Principles of Natural Selection

Charles Darwin was not the only person to develop a theory to explain how evolution may take place. An English naturalist named Alfred Russel Wallace independently developed a theory very similar to Darwin's. Both Darwin and Wallace had studied the huge diversity of plants and animals in the tropics, and both had studied the fossil record. They also were both influenced by the work of Thomas Malthus and his principles of economics.

Malthus had published a book in 1798 in which he discussed how increasing human populations would challenge the world's ability to produce enough food for everyone. Both Darwin and Wallace applied Malthus's ideas to the pressures experienced by plants and animals as populations increased. They noted that no species dominated the world, because some resource limited their ability to reproduce and survive. In an environment where resources are limited, individuals must compete for them. Those organisms that compete successfully go on to reproduce and pass on their traits.

Predict Why were Darwin and Wallace's ideas presented to other scientists before they were published?

In 1858, the ideas of Darwin and Wallace were presented to an important group of scientists in London. The next year, Darwin published his ideas in the book *On the Origin of Species by Means of Natural Selection*. The theory of natural selection explains how evolution can occur. Natural selection is a mechanism by which individuals that have inherited beneficial adaptations show differential reproductive success. This theory is built on the premise that more individuals are produced in each generation than can survive in any environment where resources are not infinite.

Genetic Variation

Darwin's theory of evolution by natural selection was based on observed patterns among plants and animals he and others studied. What he did not understand was how these changes occurred. About six years after the publication of *The Origin of Species*, a little-known monk named Gregor Mendel published his research on genetics and the basic principles of heredity.

FIGURE 14: Variation in coat color can be seen in jaguars and their offspring.

Mendel's work showed that traits are passed down from parents to offspring and that traits are inherited independently of one another. We now know that traits are coded for by genes and that alleles are different variations of the same gene. Variation in the alleles between individual organisms within a population is called genetic variation. Genetic variation is the basis for natural selection.

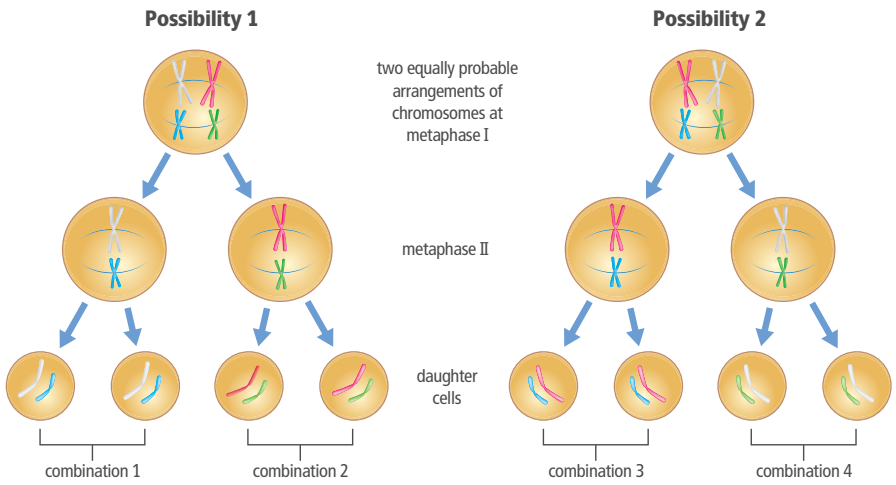
For example, the jaguar cub in Figure 14 inherited a combination of alleles that resulted in it having a different color than its mother. Therefore, there is variation in coat color in the jaguar population, and some variations may prove more beneficial than others in a given environment.

Collaborate In the owl and field mouse simulation, how did you model both variation in traits and parents passing down traits to offspring? Write your answer and discuss it with a partner.

Genetic variation is increased by sexual reproduction and meiosis. In sexual reproduction, the offspring receives two forms of each gene, one from each parent. Genes are segregated during the formation of gametes. If the genes are not linked, they will segregate separately, or undergo independent assortment. As genes are lined up and shuffled in different ways during meiosis, various combinations of genetic material are generated. As a result, sexually reproducing organisms exhibit variety in their traits. For example, Figure 15 shows the variation that can be seen in color patterns on Asian beetles. It is this type of variation that natural selection acts on. Crossing over during meiosis also allows for new combinations of genetic material. This generates an even higher number of possible combinations of genes.

FIGURE 15: Sexual reproduction increases genetic variation.

FIGURE 16: Chromosomes separate independently during meiosis. As a result, gametes have many different combinations of genes.



Heritable mutations also increase genetic variation. Damage to DNA is often caught at checkpoints in the cell cycle. The cell cannot proceed through the cell cycle until the damage is repaired or the cell self-destructs. However, sometimes the checkpoint fails, and cells with mutations proceed with replications. If a mutation is heritable, or passed on to an organism's offspring, it can increase genetic diversity within a population.

Model Explain how you could have modeled a new trait arising from a mutation in the owl and mouse simulation.

Keep in mind that natural selection acts on phenotypes, or physical traits, rather than on the genetic material itself. New alleles are not made by natural selection—they occur by genetic mutation. In addition, these mutations must be heritable, or passed down to offspring. Only mutations that occur in sex cells are passed on to offspring.

Overproduction

It was the work of Thomas Malthus that inspired many of Darwin's ideas about modification by natural selection. In his work, Malthus pointed out the potential of human populations to grow exponentially if there was a constant birth rate and ideal conditions. Such conditions would include unlimited resources and an absence of predators or disease. However, populations do not grow in an unchecked way. As Malthus pointed out, human populations are limited by many factors, such as disease, war, and limited resources.

FIGURE 17: Malthus predicted that population growth would outpace food production, causing a "Malthusian catastrophe."

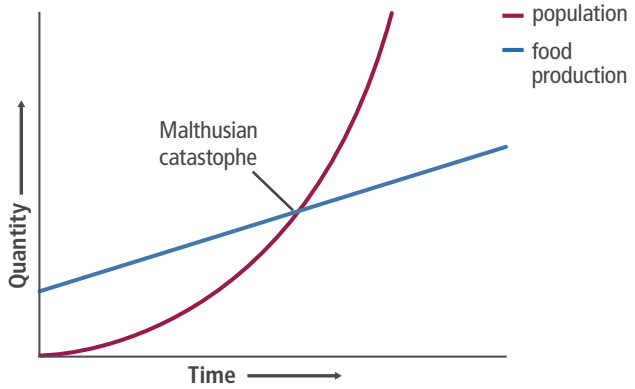


FIGURE 18: Individuals compete for resources such as food.

Predict The birds in Figure 18 are competing for a piece of food. What are some traits that might allow a bird to outcompete other birds for food?

Competition

Darwin noted that more offspring are born than can survive and that, without limits, any one species might overrun Earth. However, environments place limits on population growth, where some individuals are more successful at survival than others. Those individuals that survive better and produce more offspring will have their traits passed on to subsequent generations.

Building on Malthus's ideas that there were limits to human population growth, Darwin reasoned that a similar struggle for resources took place in nature. The challenge is for each individual to be better at obtaining available resources, such as food, water, and shelter.

Adaptation

Sometimes, a certain variation allows an individual to survive better than other individuals it competes against in its environment. More successful individuals are "naturally selected" to live longer and to produce more offspring that share those adaptations. Over time, natural selection will result in species with adaptations that are well suited for survival and reproduction in an environment. More individuals will have the trait in every following generation, as long as the environmental conditions continue to remain beneficial for that trait.

A well-studied example of natural selection in jaguars is shown in Figure 19. About 11,000 years ago, many species faced extinction. Large cats, including jaguars, faced a shortage of food due to the changing climate of that time. Fewer mammals were available to eat, so the jaguars had to eat other animals, such as reptiles. The jaguar population showed variations of jaw and tooth size that became important for survival.

FIGURE 19: Natural selection has led to changes in the jaguar species over time.

a Like many other species, jaguars can produce more offspring than can be supported by the environment. Some jaguars may be born with slightly larger jaws and teeth (skull 1) due to natural variation in the population.

b Jaguars with large jaws and teeth are able to eat armored animals, such as shelled reptiles. These jaguars are more likely to survive and to have more offspring than jaguars that can eat only mammals.

Explain Why did larger jaws and teeth become more common in the jaguar species over time? How do the four principles of natural selection explain these changes?

In biology, the term fitness is a measure of the ability of an organism to survive and produce more offspring relative to other members of the population in a given environment. An individual with high fitness is well adapted to its environment. After the change in climate, jaguars that had larger teeth and jaws had a higher fitness than other jaguars in the population. Jaguars that ate less did not necessarily all die or stop producing altogether; they just reproduced a little less.

It is important to note that fitness does not simply mean being the biggest and strongest individual. For example, being small is beneficial for some types of male spiders. Their lower body weight makes it easier for these males to cast a strand of silk into the air and be carried by the wind to a new location. As a result, these males have more opportunities to find mates and pass on their genes.

Understanding Natural Selection

In order to fully understand the theory of natural selection, it is important to consider how changes in the environment can influence fitness. It also is useful to examine some of the common misconceptions about how natural selection occurs.

Changing Environments

As an environment changes, different traits will become beneficial. Ecologists Peter and Rosemary Grant observed an example of natural selection acting on existing traits within a population of medium ground finches on one of the Galápagos Islands. A drought in 1977 reduced the number of the small, soft seeds that the finches preferred. However, there were still plenty of large, tough-shelled seeds.

The two graphs in Figure 20 represent the number of birds with each size of beak. In 1976, a total of 751 birds were measured. The distribution of beak size is shown in the histogram on the left. After the drought, the Grants again measured the beak sizes of the 1978 survivors. There were 90 birds measured to construct the histogram on the right. The Grants noticed that the distribution of beak sizes changed after the drought affected the types of available food in the environment.

Cause and Effect

Natural selection causes populations to adapt over time. The main principles of natural selection are:

Genetic Variation There is natural variation in the population.

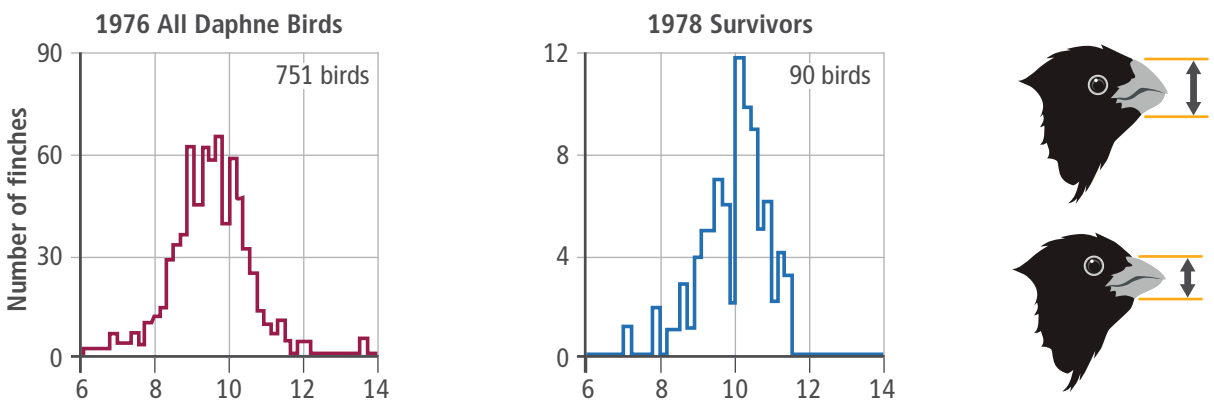
Overproduction More offspring are produced than can survive.

Competition Individuals must compete for resources, and some will outcompete others.

Adaptation Over time, beneficial traits become more common in the population, as individuals with those traits survive better and reproduce more often.

Analyze How did the distribution of beak sizes change after the 1977 drought? Explain how changes in the environment and the process of natural selection resulted in these changes.

FIGURE 20: The data in these graphs shows finch beak size before and after a drought.



The numbers of large-beaked finches on this Galápagos island kept rising until 1984, when the supply of large seeds went down after an unusually wet period. These conditions favored production of small, soft seeds, and small-beaked birds were now better adapted for the environment. With evolution, a trait that is an advantage today may be a disadvantage in the future.

Misconceptions About Natural Selection

It is tempting to assume that any feature on an organism must be the ideal trait for that organism's environment. However, not all traits are adaptations. For example, humans have a tail bone, but this anatomical feature is not the result of natural selection in humans. A feature such as this may have resulted from natural selection for a previous function, but it now serves no specific function. This trait is heritable, so it is passed down from person to person, but it no longer serves its original purpose.

FIGURE 21: This cartoon depicts a misconception about natural selection.

Explain The cartoon in Figure 21 depicts a cat who has developed a can opener for a hand. How does this cartoon demonstrate a misunderstanding of the theory of natural selection?

It also is important to keep in mind that natural selection does not produce individuals which are perfectly suited to their environment. This is partly because organisms have combinations of traits that result from complex sets of tradeoffs. For example, having large horns may help an organism fight successfully for mates, but they may make it difficult for the animal to escape predators as effectively as it could with lighter horns. Therefore, it would be difficult for selective pressures to produce "ideal" traits, because a trait that is ideal for one purpose may be less than ideal in other contexts.

Another reason natural selection does not produce ideal traits is that natural selection acts only on traits that already exist. Genetic variation within a population is what allows for the environment to "select" for certain traits. New alleles are not made by natural selection—they occur by genetic mutations.

Many mutations have harmful results and therefore are not likely to produce a trait that is beneficial in a given environment. However, some mutations lead to traits that might be advantageous to certain individuals. A mutation could change an organism's DNA in a way that leads to the production of a new type of protein. If this results in a trait that increases an organism's fitness, this trait would be selected for. Therefore, new traits can occur, but they are not created through natural selection.

Analyze You may have heard someone use the phrase "We'll have to adapt" to describe the way people adjust to their surroundings. Explain why this phrase could lead to misconceptions about natural selection.

Another common misconception about natural selection is that individuals can adapt to their environment. Natural selection leads to changes in populations, not in individual organisms. Evolution is a change in the proportion of alleles in a population over many generations. Therefore, individuals do not adapt to their environment over the course of one lifetime. Adaptations occur in populations, and those adaptations evolve over time through the process of natural selection. This process may take millions of years, or it may occur very quickly, as it does in single-celled organisms, such as bacteria.

Model Think back to the owls and field mice simulation. Were the four main principles of natural selection modeled accurately? How could you improve this model to reflect the principles of natural selection more effectively?