SBI3U-C

Lesson 3

Evolutionary Mechanisms

Introduction

You have learned how Darwin's theory of evolution was developed and the types of evidence that support it. You now know that evolution can lead to the appearance of new species, usually as a result of many genetic changes building up over time. But evolution is not just defined as the appearance of a new species. It means any change in the genetic frequencies within a species over time. In this lesson, you will learn how evolution actually happens by studying the mechanisms that can cause the gene frequencies to change.

Planning Your Study

You may find this time grid helpful in planning when and how you will work through this lesson.

Suggested Timing for This Lesson (hours)	
Evolutionary Mechanisms	½
Mechanisms of Genetic Variation	1½
Humans as Agents of Evolutionary Change	¾
Key Questions	1½

What You Will Learn

After completing this lesson, you will be able to

- use appropriate terminology related to evolution
- explain the fundamental theory of evolution, using the evolutionary mechanism of natural selection to illustrate the process of biological change over time
- describe some evolutionary mechanisms (such as natural selection, artificial selection, sexual selection, genetic variation, genetic drift, and biotechnology), and explain how they affect the evolutionary development and extinction of various species
- demonstrate an understanding of the theory of evolution, the evidence that supports it, and some of the mechanisms by which it occurs
- analyze the economic and environmental advantages and disadvantages of an artificial selection technology, and evaluate the impact of environmental changes on natural selection and endangered species

Evolutionary Mechanisms

Evolution occurs when the relative frequencies of different genotypes in the population change over time. For example, there are many different versions of the gene for hair colour. These different versions are called alleles. There are alleles that code for brown hair, blond hair, red hair, etc. In this lesson, you will examine how the mechanisms of evolutionary change alter the genotype frequencies in a population over time.

Natural selection is the main mechanism of change, but three others—mutation, migration and genetic drift—can also be important mechanisms of evolution. All four mechanisms can cause changes in a population over generations. However, natural selection and genetic drift cannot operate unless there is a key ingredient: genetic variation. That is, evolution is not possible unless some individuals are genetically different from the others.

Genetic Variation

What does genetic variation mean? It means that there is variation in the forms of each gene. For example, each of us has a gene that helps determine our eye colour. But there are several different eye colours possible—brown, blue, green, hazel, grey—all caused by a different form (allele) of the gene. If a gene has more than one form in a population, there is genetic variation for that trait. Differences in genetic variability lead to variation within species, which is a necessary ingredient for natural selection.

Geneticists have begun to analyze and compare the genetic code (genome) of individuals, populations, and entire species. They have noticed that the amount of DNA varies drastically across species. For example, a bacterium may have 470 genes, whereas a fruit fly has 13 000, and humans have about 23 000. Organisms with larger genomes have the potential for greater genetic diversity. However, genome size is not a very reliable guide, because many organisms have genetic material known as "junk genes," which are not expressed. Also, some organisms, such as corn, have many copies of their DNA instead of just two.

In general, organisms that reproduce sexually have more genetic variation than species that reproduce asexually. Sexual reproduction results in the random recombination of genes between the parents, thus creating new combinations of genes. This tends to create greater diversity within populations.

Support Questions

Be sure to try the Support Questions on your own before looking at the suggested answers provided.

14. What key ingredient in the population do natural selection and genetic drift need in order to act as mechanisms of evolution? Suggested answer

15. Does a butterfly species with 10 000 genes always have more genetic diversity than a worm species with only 5000? Explain. Suggested answer

Mechanisms of Genetic Variation

Genetic variation can change in a population as a result of four mechanisms.

Biologists call these the four evolutionary forces:

- mutation
- migration
- genetic drift
- selection

Mutation is the only one of these four that actually introduces genetic variation into the population. The other three merely alter the relative frequency of the existing genotypes. You will now examine how each of these evolutionary forces works.

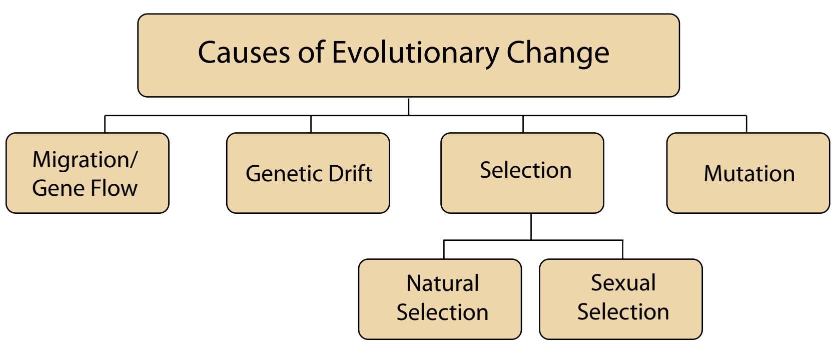

Figure 3.1: Diagram showing the different causes of evolutionary change

Mutation

Mutations are random changes in the genetic code. They are the only source of new alleles. Ultimately, all genetic variation begins with mutations in the genetic code. Mutations in your body cells (somatic cells) occur most frequently, but do not affect evolution because they are not passed on to the next generation. Only mutations that occur in the gametes (sperm and egg cells) can be passed on and become part of the gene pool. For example, brown beetles could have been produced by a mutation of the gene in an egg cell that determines body colour. This may have caused a green beetle to have offspring with a gene for brown coloration, making the genes for brown beetles available to be selected in the population.

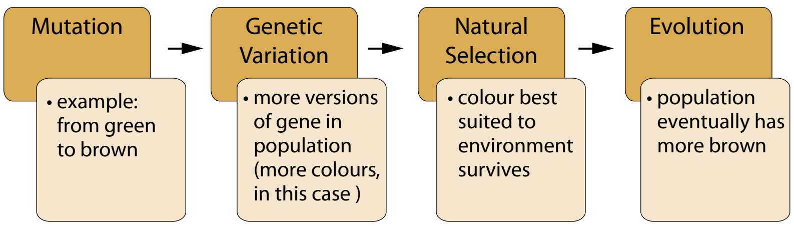

Figure 3.2: Diagram of the evolutionary process. Mutations occur in a population, creating more variation in the gene pool (genetic variation). Natural selection determines which version of the gene is better suited to survive, and eventually the population changes.

Mutations can be harmful, beneficial, or neutral. A harmful mutation reduces an organism's fitness, and a beneficial mutation increases its fitness. A neutral mutation is one that has no immediate effect on an organism's fitness.

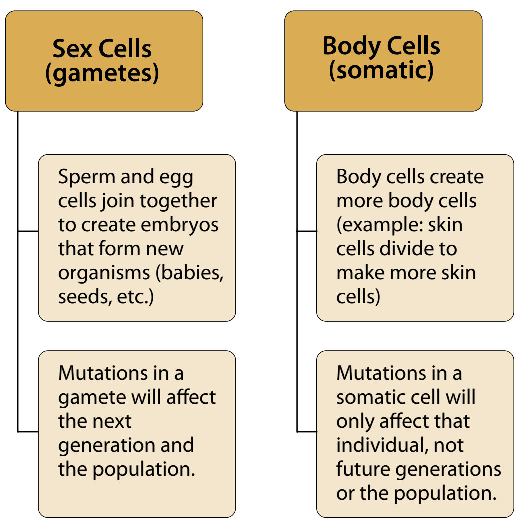

Figure 3.3: Overview of the way mutations affect gametes or somatic cells. When studying evolution, we are only interested in mutations in the sex cells (gametes) because they are passed on to future generations and can change the population.

Types of Mutations

There are many kinds of mutations, each defined by how it affects the genetic code. If you think of your genetic code as a book describing how to build your body, then mutations could affect individual letters, words, sentences, complete chapters, or any combination of these. Genetic mutations can range from changing only one base pair in the DNA code to changing entire genes or sections of chromosomes.

Support Questions

16. Mutations in sex cells (sperm and egg cells) can be passed on to offspring. Why is this not true for mutations that happen in other body cells (such as skin cells)? Suggested answer

Migration/Gene Flow

Migration is also a force for evolutionary change. Individuals moving into or leaving a population (migrating) can change the genetic variation within that population. The movement of alleles from one population to another is called gene flow. In many species, the migration of individuals between populations ensures that there is a lot of gene flow between populations, which prevents inbreeding. For example, in many species of mammal, maturing males are driven out of their families and forced to migrate to other areas. As a result, the alleles carried by these young males flow into other populations, keeping the genetic variability of all populations high. Many other species migrate long distances to find mates. For example, large sharks and whales have been known to cross entire oceans to find mates.

Genetic Drift

Genetic drift can be a powerful force for evolutionary change. Drift is the result of chance differences in reproductive ability among individuals. In each generation, some individuals may, by chance, leave behind a few more offspring than other individuals. The alleles of these luckier individuals will be more frequent in the next generation; however, the alleles from the better-adapted individuals may not be as frequent as they were in the generation before.

You can see how this works with a bowl of party snacks containing a mixture of different kinds of salty treats (pretzels, nuts, chips, etc.). If you randomly grabbed a small handful, chances are you would not have all the kinds of treats available; some kinds would be over-represented and others would be missing. Each reproduction event is like grabbing a handful of snacks from the bowl. If only that handful was used to make the next bowl of treats, the ones that were missing would not appear in the new bowls.

Drift usually happens slowly over many generations. When population sizes are very large, the role of chance in affecting allele frequencies is very small: so many reproduction events are taking place that the allele frequencies in the next generation will closely match those of the previous generation. But when population sizes are very small, especially under a few hundred, drift can cause large changes in allele frequencies over time. Genetic drift is a real problem for endangered species or small populations confined to islands or isolated in parks. It can cause big losses of genetic variation for these small populations, with the result that they may lose important alleles that might protect them from disease or help them survive droughts or famines.

Two special cases of genetic drift can cause rapid and dramatic changes in allele frequencies over one generation. They are population bottlenecks and founder effects.

Population Bottlenecks

Population bottlenecks occur when a population's size is drastically reduced for at least one generation. Either because of death or problems in reproducing, only a few individuals in the population get to pass on their alleles to the next generation. Because the proportion of individuals reproducing is so small, there is a strong chance that many of the alleles in the population will be lost. This is called a bottleneck effect because it is like passing the alleles of the population through a narrow bottleneck, allowing only a few alleles to get through. Figure 3.4 demonstrates this: the population contains two colours of marbles in equal amounts. If only a few are allowed to pass through the bottleneck, it is unlikely that equal amounts of each colour will be present. In this case, more dark ones are found. In one generation, the population of marbles has gone from having two colours in equal amounts to being almost entirely composed of one colour.

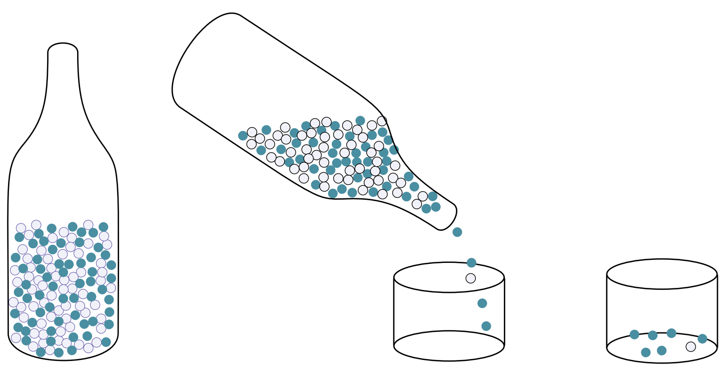

Figure 3.4: The bottleneck effect demonstrated using marbles in a glass bottle

Source: ILC

An example of a population bottleneck in nature is seen in the genetic diversity of the northern elephant seal. Today, northern elephant seals have reduced genetic variation probably caused by human over-hunting in the 1890s. Hunting reduced their population size to as few as 20 individuals by the end of the nineteenth century. Their population has since rebounded to over 30 000—but their genes still carry the marks of this bottleneck. They have much less genetic variation than a similar population of southern elephant seals that was not so intensely hunted.

Founder Effect

The founder effect occurs when a new colony is started by a few members of the original population (the founders). This small population size means that the colony may have reduced genetic variation compared to the original population, or may represent a non-random sample of the genes in the original population.

For example, the Afrikaner population of Dutch settlers in South Africa is descended from a few colonists. Today, the Afrikaner population has an unusually high frequency of the gene that causes Huntington's disease. Huntington's disease causes nerve cells in the brain to die off, resulting in uncontrolled movements, loss of intellectual faculties, and emotional disturbance. Those few original Dutch colonists just happened to be carrying that gene with unusually high frequency.

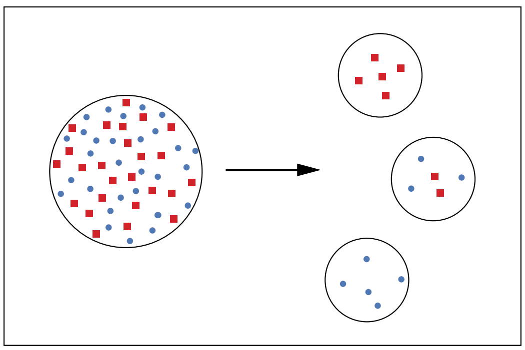

Figure 3.5: Diagram illustrating the founder effect. The original population on the left has created three new populations from a few members of the original population.

Selection

You have already learned about natural selection and how it tends to make species more adapted to their environment. But there is another form of selection that occurs in nature that can produce features in species that appear to be non-adaptive. Have you ever wondered about the size of a peacock's colourful tail, as shown in Figure 3.6? How can it fly with that huge bushy tail? Doesn't it make it easier for predators to catch it? How could such a tail evolve if it made the male peacock less fit in his environment?

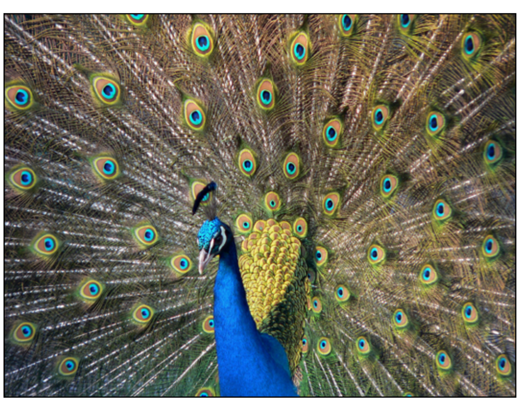

Figure 3.6: Photograph of a male peacock showing off his large and colourful tail to impress a female
Source: Wikipedia

Darwin struggled with this question for many years. He eventually concluded that there were two types of selection in nature: natural selection and sexual selection. Both might be occurring at the same time, but each might be selecting for different features. Darwin proposed that natural selection was the result of the struggle for existence, while sexual selection was the result of the struggle for mates.

Natural Selection

Natural selection is the strongest of the forces causing evolutionary change. Even a small amount of selection pressure can usually override the effects of migration, genetic drift, and mutation. For example, even if drift or migration temporarily increased the frequency of alleles with lower fitness, natural selection would tend to remove them fairly quickly. Harmful mutations are usually removed by natural selection within a few generations.

Sexual Selection

All sexually-reproducing organisms must mate with another individual to produce offspring. Sexual selection favours any trait that influences the mating success of an individual.

Most organisms use distinct strategies to increase their chance of reproducing successfully. Many organisms, including humans, exhibit sexual dimorphism—differences between the male and the female of the species above and beyond the differences in their reproductive organs. Some examples include the colourful plumages in birds, the thick hairy manes on male lions, antlers on male deer, and the male courtship songs of many birds and insects. Usually, the male is the showier of the two sexes in an effort to attract the female. This is because the female often chooses her mate based on physical traits such as bright coloration or physical size (with the male often being larger).

Darwin recognized sexual selection as a separate selection process leading to variation between the sexes (sexual dimorphisms). He realized that natural selection and sexual selection could work together or in opposition. For example, brightly-coloured plumage on a male bird may help attract mates, but it could also make the male more visible to predators. The evolutionary outcome often is a compromise between the two selection forces. The result would be males with just enough coloration to attract females, but not enough to lead to a high death rate. Sometimes, the traits that are favoured under sexual selection are also favoured under natural selection. For example, large antlers on male deer attract females and can also be used to fight off predators.

Support Questions

17. Match the following causes of evolutionary change with the correct description.

1. Genetic Drift	a. Individuals move into or leave the population.
2. Gene Flow	b. Population sizes are very small and a random difference in the ability to reproduce causes new populations to be created.

Suggested answer

18. You have learned that the overuse of antibiotics has led to antibiotic-resistant bacteria. Explain how this is an example of a bottleneck effect.

Suggested answer

19. Explain how natural selection and sexual selection can work in opposite directions to cause the evolution of bright coloration on some male birds.

Suggested answer

Humans as Agents of Evolutionary Change

Not all mechanisms of evolution are natural. In the previous lesson, you learned about artificial selection—humans breeding organisms for special traits such as cows that give a lot of milk or faster racehorses. We now have another way to artificially direct evolution: we can use biotechnology to directly modify the genes of organisms. This human-directed evolution is controversial, but it has yielded some impressive results. In the following sections, you will examine some of the applications of this new technology and its potential benefits.

Genetically Modifying Organisms and Designer Genes

Geneticists are now able to direct the course of evolution. Instead of waiting for useful mutations to randomly appear, biologists can sit down at a computer and design their own genes. These genes can then be inserted into bacteria or other organisms and become part of the gene pool for that species. This approach of designing genes is known as synthetic biology.

This is not science fiction. This is, in fact, what Dr. Yiannis Kaznessis from the University of Minnesota did to create *E. coli* capable of detecting diseases in humans. Kaznessis wanted bacteria that would release a fluorescent green glow when they encountered chemicals related to specific diseases. Such an invention could be used, for example, to help detect cancer. If these *E. coli* found cancerous cells in a tumour, they would turn neon green. Doctors could then see the exact location of the cancerous tissue so they could remove it.

Today, geneticists use human-directed evolution for many purposes. They use it to create food that is superior in taste or has a longer shelf life. They can also modify genes to cure or treat illnesses.

Herbicide-Resistant Corn

Over half of the corn and canola currently grown in North America is genetically modified. It contains recombinant DNA (DNA from more than one species). So far, over 50 types of genetically-modified crop plants have been approved by the Canadian government. One interesting type of genetically-modified corn is herbicide-resistant corn.

Cornfields are often invaded by weeds that out-compete the crop plants for space. Farmers need to spray their fields with herbicides to remove the weeds. Unfortunately, the herbicides often hurt the growth of the corn as well. Farmers needed a way to kill the weeds without harming their crops. Genetic modification provided an answer.

Scientists discovered bacteria that were naturally resistant to herbicides. They were able to isolate the gene for herbicide resistance from the bacteria, then insert it into corn DNA. The corn grew and expressed the gene for herbicide resistance. Farmers can now spray their genetically-modified crops with herbicides without suffering any crop losses.

Human Insulin

Insulin is important in the treatment of diabetes. Patients need a regular supply of insulin to inject several times a day to control their blood sugar levels. Insulin was initially obtained directly from animals such as cows and pigs. Unfortunately, this non-human form of insulin caused severe allergic reactions in some patients.

Geneticists were able to isolate the insulin gene from healthy human cells and insert it into bacteria. These genetically-modified bacteria were then able to produce human insulin for use by diabetic patients. This new source of insulin is less expensive to make and causes no allergic reactions. This has saved the lives of many diabetes patients around the world.

Figure 3.7: Insulin

Source: Wikipedia

PCB-Eating Bacteria

PCBs are an oily pollutant used in the making of electronics. This highly toxic chemical can build up in soil and accumulate in the food chain. It can harm human health and hurt animals like whales and polar bears. Cleaning up contaminated sites and removing PCBs from the food chain is difficult and expensive. One method is to release bacteria that are naturally able to break down PCB chemicals into safer molecules; however, bacteria are not always the best organisms for this kind of work, particularly in dry soil.

Geneticists learned how to isolate the gene for breaking down PCBs from the bacteria and insert it into other micro-organisms that can survive in dry soil and break down the chemicals. This breakthrough should help solve a very important environmental problem.

Support Questions

20. How can synthetic biology and biotechnology change the course of evolution?

Suggested answer

Key Questions

Now work on your Key Questions in the online submission tool. You may continue to work at this task over several sessions, but be sure to save your work each time. When you have answered all the unit's Key Questions, submit your work to the ILC.

(18 marks)

8. **a)** Explain how genetic drift can lead to a reduction in the genetic variation within a population. **(3 marks)**

b) Under what conditions is drift most likely to occur? **(1 mark)**

c) A flock of migrating birds is blown off course by a storm and carried towards a small island that has no birds. Only three of the birds survive the storm and make it to the island. They start to reproduce and, after several years, there are 500 birds on the island. Does the genetic variation in this population of birds result from a population bottleneck or the founder effect? Explain. **(2 marks)**

9. Describe the relationship between mutations, genetic variation, natural selection, and evolution. Your description should include what a mutation is, which type of cells mutations must occur in to increase genetic variation, and how variation is required for natural selection. **(4 marks)**

10. Explain how natural selection and sexual selection can work together to cause the evolution of large antlers on male moose. **(4 marks)**

11. Suggest two ways a synthetic biologist can change the course of evolution. **(4 marks: 2 marks for each)**

Now go on to Lesson 4. Send your answers to the Key Questions to the ILC when you have completed Unit 1 (Lessons 1 to 4).