NASCA Biology Materials Draft 1

Topic 3: Evolution

Topic 3: Evolution
Sub-topic 1: The theory of evolution by natural selection

Overview

You have learnt about the hereditary material in your cells: DNA. You have discovered how it functions, coding for the making of all the proteins in your cells, both structural proteins as well as functional proteins such as enzymes that control and regulate every function in your cells. You have learnt how DNA is inherited, and how small changes in the DNA can produce new alleles and thus bring about variation. You have also seen that meiosis shuffles the alleles in a population, ensuring that a population is rich in genetic variation.

In Topic 1, Sub-topic 3, you made a timeline showing the history of life. You recognised that organisms change over time. This Topic studies *how* life changes over time. You will investigate the mechanisms that drive change over time.

New species evolve from previously-existing species by a process of natural selection. Evolution by natural selection is supported by evidence from the fossil record, comparative anatomy and biogeography. Artificial selection illustrates how natural selection takes place. These are all concepts you will become familiar with in Topic 3.

Unit 1: Development of the theory of evolution by natural selection

Unit 1 learning outcomes

By the end of this unit, you should be able to:

1. Describe the contributions of Charles Darwin and Alfred Wallace to the development of the theory of evolution.

The theory of evolution by natural selection was presented to the scientific world by Charles Darwin and Alfred Wallace. This unit describes the history of how they jointly arrived at the same theory completely independently.

Unit 1.1: Charles Darwin's early life

Watch these videos. As you watch them, pause the video often, and in your workbook, write down:

- ten facts about Darwin's personal life
- ten facts about his voyage on the Beagle
- ten facts about his scientific observations and theory.

(If you are unable to find ten facts from watching the videos, leave sufficient space in your workbook, so that you can add to your lists as you work through the notes.)

Charles Darwin's Observations: https://www.youtube.com/watch?v=WAKppAtIeh8 (Duration: 3.17)
Darwin's Voyage of Discovery: https://www.youtube.com/watch?v=ZH6abZW6xjg (Duration: 11.07)

As you read the notes, add to your lists in your workbook.

Charles Darwin (1809-1882) was the son of a doctor. As a young boy, he loved spending time outdoors, collecting bird's eggs and insects, especially beetles. Encouraged by one of his teachers, Darwin assembled a large beetle collection, including some very rare species of beetle. Darwin did not do very well at school. As he wrote later, "I believe that I was considered by all my masters [teachers] and by my father as a very ordinary boy, rather below the common intelligence."

Darwin's father wanted him to become a doctor, so in 1825 Darwin went to Edinburgh Medical School. However, he left after two years, because he was bored by the lectures and could not stand to watch the surgery, which at that time was done with no anaesthetic [sedative that acts as a painkiller during a surgical operation]. After Darwin gave up medicine, his father arranged for him to study to become a priest. In 1828, Darwin went to Cambridge University to study *theology* [study of religious beliefs]. He studied , but spent a great deal of time collecting plants and animals, and studying rock formations in Britain. Darwin became friends with two Cambridge professors, geologist Adam Sedgwick and botanist John Henslow; Darwin studied their writings and discussed with them things that interested and puzzled him about the natural world.

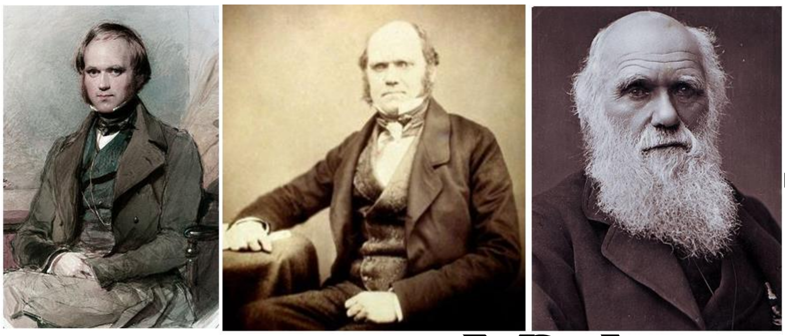

Figure 98: Charles Darwin – as a young man, in his middle age and as an old man [insert AWB Figure 98]
Source: Adapted from:
https://en.wikiquote.org/wiki/Charles_Darwin#/media/File:Charles_Darwin_by_G._Richmond.jpg
https://en.wikipedia.org/wiki/File:Charles_Darwin.jpg#/media/File:Charles_Darwin.jpg
https://commons.wikimedia.org/wiki/File:Charles_Darwin_photograph_by_Herbert_Rose_Barraud,_1881.jpg#/media/File:Charles_Darwin_photograph_by_Herbert_Rose_Barraud,_1881.jpg

Unit 1.2: The Voyage of the Beagle

As Darwin completed his studies, and was thinking about his future, an around-the-world voyage of scientific discovery on the ship *HMS Beagle* was being arranged by the Royal Navy. Robert Fitzroy, captain of the *Beagle*, asked Professor Henslow to recommend a naturalist [person who studies plants, animals and the natural world] the journey. Henslow recommended Darwin.

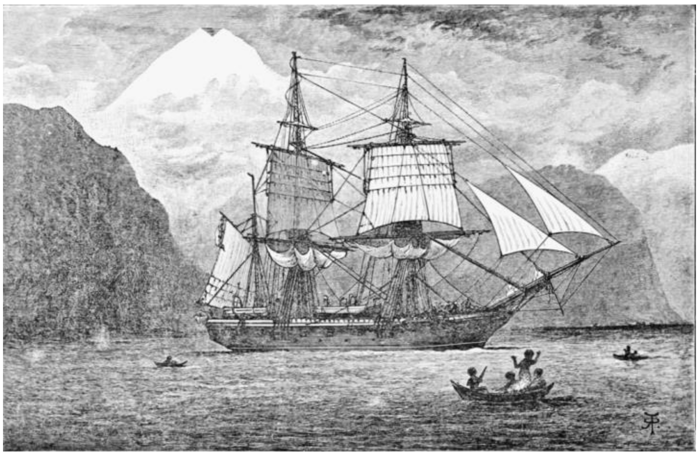

Figure 99: The *HMS Beagle* docked in the Straits of Magellan, at the southern tip of South America [insert AWB Figure 99]
Source: Source:
https://en.wikipedia.org/wiki/HMS_Beagle#/media/File:PSM_V57_D097_Hms_beagle_in_the_straits_of_magellan.png

Darwin joined the expedition on the *HMS Beagle*. The voyage took 5 years, and had a deep effect on Darwin's later ideas. The ship travelled around the southern hemisphere, visiting South America, New Zealand, Australia and also, Cape Town, South Africa. The ship also stopped at various islands along the way.

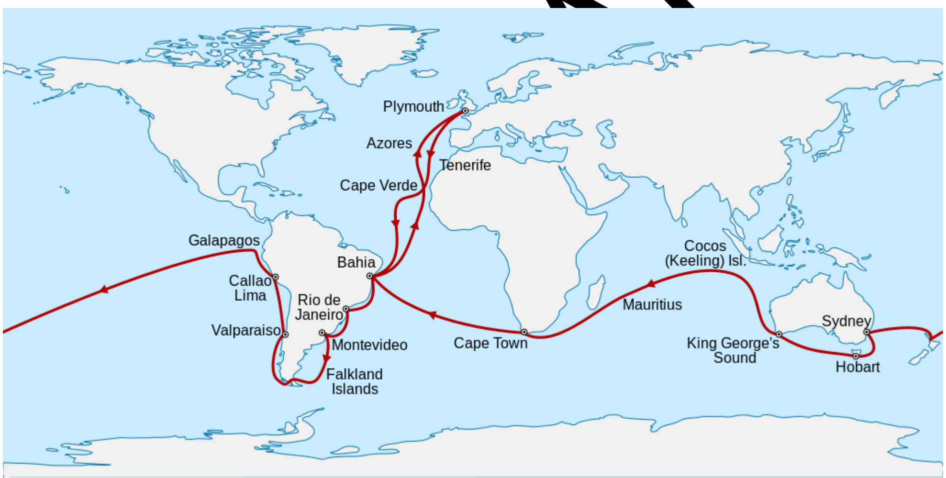

Figure 100: Voyage of the *HMS Beagle* [insert AWB Figure 100]
Source: https://commons.wikimedia.org/wiki/File:Voyage_of_the_Beagle-en.svg

While he was travelling, Darwin collected many plant animal specimens, including fossils. These were carefully labelled, preserved and sent back to various naturalists for identification. During the voyage, Darwin read a book called *Principles of Geology*, which suggested that the Earth changed slowly over long periods of time. The same geological processes that are happening today could explain the past. Darwin developed ideas and questions about life that existed in the past and how it changed to become the way it is now.

Unit 1.3: Darwin's observations on the journey

Although Darwin made important observations at many sites during the five year journey, it was his time in South America and in particular at the Galapagos Islands, where he made crucial observations that would inform his theory later in life.

Figure 101: The Galapagos Islands [insert AWB Figure 101]
Source: Adapted from:
https://commons.wikimedia.org/wiki/Atlas_of_the_Gal%C3%A1pagos_Islands#/media/File:Galapagos_Islands_-_Overview.PNG
https://commons.wikimedia.org/wiki/File:Galapagos%2Bmap.jpg

In 1835, after leaving South America, the *Beagle* sailed to the Galapagos Islands. This is an archipelago [small group of islands], off the coast of Ecuador. On the islands he saw many unique animals found only on those islands, but similar to those on the mainland.

He saw marine iguanas which are found no where else on earth. He saw giant tortoises, which he noted were similar to species on the mainland, but which had differences depending on which island they came from. The people of the Galapagos islands could tell from which island a tortoise came by the shape of its shell.

On the Galapagos Islands, Darwin also saw several different types of finch, a different species on each island. He noticed that each finch species had a different type of beak, depending on the food available on its island. The finches that ate large nuts had strong beaks for breaking the nuts open. Finches that ate small nuts and seeds had beaks for cracking nuts and seeds. Darwin noticed that fruit-eating finches had parrot-like beaks, and that finches that ate insects had narrow, poking beaks. He wrote: "One might really fancy that from an original paucity [scarcity] of birds ... one species had been taken and modified for different ends."

Later, Darwin concluded that several birds from one species of finch had probably been blown by storm or otherwise separated to each of the islands from one island or from the mainland. The finches had to adapt to their new environments and food sources. They gradually evolved into different species. (You will learn in Unit 2 how Darwin suggested that this happened.)

The following is a summary of some of the important observations Darwin made, that contributed to the theory he later formulated:

- In South America, Darwin found fossils of giant animals that were named glyptodonts that lived in the area in prehistoric times. They resembled the smaller armadillos that were found in the same area in present times. Darwin wondered if the small armadillos had evolved from the glyptodonts.

Figure 102: Glyptodon and Armadillo [insert AWB Figure 102]
Source: https://upload.wikimedia.org/wikipedia/en/b/bc/Glyptodon-Armadillo.jpg

- Darwin discovered layers of fossilised seashells high upon a cliff face. He interpreted this as evidence that sea levels have changed over long periods of time.
- He noticed that every continent had its own types of plants and animals, most quite different from other continents. He wondered why, if the earth had been created at one time, there was so much diversity.
- Lands with similar climates don't always have similar animals (for example, there are no penguins in the Arctic, and no polar bears in the Antarctic, despite the similar environmental and climatic conditions). This suggested that biodiversity is not just a function of adaptation to climate and environment.
- Darwin noticed that the same set of bones could be found in all vertebrate forelimbs. He wondered if all vertebrates had descended from one ancestor.   You will return to this in Sub-topic 2, Unit 3.

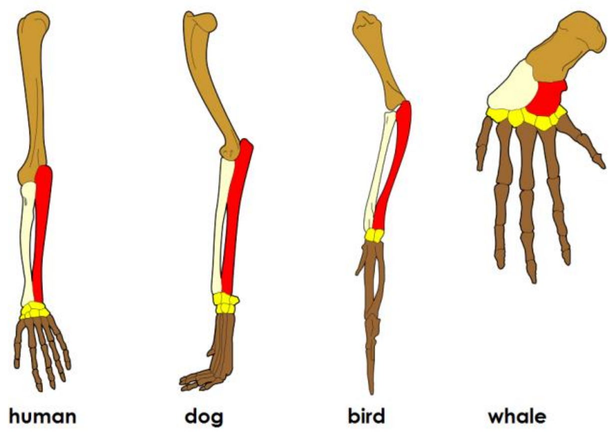

Figure 103: A comparison of vertebrate forelimbs [insert AWB Figure 103]
Source: https://commons.wikimedia.org/wiki/File:Homology_vertebrates-en.svg#/media/File:Homology_vertebrates-de.svg

- Darwin had read the works of Charles Lyall, a geologist, who stated that the physical features of the earth developed slowly over very long periods of time, and that the earth was far older than suggested by biblical scholars. Darwin's observations of rock formations that he saw on the journey convinced him that Lyell was correct: the Earth has changed and is still changing over long periods of time. The Earth is in fact very old.

Darwin returned to England, and for the next few years he spent his time cataloguing and recording what he had collected on the voyage. He began revising his earlier thinking and things he had been taught. He was convinced that the life presently on Earth had evolved from previous life forms, but he did not know how the process of evolution takes place.

Darwin was strongly influenced by an essay written by Thomas Malthus. Malthus argued that humans were increasing in number. As human populations increased, they were competing with each other to survive. The competition resulted in famine, disease or war. The winners were healthier and wealthier than the losers.

Darwin began to think that the same principle could apply to all species. He called his idea *natural selection*. He was convinced that evolution occurred by natural selection.

In 1839 Darwin married his cousin, Emma Wedgwood, and they moved into Down House, near Bromley, England, where he lived for the rest of his life. Though he was not always well and became considerably more ill, Darwin continued his research, studying his *Beagle* specimens and notes made during his journey as evidence for evolution. Darwin also talked to pigeon breeders as part of his research. Darwin's grandfather had studied diversity in selective breeding of domestic animals such as dogs, cattle and pigeons. Darwin drew on his grandfather's observations and made more observations of his own in this field. Darwin became more and more convinced of his theory of evolution by natural selection. However, Darwin was hesitant to publish his ideas because they went so strongly against the ideas of the day. Darwin thought that society was not yet ready for his ideas, and he knew that there would be a lot of objection and disapproval.

What finally caused Darwin to publish his work was a letter from English naturalist Alfred Wallace, who knew that Darwin was interested in evolution. The letter came in June, 1858, from Malaya. With it was a summary of Wallace's theory, *On the Tendency of Varieties to Depart Indefinitely from the Original Type*. Darwin was amazed! This was his own theory written out by Wallace. He even said: "Even his terms stand as heads of my chapters."

Unit 1.4: Alfred Wallace and Darwin and the theory of natural selection

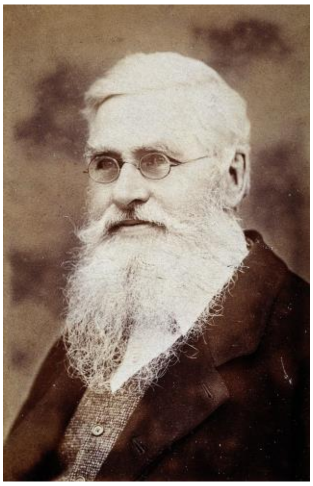

Figure 104: Alfred Wallace [insert AWB Figure 104]
Source:
https://commons.wikimedia.org/wiki/File:Alfred_Russel_Wallace._Photograph_by_Sims,_1889._Wellcome_V0027305.jpg#/media/File:Alfred_Russel_Wallace._Photograph_by_Sims,_1889._Wellcome_V0027305.jpg

Watch the following video that tells the story of how Charles Darwin and Alfred Wallace developed the theory of evolution. In your workbook, summarise, in point form, how Wallace came to his theory of evolution. Also, write some points relating to how Darwin's and Wallace's ideas came together to form the theory of evolution.

The Making of a Theory: Darwin, Wallace, and Natural Selection:
https://www.youtube.com/watch?v=XOiUZ3vcZwU (Duration: 31.02)

Alfred Wallace was a naturalist who had been studying plants and animals in the Amazon basin and the Malay islands. He had also read Thomas Malthus' essay. He wrote a paper in which he explained the diversity of life in terms of evolution by natural selection. His essay presented exactly the same theory as Charles Darwin.

Wallace communicated his ideas to Darwin by letter. Darwin was astonished that his own ideas were mirrored in Wallace's writings. Darwin approached two scientists, whose works and opinions he respected, with his dilemma: he knew he had developed the same ideas as Wallace, but before Wallace. However, Wallace was about to publish his ideas and would be credited with the scientific theory. The scientists, Lyell and Hooker, advised Darwin and Wallace to have their work read to a scientific meeting. The work was read at the Linnaean Society in London, in July of 1858. Charles Darwin and Alfred Wallace were co-authors of the paper, but neither was present at the meeting. After this, Wallace agreed that Darwin should continue with their theory while he himself stood on the sidelines, because Darwin had collected so much more evidence to support it.

On November 24, 1859, Darwin published the theory in his book, titled *On the Origin of Species*, 25 years after he started writing the book. It presents an argument that draws on evidence from a variety of sources. Darwin had led the scientific world into a new era. Wallace himself published a book called *Darwinism*!

Darwin continued his research and writing, publishing several more books in the 1870s. Darwin died on April 19, 1882, at age 73. By the time he died, Darwin had become a national figure and was considered one of the greatest scientists of all time. He received the honour of being buried at Westminster Abbey, London, next to Isaac Newton.

[START TEXT BOX]

What's the main idea?

Charles Darwin and Alfred Wallace developed the theory of evolution by natural selection independently. Both assembled an enormous amount of physical evidence that supported the theory of evolution by natural selection.

[END TEXT BOX]

Activity 1.1: Darwin and Wallace

Suggested time:

15 minutes

Aim:

In this activity, you will test your understanding of what you have read and watched.

What you will do:

Put these sentences in the correct order to represent the development of the theory of evolution by natural selection. Write the final correct order into your workbook.

1. In 1831, Darwin set out on a five-year journey around the world on the *HMS Beagle*.
2. The theory of evolution by natural selection was immediately accepted by many scientists, but there was a public outcry against Darwin and his writings.
3. The *Beagle* visited South Africa.
4. Darwin noticed fossils of giant extinct animals in the area where similar species now exist in South America.
5. Darwin and Alfred Wallace were influenced by an essay written by Thomas Malthus.
6. Darwin published a book called *On the Origin of Species by Natural Selection*.
7. Darwin observed strange animals in Australia, that occurred nowhere else in the world.
8. Darwin and Wallace jointly presented the theory of evolution by natural selection to a science society.
9. Darwin visited the Galapagos Islands.
10. Alfred Wallace sent a paper he had written outlining a theory of evolution by natural selection to Charles Darwin.

Discussion of the activity

Understanding how scientific ideas change over time, and how they develop is fascinating and enriches your understanding of science. You can think back to the work you did on how scientific knowledge arises in the Nature of Science Topic you did earlier.

Exemplar answer

1; 4; 9; 7; 3; 5; 10; 8; 2; 6

Moving on

In the next Unit, you will learn precisely what is meant by natural selection, and how it brings about evolution.

Topic 3: Evolution

Sub-topic 1: The theory of evolution by natural selection

Unit 2: The theory of evolution by natural selection

Unit 2 learning outcomes

By the end of this unit, you should be able to:

2. Describe the theory of evolution by natural selection.

Evolution is a change in a line of descent. It means that all present organisms are descended from earlier species (which may be extinct now), which themselves evolved from even older species. It means that all species that have ever lived were not created at the same time. There have been long chains of species, extending back 3,5 billion years to the first life on Earth. Remember the timeline you created in Topic 1, Sub-topic 3: it shows the evolution of life since the very first cells.

Although many scientists accepted that evolution happened, until Darwin and Wallace, no satisfactory explanation had been given, with evidence, for *how* evolution happened.

Charles Darwin was the first person to come up with an acceptable explanation for the *mechanism* of evolution that is, *how evolution takes place.* He called this mechanism *natural selection.*

The key elements on which Darwin based his explanations were:

- Each species produces more offspring than can survive. Only a limited number actually do survive and produce further offspring of their own.
- The reason for this is that *resources* (food, water, habitats) in the environment are limited and there is *competition* between organisms for the resources.
- Individuals within a species *vary*. There is great genetic variation due to different alleles being present for different characteristics.
- The individuals that possess the genes or alleles that allow them to compete successfully and therefore have more offspring (who will inherit its successful genes) are the '*fittest'* individuals in the population. (Note that *fit* in this context doesn't mean strong or athletic, but rather 'best suited', or 'most suitable for the environment'. For example, the genes a polar bear possesses make it fittest for the Arctic, but these genes would not make it fittest in a desert environment.)
- Those individuals less fit to adapt in the environment will die, or have less offspring.
- Survivors pass on their genes/alleles and therefore, the 'fitter' genes/alleles become more frequently encountered in a population because survivors have more offspring.
- Thus, there is *survival of the fittest* or *natural selection*.

In the words of Charles Darwin: "Can we doubt. . .that individuals having any advantage, however slight, over others would have the best chance of surviving and procreating [reproducing] their kind? On the other hand, we may feel sure that any variation in the least degree injurious would be rigidly destroyed. This preservation of favourable variations, I call “natural selection” or “survival of the fittest”.

Let’s look precisely at what we mean by evolution and natural selection.

A term that is important for you to understand is *gene pool.* The gene pool of a population is all the possible gene variations (or alleles) that exist in a population. So while you might be right handed, and have the alleles that code for this characteristic, there are left handed people in your population. The alleles that control the phenotype ‘right handedness’ and ‘left handedness’ are in the gene pool of your population. You just happen to have certain of the alleles expressed in your body.

Evolution happens when there is a *change in the frequency of alleles in the gene pool of a population over time*. Natural selection is one of the processes that is responsible for this change.

If we were to count up the number of times a particular allele of a gene is expressed in a population, we would be calculating the *allele frequency* in the *gene pool* of the population. If we come back at a later time and do the same thing, we may find that the allele frequencies have changed.

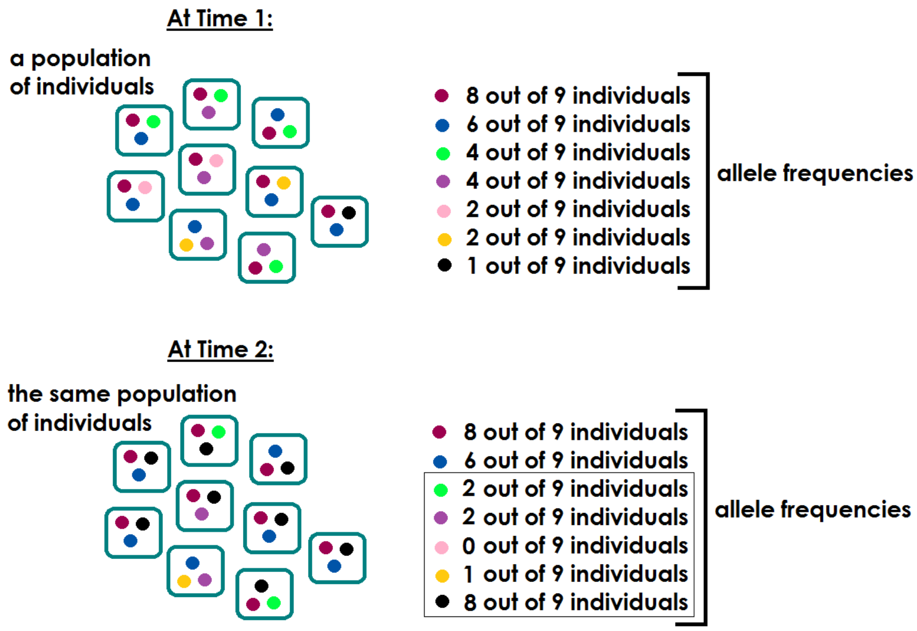

Figure 105: Allele frequencies in a gene pool of a population [insert AWB Figure 105]

Study Figure 105. In this population, we could do an allele count and work out the frequency (or number times) that each allele appears in the population. For example, at Time 1, the ‘black allele’ appears only once in nine individuals, while the ‘red allele’ appears 8 times in nine individuals. Let’s imagine that over the years, the ‘black allele’ gave some advantage to the individuals of this population. Individuals with the ‘black allele’ would therefore have a higher reproductive rate and survival rate than the individuals without the ‘black allele’.

So, over years, if the population was reassessed, you would find that the frequencies of the genes in the gene pool had changed significantly. From the ‘black allele’ being only a 1 in 9 frequency, now, years later, the ‘black allele’ has a frequency of 8 in 9 individuals. One would say that the population has evolved.

It is very important to remember that the individuals didn't change or evolve in their life time – it was the population that changed or evolved over many generations and thus long periods of time.

But something has to happen to make that allele frequency change. It doesn't just happen by itself. There has to be a *driver* or something that forces the frequency of alleles to change. The *mechanism* (or means or method) that drives evolution is *natural selection*.

Let's use a *hypothetical* [imaginary] example to show how evolution is driven by natural selection. Study Figure 106.

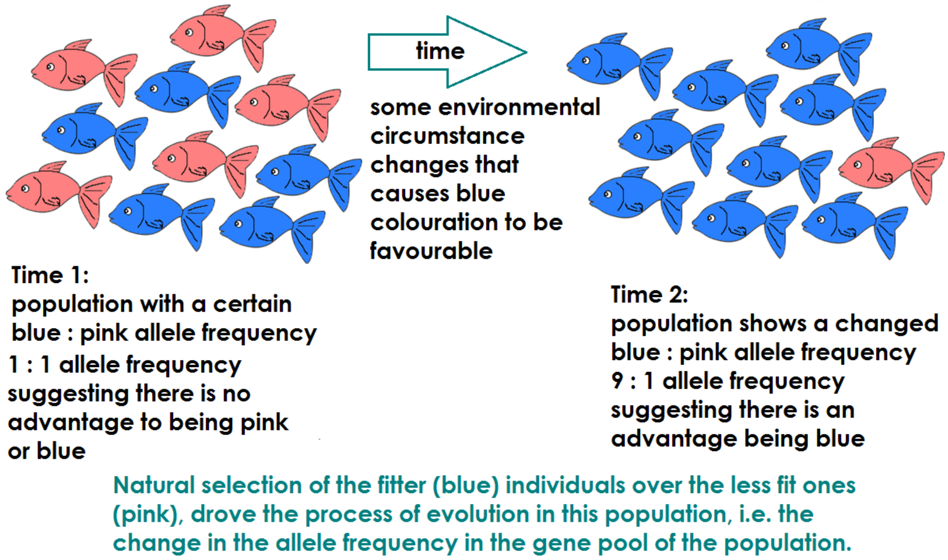

Figure 106: Natural selection as the mechanism for evolution [insert AWB Figure 106]

Let's imagine that we are examining a population of fish in a lake. In our imaginary fish population, there are more or less equal numbers of the alleles that code for blue fish and alleles that code for pink fish in the gene pool. The fish live in their lake for many generations, some being blue and some being pink. The blue fish produce just as many offspring as the pink fish and both kinds of fish live as long as the other. In other words there is no advantage or disadvantage to being blue or pink. Their colour is simply a variation, like blonde hair and black hair in humans. Because there is no advantage to being one or the other colour, there are more or less equal numbers of both colours of fish in the lake.

But then, over time, a change is introduced into the environment. Let's say a population of birds moves into the lake environment. These birds are well adapted to flying over the water, swooping down and eating fish! But the birds can see pink fish better than they can see the blue fish. Suddenly, for this fish population, being blue is advantageous. You stand a far greater chance of being eaten if you are pink, because the birds can see you better. You will probably survive if you are blue. So we could say that the individuals with the allele for pinkness will become less in number, as they are eaten. Individuals with the allele for blueness become greater in number, simply because they have a greater survival rate and therefore survive long enough to produce offspring. Of course, their offspring inherit the gene for blueness. Pink fish tend to get eaten before they have a chance to reproduce.

Do you see what has happened over time? Individuals with the allele for blue colouration have a greater survival rate and produce many offspring. After time, the population will consequently have fewer individuals with the allele for pinkness and more individuals with the allele for blueness.

If the environmental circumstances favour the blue characteristic, then individuals with the pink characteristic will slowly become less and less in number. But individuals with blueness will be selected for. This means they will grow in number. Eventually, it could happen that the population has no individuals left with pinkness. In this way, the population has changed. Look very carefully at our example. The population has evolved. No individual fish changed their colour overnight! The frequency of the blue allele and the frequency of the pink allele changed with time. Pink became less and blue became more.

This is precisely what we mean when we say that natural selection is the mechanism that brings about evolution. The blue fish were naturally selected for, because they were best at survival. The pink fish were naturally selected against, as they were not best at survival. Evolution is driven by selective pressures. Something has to happen to make that allele frequency change. It doesn't just happen by itself. There has to be a 'driver' or something that forces the frequency of alleles to change. The mechanism (or means or method) that drives evolution is natural selection.

The concept natural selection is very closely associated with the idea of 'fitness', which was mentioned earlier. Biologists use the word 'fitness' to describe how good a particular genotype is at leaving offspring in the next generation relative to how good other genotypes are at it. In our example, blue fish were fitter than pink fish. Fitness is relative. A genotype's fitness depends on the environment in which the organism lives. The fittest genotype during an ice age, for example, is probably not the fittest genotype once the ice age is over. Charles Darwin stated that it is not the strongest species that survive, nor the most intelligent. It is the species that is the most responsive to change that will survive. Although in his day Darwin did not know about genes and alleles, we can now say that the species with the greatest variation in alleles (i.e. the greatest genetic variation) will have the best chance at survival, should environmental circumstances change. Do you now see why the previous Topic stressed the importance of genetic variation in organisms? Increased genetic variation means increased chances for survival.

Watch the short video that animates natural selection at work:
Natural Selection Animation: https://www.youtube.com/watch?v=M3bROOvWMcM (Duration: 1.56)

[START TEXT BOX]
What's the main idea?
Evolution is the change in the allele frequency in the gene pool of a population over time. Natural selection is the process that causes the allele frequency to change over time. Individuals with the fittest alleles leave more offspring than other individuals. The number of individuals with the fittest alleles increase in the population.
[END TEXT BOX]

Activity 2.1: Natural selection and evolution

Suggested time:

25 minutes

Aim:

In this activity, you will test your understanding of natural selection and evolution.

What you will do:

Answer all the questions in your workbook.

1. Which statement concerning evolution is correct?
   A. Evolution is change in the gene pool of a population over time.
   B. Evolution is a theory which has yet to be proven.
   C. Natural selection and evolution are the same thing.
   D. There is no evidence for evolution.

2. If we talk about the change in frequency of alleles in a population's gene pool, we really mean …
   A. That an individual's alleles change over its lifetime.
   B. The number of genes change over time.
   C. The number of times a certain allele is expressed in a population can change over time.
   D. An individual evolves over time.

Figure 107 applies to questions 3 – 5.

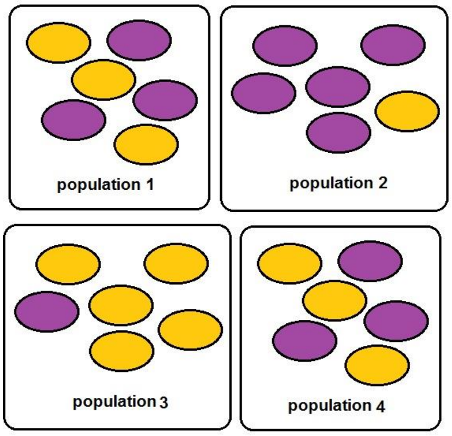

Figure 107: Allele frequencies in a population over time [insert AWB Figure 107]

3. If population 1 was the original population, which population would you expect to see after 20 generations, where yellow alleles gave an advantage to the population?
   A. Population 2
   B. Population 3
   C. Population 4
   D. Insufficient information to give an accurate answer

4. If population 1 was the original population, and population 4 is the final population after 20 generations, which statement is true?
   A. The purple allele was dominant.
   B. Ultimately, having the purple or the yellow alleles gave no special advantage to the individuals.
   C. The yellow allele gave an advantage to the individual by allowing the individual to survive more successfully.
   D. Natural selection did not act on this population and it did not evolve at all.

5. If population 1 was the original population and population 2 the population after 20 generations, which statement regarding evolution is false?
   A. Over time, the purple allele must have conferred an advantage to the individuals in the population.
   B. Individuals with the purple allele were reproductively more successful than individuals with the yellow allele, over time.
   C. Natural selection favoured individuals possessing the purple allele.
   D. The individuals in the population changed their genes over time.

6. What is the driving mechanism for the evolution of a population?
   A. The changes in the gene pool.
   B. The changes in the individuals.
   C. Natural selection.
   D. Time.

7. What do we call all the genes and their alleles in a population?
8. Does the gene pool of a population stay static/unchanging over time?
9. What do we call changes in the frequency of alleles in the gene pool of a population over time?
10. Does the frequency of alleles in the gene pool of a population change randomly?
11. Do the genes or alleles of an individual change over time?
12. Do all individuals in a population have the same alleles?
13. What would bring about a change in the frequency of alleles in the gene pool of a population?
14. What happens if an individual does not have the genes/alleles that will enable its survival?
15. What do we call the driving mechanism of change in a population?
16. What do we mean by 'survival of the fittest'?
17. How would Darwin have explained the evolution of a long trunk in elephants? (Elephant ancestors such as *Phiomia* had much shorter 'noses' that were called a proboscis.)

Figure 108: *Phiomia*, an ancestor of modern elephants [insert AWB Figure 108]

Source: https://en.wikipedia.org/wiki/Phiomia#/media/File:Phiomia_NT_small.jpg

Discussion of the activity

You must be able to describe how natural selection affects changes in the allele frequencies in the gene pool of a population over time.

Exemplar answer

1. A
2. C
3. B
4. B
5. D
6. C
7. gene pool
8. It is highly unlikely. The frequency of the genes/alleles in the gene pool changes over time, as environmental circumstances change.

9. evolution
10. No. There must be a reason or a driving force which changes the frequencies of alleles over time.
11. No. Not unless there is a mutation in a gene. An individual keeps their genes for their life time.
12. No. There is variation in the alleles of genes in the population.
13. A change in the environment that makes certain individuals (with their complement of alleles) more likely to survive than others.
14. It will die. It is not likely to survive long enough to reproduce and pass on its genes to offspring.
15. natural selection
16. Survival of the individuals that are most likely to adapt to changes in the environment.
17. There was a great deal of variation in the population of *Phiomia.* Some would have had a slightly longer proboscis, while others had a slightly shorter one. This phenotypic characteristic would have been controlled by a range of alleles. There would have been competition for resources amongst the individuals in the population, particularly for food. There may have been a change in environmental conditions, such as smaller shrubs died off and the only food available was on higher trees. The individuals would have needed to reach the leaves higher in the trees. Those individuals that had a longer proboscis would have been more successful at getting food. They would have survived. They would have reproduced and passed on the range of alleles that coded for a longer proboscis to their offspring. The next generation of animals would have had a greater proportion of individuals with a longer proboscis. These animals would have been fitter and survived, passing on the alleles for a longer proboscis to each successive generation. In time, the length of the proboscis would have increased. Modern elephants have a much longer trunk. (Be careful NOT to say that the ancestors of elephants stretched their proboscis and it became longer! Remember that an individual cannot change its genes, and also, acquired characteristics are not inherited by offspring!)

Moving on

In the next Unit you will learn about a real life situation where we can see natural selection and evolution in action today.

Topic 3: Evolution

Sub-topic 1: The theory of evolution by natural selection

Unit 3: Natural selection in action: antibiotic resistance

Unit 3 learning outcomes

By the end of this unit, you should be able to:

3. Exemplify natural selection using the example of antibiotic resistance.

Which statement do you think is true regarding evolution in present times?

A. Evolution never takes place in modern times.
B. Evolution is limited to events that occurred millions of years ago.
C. Evidence for evolution in modern times is found in insect resistance to insecticides and bacterial resistance to antibiotics.
D. It is impossible to document evolution as it takes place too slowly.

The statement that is correct is statement C.

A common misconception is that evolution has never been observed in action. Another common misconception is that evolution happened long ago to produce modern life forms and that evolution has now stopped. These ideas are incorrect. There are many cases where you can observe evolution in action.

One example of evolution (which is a change in the frequency of alleles in the gene pool of a population over time) is bacteria developing *resistance* to antibiotics over a period of time. When an organism develops a *resistance* to a chemical, it means that the chemical no longer has an effect on it.

Antibiotics are drugs that are used to treat bacterial infections such as pneumonia and tuberculosis (TB) very effectively. A commonly used antibiotic that you may have heard of, or even taken yourself, is penicillin. Figure 109 explains how penicillin works to kill bacteria.

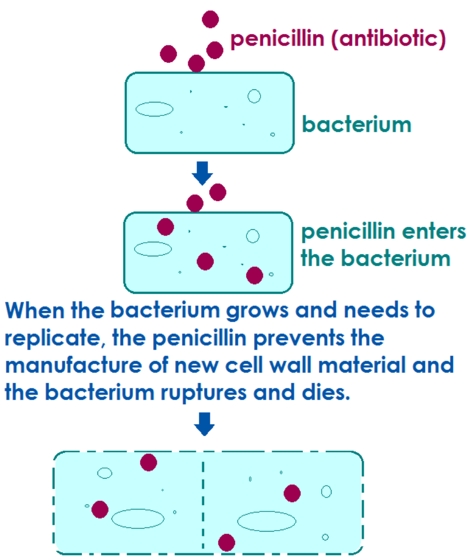

Figure 109: Action of an antibiotic [insert AWB Figure 109]

But how does *antibiotic resistance* happen? Study Figure 110:

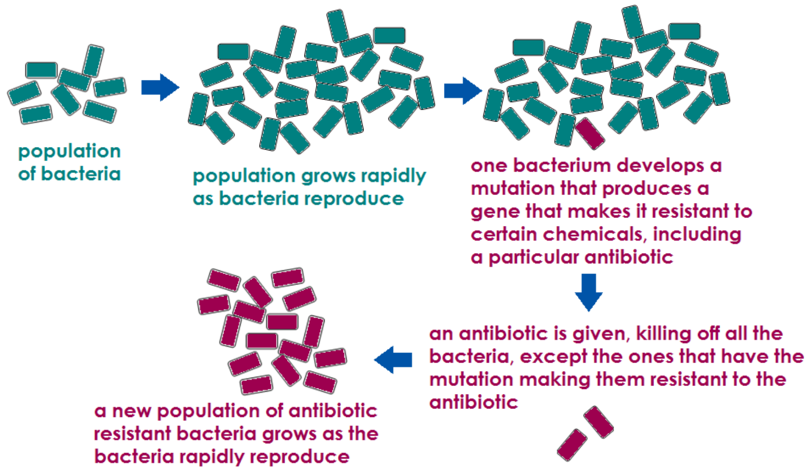

Figure 110: How antibiotic resistance happens [insert AWB Figure 110]

Some things to keep in mind as you study Figure 110:

- The bacteria did not 'decide' to become resistant to the antibiotic. Just as you cannot decide to change the genes that give you your nose shape, organisms cannot mutate their genes 'on demand' to overcome some environmental stress or crisis.
- The mutation did not happen as a *result* of the presence of the antibiotic. The mutation may have happened generations before the antibiotic was present. When there was no antibiotic present, having the mutation was neither beneficial nor detrimental [neither good for the bacteria nor bad for them], it was simply neutral. It gave the bacteria no added selective advantage.
- When the antibiotic was present only then did the presence of the mutation confer an advantage on the bacteria that had it.

Have you ever been prescribed an antibiotic and been told to finish the course of antibiotics, even if you feel better?

Read the following *case study* to learn how not following the correct medication procedure and antibiotic resistance has caused huge medical problems relating to bacterial infections. Although the case study refers to TB, the situation is the same with many kinds of bacterial infections, resulting in the evolution of 'super bugs' which are resistant to all known antibiotics.

[START TEXT BOX]

What's a case study?

A case study presents some problem or situation, not simply as a set of facts, but in the context of a *real-life situation.* A case study is a classic example of a particular problem in real-life.

[END TEXT BOX]

> *Case Study: Patient Tumi*
> *Tumi was diagnosed with tuberculosis and was started on a course of antibiotics known to kill the bacterium that causes TB,* Mycobacterium tuberculosis. *Tumi was instructed by his doctor and the clinic sister to take the antibiotics for six months. After one month, Tumi felt much better, so he stopped taking his antibiotics. He claimed that the clinic was far away from his home and he did not see the need to continue his medication given that it he would have to travel so far to get the repeated medication.*

Two months later, Tumi began feeling ill again, so he started taking his antibiotics once more. This time the antibiotics did not make him feel better. Tumi returned to the doctor and underwent more tests. After trying other more powerful drugs that still did not help him, Tumi was told he had Multi-Drug Resistant TB. The doctor explained that some of the bacteria that had caused his initial infection may have been resistant to the first lot of antibiotics.. The doctor said that antibiotics help the body to kill all the bacteria that cause TB. If the patient takes the antibiotics correctly, most *of the bacteria will be killed within a few weeks. Treatment continues for six months to make sure that* all *the bacteria have been killed.*

The doctor told Tumi that if a patient forgets to take his medication regularly, or stops taking it as Tumi did, the few bacteria may be resistant to the antibiotic. The resistant bacteria survive and multiply. They have a selective advantage over normal bacteria, because they are resistant to antibiotics. Eventually, the whole population of bacteria causing TB in the patient are resistant to the first antibiotics. The patient is very ill again. The patient has to change to different antibiotics and take them strictly for the full six months.

The doctor sent Tumi away with new antibiotics and very strict instructions to take the medication as prescribed. He also gave Tumi a pamphlet warning him of the dangers of a new form of TB: Extensively Drug Resistant TB that appeared in Kwa-Zulu Natal in 2006 – these bacteria were resistant to most *antibiotic drugs, even the most powerful ones he was currently taking. Tumi knew that if he developed this form of TB, he would probably die, as the pamphlet said that 70% of the cases of XDR-TB resulted in death. He had learnt his lesson and he took the new antibiotics exactly as prescribed, willingly travelling to the clinic to get his repeated prescriptions and warning other patients of what would happen if they did not take their medication as instructed by the doctor.*

Watch the following video about natural selection and antibiotic resistance:
Natural Selection:
https://www.youtube.com/watch?v=7VM9YxmULuo&index=41&t=0s&list=PLwL0Myd7Dk1F0iQPGrjehze3eDpco1eVz (Duration: 7.22)

After watching the video, think back to Figures 109 and 110.
Then do the following in your workbook:

- Propose a reason why antibiotics don't kill your cells you when you take them.
- Predict what characteristics a species of bacteria might have that could make it resistant to penicillin?

This video shows how antibiotic resistance grows – what you are seeing is evolution in action!
Watch antibiotic resistance evolve: https://www.youtube.com/watch?v=yybsSqcB7mE (Duration: 2.02)

Activity 3.1: Interpret a poster about antibiotic-resistance

Suggested time:

25 minutes

Aim:

In this activity, you will analyse a poster and use what you have learnt in the case study to answer the questions.

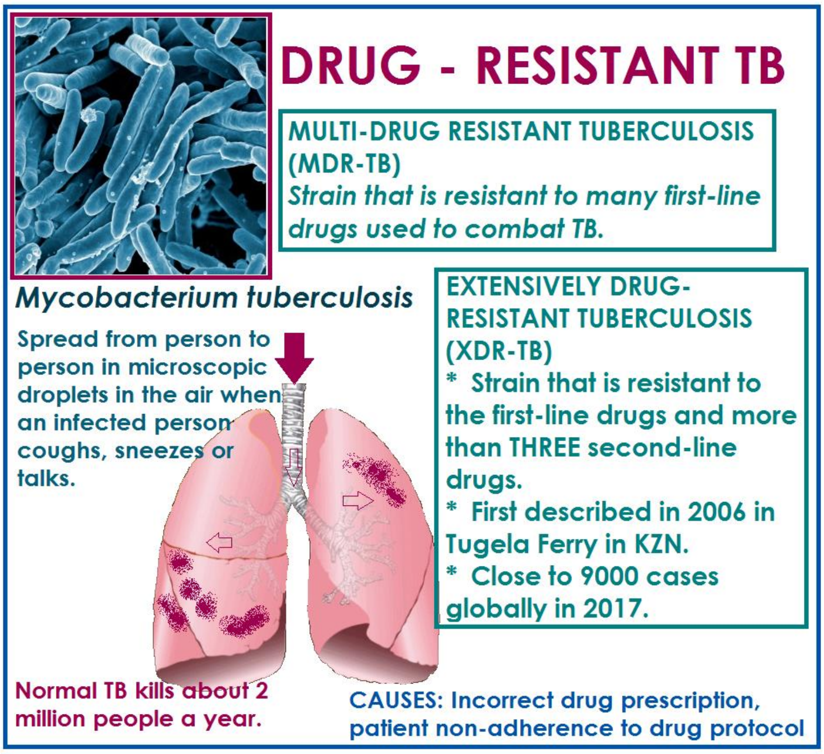

Figure 111: Antibiotic resistant TB Poster [insert AW Figure 111]

What you will do:

Study the poster in Figure 111 and read the case study in your notes, then answer the following questions in your workbook.

1. What is the scientific name of the bacteria that causes TB?
2. How does TB normally spread from one person to another?
3. How many people die from TB each year?
4. What do you think is meant by “first-line” and “second-line” drugs against TB?
5. Why do you think second-line drugs would need to be given to people with MDR-TB?
6. Where was Extensively drug-resistant TB first discovered?
7. Explain the reasons for people getting a drug resistant form of a disease.
8. Explain how a mutation can cause antibiotic resistance.

Exemplar answer

1. *Mycobacterium tuberculosis*
2. Spreads through the air in microscopic droplets when an infected person coughs, sneezes or even talks. The bacteria are inhaled into the lungs.
3. About 2 million people per year.
4. First-line drugs are the first antibiotics prescribed when a person is diagnosed with TB. When these fail to cure the person, other, more powerful drugs are given. These are second-line drugs.

5. The TB does not respond to the first-line drugs, indicating that a person has MDR-TB, so second-line drugs are prescribed.
6. Tugela Ferry, KZN, South Africa.
7. Incorrect prescription (doctors not recognizing that a patient had MDR-TB and prescribing the less powerful antibiotics), patient not taking the drugs correctly (either stopping the dose too early or forgetting to take doses).
8. A mutation introduces a new gene that makes the bacteria resistant to certain antibiotic drugs.

Activity 3.2: Insecticide resistance in mosquitoes

Suggested time:

25 minutes

Aim:

In this activity, you will apply what you have learnt about antibiotic resistance to a new situation: insecticide resistance.

What you will do:

Answer the question in your workbook.

A population of mosquitoes was known to carry malaria parasites in a particular area. The Health Authorities decided to use a particular insecticide [chemical that kills insects] to kill off the mosquito population, in order to prevent the spread of malaria. The insecticide was successfully used for five years. After five years, the Health Authorities noted that the mosquito population was growing again, in spite of continued use of the insecticide. Experts were called in to investigate the problem. They determined that the mosquito population had become resistant to the insecticide.

Write a mini-essay in which you describe, at a genetic level, how the mosquito population became resistant to the insecticide through natural selection.

Consult your Student Handbook for guidelines and assistance when writing your essay.

Discussion of the activity

You must be able to apply your knowledge to a new context. Don’t panic when you see a question in an exam that introduces new information or a new example that you have never heard about. Carefully look at the question and note what it is about: in this case, resistance to a chemical and natural selection. You have learnt about antibiotic resistance in bacteria. Now you are being asked about insecticide resistance in insects. It is the same principle, but a different context. Apply what you have learnt to the question. Think it through logically and answer the question!

Exemplar answer

Your essay must have an introduction, be divided into paragraphs that are logically structured and ordered, and it must have a conclusion.
Consult your Student Handbook for guidance on essay writing.
Here are some of the points that should appear in your essay:

- There is a population of mosquitoes. These insects are considered pests as they bite humans and transmit diseases.
- There is an insecticide which kills these insects. In this population of mosquitoes, there is a gene in normal insects for non-resistance to insecticide. Individuals with this genetic characteristic (A) may live long enough to produce offspring, but these offspring are killed by the insecticide.
- However, there is a good chance, if the insecticide is used at a time just before the insects reproduce, that these insects won't even reproduce and will die before they have increased the population. This is how an insecticide can be successful on repeated generations of insects over time.
- But now let's say a few individuals mutate by chance, or have a mutation, that gives them a slightly different genetic characteristic (say B) which gives them resistance to the insecticide.
- It could be that this allele B existed in the population for many, many generations, but because it never conferred an advantage on the individuals with the gene, it was never selected for. However, now, in the changed environmental conditions, insects with this gene will survive being sprayed by the insecticide. Further, they will be able to produce many offspring.
- Mosquitoes with allele B have an advantage in the changed environment. Suddenly it is advantageous to have allele B, because it means that if you have allele B, you will not die when the insecticide is sprayed on your population. You have a survival advantage. You also have a reproductive advantage. Your chances of living long enough to produce offspring are increased. You are able to pass this inherited characteristic on to your offspring. Your offspring are now at an advantage as they are stronger, or fitter in the given environment.
- Eventually, the population has no individuals left with characteristic A and the entire population is insecticide resistant. The population has evolved.
- If it were not for the pressure of the insecticide, this insect population would never have evolved in this particular way. The presence of the insecticide drove the changes in the population. We say that the insecticide was a selective pressure which brought about evolution in the population.
- Remember that when the population was evolving, the ratio of different genetic types in that population was changing. Each individual within the population did not change. The frequency of insecticide-resistant individuals increased, but the insects themselves did not change from being susceptible to insecticides to being resistant in their lifetimes. One organism does NOT turn into another organism!

Before working on the activities, you were asked to:

- Propose a reason why antibiotics don't kill your cells you when you take them.
- Predict what characteristics a species of bacteria might have that could make it resistant to penicillin?

Read the following and see if your predictions were correct:

Penicillin and other similar antibiotics work by inactivating the bacterial enzymes responsible for making cell walls in bacteria that are replicating or reproducing. These antibiotics are effective only against bacteria that are producing cell walls. This is why they cannot kill your cells: your cells do not have cell walls.

A characteristic that would prevent penicillin from destroying a bacterium might be possession of an enzyme that could break down penicillin before it needed to reproduce. Some bacteria, such as *Staphylococcus* have developed an enzyme, called penicillinase, that does just this! So scientists have developed penicillinase-resistant penicillin. And would you believe…some bacteria have been found that are resistant to this drug as well. Methicillin-resistant *Staphylococcus areus* or (MRSA) is one of the super-bugs that causes serious infections in hospitals.

Other characteristics that might make a bacterium resistant to an antibiotic could be: A mutation that made the bacterial cell wall reject penicillin/the antibiotic, or even, a bacterium with a thicker cell wall or a slimy capsule around the outside of the cell wall.

Were your proposals and predictions correct…or nearly correct? Keep on thinking creatively! That's how many scientific puzzles are solved.

You might have some time, and want to check out these examples of natural selection in action today:
Tibetans surviving at high altitudes:
https://www.biologycorner.com/2018/04/02/case-study-how-do-tibetans-survive/
Human evolution and lice:
https://www.biologycorner.com/2016/11/13/case-study-lice/

[START TEXT BOX]
What's the main idea?
Antibiotic resistance in bacteria arises due to natural selection. This is an example of evolution in present times.
[END TEXT BOX]

Moving on

In the next Unit you will see how natural selection can produce a new species from an existing species.

Topic 3: Evolution
Sub-topic 1: The theory of evolution by natural selection

Unit 4: Mechanisms of speciation and reproductive isolation

Unit 4 learning outcomes
By the end of this unit, you should be able to:

4. Illustrate how geographical isolation gives rise to speciation, with specific reference to Galapagos finches.
5. Explain mechanisms of reproductive isolation including temporal, ecological, and behavioural isolation, gamete incompatibility and hybrid sterility.

Unit 4.1: Speciation

Write the heading 'Speciation' in your work book. Answer each of the following questions, using what you have learnt and already know. Leave a few lines under the answer of each question for revisions and corrections.

1. What do biologists mean by the term 'species'?
2. Briefly explain what is meant by 'evolution by natural selection'.
3. You have seen how natural selection can change a population and allow it to adapt to its environment. Predict how the process of natural selection could give rise to a new species.

As you work through the notes and videos, come back to your answers and revise or correct them.

Watch this video to remind yourself of what a species is:
What is a species? https://www.fuseschool.org/communities/147/contents/1136 (Duration: 4.49)

Remember from Topic 1, you learnt that a species is defined as a group of organisms that may look similar, but more importantly, can breed successfully together, producing fertile offspring.

In Units 2 and 3 of this Sub-topic, you studied natural selection. You learnt that organisms that are the most successful at reproducing, contribute most to the gene pool of a population. The alleles that ensure survival are passed on to future generations. This means that over time, the allele frequencies in the gene pool of a population may change. This is called evolution.

Speciation is the development of a new species of organism from an existing species. Speciation requires that natural selection goes further: the well-adapted population might eventually change so much that it is unable to breed with its parent population. If this happens, then the new population has become a new species.

If you were to look at a *phylogenetic tree* [a branching diagram that represents the evolutionary relationships among organisms; ancestors at the base of the 'tree' and descendents at the tips of the 'branches'; you encountered phylogenetic trees in Topic 1], every branching point is a speciation event.

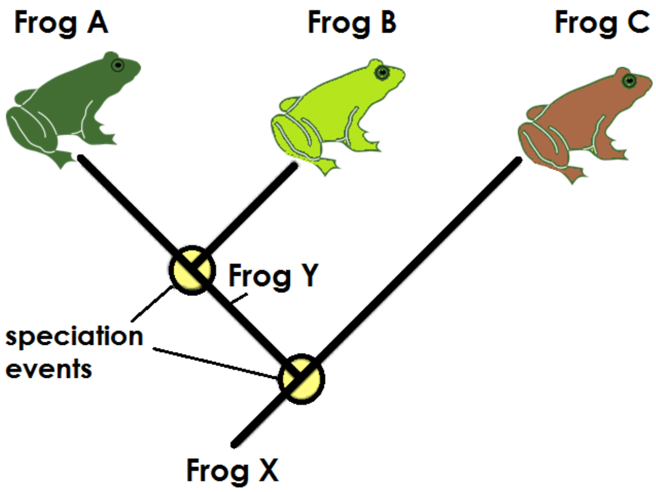

Figure 112: Speciation [insert AWB Figure 112]

In Figure 112, you can see that splits or branches in a line over time indicate a new species being formed.

What is important about the diagram in Figure 112?

1. New species come from existing species.
2. Something caused the speciation event.
3. There was a series of events that brought about sufficient change in the allele frequency of the gene pool of the original population, that the new population was no longer able to recognise the original population as potential mates.
4. This means that Frog A, Frog B and Frog C all had an original common ancestor: Frog X. Frog X is now extinct.
5. Frogs A and B had a more recent common ancestor: Frog Y. Frog Y is now also extinct.
6. We know that Frogs X and Y are extinct, because we do not see them at the tips of the branches, along with Frogs A, B and C.
7. Frog X did not become Frog Y, which in turn did not become Frog A.
8. Likewise, Frog A did not become Frog B, and Frog B did not become Frog C.

Now read further and study the hypothetical example of how speciation might take place in Figure 113:

9. Most often, in order for speciation to take place, two populations of one species must become *geographically isolated*. This means that a physical barrier separates a population into two groups. Maybe an earthquake separated a population of frogs into two separate groups. Maybe a large highway was built which cut off part of the population. Scientists think that geographic isolation is a common way for the process of speciation to begin: rivers change course, mountains rise, continents drift, organisms migrate, and what was once a continuous population is divided into two or more smaller populations. It doesn't even need to be a physical barrier like a river that separates two or more groups of organisms — it might just be unfavourable habitat between the two populations that keeps them from mating with one another. What follows is called *allopatric speciation*.
10. There must be *reduced gene flow* between the two populations. What this means is, there is no or very little reproduction between the two populations. The genes and subsequent mutations that give rise to new alleles in population A are separate from the genes and subsequent mutations in population B

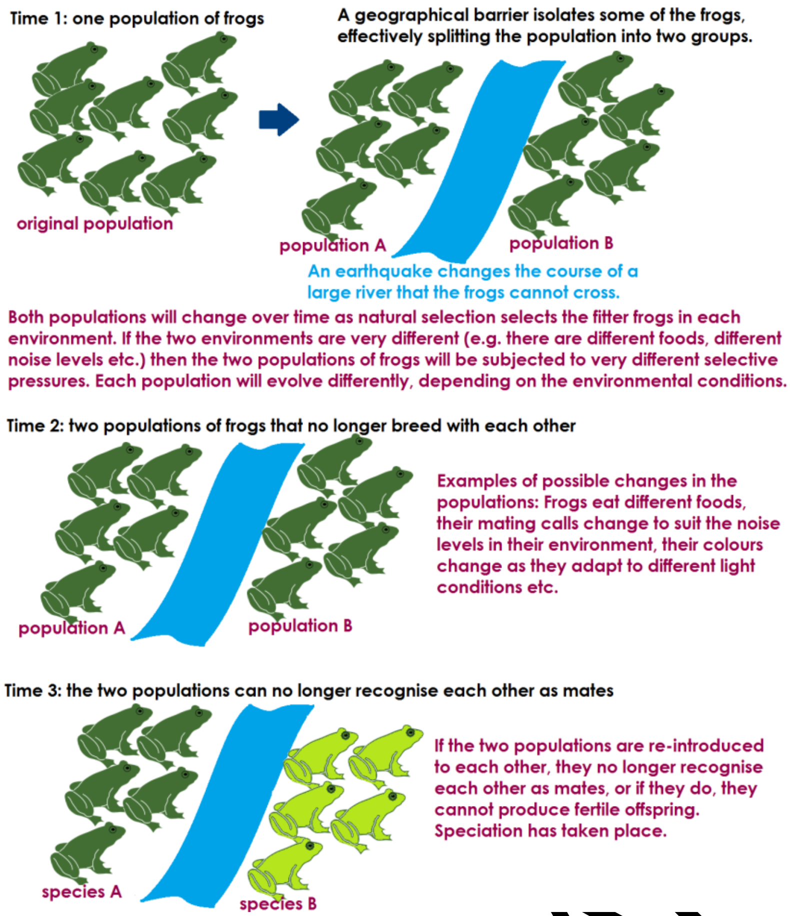

Figure 113: Allopatric speciation [insert AWB Figure 113]

Now let's investigate a real example, explained originally by Charles Darwin, to explain how and why speciation events take place. We will study the evolution of different species of finches on the Galapagos Islands. (Remind yourself of Darwin's observations made on the Galapagos Islands in Unit 1 of this Sub-topic.)

Speciation of finches on the Galapagos Islands

Charles Darwin observed the results of speciation on the Galapagos Islands. The finches on the islands resemble finches on the mainland, but they are not all one species. The islands are about one thousand kilometres away from the mainland. The islands are volcanic, the oldest being about 5 million years old.

Darwin's finches could have evolved from one ancestral species into may species in the following manner:

- The ancestral finch species lived on the mainland of South America. The birds are too small to fly 1 000 km to the Galapagos Islands. However, storms often blow flocks of small birds out into the ocean. A few finches must have landed on the Galapagos Islands. They were geographically isolated from the mainland finches.
- In order to survive, the finches had to eat foods found on the islands, but not necessarily the same foods their beaks were adapted for back on the mainland. Only those finches with variations in their beaks that allowed them to adapt to new diets, were able to survive.
- The small flock of finches reproduced. Through natural selection, they became adapted to the island environment.

- Some finches flew to a second island, where they were geographically isolated from the first species. Through natural selection, the finches on the second island became adapted to the food available on that island.
- After a long period of isolation, the finches on different islands could no longer interbreed. They could not interbreed with the mainland finch species. They are new species.
- This process may have occurred many times as finches flew between islands. It has resulted in 14 finch species.

Each species of finch developed a unique beak that is especially adapted to the kinds of food it eats. Some finches have large, blunt beaks that can crack the hard shells of nuts and seeds. Other finches have long, thin beaks that can probe into cactus flowers without the bird being poked by the cactus spines. Still other finches have medium-size beaks that can catch and grasp insects. Because they are isolated, the birds don't breed with one another and have therefore developed into unique species with unique characteristics.

You can do this interactive activity to see if you can tell the different Galapagos finch species apart, based on their song and their beak shapes:
Sorting finch species: https://www.hhmi.org/biointeractive/sorting-finch-species
You can read more about the speciation of the Galapagos finches at:
https://evolution.berkeley.edu/evolibrary/news/100201_speciation and
https://www.hhmi.org/biointeractive/beaks-tools-selective-advantage-changing-environments

Watch this video which explains speciation:
Speciation: https://www.youtube.com/watch?v=2oKlKmrbLoU (Duration: 10.24)

Go back to your original questions you answered in your workbook, at the start of this Unit. Revise and consolidate your ideas.

[START TEXT BOX]
What's the main idea?
Allopatric speciation explains how speciation, through natural selection, occurs in geographically isolated populations. The finches on the Galapagos Islands illustrate allopatric speciation.
[END TEXT BOX]

Activity 4.1: The Galapagos tortoises

Suggested time:
25 minutes

Aim:
In this activity, you will apply what you learnt about the speciation of the Galapagos finches to a new context: the Galapagos tortoises.

What you will do:
Study the diagram in Figure 114 and answer the question in your workbook.

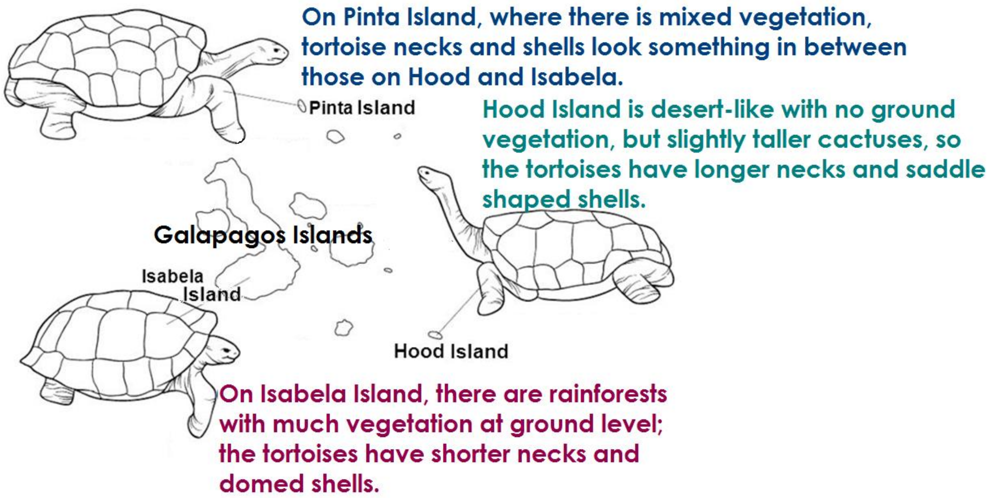

Figure 114: Galapagos tortoises [insert AWB Figure 114]

The tortoises on the Galapagos Islands show distinct variation in neck length and shell shape.

Use what you have learnt about speciation to describe how the tortoises on Hood Island came to be a different species to the tortoises on Isabela Island. Start your explanation using the tortoises on Isabela as the original population of tortoises.

Discussion of the activity

This is another activity that requires you to use application skills in applying old knowledge to a new context. If you can describe speciation of the Galapagos finches, then you can apply that information and the concept of speciation to the Galapagos tortoise example.

Exemplar answer

Maybe a few tortoises from Isabela were washed away to Hood Island in a bad storm. The two divided populations are isolated from each other because of the geographical or ecological barrier of the ocean and no interbreeding can take place. There is no gene flow between the two populations. Because the areas are geographically isolated, the ecological or environmental pressures are different. On Isabela Island, the vegetation, which is the food source for the tortoises, is low lying. Isabela tortoises tend to have shorter necks as there is no selective advantage to a longer neck. However, on Hood Island, conditions are very different. There is no low lying vegetation, only slightly taller cactuses. The first Isabela tortoises to reach Hood would have been under pressure to find food for their survival. Those tortoises that had slightly longer necks, due to natural genetic variation, would have been more successful than the shorter necked individuals. These tortoises with the slightly longer necks would have been able to reach food, survive, and of course, reproduce, passing on alleles for longer necks. Over the years, the neck length in Hood tortoises would have increased.

Over the years, different genetic variation occurs in each population. Mutations occur in each population. So different selection pressures are placed on the two populations. The saddle backed shaped shell of Hood tortoises and the slightly more domed shape shell of Isabela tortoises have nothing to do with the diet of these tortoises, but the two populations changed separately over time, with respect to their shell shape, and so their shell shapes changed as well. This would have made mating between the two populations more difficult. Natural selection takes place in each population, causing the populations to become totally different genetically. Interbreeding then becomes impossible, if the two populations are reintroduced to each other, because they differ too much genetically. A new species has been formed.

Unit 4.2: Methods of reproductive isolation

You have learnt that when two populations are separated, there is a reduction in gene flow between the two populations. This can ultimately bring about speciation. Speciation requires that the two populations be unable to produce fertile offspring together or that they avoid mating with members of the other group. And so, once two populations have been isolated from each other to the point that speciation has taken place, various mechanisms exist to keep the two populations reproductively *isolated* [cut off; separate] from each other.

The most efficient mechanisms of reproductive isolation happen before two individuals meet and mate. Four examples are described below.

1. *Temporal* [to do with time] *isolation* means that the two species breed at different times of the day or the year. For example, one plant species may flower in spring and the other species flowers in autumn. The chances of inter-breeding is reduced.
2. *Ecological isolation* means that the two species occupy different parts of an ecosystem. For example, one butterfly may live and breed in the topmost canopy of trees, while another lives in the plants lower down and closer to the ground. They are ecologically isolated from each other.
3. *Behavioural isolation* means that the two species use different signals to attract a mate. For example, male frogs use mating calls to attract females. Different species have different mating calls. The females respond only to the calls of their own species. The two species are behaviourally isolated.
4. *Mechanical isolation* – in animals, the position or structure of the sex organs change so that mating is no longer possible. In plants, one population may adapt to a new pollinator. In this way, the two populations are mechanically isolated from each other.

Sometimes a male and female of different species meet when they are sexually receptive. They mate, but reproductive isolation mechanisms prevent fertilisation, or ensure that the hybrid offspring do not reproduce. Two examples are described below.

5. *Gamete incompatibility* means that the sperm cannot fertilise the eggs. Pollen is easily transported from a flower of one species to a flower of another species. The pollen grain does not fertilise the eggs of the wrong species. The sperm does not penetrate the egg of the wrong species. The gametes are incompatible.
6. *Hybrid sterility* means that, even if interbreeding occurs and an offspring is produced, it is sterile. In some cases, the hybrid offspring are weak and die early before they can reproduce. Some hybrids survive to adulthood, but they are sterile. Mules are sterile hybrids of inter-breeding between a horse and a donkey.

This video summarises what you have learnt about how a new species develops from an existing species, and the various reproductive isolating mechanisms that exist:
Speciation:
https://www.youtube.com/watch?v=udZUaNKXbJA&index=43&t=0s&list=PLwL0Myd7Dk1F0iQPGrjehze3eDpco1eVz (Duration: 7.32)

[START TEXT BOX]

What's the main idea?

Species are kept reproductively isolated by temporal, ecological, behavioural, and mechanical isolation. They are also isolated by gamete incompatibility and hybrid sterility.

[END TEXT BOX]

Moving on

Pulling some ideas together before moving on:

In this Sub-topic, you have learnt about natural selection, as it was proposed by Charles Darwin and Alfred Wallace. They said:

1. Organisms tend to produce more offspring than are needed to replace themselves when they die.
2. Individuals belonging to a species vary in characteristics such as their appearance, resistance to disease or their ability to survive drought. The variation is inherited, that is, they pass it on to their offspring.
3. The individuals in an overcrowded environment compete to survive.
4. Only the best-adapted individuals survive and reproduce. Individuals that are less well-adapted, die before they reach reproductive age.
5. Over time, more and more individuals in the population have the most favourable adaptations.

Darwin and Wallace had no idea of the nature of the hereditary material. What was needed to provide support for their theory was a genetic explanation. The discovery of genetics revived interest in natural selection, and showed that it was truly a possible mechanism for evolution. The theory of natural selection was adapted to accommodate the discoveries of genetics.

The modern theory of natural selection focuses on *populations* rather than individuals. It states that:

1. Populations tend to grow because rates of reproduction usually exceed rates of death.
2. As a population grows, resources such as food and living space become limited.
3. Individuals compete for the limited resources.
4. Individuals that belong to the same species share certain phenotypic characteristics.
5. Details of the phenotypic characteristics vary within a population.
6. Shared phenotypic characteristics are inherited through genes. Variations in the phenotype are caused by different alleles of the genes.
7. Certain phenotypes may increase the chance of an individual surviving and reproducing. Such phenotypes are called *adaptive traits*.
8. An allele associated with an adaptive trait tends to become more common in the population over time.

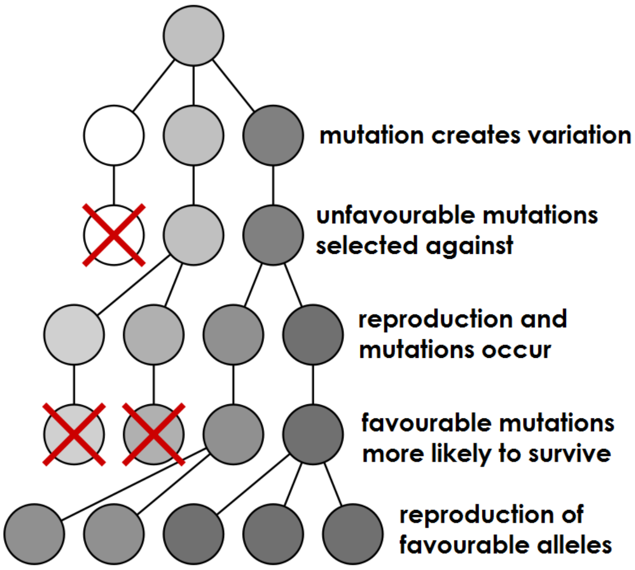

Figure 115: Mutations and natural selection [insert AWB Figure 115]

As demonstrated in Figure 115, natural selection results in favourable alleles increasing in the population.

You have now learnt about natural selection as a mechanism for evolution and ultimately speciation. In the next Unit, you will investigate evidence for evolution.

Summary assessment

1. Five mechanisms of reproductive isolation are: temporal isolation, ecological isolation, behavioural isolation, mechanical isolation, gamete incompatibility and hybrid sterility. Say which type of reproductive isolation is illustrated by each of the following examples.
   a. Four closely-related flower species produce different scents and attract different pollinators.
   b. Sheep sometimes mate with goats, but the offspring are usually stillborn.
   c. Black wildebeest and blue wildebeest are closely related. Black wildebeest prefer Grassland and Nama Karoo biomes. Blue wildebeest prefer the edge of the Savanna biome.
   d. Two butterfly species can mate, but females' eggs are never fertilised.
   e. In two bird species, males attract their mates by courtship dances and song. The dances and songs are different in the two species.
   f. Two vygie species grow near each other in the Succulent Karoo. One flowers in late July and August, while the other flowers in September. (6)

2. Match each description in Column A with the correct term in Column B.

Column A	Column B
2.1 A pond dries up during a drought to make two smaller ponds.	A Natural selection
2.2 One frog species breeds in March, while a related frog species breeds in May.	B Hybrid sterility

2.3 Tortoises with long necks survive and breed on an island with tall shrubs growing on it.	C Geographical isolation
2.4 Pollen from a lily lands on the stigma of a daisy.	D Speciation
2.5 The offspring of a zebra and a donkey cannot reproduce.	E Behavioural isolation
2.6 Members of an isolated population cannot produce fertile offspring if re-introduced to the original population.	F Ecological isolation
2.7 The courtship dance of the rock pigeon is different from that of an olive pigeon.	G Gamete incompatibility
	H Temporal isolation

(7)

3. State whether each of the following statements is TRUE or FALSE. If False, give the corrected version of the statement.
   a. The theory of evolution states that populations change over time.
   b. Darwin proposed that evolution is the way natural selection takes place.
   c. Each generation produces just enough offspring to replace itself.
   d. Alfred Wallace developed the idea of evolution after a 5-year voyage on the ship *HMS Beagle*.
   e. Natural selection is based on differences in reproductive success of individuals that have favourable adaptations.

(5)

4. The table below gives information about an investigation of survival in four varieties of mice, each having a different fur colour. The mice live in a desert area where the sand is a golden colour. They are active only at night. Their main predators are owls. The Table shows the average results for 10 mice of each variety.

Average results for four types of female mice in a desert environment.				
Variety of mouse	A	B	C	D
Fur colour	Dark brown	Gold	Red-brown	White
Average age at death (months)	3	10	4	9
Average number of offspring produced	5	12	6	10

a. Which variety of mouse (A, B, C or D) is best adapted to its environment? (1)
b. Give TWO reasons, based on the table, to support your choice. (2)
c. Explain the results in terms of natural selection. (7)

Exemplar answer

1.

a. Behavioural isolation
b. Hybrid sterility
c. Ecological isolation
d. Gamete incompatibility
e. Behavioural isolation
f. Temporal isolation

(6)

2.

Column A	Column B
2.1 A pond full of fish dries up during a drought to make two smaller ponds.	C Geographical isolation
2.2 One frog species breeds in March, while a related frog species breeds in May.	H Temporal isolation
2.3 Tortoises with long necks survive and breed on an island with tall shrubs growing on it.	A Natural selection
2.4 Pollen from a lily lands on the stigma of a daisy.	G Gamete incompatibility
2.5 The offspring of a zebra and a donkey cannot reproduce.	B Hybrid sterility
2.6 Members of an isolated population cannot produce fertile offspring if re-introduced to the original population.	D Speciation
2.7 The courtship dance of the rock pigeon is different from that of an olive pigeon.	E Behavioural isolation
	F Ecological isolation

(7)

3.

a. TRUE
b. FALSE Darwin proposed that natural selection is the way evolution takes place.
c. FALSE Each generation produces more offspring than are needed to replace itself.
d. FALSE Charles Darwin developed the idea of evolution after a 5-year voyage on the ship *HMS Beagle*.
e. TRUE

(5)

4.

a. B is best adapted to the environment.

(1)

b. B lives longer and produces more offspring than any other variety.

(2)

c. Varieties A and C will die out, because they do not survive and reproduce well in the environment. Varieties B and D have a selective advantage because they are not so visible to the owls. They will increase in proportion in the population. Variety B will increase faster than Variety D.

(7)

Key learning points

The Sub-topic The theory of evolution by natural selection focussed on the following key points:

- Charles Darwin and Alfred Wallace developed the theory of evolution by natural selection independently. Both assembled an enormous amount of physical evidence that supported the theory of evolution by natural selection.
- Evolution is the change in the allele frequency in the gene pool of a population over time. Natural selection is the process that causes the allele frequency to change over time. Individuals with the fittest alleles leave more offspring than other individuals. The number of individuals with the fittest alleles increase in the population.
- Antibiotic resistance in bacteria arises due to natural selection. This is an example of evolution in present times.
- Allopatric speciation explains how speciation, through natural selection, occurs in geographically isolated populations. The finches on the Galapagos Islands illustrate allopatric speciation.
- Species are kept reproductively isolated by temporal, ecological, behavioural, and mechanical isolation. They are also isolated by gamete incompatibility and hybrid sterility.

Topic 3: Evolution
Sub-topic 2: Evidence supporting evolution

Overview

When you completed the Nature of Science part of this subject, you learnt that scientific knowledge *must* be supported by evidence. In this Sub-topic, you will be exploring four areas that provide evidence of evolution by natural selection:

- artificial selection
- the fossil record
- comparative anatomy
- biogeography

Unit 1: Artificial selection

Unit 1 learning outcomes

By the end of this unit, you should be able to:

6. Explain how artificial selection mimics natural selection, giving examples of artificial selection.

Watch this short and simple video before beginning this section:
What is selective breeding? https://www.youtube.com/watch?v=W_CnR0Ak604 (Duration: 2.27)

Now, in your workbook, write the heading 'Artificial selection'. Under the heading, answer the following questions:

1. Explain what is meant by artificial section or selective breeding. Use Figure 116 to help you in your discussion.

Figure 116: Modern dog breeds [insert AWB Figure 116]
Source: https://commons.wikimedia.org/wiki/File:Montage_of_dogs.jpg

2. How is artificial selection like natural selection…and how does it differ?

Leave about ten lines under your answer to each question, so that you can come back to these answers after working through this section and revise and consolidate your answers.

Now watch the following video:
Selective breeding: https://www.fuseschool.org/communities/147/contents/1346 (Duration: 4.23)

You may want to return to your original answers and rework some of your ideas at this point, before continuing.

In his book *On the Origin of Species by Natural Selection,* Darwin used the example of artificial selection (mainly of pigeons and other domestic farm animals) to illustrate how a species can change through selective breeding.

Artificial selection involves a human *choosing* which individuals will breed the next generation. If the breeding programme continues for many generations, the resulting individuals may look quite different from the original parents.

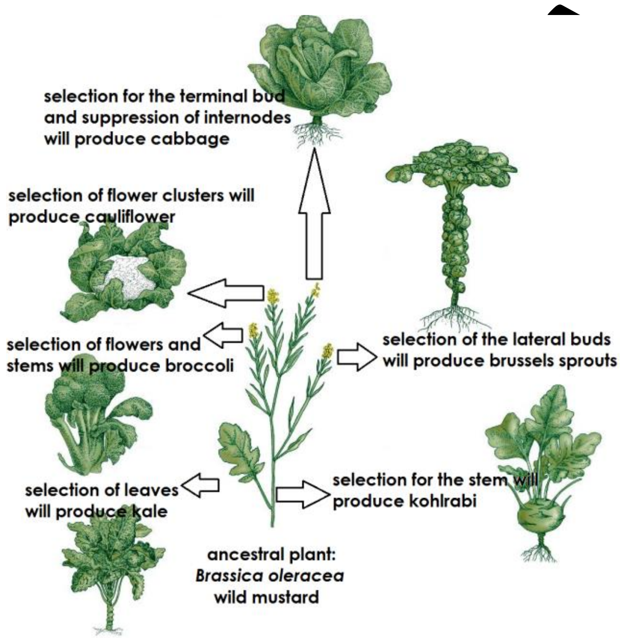

Figure 117: Artificial selection to produce vegetables from ancestral plants [insert AWB Figure 117]
Source: Adapted from:
https://www.vox.com/xpress/2014/8/6/5974989/kale-cauliflower-cabbage-broccoli-same-plant

Figure 117 shows how many different vegetables are varieties of one plant, *Brassica oleracea*. Plant breeders have artificially selected a certain characteristic. They carefully cross-pollinate plants with that characteristic. They collect the seeds and germinate them. They select the parent plants from the next generation, and repeat the process. After many generations, farmers have different vegetables such as cabbage, cauliflower, broccoli and kale. This example illustrates how selecting the parents who will breed can lead to change in a line of plants.

This video will fascinate you if you are interested in the original ancestors of some vegetables and fruits we eat today: *Ten top foods that originally looked totally different:* https://www.youtube.com/watch?v=M5Qly-VQfbo (Duration: 10.02)

All different breeds of modern cattle are descended from the original wild Aurochs that lived throughout most of Europe and Asia and north Africa. Evidence shows that domestication of the aurochs occurred between 10 000 and 8 000 years ago, giving rise to our modern varieties of cattle observed today. Figure 118 shows an Aurochs cow, and its descendant, a modern dairy cow.

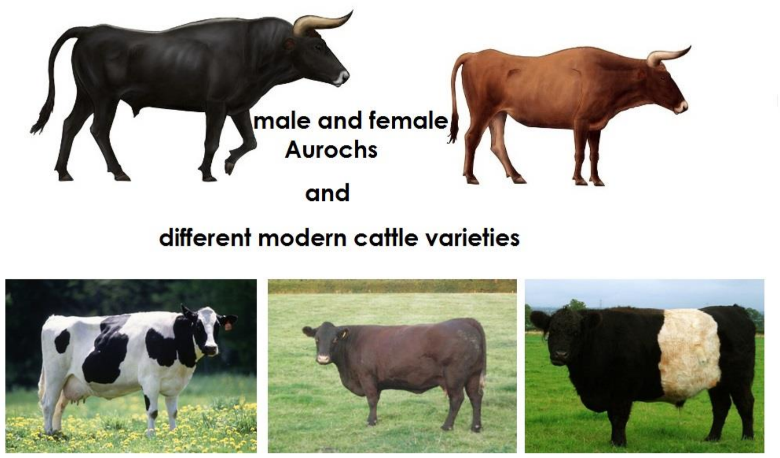

Figure 118: A male and female Aurochs and modern cattle varieties
Source: Adapted from: https://en.wikipedia.org/wiki/File:Aurochsfeatures.jpg
https://en.wikipedia.org/wiki/Holstein_Friesian_cattle#/media/File:Cow_female_black_white.jpg
https://en.wikipedia.org/wiki/Sussex_cattle#/media/File:Sussex_cow_4.JPG
https://en.wikipedia.org/wiki/Belted_Galloway#/media/File:Belted_Galloway_at_Gretna_Green.jpg

Cattle have been bred for different purposes: beef cattle for meat, dairy cattle for milk, breeds that are resistant to disease, cattle that can survive in dry conditions, and cattle that have particular coat patterns. In every case, the animal breeder breeds only from the bulls and cows that have the best qualities that he wants. Over many generations, he achieves the result he wants.

There are a number of modern back-breeding projects that are trying to produce aurochs-like cattle from modern breeds by selective breeding. Do you think this is a worthwhile project? Do you think it will succeed?
You can find out more about this at: https://en.wikipedia.org/wiki/Heck_cattle

How are artificial selection and natural selection alike? How are the different?

Watch this video, then return to the questions you answered at the beginning of this Unit and check your answers.
Natural selection vs artificial selection: https://www.youtube.com/watch?v=9hzWbTpxME8
(Duration: 2.34)

Charles Darwin used artificial selection to illustrate that a species can change over many generations. Artificial selection is similar to natural selection. The agent of artificial selection is the breeder, whereas the agent in natural selection is the environment. Natural selection generally acts more slowly on a population that artificial selection.

[START TEXT BOX]
What's the main idea?
Artificial selection illustrates that populations can change over time, due to selective breeding. Artificial selection demonstrates that natural selection is possible.
[END TEXT BOX]

Moving on

In the next Unit you will uncover more evidence for evolution as you investigate the fossil record.

Topic 3: Evolution
Sub-topic 2: Evidence supporting evolution

Unit 2: The fossil record

Unit 2 learning outcomes

By the end of this unit, you should be able to:

7. Explain how the fossil record supports evolution.

Unit 2.1: Fossil formation

In Topic 1, Sub-topic 3, you learnt that Earth has an extremely long history. You learnt that different species of organisms existed in the past, because their remains are preserved as *fossils*.

Figure 119: Fossils are evidence of organisms that lived millions of years ago [Reinsert AWB Figure 32 here as Figure 119]
Source: Adapted from: https://pixabay.com/en/shell-fossil-old-ancient-stone-219665/; https://pixabay.com/en/fish-reprint-fossils-historically-1093863/; https://pixabay.com/en/fossil-pine-cone-rock-geology-265082/; https://pixabay.com/en/fossils-bone-lizard-fossil-255547/

Fossils are the preserved remains of once-living organisms, or preserved traces left behind by living organisms. Examples of fossils are fossilised bones, wood, footprints, tree resin and even faeces. Fossils tell us about the kinds of life that existed in the past.

This simple video will introduce you to the different kinds of fossils and how they are made:
How fossils are formed: https://www.youtube.com/watch?v=TVwPLWOo9TE&feature=youtu.be
(Duration: 2.38)

Study Figure 120 to learn how petrified or body fossils are made in *sedimentary rock* [rock that forms when sand and mud settle to the bottom of seas, lakes and swamps; the mud is compressed by more sediment and by water, and turns into rock].

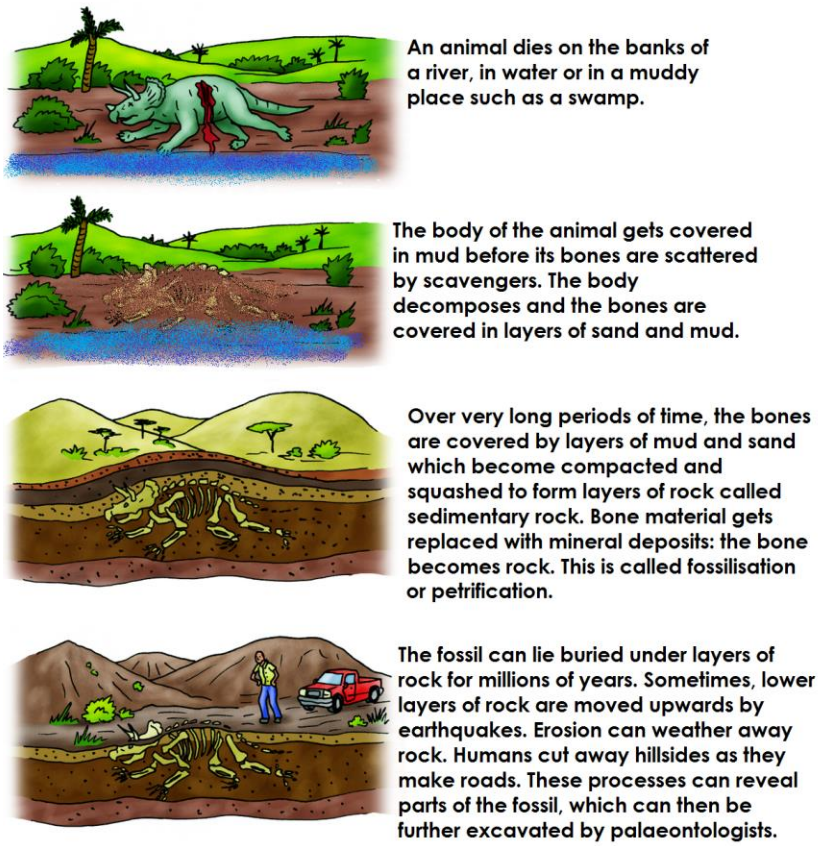

Figure 120: The fossilisation process
Source: Adapted from http://www.thunderboltkids.co.za/Grade5/04-earth-and-beyond/chapter4.html

Figure 21 shows how successive layers of sedimentary rock carry different fossils in layers. If scientists discover a fossil, they may find an older fossil in a lower layer in the sedimentary rock.

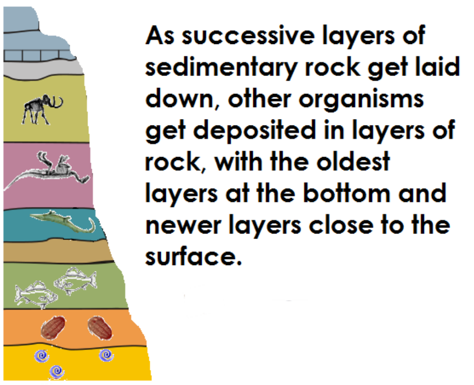

Figure 121: Sedimentary rock with fossils

Unit 2.2: Radiometric and relative dating of fossils

How do we know the age of fossils?

Look again at Figure 121 and see if you can write a deduction for working out how you would determine the oldest fossils in the diagram, in your workbook.

Radiometric dating is a method of measuring the age of fossils. Rocks contains elements that are *radioactive*. They gradually decay to non-radioactive products at a known rate. For example:

- radioactive uranium decays to lead over billions of years;
- radioactive potassium decays to argon over millions of years;
- radioactive $carbon_{14}$ decays to non-radioactive $carbon_{12}$ over thousands of years.

Scientists use special equipment to measure the proportion of the radioactive element and its non-radioactive product in the rock. If the rock contains mostly the radioactive element, the fossil is young. If the rock contains very little of the radioactive element, the fossil is very old. Radiometric dating is accurate, within a margin of error. Fossils found in volcanic rock can be dated more accurately than fossils found in sedimentary rock.

Relative dating uses the sequences of fossils in layers of sedimentary rock. Figure 122 shows that the deeper the layer of sedimentary rock in a sequence of rock, the older the fossil is. Relative dating gives an accurate *sequence* [order] of fossils, because the same sequence and combinations of fossils are found around the world. It does not tell us exactly how old a fossil is.

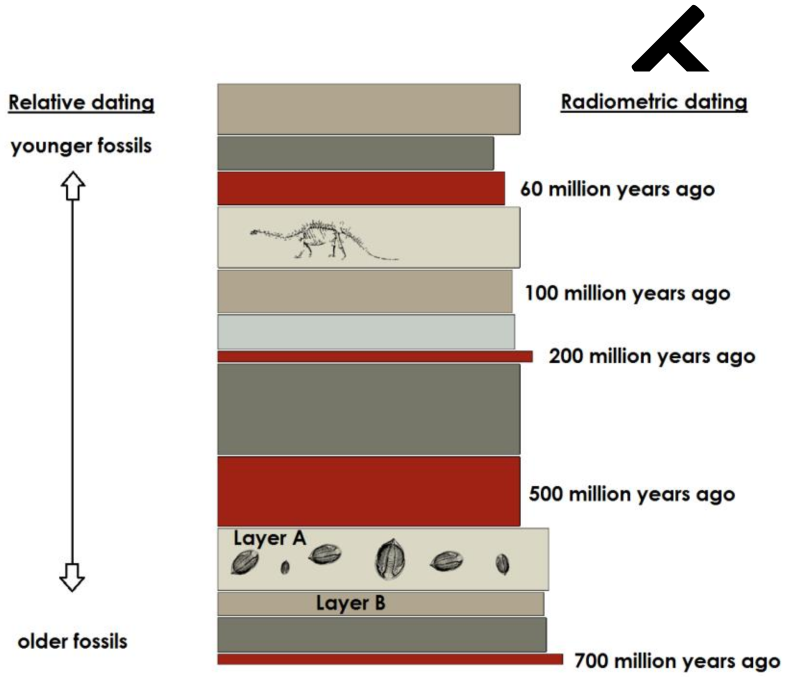

Figure 122: Radiometric and relative dating of fossils [insert AWB Figure 122]
Source: Adapted from: https://commons.wikimedia.org/wiki/File:Relative_dating_of_fossils.png

Activity 2.1: Understanding dating of fossils

Suggested time:

15 minutes

Aim:

In this activity, you will interpret a diagram to show your understanding of dating of fossils.

What you will do:

Refer to Figure 122. Answer all the questions in your workbook.

1. Use the information in Figure 122 to estimate the age of the fossils in Layer A. Explain your reasoning.
2. If you found fossils of animals in Layer B, would you say they are older or younger than the fossils in Layer A? Give a reason for your answer.
3. If you found fossils the same as those in Layer A in another part of the world, in rocks that have not been dated using radiometric methods, what claims can you make about the fossils and the rocks they are found in?
4. Which of the two dating methods gives us a more accurate and *absolute* [the exact age] age of a fossil?

Discussion of the activity

Interpretation of a resource such as a diagram or a graph is an important scientific skill. You will improve your skill if you have practise at the skill.

Exemplar answer

1. These fossils are about 600 million years old. There is a layer of rock dated at 500 million years just above Layer A. There is another layer of rock dated at 700 million years below the fossils. The fossils are between those two ages.
2. They would be older as Layer B is below Layer A, so relative dating would suggest that they are older.
3. The same fossils tend to occur at the same time in earth's history. One could therefore presume that the newly discovered fossils are of the same age as the ones in the first sample that is in dated rock. The rocks would therefore also be of the same age. This is how relative dating helps scientists to date fossils in newly discovered areas where radiometric dating has not been done.
4. Radiometric dating is more accurate than relative dating. Although radiometric dating gives us an age that ranges over many thousands or even millions of years, this kind of dating is called *absolute dating* as a more accurate and actual range of dates is given.

Unit 2.3: Patterns of succession in the fossil record

Sequences of fossils found in layers of rock give us a series of 'snapshots' of the history of life. The timeline you constructed in Topic 1 tells the story of the evolution of life, based on fossils that have been discovered. Remember that not all organisms that die become fossils. Fossilisation requires a very special set of circumstances, as you learnt in Unit 2.1. Your timeline showed that the first fish evolved about 460 mya. Before that date, there were no fish. The oldest fossilised fish are 460 million years old.

Your timeline also showed that the first mammals evolved 230 mya. Before that date, there were no mammals on earth.

Fossils show a *succession* from the oldest organisms to the present. If scientists find enough fossils of a particular group, they can see that the sequence goes from the most ancient, through a number of intermediate stages, to fossils that are similar to living species. Changes in the structure of organisms are evident in the fossils. Scientists can deduce how the organisms evolved by studying the sequence of fossils of a certain group of organisms.

South Africa has an outstanding sequence of a vertebrate group called the *mammal-like reptiles*. The oldest mammal-like reptile is 308 million years old. It was very much like a reptile. The sequence becomes progressively more like mammals.

Thrinaxodon was a key species in the evolution of mammal-like reptiles. It lived between 250 and 200 mya.

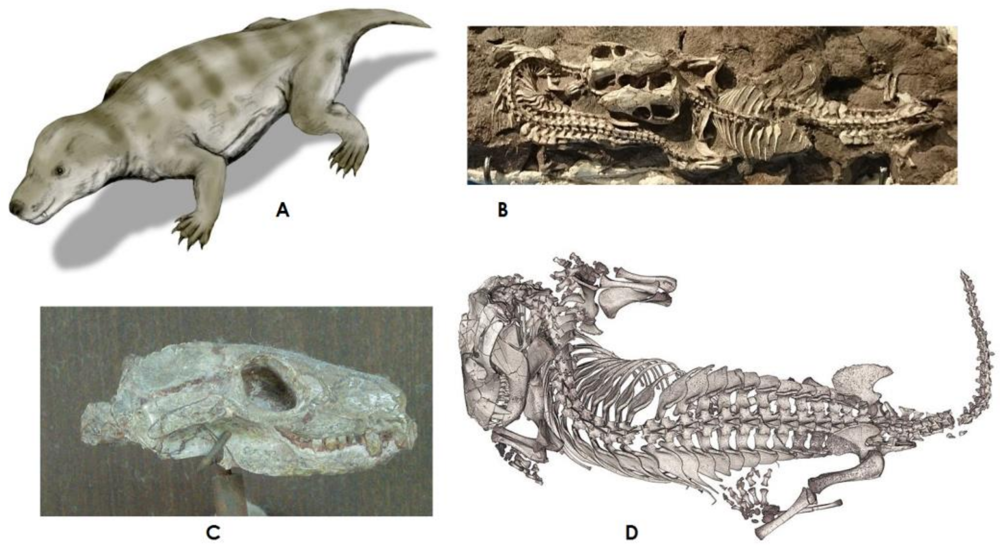

Figure 123: *Thrinaxodon* [insert AWB Figure 123]
Source: Adapted from:
https://en.wikipedia.org/wiki/Thrinaxodon#/media/File:Iziko_Thrinaxodon_fossil.JPG
https://en.wikipedia.org/wiki/File:Thrinaxodon_BW.jpg
https://en.wikipedia.org/wiki/File:Thrinaxodon_liorhinus_AMNH_5630.jpg
https://en.wikipedia.org/wiki/File:Thrinaxodon_liorhinus_BP_1_7199.jpg

Some features of *Thrinaxodon*:

- Its teeth were differentiated into incisors, canines and molars. You can see this in diagram A of Figure 123. This is a mammal-like feature.Reptiles have undifferentiated teeth.
- It had a bony palate forming the roof of the mouth. Reptiles do not have a bony palate, but mammals do.
- It had pits in the snout, showing that it may have had sensory whiskers, as mammals do. Diagrams B and C show how fossils of *Thrinaxodon* have been discovered in curled up positions in fossilised burrows. The whiskers are needed as sensory organs when digging in burrows where thay can't see. Further, only mammals curl up to sleep, to keep warm. *Thrinaxodon* may have been warm-blooded, with fur, as shown in Diagram A.
- It walked with legs splayed out to the sides, like a crocodile, as seen in Diagram A. This is a reptile-like feature.

Because *Thrinaxodon* had reptile-like and mammal-like features, it is *intermediate* [in between, halfway] between reptiles and mammals. Some people call it a ‘missing link’. Scientists refer to organisms such as *Thrinaxodon* as *transitional* as they show a transition [change] from one for to another.

The earliest true mammals found in South Africa date from 190 mya. They have been found in rocks high up in the Drakensberg mountains. The mammal-like reptiles disappear from the fossil record at about the same time as the first mammals appear.

The sequence of mammal-like reptiles to mammals found in South Africa is strong evidence that mammals evolved from mammal-like reptiles, through a sequence of intermediates or transitional forms.

Unit 2.4: Similarities and differences between fossils and modern species

In Unit 2.3, you saw how *Thrinaxodon* is a transition species between reptiles and mammals. In this section, you will look at the similarities and differences between ancient human ancestors and modern humans. You will compare a pre-human (such as *Australopithecus africanus*) and a modern human.

Watch this video, and pause it frequently to note down all the traits and behaviours that we have in common with *Australopithecus*, as well as how we differ from these ancient human ancestors: *Facts about human evolution:* https://www.youtube.com/watch?v=ROwKq3kxPEA (Duration: 12.31). If you enjoyed this video, you can also watch Hank and his brother in *Human evolution: Crash Course*: https://www.youtube.com/watch?v=UPggkvB9_dc (Duration: 16.13)

Organise your notes under two headings on separate pages:
Similarities humans share with *Australopithecus* and other human ancestors, and Differences between humans and *Australopithecus* and other human ancestors.

In your notes, make sure you mention the significance or importance of:

- *bipedalism* [walking upright on two legs],
- having *opposable thumbs* [thumb works in an opposite direction to the fingers], also related to the development of a *precision grip*,
- tool usage
- diet that included meat and cooked food
- the patterns of brain growth
- parental care and other forms of social interaction
- migrations of ancient human ancestors
- cultural development

(Note: you do not need to learn all the names of intermediates between *Australopithecus* and modern humans.)

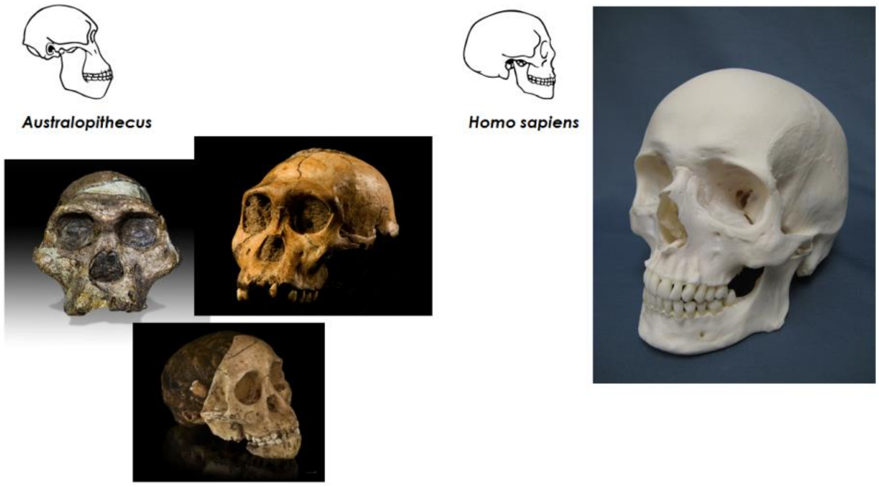

Figure 124: Comparing australopithecine skulls with a human skull [insert AWB Figure 124]
Source: Adapted by author from:
https://commons.wikimedia.org/wiki/File%3ACraniums_of_Homo.svg
https://en.wikipedia.org/wiki/Hominidae#/media/File:Caucasian_Human_Skull.jpg
https://en.wikipedia.org/wiki/Australopithecus_africanus#/media/File:Mrs_Ples_Face.jpg
https://en.wikipedia.org/wiki/Australopithecine#/media/File:Australopithecus_sediba.JPG
https://en.wikipedia.org/wiki/Taung_Child#/media/File:Australopithecus_africanus_-_Cast_of_taung_child.jpg

Figure 124 shows a comparison of skulls: on the left is a group of *Australopithecus spp*, and on the right is a modern human skull.

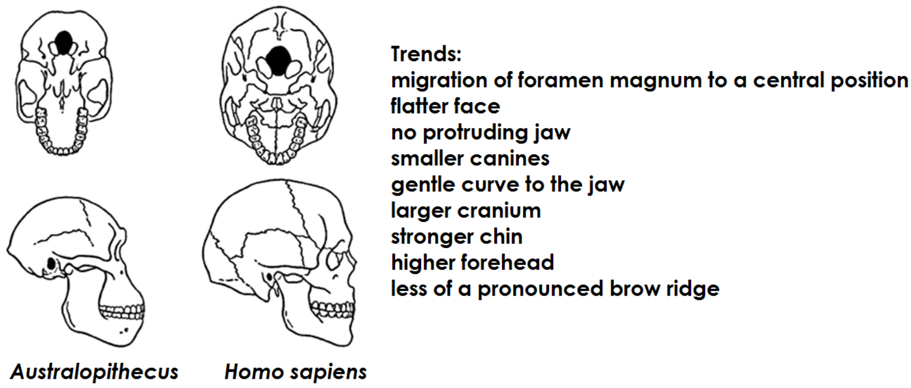

Figure 125: Trends in the evolution of modern humans from australopithecine ancestors [insert AWB Figure 125]

[START TEXT BOX]
What's a trend?
A trend is a pattern that can be observed. It shows a tendency for something to appear a certain way.
[END TEXT BOX]

Look carefully at Figures 124 and 125. Although there are similarities between ancient human ancestors and modern humans, there are also differences. What is also interesting is that if you follow *trends* in ancient human ancestors, you see a developmental pattern emerging that is clearly evident in some structure in modern humans.

Both modern humans and human ancestors have forward-facing, large eyes. Both have a rounded braincase. The teeth are similar. However, there are some marked differences between the two skulls.

- *Australopithecus* has a face that slopes forward towards the mouth. The human has a flat face.
- *Australopithecus* has no forehead. The human has a forehead.
- *Australopithecus* has a low brain-case. The human has a high braincase.
- *Australopithecus* has thick bone above its eyes. The human does not have thick bone above its eyes.
- The australopithecine *foramen magnum* [large hole where the spinal cord enters the brain case] lies slightly further back, while the modern human foramen magnum lies more centrally.
- The modern human jaw curves more gently than the more rectangular shape of the australopithecine jaw.

Were australopithecines *bipedal* [walk on two legs], as modern humans are, or were they *quadrupedal* [walk on four legs]? The position of the foramen magnum and the shape of the pelvis are very important features in answering the question.

- The foramen magnum of both *Australopithecus* and humans is under the skull. This position of the foramen magnum is associated with walking upright on two legs. However, the foramen magnum of *Australopithecus* is further back than that of humans. This indicates a trend towards bipedalism.
- The neck of the femur in both *Australopithecus* and humans is long and angled away from the pelvis. This shape and position of the femur is associated with walking upright.
- The pelvis of humans forms a shallow basin which is associated with supporting weight of the body in an upright position. The pelvis of *Australopithecus* is wide and flares outwards. It does not provide as much support as a human's pelvis.

Probably australopithecines were bipedal but maybe not as secure in their bipedalism as modern humans are. Maybe they walked a little less upright than we do. Certainly, they used tools made of bone, tooth and horns of animals, which indicates a bipedal trend too.

Different species of *Australopithecus* existed from about 5 mya until about 200 000 years ago. Modern humans evolved about 200 000 years ago. Could *Australopithecus* be the ancestor of modern humans?

Scientists believe there are enough similarities to say that *Australopithecus* could be the ancestors of modern humans. They walked upright at least part of the time. Their teeth were very similar to modern human teeth. However, their brains were smaller. Their pelvic bones were not as well adapted for walking on two legs as the human pelvis.

[START TEXT BOX]
What's the main idea?
The fossil record shows that life has changed over long periods of time. It is a strong source of evidence supporting evolution.
[END TEXT BOX]

Moving on

In the next Unit you will further investigate evidence for evolution as you consider comparative anatomy .

Topic 3: Evolution
Sub-topic 2: Evidence supporting evolution

Unit 3: Comparative anatomy

Unit 3 learning outcomes

By the end of this unit, you should be able to:

8. Explain how comparative anatomy supports evolution with reference to modification of the vertebrate forelimb.

Comparative anatomy is the study of similarities and differences [comparative] in structures [anatomy] present in different species of organisms. Charles Darwin used comparative anatomy as evidence of evolution. He used the example of similarities in the forelimb of vertebrates. In humans, the forelimb is the arm.

All vertebrates have the same basic set of bones. Human arm-bones are a good example.

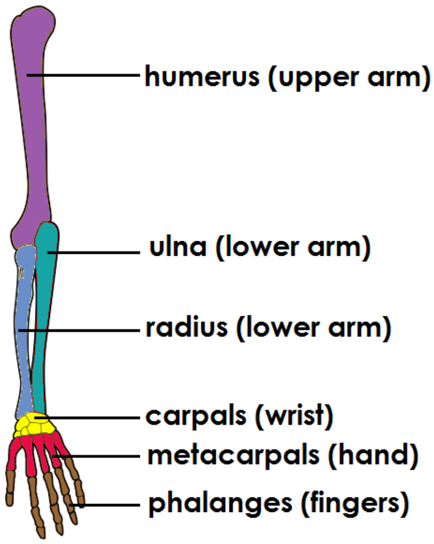

Figure 126: Human forelimb [insert AWB Figure 126]
Source: Adapted from: https://commons.wikimedia.org/wiki/File:Homology_vertebrates-en.svg#/media/File:Homology_vertebrates-de.svg

Identify the bones labelled in Figure 126 by examining your own arm.

If you study Figure 127, you can see the same bones in a human, dog, bird, whale and bat.

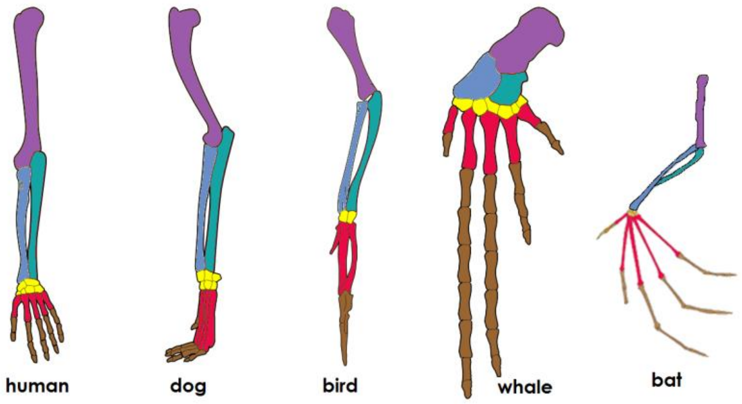

Figure 127: Comparative anatomy of vertebrate forelimb [insert AWB Figure 127]

In each case, you can see how the bones are modified for the animal's lifestyle.

Activity 3.1: Understanding adaptations

Suggested time:

25 minutes

Aim:

In this activity, you will interpret a diagram and apply what you know about adaptations.

What you will do:

Study Figures 126 and 127. Answer all the questions in your workbook.

5. Compare each forelimb with the human forelimb. Write at least three sentences describing the adaptations of each forelimb for its lifestyle. Refer to the names of the bones that have been adapted in each case.
6. Refer to either the forelimb of the whale or the forelimb of the bat. Use your understanding of natural selection to account for the anatomy [structure] of the forelimb as we see it today.

Discussion of the activity

Once again, you have used your interpretation and application skills.

Exemplar answer

1. The dog has a shorter humerus, and longer radius and ulna. The metacarpals are longer and the dog stands on the tips of the phalanges.
   The bird has a strong humerus, but lighter radius and ulna. There are few carpals and the metacarpals are fewer and fused, as are the phalanges.

The whale has a short, thick humerus, radius and ulna. There are many small bones in a row forming the carpals. The phalanges form the flipper, in particular, digits 2 and 3 are very long. The other three digits are shorter.

The bat has much thinner bones than the human. It has very long metacarpals and phalanges. It has four phalanges forming the wing, and a small thumb.

2. To answer this question, you must apply what you have learnt about natural selection to the anatomy of the whale or the bat. You need to talk about adaptation for locomotion: either swimming or flying. Talk about the resistance provided by the medium through which the animal is locomoting: either water or air. Water provides greater resistance, hence the stronger bones in the whale. Air provides less resistance, hence the lighter bones of the bat. You would need to talk about how ancestral whales with larger arm bones and longer phalanges (and hence bigger flippers) would have been more successful swimmers than others in the population, would have survived and bred more and hence passed on the more successful alleles to their offspring. Same idea with the bat – lighter animals with bigger wings would be more successful at flying, evading predators and finding food. They would have passed on these successful alleles to offspring. Thus, natural selection has produced the adaptation of the forelimb to the environment and the style of locomotion.

Why do groups of organisms have the same basic structure, but adaptations for different lifestyles? There are many examples other than the vertebrate forelimbs that you have studied here. Think of the Galapagos finches and tortoises, which have adapted to different modes of feeding.

The scientific answer is that all members of a group that share similar basic structures are descended from a *common ancestor*. In biology, a common ancestor is a species that gave rise to other species or groups of species. All vertebrates have the same basic plan of their forelimbs, therefore they are descended from a common ancestor. This idea is called *descent with modification*.

Descent with modification assumes that all organisms of a particular group have evolved from a common ancestor. Comparative anatomy provides strong evidence of descent with modification.

[START TEXT BOX]
What's the main idea?
Comparative anatomy reveals similarities in basic body structures in related groups, but adaptation to particular lifestyles. Comparative anatomy supports descent with modification, which is another name for evolution.
[END TEXT BOX]

Moving on

In the next Unit you will further investigate evidence for evolution as you consider biogeography as evidence for evolution.

Topic 3: Evolution
Sub-topic 2: Evidence supporting evolution

Unit 4: Biogeography

Unit 4 learning outcomes

By the end of this unit, you should be able to:

9. Explain how biogeography supports evolution.

Biogeography is the study of the distribution of species in different parts of the world.

Alfred Wallace based his proposal of the theory of evolution by natural selection on biogeography. However, Darwin had also thought about biogeography in his work. Darwin was particularly fascinated with the large *flightless birds* that he saw on different continents.

[START TEXT BOX]

What's a flightless bird?

Flightless birds are also called Ratites. The Ratites is a group of birds that cannot fly. Their bodies are very large in comparison to their wings. They also have flat sternums or breastbones that do not provide anchorage for flight muscle attachment. There are other birds that cannot fly, such as penguins. Penguins do not belong to the group Ratites. This discussion is focused specifically on the Ratites.

[END TEXT BOX]

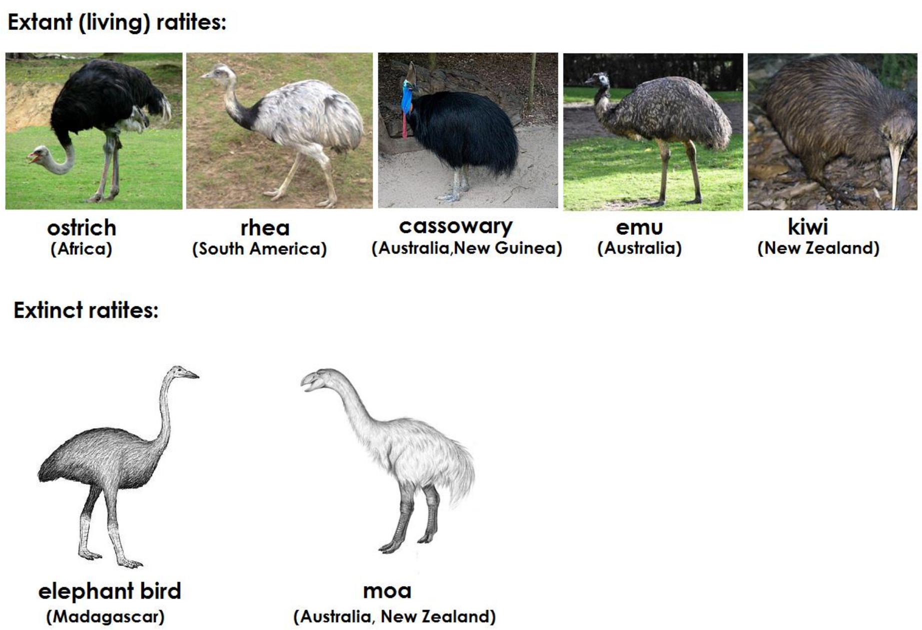

Figure 128: Flightless birds of the world [insert AWB Figure 128]
Source: Adapted by author from: https://en.wikipedia.org/wiki/Ratite

There are no large flightless birds in Europe, across northern Asia and North America. In the southern hemisphere, Papua New Guinea, Australia, South America, New Zealand and Africa have flightless birds. Before humans arrived, New Zealand and Australia had large flightless birds called moas. Madagascar had an enormous flightless bird called the elephant bird.

Why is there a different type of flightless bird on each continent or large island in the southern hemisphere? Scientists argue about the answer to this question. One possible answer is that the ancestor of the large flightless birds evolved on the supercontinent known as Gondwana. As Gondwana drifted apart, each continent and island took some of the ancestral large flightless birds with it. The birds were then geographically isolated from each other. Adaptation took place in each continent and island, resulting in the different species we see today.

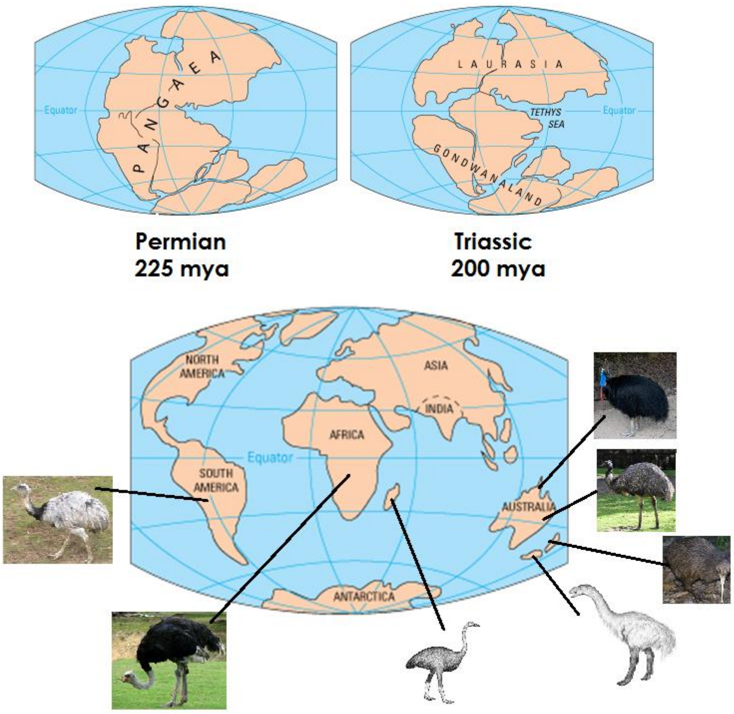

Figure 129: Movement of the continents and ratite distribution [insert AWB Figure 129]
Source: Adapted from: https://en.wikipedia.org/wiki/Pangaea#/media/File:Pangaea_to_present.gif https://en.wikipedia.org/wiki/Ratite

This animation allows you to see the continents drifting over millions of years…in a few seconds! *Continental drift animation:* https://www.youtube.com/watch?v=rhevGlUDLZA (Duration: 0.18)

This video was made by school children! It explains the distribution of Ratites. *Diversity and evolution of ratites:* https://www.youtube.com/watch?v=9dTmoq9r5K0 (Duration: 9.57) Watch the video in order to confirm what you have learnt about the biogeography of Ratites.

Evolution explains the presence of different types of large flightless birds in different parts of the world. There are many other examples of related organisms found in different parts of a continent or on a group of islands. Evolution explains the patterns of geographic distribution of species.

[START TEXT BOX]
What's the main idea?

Biogeography is the study of the distribution of species in different parts of the world. Evolution explains the patterns of geographic distribution of species.
[END TEXT BOX]

Before you begin the Summary assessment, watch this video that sums up the range of evidence supporting evolution.
Evolution: it's a thing: https://www.youtube.com/watch?v=P3GagfbA2vo (Duration: 11.43)

Summary assessment

1. Give the correct biological term for each of the following descriptions.
   1.1 A type of dating that involves studying the order of layers of sedimentary rock.
   1.2 The oldest form of life.
   1.3 A mammal-like reptile that is most likely a transitional intermediate between reptiles and mammals.
   1.4 A super-continent that existed in the southern hemisphere 175 million years ago.
   1.5 The study of the distribution of species in different parts of the world.
   1.6 The study of similarities and differences in the physical structure of organisms.
   1.7 A type of dating that accurately dates rock and fossils.
   1.8 Another name for selective breeding.
   1.9 The animal that was the ancestor of modern cattle.
   1.10 The group of flightless birds that is distributed over the southern hemisphere.
   (10)

2. Study Figure 130.

Figure 130: Fish fossil [insert AWB Figure 130]
Source: https://pixabay.com/en/fossil-petrification-fish-skeleton-201044/

   a. What are fossils? (1)
   b. Write a description of how this fish came to be fossilised. (8)
   c. Name the type of rock in which this fossil is found. (1)

3. Examine Figure 131:

Figure 131: Proteas and waratahs [insert AWB Figure 131]
Source:
https://pixabay.com/en/waratah-telopea-proteaceae-flower-2120327/
https://pixabay.com/en/protea-pink-flower-blossom-plant-3850932/

Proteas and waratahs belong to the same family of plants. Many different species are found in South America, Southern and Central Africa, Madagascar, Australia, New Zealand and many Pacific Islands. Use what you have learnt about evolution to account for their presence in these diverse places across the earth. Also comment on whether or not you think they had a common ancestor. (5)

Exemplar answer

1.

1.1 relative dating

1.2 bacteria

1.3 *Thrinaxodon*

1.4 Gondwana

1.5 biogeography

1.6 comparative anatomy

1.7 radiometric dating

1.8 artificial selection

1.9 aurochs

1.10 Ratites

(10)

2.

a. Fossils are the remains of dead organisms preserved in someway; in the case of this fish, preservation is in rock.

(1)

b. The fish died and fell to the bottom of the ocean before it was eaten by predators or scavengers. It was rapidly covered with sediment. Soft parts decayed, leaving the harder parts: scales and skeleton. More layers of sediment would have been deposited on top of the animal’s body. The sediments and the fish body would have been compressed by the weight of the water above them, and successive deposits of sediments. Minerals replaced the bone, and the skeleton was turned into rock. At some point, the fossil layer was elevated to the surface and was eroded and the fossil was exposed. Careful excavation of the fossil has produced the sample seen in the picture.

(8)

c. Sedimentary rock

(1)

3. Millions of years ago the southern continents were joined and known as Gondwana land. Scientists suggest that the ancestor of the protea grew on Gondwana. The continents moved apart millions of years ago and each species of protea has adapted and evolved to the environmental conditions on each of the continents. It is still possible to see that these plants are related to each other. They therefore must have had a common ancestor. (5)

Key learning points

The Sub-topic Evidence supporting evolution focussed on the following key points:

- Artificial selection illustrates that populations can change over time, due to selective breeding. Artificial selection demonstrates that natural selection is possible.
- The fossil record shows that life has changed over long periods of time. It is a strong source of evidence supporting evolution.
- Comparative anatomy reveals similarities in basic body structures in related groups, but adaptation to particular lifestyles. Comparative anatomy supports descent with modification, which is another name for evolution.
- Biogeography is the study of the distribution of species in different parts of the world. Evolution explains the patterns of geographic distribution of species.

Moving on

You have reached the end of the Biology component of your Natural Sciences course.