change.

References

Table 1 data adapted from Boag, P. T., & Grant, P. R. (1981). Intense natural selection in a population of Darwin's finches in the Galapagos. *Science, 214*(4516), 82–85.