THE ORIGIN OF SPECIES

1. INTRODUCTION

Before we look at the different concepts in the origin of species it might be useful to review the nature of science. Science works in specific ways, has principles and is a process. Scientific theories are central to scientific thinking and it is important that we and the learners understand this. Understanding how science works allows one to distinguish scientific issues from non-scientific and enable us to carefully formulate our questions and answers in a scientific way.

2. THE NATURE OF SCIENCE

The basis of any scientific understanding is **information gleaned from observations of nature**. Science seeks to explain the natural world and its explanations are tested using evidence from the natural world. Birds and lizards are known to exist in nature and therefore fall within the scope of science. Elves and gnomes are great fun to read about, but they do not dwell in the natural world. That means they are not appropriate for scientific study.


Science assumes that we can learn about the natural world **by gathering evidence.** The ultimate test of any conceptual understanding exists **only in real materials and observations.** Evidence is the basic stuff of science. Without evidence there is only speculation.

This we do through our senses and extensions of our senses. A flower or an animal can be directly observed with no special aids. But **using technology**, we can expand the realm of human senses to observe such invisible objects such as bacteria and faraway galaxies. Dreams, apparitions and hallucinations, on the other hand, may seem real but they do not arise from our senses and are not even extensions of our senses.

Scientific **ideas are developed through reasoning**. Inferences are logical conclusions based on observable facts. Much of what we know from scientific study is based on inferences from data, whether the object of study is an elephant or an atom. No person has ever seen inside an atom, yet we know, by inference, what is there. Atoms have been disassembled and their components determined. The history of life on Earth has likewise been inferred through multiple lines of evidence.

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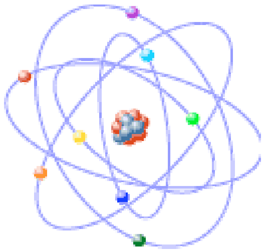

No person has ever looked inside an atom but we know what is there.

Scientific **claims are based on testing explanations against observations** of the natural world and **rejecting** the ones that fail the test. Scientific explanations are evaluated using evidence from the natural world. That evidence may come from various sources: a controlled experiment, a study of anatomy, or recordings of radiation from outer space, to name just a few. Explanations that don't fit the evidence are **rejected or are modified and tested again**. These scientific claims are subject **to peer review and replication (verification)**. Peer review is an integral part of genuine scientific enterprise and goes on continuously in all areas of science. The process of peer review includes examination of other **scientists' data and logic**. It attempts to identify **alternative explanations, and attempts to replicate observations and experiments.**

Characteristics of science

- Conclusions of science are reliable, though tentative. Might change over time
- Science is non-dogmatic.
- Science cannot make moral or aesthetic decisions.
- Science is not democratic. Science is based on evidence, not votes.

3. DISTINGUISHING BETWEEN LAW, THEORY & HYPOTHESIS

Scientific Law

This is a **statement of fact** meant to explain, in concise terms, an action or set of actions. It is generally accepted to be **true and universal**, and absolute. They don't really need any complex external proofs; they are accepted at face value based upon the fact that they have always been observed to be true.

They represent the cornerstone of scientific discovery, because if a law ever did not apply, then all science based upon that law would collapse.

Some scientific laws, or laws of nature, include the law of gravity, Newton's laws of motion, the laws of thermodynamics, Boyle's law of gases, the law of conservation of mass and energy, and Hook's law of elasticity.

Facts

It is generally accepted to be **true and universal**. Scientific facts are useful because they are both consistent and predictable in the realm of other scientific facts. They are observable such as all insects have six legs.

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Hypothesis

This is an educated guess based upon observation. It is a rational explanation of a single event or phenomenon based upon what is observed, but which has not been proved. Most hypotheses can be supported or refuted by experimentation or continued observation.

Theory

Theories are central to scientific thinking. The scientific definition of "theory" should not be confused with the way the term is commonly used to mean a guess or a hunch. In science, **a theory means much more and is far more well-founded**.

In general, both a **scientific theory** and a **scientific law** are accepted to be true by the **scientific community as a whole**. Both are used to make predictions of events. Both are used to advance technology. The "Theory of Evolution" is an evidence-based, internally consistent, well-tested explanation of how the history of life proceeded on Earth — not a hunch.

Understanding the role of theory in science is essential to scientists and vital to the informed citizen. Theories are **overarching explanations** that make **sense** of some **aspect of nature**, are based **on evidence**, allow scientists to make **valid predictions**, and have been **tested** and **verified multiple times** by detached groups of researchers. One scientist cannot create a theory; he can only create a hypothesis.

Theories are supported, modified, or replaced as new evidence appears. Theories give scientists **frameworks** within which to work. Major theories of science, such as the cell theory, gravitational theory, evolutionary theory, and particle theory, are all big ideas within which scientists test specific hypotheses.

The Development of a Simple Theory:

- **Observation:** Every swan I've ever seen is white.
- **Hypothesis:** All swans must be white.
- **Test:** A random sampling of swans from each continent where swans are indigenous produces only white swans.
- **Publication:** "My global research has indicated that swans are always white, wherever they are observed."
- **Verification:** Every swan any other scientist has ever observed in any country has always been white.
- **Theory:** All swans are white.

Prediction: The next swan I see will be white.

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Note, however, that although the prediction is useful, the theory does not absolutely *prove* that the next swan I see will be white. Thus it is said to be falsifiable. If anyone ever saw a black swan, the theory would have to be tweaked or thrown out. Real scientific theories must be falsifiable. So-called "theories" based on religion, such as creationism or intelligent designs are, therefore, not scientific theories. They are not falsifiable and they do not follow the scientific method.

Non scientific theory	**Scientific theory**
Popularly, a mere conjecture or guess	A well-substantiated explanation
No testing	Well tested, supported by the scientific community
No peer review	Peer review by means of research, articles. conferences

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4. EVOLUTION THEORIES

Definition of Biological evolution:

The gradual change of living things from one form into another over the course of time, the origin of species and lineages by descent of living forms from ancestral forms, and the generation of diversity (macroevolution).

Darwin and Lamarck each proposed a theory of evolution:

TOPIC		
Biography	Charles Darwin (1809-1882) Born in Shrewsbury on 12 February 1809. Studied medicine at Edinburgh and also prepared for a career in the clergy, but lost interest. He took an extended sea voyage and exploration of the world as naturalist on the HMS Beagle. Upon his return in 1838, he wrote down his ideas in what eventually became his theory of evolutionary change, and published it only in 1859, as "*On the Origin of Species by Means of Natural Selection*". In 1858 he received a letter from Alfred Russell Wallace containing an outline of a theory nearly identical to his own. Darwin had written 14 books. In 1871 his book "*The Descent of Man*" appeared, in which he argued that humans were no different from other forms of life, in that we too have been influenced by the forces of natural selection. In 1839 he wed his cousin Emma Wedgewood. They had 10 children, 7 surviving to adulthood. After a long illness he died on 19 April 1882.	Jean-Baptiste Lamarck (1744-1829) Born in Bazentin-le-Petit on 1 August, the youngest of 11 children. Studied at the Jesuit seminary and then joined the French army and soon promoted to officer. In 1768 he worked as a bank clerk and then studied Medicine and Botany. He was appointed assistant botanist at the royal botanical garden. Later he was appointed Professor of natural history and worms. He then published a series of books on Zoology and paleontology, including "*Philosophie Zoologique*"(1809), which clearly states his theories of evolution. Aside from his contributions to evolutionary theory, his works on invertebrates greatly advanced its classification. But Lamarck's works never became popular during his own lifetime – his peers discredited it. Lamarck married four times and lost his sight in later years. He died completely blind, in poverty and obscurity, on 28 December 1829.
Theories	Darwin's theory has the following main parts:	His theory is based on the premise that **acquired traits can be inherited**.

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	Organisms produce **more offspring** than can survive. These organisms **compete for limited resources**. All organisms are derived from common ancestors by a process of branching, i.e. organisms pass **genetic traits** to the next generation. Organisms change over time, those living today are different to those who lived in the past, i.e. there is **variation** in populations. Change is gradual and slow, taking place over a long time. The mechanism of evolutionary change was **natural selection** – those organisms with the most beneficial traits (variations) are more likely to survive and reproduce.	Lamarck's theory has two parts, viz. (1) that **use or disuse** causes structures to enlarge or shrink, and (2) that all such **changes are heritable**. The result was the **continuous gradual change** of all organisms as they become adapted to their environment. The physiological needs of organisms, created by their interactions with the environment, drive Lamarckian evolution. Lamarck believed that life started out simple and became complex, and that changes in the environment causes changes in the needs of organisms living in that environment, which in turn causes changes in their behaviour.
Significance	Darwins's theory found favour as an explanation of what happens in populations. The fossil record supports this view. Variation is caused by mutations. Darwin's view on variation and slow gradual changes is now contested by a different theory – that change occurs in episodes of rapid change and periods of stasis – called punctuated equilibrium. Natural selection is still accepted as the main driving force of evolution.	Lamarck believed that traits that changed or that were acquired in the individual's life could be passed down to its offspring, eg. giraffes that stretched to reach high leaves, acquired longer necks, would have off-spring with longer necks. This type of inheritance has since been disproven by hereditary genetics. Although Lamarck's theory fell out of favour, it broke ground in establishing the fact of evolution.

LAMARCK: THE THEORY OF TRANSFORMATION

Jean Baptiste Lamarck(1744-1829), who proposed the **mechanisms of use and disuse** and **inheritance of acquired traits** to explain how species might change over time. These theories, though in many ways incorrect and incomplete, paved the way for Charles Darwin, the father of evolution.

The classic example used to explain the concept of use and disuse is the elongated neck of the giraffe. According to Lamarck's theory, a given giraffe could, over a lifetime of straining to reach high branches, develop an elongated neck. A major downfall of his theory was that he could not explain how this might happen, though he discussed a "natural tendency toward perfection."

Another example Lamarck used was the toes of water birds. He proposed that from years of straining their toes to swim through water, these birds gained elongated, webbed toes to better their swimming.

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These two examples demonstrate how use could change a trait. By the same token, Lamarck believed that disuse would cause a trait to become reduced. The wings of penguins, for example, would be smaller than those of other birds because penguins do not use them to fly.

Lamarckian Inheritance

The second part of Lamarck's mechanism for evolution involved the inheritance of acquired traits. He believed that traits changed or acquired over an individual's lifetime could be passed down to its offspring. Giraffes that had acquired long necks would have offspring with long necks rather than the short necks their parents were born with. This type of inheritance, sometimes called Lamarckian inheritance, has since been disproved by the discovery of hereditary genetics.
An extension of Lamarck's ideas of inheritance that has stood the test of time, however, is the idea that evolutionary change takes place gradually and constantly. He studied ancient seashells and noticed that the older they were, the simpler they appeared. From this, he concluded that species started out simple and consistently moved toward complexity, or, as he termed it, closer to perfection.

The overarching component of Lamarckian evolutionism was what became known as the inheritance of acquired characters. This described the means by which the structure of an organism altered over generations. Change occurred because an animal passed on to its offspring physiological changes it had undergone in its own lifetime, and those changes came about by its responding to its survival needs.

The long legs and webbed feet of wading birds, for example, arose when those animals' ancestors responded to a need to feed on fish. In their attempt to wade in deeper and yet still keep their bodies dry, they would unconsciously adopt the habit of stretching their legs to their full extent, making them minutely longer in the process. This trait would be passed on to the next generation, who would in turn stretch their legs, until over many generations the wading birds' legs became those of the pelican. As the longer-legged birds waded deeper, it would be the habit of spreading the toes in order not to sink into the offshore mud, stretching the skin inbetween that would eventually give rise to webbed feet. Conversely, the disuse of an organ would cause it to wither and disappear, which explained how snakes lost their legs. Although no part of Lamarck's theory of acquired characters has not been substantiated by modern knowledge of genetic inheritance, the process was an ingenious interpretation of observable detail.

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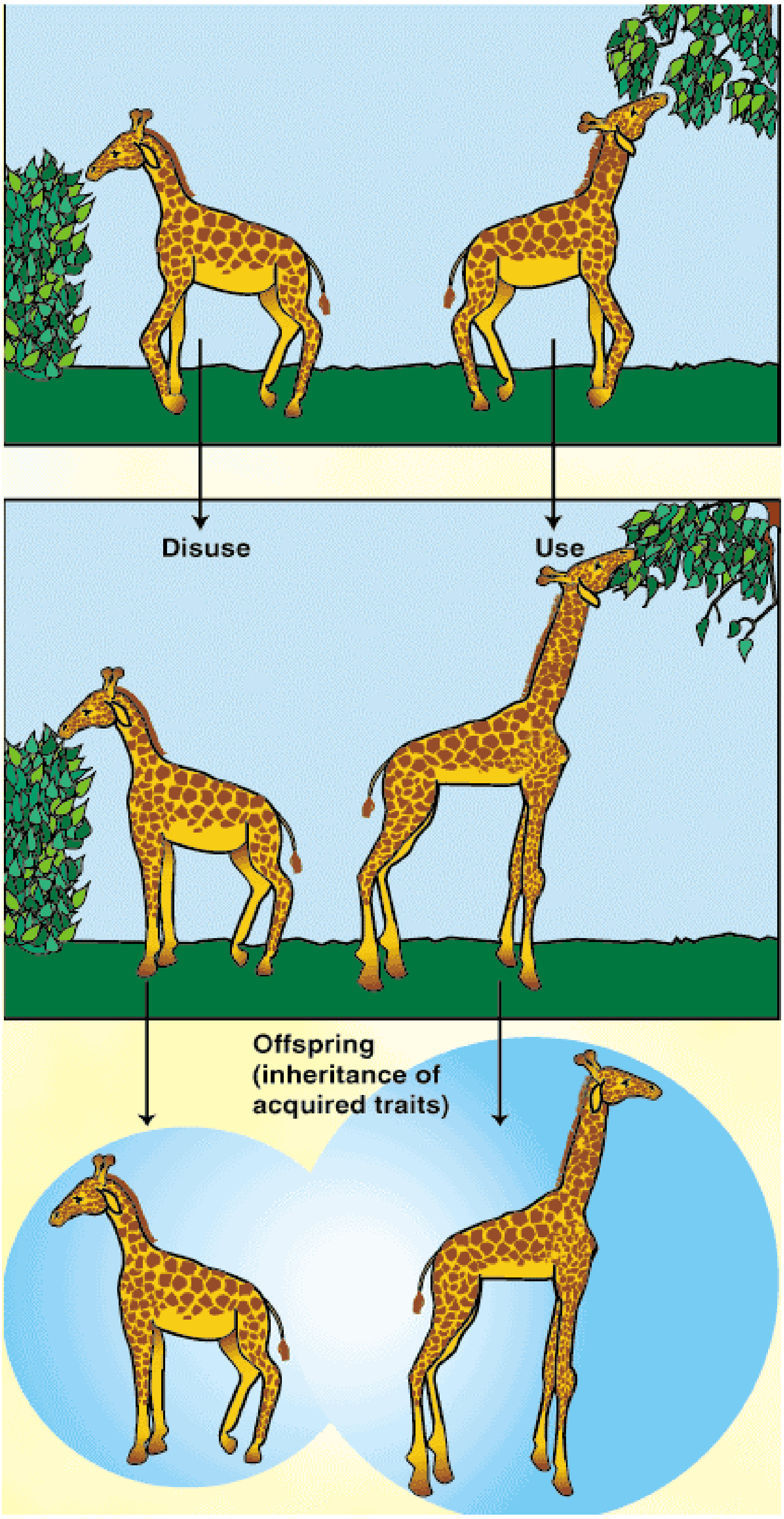

Figure 1: Use and disuse in the evolution of the neck of the giraffe

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5. MICRO-EVOLUTION

Micro-evolution is caused by small changes to the gene pool that can alter the appearance or the internal structure of the life form to keep it well adapted for its environment. Changes in the gene-pool is the result of one or more of the following factors, viz. genetic drift, gene flow, mutation and natural selection.

GENETIC DRIFT

Genetic drift is the chance increase or decrease in the relative abundance of different alleles through successive generations of a population. The effect is more marked in a small population. Sometimes a small number of dispersed individuals manage to establish a new population. The allele frequencies are likely to be different in these individuals from what they were in the original population, and the genotypic character of the new population will be determined by the new allele frequencies. This case of genetic drift is known as the **founder effect**.

The founder effect is important in the colonization of oceanic islands and other isolated locations, or when a few individuals of a species are accidentally or intentionally introduced into new environments. The founder population may eventually be different from the parent population.

Genetic drift can also occur when populations go through **bottlenecks,** i.e., when a normally large population is drastically reduced in size due to unfavourable conditions. Even though the population may eventually recover, genetic drift during the bottleneck can alter the relative abundance of alleles. This may lead to a loss of genetic variation. For example the cheetah populations have gone through bottlenecks, resulting in genetically uniform individuals. Without genetic variation, the whole population is extremely susceptible to diseases or environmental changes. It could lead to extinction.

NON-RANDOM MATING

There are two ways in which non-random mating occurs – assertive and disassortive mating. In assortive mating phenotypically similar individuals seek each other out and mate, excluding others. It increases the proportion of homozygous individuals. In disassortive mating phenotypically different individuals mate – it increases the proportion of heterozygous individuals.

GENE FLOW

Gene flow is the physical flow of alleles into and out of populations – from one population to the next. Gene flow brings new alleles into a population – it will change the allele frequency from generation to generation. It tends to decrease genetic variation between populations that arise through other evolutionary factors.

6. MUTATIONS:

These are changes in DNA that can cause changes to the genotypes and phenotypes in a population and therefore can **increase variation**.

Mutations cause changes on micro-evolutionary level. It is the main driving force behind evolutionary change. These changes may be lethal, neutral or fixed. If a

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mutation occurs in a gamete or in a cell that gives rise to gametes, it may be transmitted to offspring. If the mutation has an adverse effect on the phenotype of a human or other animal, it is referred to as a genetic disorder or hereditary disease, e.g. sickle cell anaemia, etc.

In the following examples the sentence *"the fat cat ate the wee rat"* is used as a sample gene to illustrate the changes that happen at molecular level:

Point mutations

A point mutation is a simple change in one base of the gene sequence. This is equivalent to changing one letter in a sentence, such as this example, where we change the 'c' in cat to an 'h':

Original	The fat cat ate the wee rat.
Point Mutation	The fat **h**at ate the wee rat.

This type is neutral and would have no effect on the genotype.

Frame-shift mutations

In a frame shift mutation, one or more bases are inserted or deleted, the equivalent of adding or removing letters in a sentence. But because our cells read DNA in three letter "words", adding or removing one letter changes each subsequent word. This type of mutation can make the DNA meaningless and often results in a shortened protein. An example of a frame-shift mutation using our sample sentence is when the 't' from cat is removed, but we keep the original letter spacing:

Original	The fat cat ate the wee rat.
Frame Shift	The fat ca**a tet hew eer at**

This type is lethal as there is a major change in DNA.

Deletion

Mutations that result in missing DNA are called deletions. These can be small, such as the removal of just one "word," or longer deletions that affect a large number of genes on the chromosome. Deletions can also cause frame-shift mutations. In this example, the deletion eliminated the word cat.

Original	The fat cat ate the wee rat.
Deletion	The fat ate the wee rat.

This type can be lethal.

Insertion

Mutations that result in the addition of extra DNA are called insertions. Insertions can also cause frame-shift mutations, and generally result in a nonfunctional protein.

Original	The fat cat ate the wee rat.
Insertion	The fat cat **xlw** ate the wee rat.

This type can be lethal.

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Inversion

In an inversion mutation, an entire section of DNA is reversed. A small inversion may involve only a few bases within a gene, while longer inversions involve large regions of a chromosome containing several genes.

Original	The fat cat ate the wee rat.
Inversion	The fat **tar eew eht eta tac**.

This type is lethal.

Chromosome mutations

Chromosomes mutations may results from changes in the number of chromosomes incorporated into the sex cells of the individuals. For example an extra chromosome in humans (number 21) results in Down`s syndrome. Another kind of chromosome mutation happens when one or more sets of chromosomes are added. Such mutations are called **polyploids**. This is common in plants, but lethal in animals. Polyploids occur during meiosis if the chromosomes fail to separate. The offspring of such plants would survive and grow well. Many of these plants are valued for their food or beauty.

In summary, mutations provide the raw material for evolution. Although most are harmful, mutations are essential for evolution, because ultimately all genetic variation originates as these random changes in DNA sequence. Natural selection tests new sequences through competition for survival and reproduction. Advantages mutations may spread throughout the population.

7. NATURAL SELECTION:

Natural selection is a process that occurs over successive generations. The following is a summary of Darwin's line of reasoning for how it works (*see Figure below*).

- If all the offspring that organisms can produce were to survive and reproduce, they would soon overrun the earth.
- This unbounded population growth resembles a simple geometric series (2-4-8-16-32-64...) and quickly reaches infinity.
- As a consequence, there is a "struggle" (metaphorically) to survive and reproduce, in which only a few individuals succeed in leaving progeny.
- Organisms show variation in characters that influence their success in this struggle for existence. Individuals within a population vary from one another in many traits.
- Offspring tend to resemble parents, including in characters that influence success in the struggle to survive and reproduce.
- Parents possessing certain traits that enable them to survive and reproduce will contribute disproportionately to the offspring that make up the next generation. To the extent that offspring resemble their parents, the population in the next generation will consist of a higher proportion of individuals that possess whatever adaptation enabled their parents to survive and reproduce.

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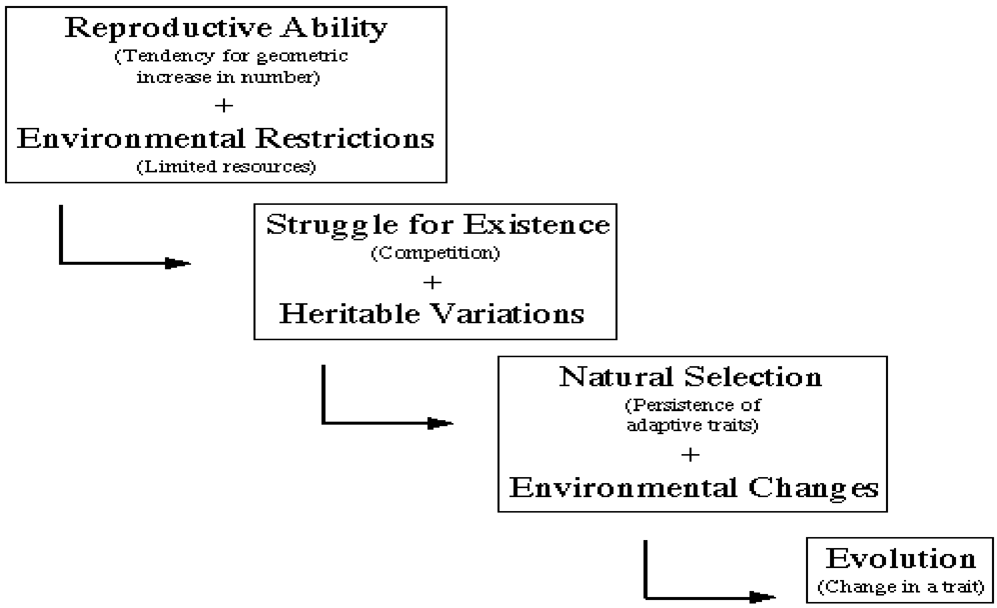

Figure that illustrates Darwin's line of reasoning of how natural selection works

Natural Selection Requires...

For natural selection to occur, two requirements are essential:

1. There must be **heritable variation** for some trait. Examples: beak size, color pattern, thickness of skin, fleetness, etc.

2. There must be **differential survival and reproduction** associated with the possession of that trait.

Modes of Natural Selection:

- **Stabilizing selection (a)**: Favours intermediate forms of a trait and operates against extreme forms. Hence the frequency of alleles representing the extreme forms decreases. Stabilizing selection tends to counter the effects of mutation and genetic drift by favouring the most common genotype, for example human birth weight [birth weight higher or lower than the average reduces the newborn's chances of survival]; the body structure of horseshoe crabs [their body plan has remained constant for 250 million years], etc.
- **Directional selection (b)**: Here the phenotypic character of the population as a whole shifts either in response to a directional change in the environment or in response to a new environment. It favours one phenotype at either extreme of the range of variation, for example industrial melanism (in peppered moths); pesticide resistance in insects (genotype of the population shifts toward more resistant phenotypes), etc.
- **Disruptive selection (c)**: Here extreme forms of a trait are favoured, and operates against intermediate forms. Hence the frequencies of alleles representing the extreme forms increase. It fosters an increase in the frequency of phenotypes at both extremes. The outcome is polymorphism (two or more distinct phenotypes). This type of selection is rare.

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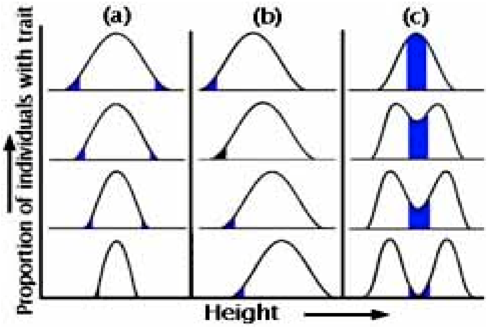

Figures a-c

Evidence of Natural Selection

Let's look at an example to help make natural selection clear.

Industrial melanism is a phenomenon that affected over 70 species of moths in England. It has been best studied in the peppered moth, *Biston betularia*. Prior to 1800, the typical moth of the species had a light pattern (*see Figure A*). Dark coloured or melanic moths were rare and were therefore collectors' items.

Figure A. Image of Peppered Moth

During the Industrial Revolution, soot and other industrial wastes darkened tree trunks and killed off lichens. The light-colored morph of the moth became rare and the dark morph became abundant. In 1819, the first melanic morph was seen; by 1886, it was far more common -- illustrating rapid evolutionary change. Eventually light morphs were common in only a few locales, far from industrial areas. The cause of this change was thought to be selective predation by birds, which favored camouflage coloration in the moth.

In the 1950's, the biologist Kettlewell did **release-recapture experiments** using both morphs. A brief summary of his results is shown below. By observing bird predation from blinds, he could confirm that conspicuousness of moths greatly influenced the chance it would be eaten.

Recapture Success

	light moth	dark moth
non-industrial woods	14.6 %	4.7 %
industrial woods	13 %	27.5 %

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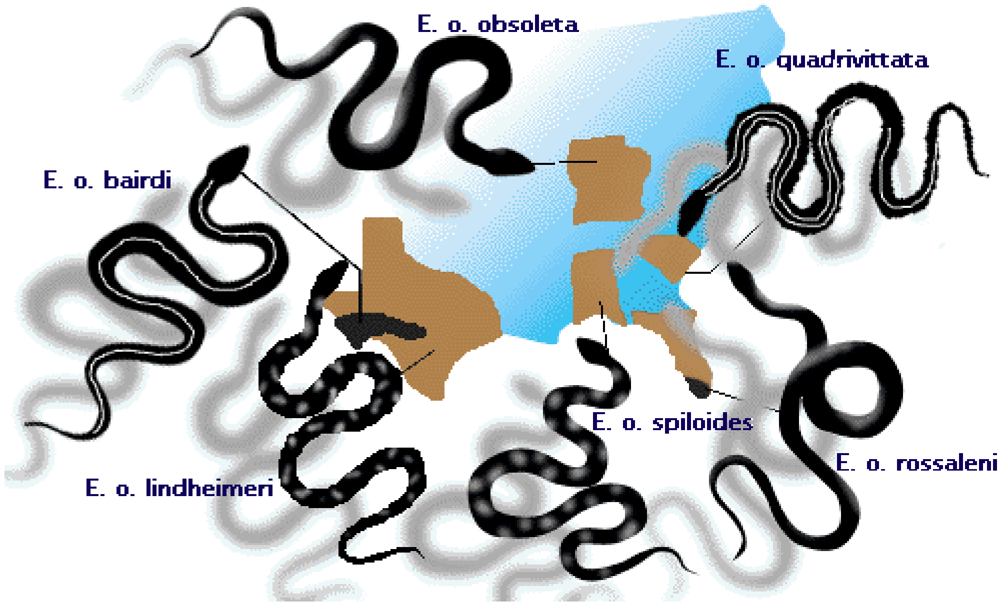
Local Adaptation

Natural selection is the **cornerstone** of evolutionary theory. It provides the mechanism for adaptive change. Any change in the environment (such as a change in the background color of the tree trunk that you roost on) is likely to lead to local adaptation. Any widespread population is likely to experience different environmental conditions in different parts of its range. As a consequence it will soon consist of a number of sub-populations that differ slightly, or even considerably.

The following are examples that illustrate the adaptation of populations to local conditions.

- The rat snake, *Elaphe obsoleta*, has recognizably different populations in different locales of eastern North America (*see Figure 4*). Whether these should be called geographic "races" or subspecies is debatable. These populations all comprise one species, because mating can occur between adjacent populations, causing the species to share a common gene pool.



Subspecies of the rat snake Elaphe obsoleta, which interbreed where their ranges meet.

- Galapagos finches are the famous example from Darwin's voyage. Each island of the Galapagos that Darwin visited had its own kind of finch (14 in all), found nowhere else in the world. Some had beaks adapted for eating large seeds, others for small seeds, some had parrot-like beaks for feeding on buds and fruits, and some had slender beaks for feeding on small insects (*see Figure below*). One used a thorn to probe for insect larvae in wood, like some woodpeckers do. (Six were ground-dwellers, and eight were tree finches.) This diversification into different ecological roles, or **niches**, is thought to be necessary to permit the coexistence of multiple species. To Darwin, it appeared that each was slightly modified from an original colonist, probably the finch on the mainland of South America, some 600 miles to the east. It is probable that **adaptive radiation** led to the formation of so many species because other birds were few or absent, leaving empty niches to fill; and because the numerous islands of the Galapagos provided ample opportunity for geographic isolation.

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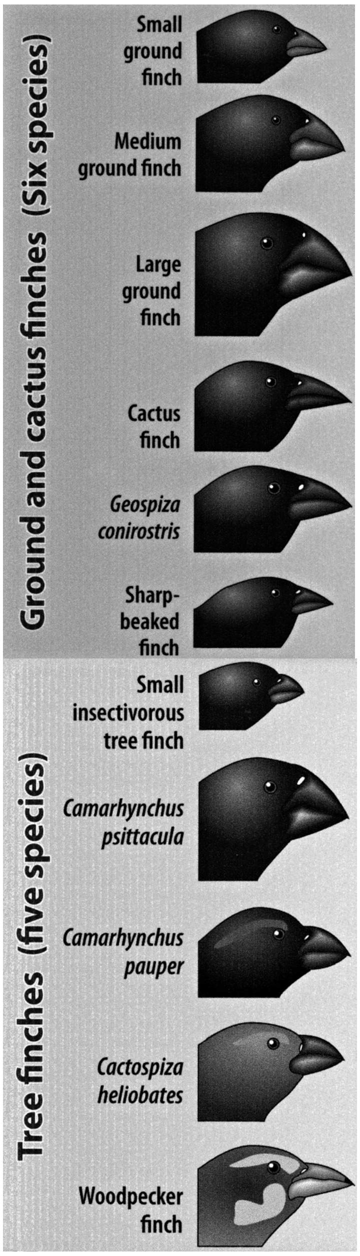


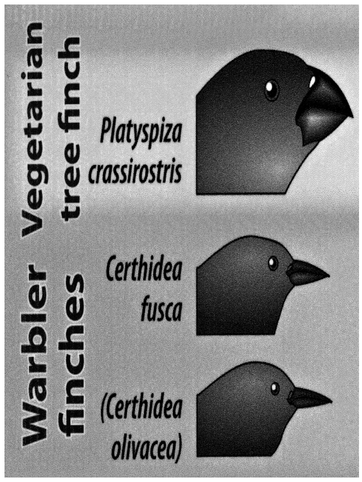


Figure: Darwin's finches

Misconceptions about natural selection:

- Natural selection is not all-powerful; it does not produce perfection. If your genes are "good enough," you'll get some offspring into the next generation.
- It's more accurate to think of natural selection as a process rather than as a guiding hand. It is mindless and mechanistic. It has no goals; it's not striving to produce "progress" or a balanced ecosystem. The population or individual does not "want" or "try" to evolve, and natural selection cannot try to supply what an organism "needs". Natural selection just selects among whatever variations exist in the population. The result is evolution.
- Natural selection is sometimes interpreted as a random process. This is also a misconception. The genetic variation that occurs in a population because of mutation is random – but selection acts on that variation in a very non-random

way: genetic variants that aid survival and reproduction are much more likely to become common than variants that don't. Natural selection is NOT random!

Examples of micro-evolution

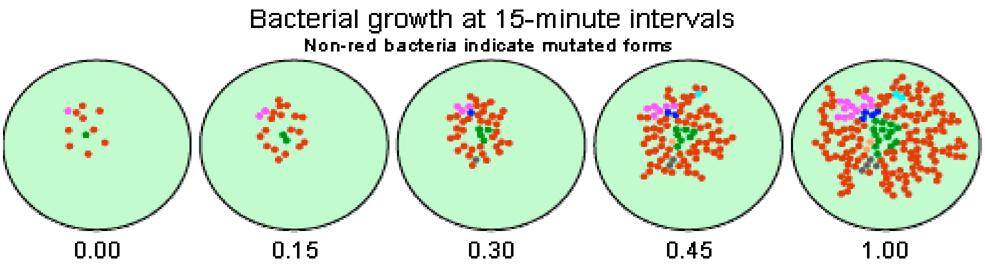
Scientists have actually observed many cases of natural selection in the wild:

The size of sparrows

House sparrows were introduced to North America in 1852. Since that time, the sparrows have evolved different characteristics in different locations. Sparrow populations in the north are larger-bodied than sparrow populations in the south. This divergence in populations is probably at least partly a result of natural selection: larger-bodied birds can often survive lower temperatures than smaller-bodied birds can. Colder weather in the north probably selects for larger-bodied birds. As this map shows, sparrows in colder places are now generally larger than sparrows in warmer locales.

Evolving resistance

Science has documented many examples of the evolution of resistance — of pests to pesticides, weeds to herbicides, and pathogens to medicines — all of which are cases of microevolution by natural selection. In the case of antibiotic resistance, for example, a bacterial strain's huge population size and short generation time mean that natural selection acts quickly. In each bacterial generation, new mutations and gene combinations are generated. If any of these confer resistance to a drug to which the bacteria are exposed, natural selection will favor those gene versions. Over the course of many bacterial generations (a small fraction of a single human lifetime), the bacteria adapt to our defences, evolving right out from under our attempts to rid ourselves of them.



This general scenario has played out many, many times. Just a few examples include:

- Mosquitoes evolving resistance to DDT
- Whiteflies evolving resistance to pesticides
- Gonorrheal bacteria strains evolving resistance to penicillin
- HIV strains evolving resistance to antiviral medicines
- Tuberculosis bacterial strains developing resistance to antibiotics

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8. SPECIES & SPECIATION

A **species** is one or more populations whose members **actually or potentially interbreed** under natural conditions, produce **fertile offspring** and are **reproductively isolated** from other such groups.

Types of Reproductive Isolation: There are pre-mating (prezygotic) and post-mating (postzygotic) isolating mechanisms, viz.

Prezygotic isolating mechanisms (Prevent the formation of hybrid zygotes)

1. Ecological isolation: Species occupy different habitats. The lion and tiger overlapped in India until 150 years ago, but the lion lived in open grassland and the tiger in forest. Consequently, the two species didn't hybridize in nature.

2. Temporal isolation: Species breed at different times. In North America, five frog species of the genus Rana differ in the time of their peak breeding activity.

3. Behavioral isolation: Species engage in distinct courtship and mating rituals.

4. Mechanical isolation: Interbreeding is prevented by structural or molecular blockage of the formation of the zygote. Mechanisms include the inability of the sperm to bind to the egg in animals, or the female reproductive organ of a plant preventing the wrong pollinator from landing, etc.

Postzygotic isolating mechanisms (Cause hybrid zygotes to fail, develop abnormally, or cannot self-reproduce and establish viable populations in nature).

1. Hybrid inviability. Development of the zygote proceeds abnormally and the hybrid is aborted. (For instance, the hybrid egg formed from the mating of a sheep and a goat will die early in development.)

2. Hybrid sterility. The hybrid is healthy but sterile. The mule, the hybrid offspring of a donkey and a mare, is sterile; it is unable to produce viable gametes because the chromosomes inherited from its parents do not pair and cross over correctly during meiosis.

3. Hybrid is healthy and fertile, but less fit, or infertility appears in later generations (as witnessed in laboratory crosses of fruit flies, where the offspring of second-generation hybrids are weak and usually cannot produce viable offspring).

Species Formation

The most common way for species to form is when the population becomes geographically isolated into two populations. This is referred to as **allopatric (geographic) speciation**. Geographic isolation leads to reproductive isolation. Once two populations are reproductively isolated, they are free to follow different evolutionary paths. They are likely to differentiate for two reasons:

1. Different geographic regions are likely to have different selective pressures. Temperature, rainfall, predators and competitors are likely to differ between two areas 100's or 1,000's of kilometers apart. Thus, over time, the two populations will differentiate.

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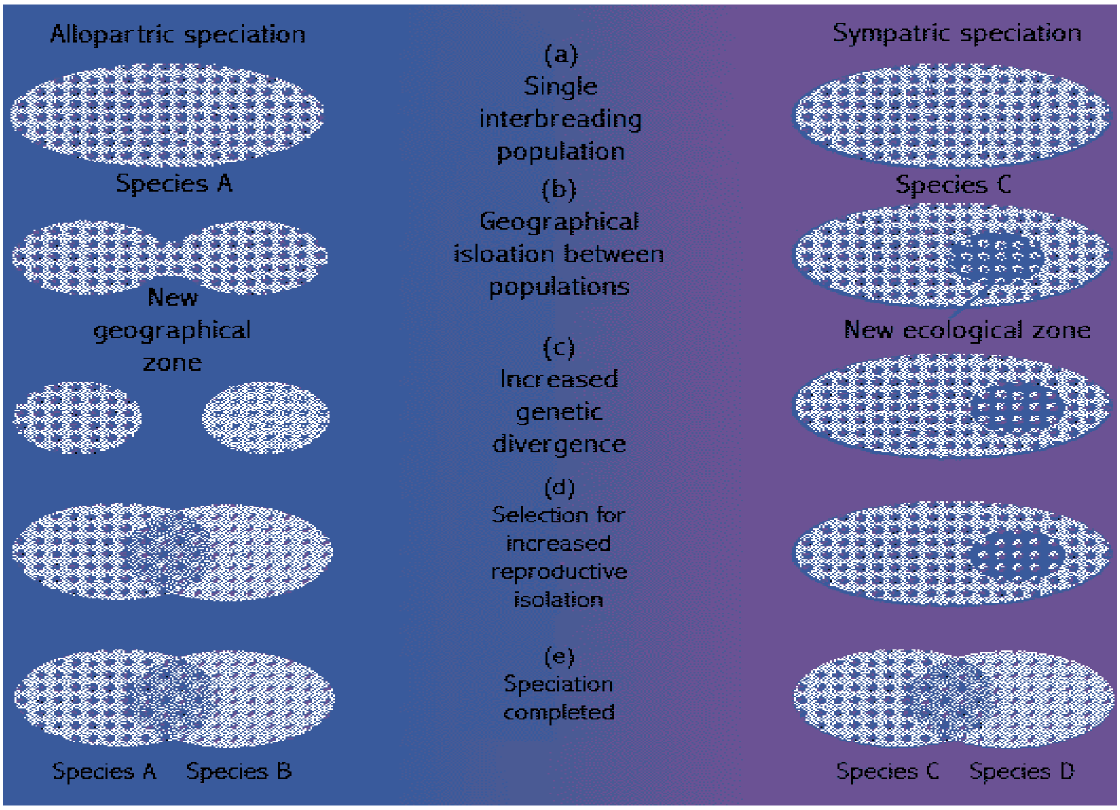
2. Even if the environments are not very different, the populations may differentiate because different mutations and genetic combinations occur by chance in each. Thus, selection will have different raw material to act upon in each population.

In short, physical isolation turns a single population into two, which, because of their lack of connectedness, **may** follow different evolutionary paths. The fate of the populations depends upon time and factors related to their different environments. If the two populations are soon rejoined, they may not differ very much, and likely will become a single population again. Thus allopatric (geographic) speciation is the differentiation of physically isolated populations to the point that reunion of the two populations does not occur if contact is re- established.

In **sympatric (genetic) speciation**, intrinsic factors, such as chromosomal changes (eg. polyploidy in plants) and non-random mating (in animals), alter the gene flow. Sympatric populations become genetically isolated even though their habitats or ranges overlap.



Models of speciation. A single population (a) is fragmented by a barrier (b); geographical isolation leads to genetic divergence (c); when the barrier is removed, the two populations come back into contact with each other, and there is selection for increased reproductive isolation (d); if reproductive isolation is effective, speciation is complete (e).

INBREEDING AND OUTBREEDING (OUTCROSSING) IN POPULATIONS

Inbreeding is the mating together of closely related organisms, for example mother/son, father/daughter, sibling/sibling mating and half-sibling/half-sibling mating. It is the pairing of animals that are more closely related than the average population. However, inbreeding holds potential problems. The limited gene pool caused by

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continued inbreeding means that harmful genes become widespread and the breed loses vigour.

In nature, a feral colony that is isolated from other colonies, by geographical or other factors, can become very inbred especially if a dominant male mates with his sisters, then with his daughters and granddaughters. The effect of any harmful genes becomes noticeable in later generations as the majority of the offspring inherit these genes.

Inbreeding has influenced the gene pool of the cheetah. Confined to ever-smaller areas such as wildlife reserves, the populations have become genetically isolated from each other. In one population there is an increasing frequency of misaligned jaws and kinked tails. Continued inbreeding will reinforce, or fix, these traits. Ultimately, they could reduce the cheetah's hunting effectiveness - the kinked tail will reduce its agility and cornering ability and the misaligned jaws may not be able to hold onto prey. In the cheetah, the lack of genetic diversity makes them susceptible to disease since they lack the ability to resist certain viruses. Extreme inbreeding affects their reproductive success with small litter sizes and high mortality rates.

Some scientists hope that the appearance of the "King Cheetah", characterised by its blotched markings, means that the cheetah can develop a healthier gene pool through mutation (provided man doesn't wipe them out in the meantime). Mankind has contributed to the loss of diversity by sport-hunting cheetahs and reducing the number of available mates. Hunters preferred to shoot unusual specimens (i.e. genetically diverse ones) for the trophy room and this previously included longhaired "woolly cheetahs" and grey/blue cheetahs, indicating much greater genetic diversity in the past.

Outcrossing or outbreeding takes place between two parents who are totally unrelated. This is a way to ensure that new traits are introduced and the gene pool expanded. Lost traits may be reintroduced. It ensures genetic variety and increased hybrid viability.

The ultimate result of continued inbreeding is terminal lack of vigour and probable extinction as the gene pool contracts, fertility decreases, abnormalities increase and mortality rates rise. On the other hand, too much outbreeding will cause loss of type and therefore the loss of a distinct breed.

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PROS AND CONS OF INBREEDING, OUTBREEDING & HYBRIDIZATION:

	PROS	CONS
INBREEDING (Mating of closely related pairs)	Produces uniform or predictable offspring. Hidden (recessive) genes show up and can be eliminated. Individuals will "breed true" and are "pure." Doubles up good genes. Eliminates unwanted traits.	Doubles up on faults and weaknesses. Progressive loss of vigor and immune response. Increased reproductive failures, fewer offspring. Emphasis on appearance means accidental loss of "good" genes for other attributes. Genetically impoverished individuals.
LINE-BREEDING (Mating of less closely related individuals)	Avoid inbreeding of very closely-related organisms, but they are still "pure". Produces uniform or predictable offspring. Slows genetic impoverishment.	Require excellent individuals. Does not halt genetic impoverishment, only slows it down.
OUTBREEDING (Mating of unrelated individuals within the same breed)	Brings in new qualities or reintroduces lost qualities. Increases vigour. Organisms are still "pure".	Less consistency and predictability of offspring. May have to breed out unwanted genes accidentally introduced at same time. May be hard to find individuals that are true outcrosses.
HYBRIDIZATION (Mating of unrelated individuals of different breeds)	Brings in new qualities or reintroduces lost qualities. Increases vigour, may improve immune system and reproductive capacity. Introduces totally new traits e.g. colour, fur type, etc. May result in new breeds. The offspring are considered "impure" for many generations.	Unpredictable - new traits may not all be desirable. Must choose an outcross breed whose qualities complement or match own breed. May take years to eliminate unwanted traits/loss of type. May take years to get consistent offspring. Produces many variants not suitable for use in breeding programs.

9. MACRO-EVOLUTION

It encompasses changes large enough to cause the origin or extinction of a species. Mutations provide the raw material for evolution. Although most are harmful, mutations are essential for evolution, because ultimately all genetic variation originates as these random changes in DNA sequence and that leads to macro-evolution. Natural selection tests new sequences through competition for survival and reproduction. Advantages mutations may spread throughout the population.

Patterns in macro-evolution

Stasis: It means that populations don't change much for a long time. Some lineages have changed so little for such a long time that they are often called living fossils. Coelacanths comprise a fish lineage that branched off of the tree near the base of the vertebrate tree. Until 1938, scientists thought that coelacanths went extinct 80 million years ago. But in 1938, scientists discovered a living coelacanth from a population in the Indian Ocean that looked very similar to its fossil ancestors. Hence, the coelacanth lineage exhibits about 80 million years' worth of morphological stasis.

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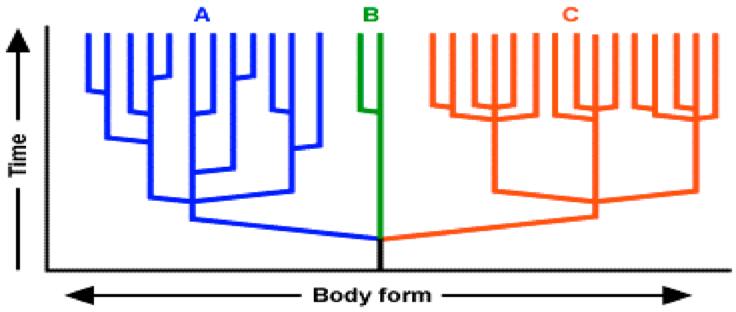
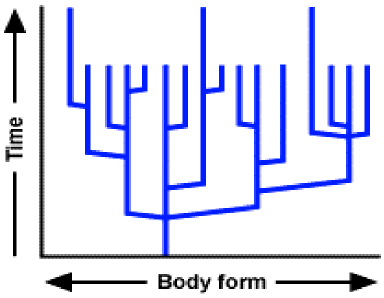
Character change: Lineages can change quickly or slowly. Character change can happen in a single direction, such as eg. trilobites evolving additional segments, or it can reverse itself by gaining and then losing segments. Changes can occur within a single lineage or across several lineages.

Lineage-splitting (or speciation): Patterns of lineage-splitting can be identified by constructing and examining a phylogeny. The phylogeny might reveal that a particular lineage has undergone unusually frequent lineage-splitting, generating a "bushy" tuft of branches on the tree (Clade A, below). It might reveal that a lineage has an unusually low rate of lineage-splitting, represented by a long branch with very few twigs coming off (Clade B, below). Or it might reveal that several lineages experienced a burst of lineage splitting at the same time (Clade C, below).



Extinctions: Extinction is extremely important in the history of life. It can be a frequent or rare event within a lineage, or it can occur simultaneously across many lineages (mass extinction). Every lineage has some chance of becoming extinct, and overwhelmingly, species have ended up in the losing slots on this roulette wheel: over 99% of the species that have ever lived on Earth have gone extinct. In this diagram, a mass extinction cuts short the lifetimes of many species, and only three survive.



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10. CURRENT THINKING ON EVOLUTION

EVOLUTIONARY DEVELOPMENTAL BIOLOGY ("EVO-DEVO")

Evolutionary developmental biology (**evolution of development** or informally, **evo-devo**) is a field of biology that compares the developmental processes (by which a zygote becomes an adult) of different animals and plants in an attempt to determine the ancestral relationship between organisms and how developmental processes evolved. Evo-devo addresses the origin and evolution of embryonic development, how modifications of development and developmental processes lead to the production of new (novel) features and how ecology impacts on development and evolutionary change.

Evo-devo is pioneered by inter alia Rudolf Raff, Loren Rieseberg, Thomas Kaufman, Michael Lynch and Jeffrey Palmer of Indiana University, Bloomington, Sean B. Carroll of the University of Wisconsin-Madison, and others. Evo-devo scientists study the **mechanisms** that produce evolutionary changes in body plans over time. The researchers are finding that the evolution of complex new forms can be accomplished by **small adjustments** to already **existing** genes and development plans, rather than needing many new mutations as previously thought. They are also finding that surprisingly **few genes** and DNA sequences need to be adjusted to create new shapes and body parts.

Charles Darwin pointed out more than a century ago that developing forms of life would be central to evolution. Little became of it initially. But the advent in the 1980's of molecular biology focused anew on the study of development – evo-devo quickly caught scientists' attention when it was shown that the **same master genes** were coding for basic body plans and body parts **throughout** the animal kingdom. For example, researchers discovered that genes in the *Pax6* group could activate the development of eyes in animals as diverse as flies and humans.

A team of scientists led by Dr. Cliff Tabin of Harvard Medical School, investigated a classic example of evolution by natural selection, viz Darwin's finches on the Galapagos Islands. These finches have thrived in isolation. They were all descendants of an original pioneering finch, and through adaptive radiation developed a variety of beaks adapted to new foods on the islands. Researchers assumed that the dramatic changes in the beak would have required the accumulation of **many chance mutations** in many different genes. But evo-devo has shown that the development of a new beak was **simpler**. Tabin found that the thicker and taller the beak, the more strongly it expressed a gene, called *BMP4,* in its early development. They verified this in experiments with chickens. They found another gene that, when expressed strongly early on, led to the development of long, slender beaks. This was also verified in experiments with chickens. Thus, with just **two genes** the scientists found the potential to recreate a **variety** of beaks.

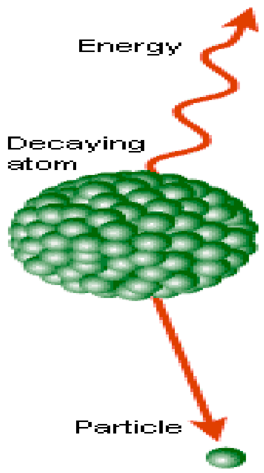
Evo-devo has also shown how different species will come up with **similar solutions** when confronted with **same challenges**, for example the placental mammals of the Americas and the marsupials of Australia, the same sort of animals have evolved independently. In the same way cichlids have evolved pairs of matching species, arising independently in separate lakes in Africa.

Evo-devo is cross-disciplinary in nature, for example, using information from paleontology and microbiology to show evolutionary trends. For example, in 2006 Dr Neil Shubin of University of Chicago reported the discovery of a fossil fish, which they named *Tiktaalik*, on Ellesmere Island in northern Canada. This fossil fish had a flat head with eyes on top, gills and lungs, as well as **wrists**. The latter feature was thought to be an innovation confined strictly to animals that already made the transition to **land**. They surmised that this fish was, in the words of Shubin “exploring the interface between water and land”, and indicated that a piece of the genetic toolkit to make arms and legs could very well be present in fish. Shubin and colleagues then studied the living but ancient paddlefish. They found that the paddlefish were **turning on control genes** known as *Hox* genes, in a manner characteristic of **terrestrial** tetrapods. In other words, the **potential** for making hands and feet, crucial innovations for moving from water to walking on land, appears to have been **present in fish long before they began finding their way out of water**. All that was needed was the **right environmental conditions** where these structures would be useful.

Evo-devo has proved useful to show that major evolutionary events like the transition from life in water to that on land are not necessarily set off by the arising of the genetic mutations that will build the required body parts, as had long been assumed. It is rather pointing in the direction of thinking that the **right ecological situation**, the right habitat in which such new and bold forms of life **will prove to be advantageous**, may be what is needed to set these major events in motion.

11. RADIOMETRIC DATING

Radioactivity providing a basis for determining the age of fossils in the form **of radiometric dating**.
Ernest Rutherford and Frederick Soddy had continued their work on radioactive materials and concluded that radioactivity was due to a spontaneous transmutation of atomic elements.



In radioactive decay, **an element** breaks down into another, **lighter element**, releasing alpha, beta, or gamma radiation in the process. They also determined that a particular radioactive element decays into another element at a **distinctive rate**. This rate is given in terms of a **"half-life"**, or the amount of time it takes half of a mass of that radioactive material to break down into its "decay product". Some radioactive materials have **short half-lives**; some have **long half-lives**. **Uranium, thorium, and radium** have long half-lives, and so persist in the **Earth's crust. To be able to determine the age of an object that is** 40,000 years old or younger **carbon dating** is used. Carbon-14 decays by very weak beta decay to nitrogen-14 with a half-life of approximately 5,730 years, but after the organism dies it stops taking in new carbon..

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How does scientist use Carbon-14 to determine the age of a fossil?

To measure the amount of radiocarbon left in a fossil, scientists burn a small piece to convert it into carbon dioxide gas. Radiation counters are used to detect the electrons given off by decaying Carbon-14 as it turns into nitrogen. In order to date the fossil, the amount of Carbon-14 is compared to the amount of Carbon-12 (the stable form of carbon) to determine how much radiocarbon has decayed. The ratio of carbon-12 to carbon-14 is the same in all living things. However, at the moment of death, the amount of carbon-14 begins to decrease because it is unstable, while the amount of carbon-12 remains constant in the sample. Half of the carbon-14 degrades every 5,730 years as indicated by its **half-life**. By measuring the ratio of carbon-12 to carbon-14 in the sample and comparing it to the ratio in a living organism, it is possible to determine the age of the fossil.
There are several different methods scientists use to determine age of fossils. Sometimes, it is possible to determine age directly from the fossil. Many times however, fossils are too old to have their age directly measured. Instead, age can be determined from radioactive elements occurring within rock found in association with the fossils.

Half-life refers to the length of time required for 50% of the parent material to decay into the daughter product e.g.

- Uranium 235 to Lead 207 (half-life = 710,000,000 years)
- Uranium 238 to Lead 206 (half-life = 4,500,000,000 years)
- Thorium 232 to Lead 208 (half-life = 14,000,000,000 years)
- Rubidium 87 to Strontium 87 (half-life = 47,000,000,000 years) - this is the most common system used for dating rocks older than 100 million years.
- Potassium 40 to Argon 40 (half-life = 1,300,000,000 years) - this method is very often used to date rock less than 60 million years old.
- Carbon 14 to Nitrogen 14 (half-life = 5,570 years)--- There are 3 forms (isotopes) of carbon occurring in nature: Carbon 12 (accounts for 99%), Carbon 13 (accounts for 1%), and Carbon 14 (accounts for less than 1%). While alive, plants and animals incorporate these isotopes of carbon into their tissues at the ratio found in the atmosphere. Upon death, the Carbon 14 in their tissues begins to decay. By measuring the remaining amount of Carbon 14, the age of the fossil can be determined. This method can be used to date material ranging in age from a few hundred years to about 50,000 years. The use of Carbon 14 permits the determination of age directly a fossil.
- For fossils greater than 50,000 years old, the age of the fossil is found indirectly by determining the age of the rock associated with the fossil.

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ADDENDUM A

ACTIVITY PACKAGE

Activity 1: Investigation

LO 1 : AS 1,2,3
Instructions: 1 Choose any sport equipment, music instrument, vehicle, electronic device or any other non-biological item, which plays an important role in your life. 2 Use the internet, reference books, magazines, etc., to research the evolution thereof over a period of time. 3 Refer to the role that the environment, technology and society played in this evolution process.

Activity 2 Natural selection

Draw graphs and interpret data on evolutionary trends in a bird population (individual activity)

LO1 : Assessment standard 1,2 & 3
LO2 : Assessment standard 2
LO3 : Assessment standard 1

Below is some data from research of biologist Peter and Rosemary Grant from Princeton University USA .Since 1972 these scientist together with their student and colleagues have studied finch populations Galapagos Archipelago. The table shows their data for one finch population on one island (Daphne Major), for a period of 7 years.

Conditions on the island of Daphne Major in the Galapagos Archipelago							
Year	1974	1975	1976	1977	1978	1979	1980
Rainfall (mm)			130	20	130	70	50
No. of finches	1200	1400	1200	150	350	300	200
Small seeds (mg/m^2)		800	600	90	300	70	50

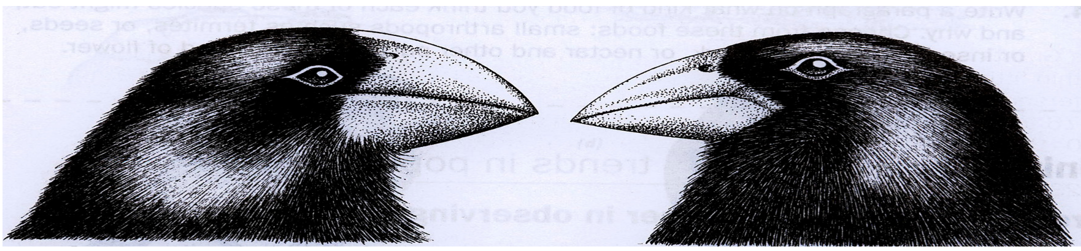

Figure that illustrates two medium ground finches from one population, showing differences between their beak sizes.

Questions

1 Draw three separate line graphs on one the same page, using the three sets of figures in the table.

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2 Answer the following questions using the information on your graphs.

2.1 When was the largest drop in annual rainfall? Calculate the percentage drop.

2.2 When was the largest decrease in the number of small seeds?

2.3 In what way could these events be connected?

2.3.1 When was the largest drop in the number of inches

2.3.2 What was the number of finches before and after the largest decrease in the size of the population?

2.3.3 What was the percentage decrease?

2.3.4 Do you think the decrease in population size had any connection with the number of small seeds available? Explain

2.3.5 When the number of finches decreased, there were still plenty of large seeds on the island. What does this tell you about the seed eating habits of the finches that died?

2.3.6 Do you think there was a difference in the beak sizes of the dead finches and the surviving finches? Give reasons for our answer.

Marks

Assessment criteria	**0**	**1**	**2**	**3**
Presents data as three graphs	No graphs presented	Attempt made to produce three graphs	Three graphs drawn but some errors	Graphs drawn headed and labeled correctly
Plots points correctly	Points not plotted	Most points plotted incorrectly	Some points plotted correctly	All points plotted correctly
Critically analyses data	No data analysed	Analyses some data questions1 -2 answered	Analyses most data questions1,2 & 4 answered	Analyses all data questions1, 2,4 &7 answered
Integrate knowledge from different graphs(sources) Question 3,5,6	No integration	Some integration, answers question 3	Answers questions 3 & 5	Answers questions 3 ,5 & 6
Performs calculation in questions 1& 4 C	No attempt made	Calculation attempted but incorrect	One correct calculation	Both calculation correct

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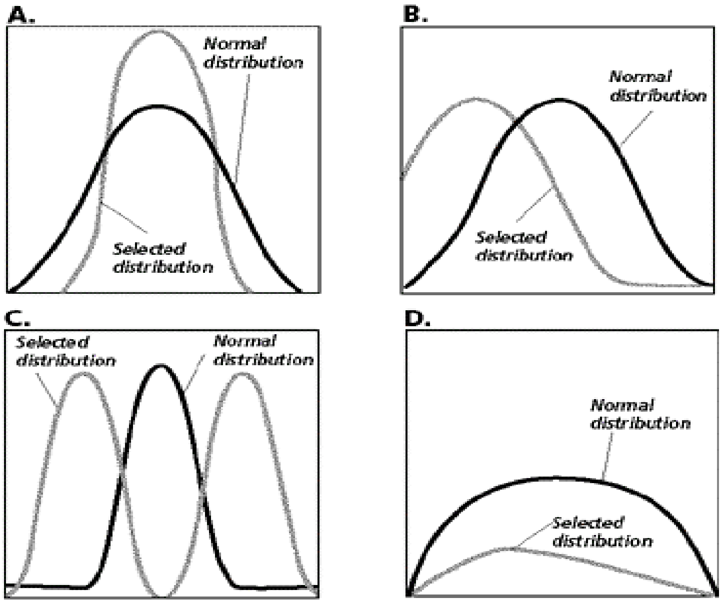
Activity 3: Natural Selection

LO 1: AS 1, 2, 3
LO 2: AS 1, 2, 3

Study the following graphs and answer the questions that follow:



1. Briefly explain what is depicted by each of the graphs A – D. (8)
2. Consider each of the following cases and indicate whether it is an example of graph A, B, C or D:

2.1 In an insect population, some individuals have a carapace that is more thickly calcified, enabling them to resist insecticides. An application of insecticide kills off most of the insects, with the thicker carapaced ones surviving. (2)

2.2 The birth weight of babies varies from 1,2 kg to 5,5 kg. However, the mortality rate of babies weighing 1,2 – 2,5 kg and 4,5 – 5,5 kg is great. (2)

2.3 In Britain's industrial regions, with greater pollution levels, birds were catching more light-coloured than dark-coloured peppered moths. Years after pollution controls were implemented, birds were catching more dark-coloured moths. (2)

2.4 Horseshoe crabs are very well adapted to scavenging on sandy and muddy bottoms of shallow waters. Their body shape and functions have changed very little over 250 million years. (2)

3. Various possibilities are given to answer the following questions. Select the correct possibility and write down only the letter:

3.1 Survival of the fittest implies:
a. the weak survive the battle to be strong
b. the strong survive and procreate
c. the weak procreate while the strong fight
d. weak and strong have equal opportunities in nature (2)

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3.2 The rise and fall of certain species may be due to:
a. change in environment
b. competition
c. lack of genetic variation
d. all of these could cause a decrease in population (2)

3.3 Natural selection of species suggests that:
a. those species who are best adapted to their surroundings survive to reproduce
b. those species who do not adapt procreate
c. those species who procreate always produce a new species
d. those species who adapt have no genetic variation (2)

3.4 A white mouse is eaten more often than a blue mouse in the same ecosystem. What statement might explain this observation?
a. White mice are stronger and produce more offspring.
b. Blue mice taste better than white mice.
c. White mice are less adapted to their environment.
d. Blue mice are less adapted to their environment. (2)

[24]

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Activity 4: Evolution by Natural Selection

Adapted from the University of California, Los Angeles Life Sciences 1 Demonstration Manual
Copyright 2006 by Jennifer Doherty and Dr. Ingrid Waldron, Department of Biology, University of Pennsylvania

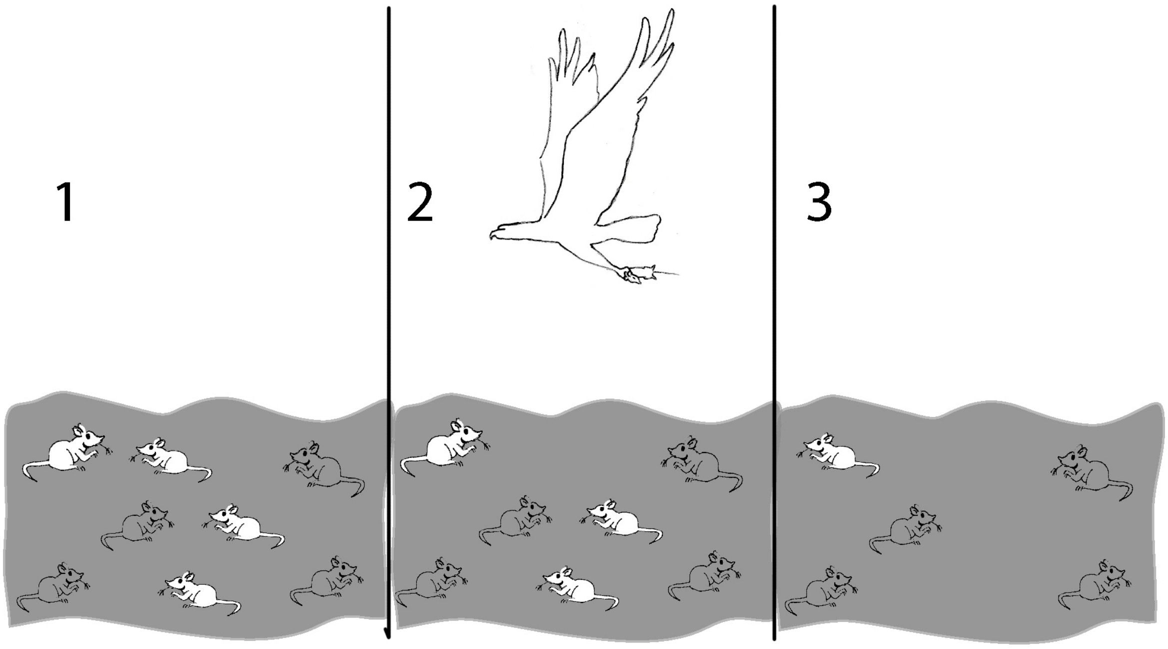
What are some differences you have noticed in the size and shape of dogs in your neighbourhood?

Do their differences make them better at some things, but not well-suited for others?

What would happen if the world suddenly changed, so the only thing that dogs could eat was deer and there was absolutely no way for a dog to eat if it wasn't big or strong enough to catch and kill a deer?

Most likely, smaller dogs would die off, and the bigger ones would survive and reproduce. After a while, instead of a population of dogs of all sizes, most of the dogs in the population would be big dogs.

Study the diagram about the mice shown below. Describe what is happening in figures 1-3.



Living things that are well adapted to their environment survive and reproduce. Those that are not well adapted don't survive and reproduce. An **adaptation** is any characteristic that increases **fitness**, which is defined as the ability to survive and reproduce. What are some characteristics of animals or plants that affect their fitness?

Below are descriptions of four female mice that live in a beach area that is mostly tan sand with scattered plants. According to the definition given for fitness, which mouse would biologists consider the fittest? Explain why this mouse would be the fittest.

Colour of fur	Brown	Tan	Tan and Brown	Cream
Age at death	2 months	8 months	4 months	2 months
# Pups produced by each female	0	11	3	0
Running speed	8 m/min.	6 m/min.	7 m/min.	5 m/min.

If a mouse's fur colour is generally similar to its mother's colour, what colour fur would be most common among the pups?

A more complete definition of fitness is the ability to survive and produce offspring who can also survive and reproduce. Below are descriptions of four male lions. According to this definition of fitness, which lion would biologists consider the "fittest"? Explain why.

Name	George	Dwayne	Spot	Tyrone
Age at death	13 years	16 years	12 years	10 years
# cubs fathered	19	25	20	20
# cubs surviving to adulthood	15	14	14	19
Size	10 feet	8.5 feet	9 feet	9 feet

(Adapted from Michigan State University, Occasional Paper No. 91, Evolution by Natural Selection: A Teaching Module by Beth Bishop and Charles Anderson, 1986)

Suppose that Tyrone had genes that he passed on to his cubs that helped his cubs to resist infections, so they were more likely to survive to adulthood. These genes would be more common in the next generation, since more of the cubs with these genes would survive to reproduce. A characteristic which is influenced by genes and passed from parents to offspring is called **heritable.**

Over many generations heritable adaptive characteristics become more common in a population. This process is called **evolution by natural selection**. Evolution by natural selection takes place over **many, many** generations.

Evolution by natural selection leads to adaptation within a population. The term evolution by natural selection does not refer to individuals changing, only to changes in the frequency of adaptive characteristics in the population as a whole. For example, for the mice that lived in the beach area with tan sand, none of the mice had a change in the color of their fur; however, due to natural selection, tan fur was more common for the pups than for the mother mice.

In summary, a heritable characteristic that helps an animal or plant to have more offspring which survive to reproduce will tend to become more common in a population as a result of evolution by natural selection.

Questions

1. Explain why a characteristic which helps an animal to live longer will generally tend to become more common in the population as a result of evolution by natural selection.

2. Not all characteristics which contribute to longer life become more common in the population. Some characteristics contribute to long life, but not more offspring. For example, a female cat that is sterile and cannot have any offspring may live longer because she will not experience the biological stresses of repeated pregnancies. Explain why a characteristic like this which contributes to a long life, but with few or no offspring, would not become more common as a result of evolution by natural selection.

Simulation of Natural Selection

We will now play a **simulation** game to demonstrate how natural selection works.

A simulation is a good way to simplify the problem in such a way that we can observe how evolution by natural selection may work in a real population. This simulation involves pom poms that can reproduce. These pom poms live out their lives on a Black Forest or Red Grassland habitat in the middle of the classroom. The only concern our pom pom creatures have is the presence of ravenous hunters (that's you!). All we need is a system that has three necessary conditions for evolution by natural selection.

1. **Variation in characteristics**: For natural selection to occur, different individuals in a population must have different characteristics. In our simulation, pom poms vary in colour; they are black, red, and white. The hunters vary as well; hunters have three distinct types of feeding structures: forks, knives, and spoons.
2. **Differences in fitness**: For natural selection to occur, the different characteristics of different individuals must contribute to differences in fitness (i.e. differences in ability to survive and reproduce). It seems possible that variation in pom pom colour will influence the probability that a pom pom is snatched up by a hungry hunter. It also seems possible that different feeding types may vary in their success in capturing pom poms. These differences contribute to survival and therefore success in reproducing.
3. **Heritability of characteristics**: For natural selection to occur, the characteristics that affect fitness must be heritable (i.e. passed by genes from one generation to the next). In our simulation, a pom pom that is born into the pom pom population is the same colour as its parent and a hunter that is born into the hunter population has the same feeding structure as its parent.

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Instructions:

1. Split your class into two groups which will carry out the simulation using two different habitats: Black Forest (represented by a rough black material such as false fur) and Red Grassland (represented by a red fleece material).

2. Pom poms come in three colours: black, red, and white. Your teacher will "plant" an equal number of each colour on the Black Forest and on the Red Grassland at the beginning of the simulation. Which colour pom pom do you think will be more likely to survive in each habitat?

   Black Forest:

   Red Grassland:

   Why do you think that?

3. Now it is time to arm the hunters. There are three different feeding types: forks, knives, and spoons. Your teacher will distribute the feeding structures so that there are equal numbers of each. You will also be given a cup. This cup will serve as your "stomach;" a pom pom capture is only successful if you can manage to get the pom pom into your cup using just your feeding apparatus. Which feeding structure do you think will do better in each habitat?

   Black Forest:

   Red Grassland:

   Why do you think that?

4. Your teacher will record the initial numbers of each type of pom pom and each type of hunter in each habitat on the board.

5. At your teacher's signal, start feeding. Don't be shy about competing with your fellow hunters. However, once a pom pom is in a cup it is off limits. When your teacher calls time, **STOP** feeding.

6. Now count how many pom poms you have eaten and line up with your classmates, least to greatest. Only the top half of the hunters will survive and reproduce. Your teacher will tell you who lives and who dies. Those who die will be reborn as the children of the survivors and will now have the same type of feeding structure as their parents had.

7. Your teacher will count how many pom poms of each colour were eaten, calculate how many pom poms survived, and help the surviving pom poms reproduce. Only the pom poms that were not eaten will reproduce.

8. You will run through the simulation two times. Your teacher will post on the board the numbers of pom poms of each colour and hunters of each type at the beginning of the simulation (generation 1) and at the end of each cycle (generations 2 and 3). Copy down the numbers on the board in the table

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below. Then, for each generation of pom poms in each habitat, calculate the percent that are black, red, or white. Similarly, for each generation of hunters in each habitat, calculate the percent that have spoons, forks, or knives as their feeding implement.

	Red Grassland				Black Forest			
	Pom poms				Pom poms			
	Black	Red	White	Total	Black	Red	White	Total
Generation 1 Number								
Percent				100%				100%
Generation 2 Number								
Percent				100%				100%
Generation 3 Number								
Percent				100%				100%

	Red Grassland				Black Forest			
	Hunters				Hunters			
	Spoon	Fork	Knife	Total	Spoon	Fork	Knife	Total
Generation 1 Number								
Percent				100%				100%
Generation 2 Number								
Percent				100%				100%
Generation 3 Number								
Percent				100%				100%

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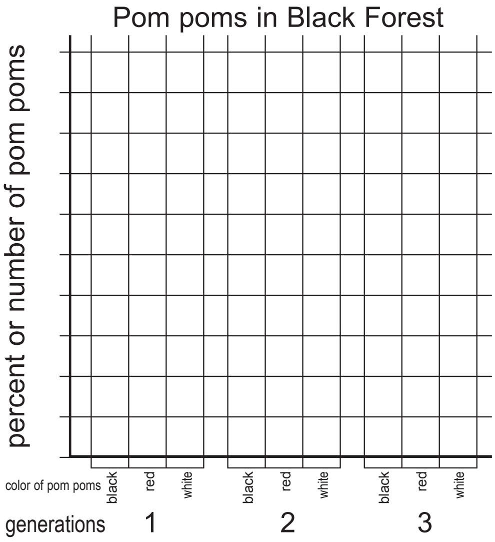
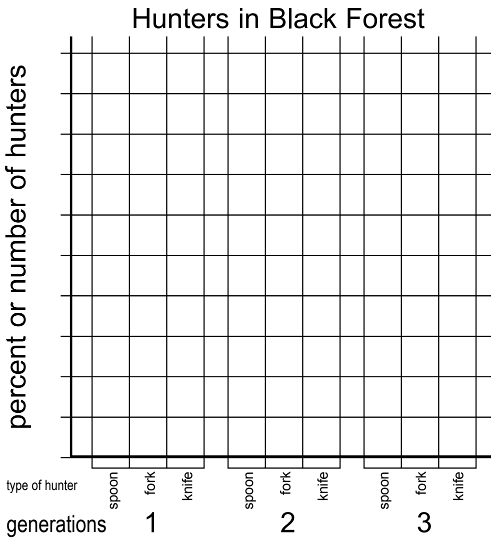
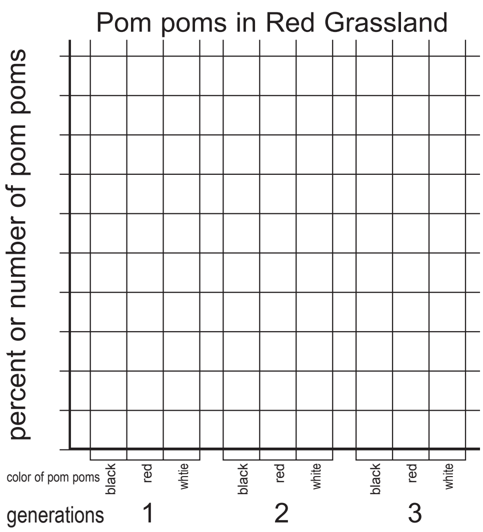
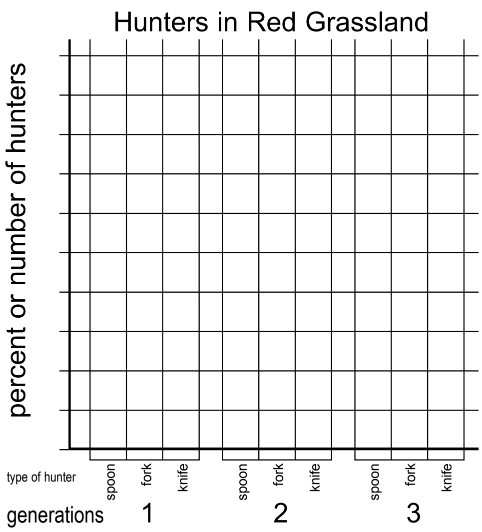
9. Use the data to complete the following 4 bar graphs. Show the changes in the percent or number of pom poms of each colour and hunters of each type over the three generations in each habitat.









10. Did evolution by natural selection occur in each pom pom population? In other words, did one pom pom colour become more common over time while the other colours became less common? What traits contributed to the survival of pom poms that survived to reproduce?

Black Forest:

Red Grassland:

Remember that the pom pom populations were the same on the Black Forest and Red Grassland at the beginning. Explain why the trends differ in these two different habitats and the two populations of pom poms end up so differently.

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11. For each population of hunters, did one feeding type become more common while other feeding types became less common? What traits contributed to the survival of hunters that survived to reproduce?

Black Forest:

Red Grassland:

Explain the differences in the trends in the feeding type of the hunters in the two habitats.

12. Did any individual pom poms change colour or adapt? If not, then why did the colours of the pom poms in the final population differ from the colours of the pom poms in the original populations?

13. If we ran the simulation for 50 more generations, what would you predict about the colours of the pom poms and the hunter types in each habitat?

Black Forest:

Red Grassland:

14. What do you think would happen to the hunter and pom pom populations if the black forest experienced a decade long drought and became red grassland? First, make your prediction of what would happen if the population of pom poms in the black forest at the beginning included red, white and black pom poms.

Pom pom population:

Hunter population:

Next, suppose that natural selection over many generations had resulted in only black pom poms surviving in the black forest, and then a prolonged drought resulted in this habitat turning into a red grassland. Would natural selection for pom pom colour occur?
Based on this example, explain why evolution by natural selection cannot occur if there is no variation in a characteristic.

15. Explain why evolution by natural selection cannot occur if the variation in a characteristic does not contribute to differences in fitness. Suppose, for example, that all the hunters in the simulation were blind-folded and could only find pom poms by touch. Would you expect evolution by natural selection in the colour of the pom poms?

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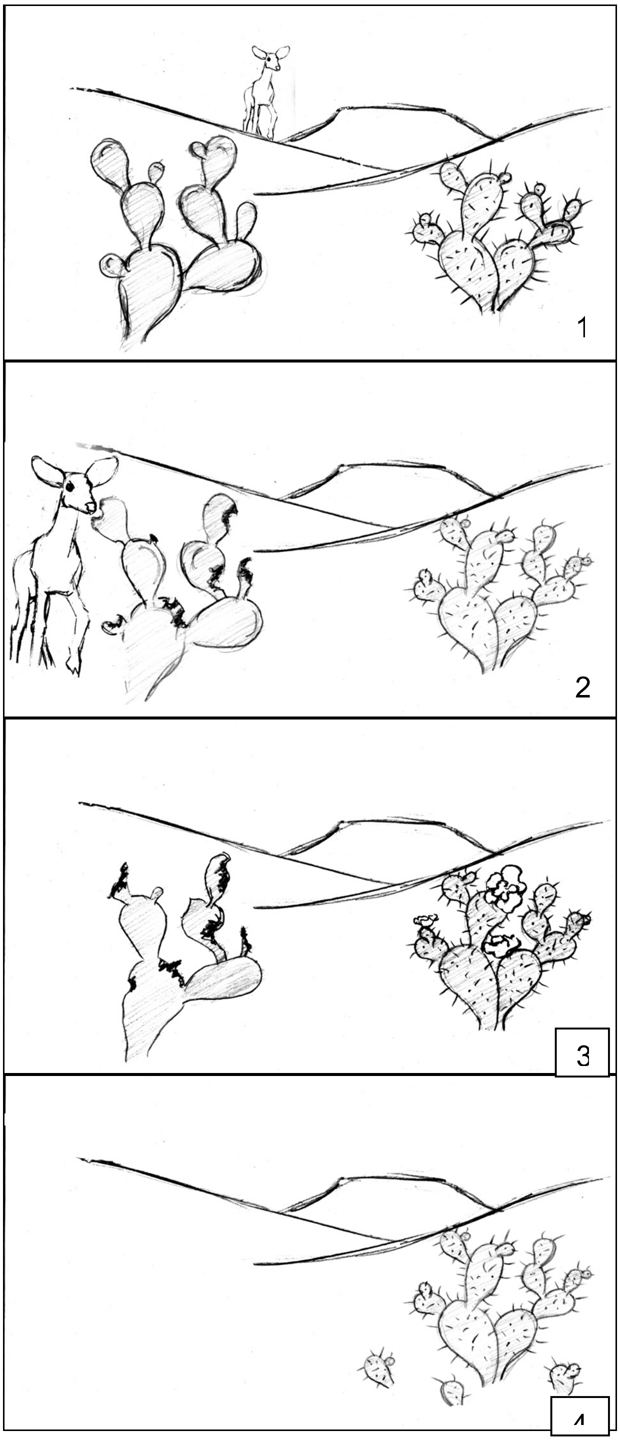
16. Explain why evolution by natural selection cannot occur if the variation in a characteristic is not heritable. Suppose, for example, a tree limb fell on a young lion and broke his leg, and the leg never healed normally. Obviously, this would affect the lion's ability to survive and reproduce. However, if this lion did manage to have cubs, the offspring would each have four normal legs. Explain why natural selection does not operate on characteristics like this that affect fitness but are not heritable.

17. Below is a series of pictures representing changes in a population of cacti over many generations.



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Why would a deer be more likely to eat the left cactus than the right cactus?

In figure 3, the right cactus has flowers, but the cactus that has been eaten by the deer is too damaged to make flowers. Figure 4 shows the situation several months later. What has happened? Do you think that evolution by natural selection is occurring in this cactus population? Explain why or why not.

What adaptation seems to increase the fitness of the cacti? How do you think this adaptation increases the ability of cacti to **both** survive and reproduce?

18. "Survival of the fittest" is a common expression. What do you think most people mean by this expression? How would you explain this expression to help someone understand how natural selection actually functions?

19. What characteristics of humans do you think helped them survive and reproduce during the hundreds of thousands of years when they were hunter-gatherers?

Teacher Preparation Notes for Evolution by Natural Selection Activity

This hands-on activity is intended for students who have a basic understanding of genetics. In our experience, this natural selection activity takes approximately 90-100 minutes with an average class of high school students. (For students with poor graphing skills, you may need more time.)

Equipment and Supplies:

- 5'x5'-7'x7' Black cloth for habitat—should be false fur or some other rough cloth (1 per class)
- 5'x5'-7'x7' Red cloth for habitat—should be furry fleece (1 per class)
- 7 or 10 mm black, red and white pom poms (200 of each color per class) Pom poms can be purchased at your local craft store. The specific colours of the pom poms and habitats need not be black, red and white, so long as there is a good color match between each habitat and one colour of the pom poms. (This activity can also be done with different colour beans, but we have found that it is easier to get a good match between the colours of the pom poms and the habitats, resulting in better camouflage and more interesting results from the simulation. Pom poms of different colours also have the same size and weight, whereas different colour beans often differ in size and weight.)
- Containers to store pom poms (1 per pompom colour)
- Plastic forks, knives, and spoons for hunter implements (1 of each for each student)
- Cups for hunter stomachs (1 per student) (To make the hunting task a little more challenging, you can use small plastic test tubes or the small plastic tubes that florists put on the ends of cut roses. Alternatively, plastic bottles with narrow necks can be used for hunter stomachs if you have trouble preventing your students from cheating, i.e. laying their cups on the habitat and shoveling multiple pom poms in with their implement.)
- 6 Index cards and tape for labeling staging areas (if you are using Method 1 in step 9 below)
- calculator for calculating percents (page 5 of protocol) and watch or timer for timing 30 second feeding times

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Teacher Preparations:

1. Before class, count out 2 batches of pom poms with 30 pom poms of each colour in each batch. (If you have a particularly large class, you may want to have 40 pom poms of each colour in each batch.) Prepare two charts on the board for recording the numbers of each type of pompom and hunter in both of the habitats for all three generations (see 8 on page 5 in the student protocol). For each class you teach, you will need two copies of the data sheet in 8 below. Also, if you are using Method 1 in step 9 below, tape two sets of three index cards to the wall; each set will have spoon, fork, and knife cards, which will be labeled either red habitat or black habitat; each card should be a good distance from the others, as students will have to gather at each card.
2. During class, disperse 1 batch of pom poms in each habitat.
3. You may want to choose one or two students to be your helpers during the simulation.
4. When you are ready to begin the simulation, split the class in half (with each half of students becoming the hunters on one habitat type) and give each student a fork, spoon or knife (one third each). Explain the rules of the game to the students again.
5. They will have 30 seconds in which to feed. (You may need to adjust this number of seconds, depending on the number of students you have, cloth size, etc.)
    a. During this time they must try and pick up as many pom poms as possible and transfer them to their cups. They must pick up the pompom with their implement and put it in the cup.
    b. They must keep their cups upright at all times and are not permitted to tilt the cups and shovel pom poms into them.
    c. Competition for resources is fair (and acceptable) but once a pompom is in a cup, it is off limits.
6. Start the students feeding and call stop after 30 seconds.
7. After feeding the students will count how many items of prey (pom poms) they have in their stomachs (cups). Students from each habitat type will then line up separately in order of how many pom poms they have in their stomachs (least to greatest).
8. Once they are in line, each helper needs to go down the line of students and record how many pom poms of each colour were eaten and calculate how many pom poms of each colour survived. Since each surviving pompom is joined by two offspring, the number of pom poms to add to each cloth/habitat type will be twice the number of surviving pom poms for each colour. A data sheet showing the calculations is provided below. It is important that students stay in order during this process so it is easy to perform step number 9.

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Habitat Type:			
Pompom Color	Black	Red	White
# in generation 1			
# eaten			
# remaining *(# generation 1 - # eaten)*			
# new *(2 X # remaining)*			
# in generation 2 *(# remaining + # new)*			
# eaten			
# remaining *(# generation 2 - # eaten)*			
# new *(2 X # remaining)*			
# in generation 3 *(# remaining + # new)*			
Hunter Type	Spoon	Fork	Knife
# in generation 1			
# in generation 2			
# in generation 3			

9. When the pompom counting is finished it is time to determine which predators will get to survive and reproduce, i.e., which ones caught enough prey. Use Method 1 or Method 2, described below.

<u>Method 1.</u> For each habitat, start at the top consumer and count back until you have reached half of the students. These are the surviving students. They should move to the cards that indicate which implement they had. Each student that died is now reincarnated as the offspring of one of the ones that survived, and is given the same feeding implement as the parent. Record how many hunters of each type there are in the next generations **after** the implements have been changed.

<u>Method 2</u>. For each habitat, have the students stay in line. Start with the person with the lowest number of pompoms, and give the student that "died" the same implement as the person with the highest number of pompoms. Work your way up, matching each low person with the next person from the high end of the line. Record how many hunters of each type there are in the next generations **after** the implements have been changed.

10. When everyone has their new implements it is time to count out the new pom poms. Enlist students to help and it will happen quickly.
11. Reseed the habitat and off they go for the second round.
12. After the second round is finished and all the counting and recording is done (make sure not to forget to get predator numbers for generation 3) the students sit down. Put the data on the board and have the students record the data in their worksheet.

Teaching Points:

- Different individuals in a population have different characteristics; this is **variation**.
- Some of this variation in characteristics is passed down from parent to offspring; these are **heritable characteristics**.
- Some of this variation in characteristics makes some individuals better at surviving and, more importantly, better at reproducing than others. <u>**Fitness**</u> refers to the ability to survive and produce offspring which are capable of

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reproducing. The specific characteristics which contribute to fitness will differ in different environments.

- A characteristic that increases an individual's fitness is an **adaptation**.
- The process of adaptive characteristics becoming more common in a population over many generations is called **evolution by natural selection**.
- Evolution by natural selection is a gradual process that takes place over many, many generations. (Remind them that the simulation is a simplified version of reality.)
- Evolution by natural selection results in population level changes, not changes in an individual.
- The specifics of which characteristics are adaptive and how a population evolves depend on what kind of environment the population is in. The same population will evolve differently if placed in a different environment. Organisms are not evolving to some pre-ordained "perfection" but are evolving to maximum fitness in a given environment.

Depending on your students, it may be useful to discuss the original sources of variation in heritable characteristics, including random mutation and, in sexually reproducing organisms, recombination and independent assortment.

Additional Resources:
Two good web sites with information and activities for teaching evolution:
http://evolution.berkeley.edu/ and http://www.pbs.org/wgbh/evolution

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ADDENDUM B

LESSON PLANS

***LESSON PLAN:* The Nature of Science**

ORIGIN OF SPECIES: SCIENTIFIC BASIS – EXAMINING THE NATURE OF SCIENCE

<table>
<tr><td>Educators:</td><td colspan="4">Grade: Grade 12</td><td colspan="2">School:</td></tr>
<tr><td>Learning outcomes</td><td colspan="6">LO 1: Scientific inquiry and problem-solving skills
LO 3: Life Sciences, Technology, Environment and Society (History and nature of Science)</td></tr>
<tr><td>Focus assessment standards</td><td colspan="6">AS 3: Analysing, synthesising, evaluating data and communicating findings
AS 3: Comparing the influence of different beliefs, attitudes and values on scientific knowledge</td></tr>
<tr><td>Integrated Life Science learning outcomes</td><td colspan="6">LO 2: Assessment Standard 3: Showing an understanding of the application of Life Sciences knowledge</td></tr>
<tr><td rowspan="3">Learning outcomes and assessment standards</td><td>LO 1</td><td>AS1</td><td>AS2</td><td>AS3</td><td colspan="2" rowspan="3"></td></tr>
<tr><td>LO 2</td><td>AS1</td><td>AS2</td><td>AS3</td></tr>
<tr><td>LO 3</td><td>AS1</td><td>AS2</td><td>AS3</td></tr>
<tr><td>Integrated learning outcomes from other subjects</td><td colspan="6">Physical Sciences: LO 1, AS 3
Mathematics: LO 1, AS 1, 2; LO 2, AS 1, 2</td></tr>
<tr><td>Knowledge area</td><td colspan="6">Diversity, Change & Continuity</td></tr>
<tr><td>Prior learning</td><td colspan="6">Genetics, Nucleic acids.
Concepts such as analysis, evaluating, inference, arguments, counter-arguments, backing of arguments (evidence), consensus, defend decisions with reasons
PowerPoint Slides explaining the elements of the scientific method.</td></tr>
<tr><td>Where the lesson fits in</td><td colspan="6">➢ This lesson fits in on the section on evolution, natural selection and the origin of species.</td></tr>
</table>

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TEACHER ACTIVITIES	LEARNER ACTIVITIES	RESOURCES	ASSESSMENT METHODS	TIME
Overview Create the opportunity for the learners to explore the scientific method, the nature of science, to differentiate between hypothesis, theory, law.	Learners able to demonstrate an understanding that scientific knowledge ▪ often depends on social, religious and political beliefs, ▪ needs to be evaluated, ▪ relates to their everyday lives, to the environment and ▪ has an impact on human lives.	Textbook, printed notes, video clips, slides.	Assessment for learning – matching elements with statements (elements of argumentation)	1 hr
Setting the scene/Context Explanation of the outcomes of the activities **Main activity** Stress the importance of claims with backings / evidence. Interventions: Keep learners focussed Summary on writing board during feedback by teacher	Study the notes and articles; discussions. Reasoning, views and opinions to be summarised on the worksheet. Feedback – identify the main features the nature of science. **Follow-up/Homework** Each individual writes a summary on the nature of science.	Hand out notes & work sheets. Web site addresses.	Assessment for learning: Informal - during small group intervention – verbal feedback to improve learning **Teacher assessment criteria:**	1 notion al hour
Expanded opportunities / Special needs Debate using examples on what constitutes the nature of science				
Reflection by teachers and learners What is science and what is non-science, what is scientific and what is non-scientific.				

***LESSON PLAN:* Evolution theories**

Examining the theories of Darwin and Lamarck.

Educators:	**Grade: Grade 12**	**School:**
Learning outcomes	LO 1: Scientific inquiry and problem-solving skills LO 2: Constructs and applies Life Sciences knowledge	
Focus assessment standards	LO 1, AS 3: Analysing, synthesising, evaluating data and communicating findings LO 2, AS 1: Accessing knowledge. LO 2, AS 2: Interpreting and making meaning of knowledge.	
Integrated Life Science learning outcomes	LO 1 LO 2	
Learning outcomes and assessment standards	LO 1 | AS1 | AS2 | AS3 LO 2 | AS1 | AS2 | AS3 LO 3 | AS1 | AS2 | AS3	
Integrated learning outcomes from other subjects	**Languages** **Social Sciences** **Life orientation**	
Knowledge area	Diversity, Change & Continuity	
Prior learning	GET Natural Sciences knowledge. FET Life Sciences Grade 10 & 11 knowledge.	
Where the lesson fits in	➢ This lesson could link with Genetics and with Population Studies.	

TEACHER ACTIVITIES	**LEARNER ACTIVITIES**	**RESOURCES**	**ASSESSMENT METHODS**	**TIME**
Overview Define the concept biological evolution. Create the opportunity for the learners to explore the theories of Darwin and Lamarck. Divide class into 2 groups. Explain the role of each group in the debate.	Learners able to demonstrate an understanding of the interaction between the environment and living organisms. Develop a working definition of biological evolution.	Typed notes – info on the two theories; info on the lives of the two persons. Video tapes (if available) of eg.footage of organisms with physiological or behavioural adaptations (eg. David Attenborough's work, etc.). Power Point presentation.	Formative and summative methods.	1 hr

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Setting the scene/Context Explanation of the outcomes of the activities **Main activity** Stress the importance of being objective – keep in mind the nature of science. Interventions: Keep learners focussed Summary on writing board/ OHP during feedback by teacher.	Study the notes the two theories. Each group elaborates a theory and outlines the strengths and weaknesses of each. Each group to generate as many arguments as possible in favour of and against the theories. Groups to decide on which theory would be most plausible to explain evolutionary changes in organisms. **Follow-up/Homework** Each individual writes a short article giving an account of both theories. Learners could design an investigation to test Lamarck's theory.	Hand out notes, Activities to be completed.	Assessment for learning: Informal - during small group intervention – verbal feedback to improve learning. Use rubrics to assess the article and investigation.	2 notional hrs

Expanded opportunities / Special needs Provide learners with notes. A discussion on beliefs about creation and evolution, attitudes and ethics may form part of proceedings.
Reflection by teachers and learners Feedback on the lesson by teachers and learners – ensure that the concepts are fully understood, that misconceptions are identified and explained.

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WORK SHEET

Darwin and Lamarck each proposed a theory of evolution:

TOPIC		
Biography		
Theories		
Significance		

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LESSON PLAN: **Natural Selection**

Examining the concept and nature of Natural Selection.

Educators:	**Grade: Grade 12**	**School:**
Learning outcomes	LO 1: Scientific inquiry and problem-solving skills LO 2: Constructs and applies Life Sciences knowledge LO 3: Life Sciences, Technology, Environment & Society.	
Focus assessment standards	LO 1, AS 2, 3 LO 2, AS 1, 2 LO 3, AS 1	
Integrated Life Science learning outcomes	LO 1 LO 2 LO 3	
Learning outcomes and assessment standards	LO 1 AS1 AS2 AS3 LO 2 AS1 AS2 AS3 LO 3 AS1 AS2 AS3	
Integrated learning outcomes from other subjects	**Languages** **Social Sciences** **Mathematical Literacy**	
Knowledge area	Diversity, Change & Continuity	
Prior learning	GET Natural Sciences knowledge. FET Life Sciences Grade 10 & 11 knowledge.	
Where the lesson fits in	➢ This lesson could link with Genetics and with Population Studies, as well as mutations..	

TEACHER ACTIVITIES	**LEARNER ACTIVITIES**	**RESOURCES**	**ASSESSMENT METHODS**	**TIME**
Overview Advance preparation: Educator needs to prepare a number of materials to be used in various activities on inter alia Galapagos finches, simulations of natural selection. Create the opportunity for the learners to explore the concept of natural selection as it flows from Darwin's theory.	Learners able to demonstrate an understanding of the influence of the environment on living organisms. Develop a working definition of biological evolution.	Typed notes of activities, including the classic pepper moth experiments, et al; video tapes, Power Point presentation.	Informal baseline assessment; Formative and summative assessment.	1 hr

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Setting the scene/Context Explanation of the outcomes of the activities **Main activity** Individual activities and learning. The key concepts are clarified by activities. The theory of Darwin elucidated through explanations of the mechanism of natural selection. Interventions: Keep learners focussed Summary on writing board/ OHP during feedback by teacher.	Study the notes the two theories. Each group elaborates a theory and outlines the strengths and weaknesses of each. Each learner is to master the concept of natural selection by working through a number of activities. Learner to gain insight into the requirements for selection, the modes of selection and the evidence for natural selection. **Follow-up/Homework** Each individual completes the activities and include them in the portfolio.	Textbook and other printed resources, notes, and copies of Activities to be completed.	Assessment for learning: Informal - during small group intervention – verbal feedback to improve learning. Use a rubrics and memoranda to assess the activities.	4 notional hrs
Expanded opportunities / Special needs Provide learners with notes.				
Reflection by teachers and learners Feedback on the lessons by teachers and learners – ensure that the concepts are fully understood, that misconceptions are identified and explained.				

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***LESSON PLAN:* Mutations, adaptation and variation in populations**

Examining the interactions and influence of these factors on the process of evolution.

<table>
<tr><td>Educators:</td><td colspan="4">Grade: Grade 12</td><td>School:</td></tr>
<tr><td>Learning outcomes</td><td colspan="5">LO 1: Scientific inquiry and problem-solving skills
LO 2: Construction and application of Life Sciences knowledge
LO 3: Life Sciences, Technology, Environment and Society</td></tr>
<tr><td>Focus assessment standards</td><td colspan="5">LO 2, AS 1: Accessing knowledge
LO 2, AS 2: Interpreting and making meaning of knowledge
LO 2, AS 3: Showing an understanding of the application of knowledge in everyday life.</td></tr>
<tr><td>Integrated Life Science learning outcomes</td><td colspan="5">LO 1
LO 3</td></tr>
<tr><td rowspan="3">Learning outcomes and assessment standards</td><td>LO 1</td><td>AS1</td><td>AS2</td><td>AS3</td><td></td></tr>
<tr><td>LO 2</td><td>AS1</td><td>AS2</td><td>AS3</td><td></td></tr>
<tr><td>LO 3</td><td>AS1</td><td>AS2</td><td>AS3</td><td></td></tr>
<tr><td>Integrated learning outcomes from other subjects</td><td colspan="5">Physical Sciences: LO 1, AS 3
Mathematics: LO 1, AS 1, 2

Languages: LO 2, 3</td></tr>
<tr><td>Knowledge area</td><td colspan="5">Diversity, Change & Continuity</td></tr>
<tr><td>Prior learning</td><td colspan="5">GET Natural Sciences knowledge
FET Grade 10 & 11 Life Sciences knowledge (Genetics, Nucleic acids).
Concepts such as analysis, evaluating, inferences.</td></tr>
<tr><td>Where the lesson fits in</td><td colspan="5">➢ This lesson leads in the basic mechanisms of evolution, showing that all people belong to one species and are biologically very similar and closely related to each other.</td></tr>
</table>

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TEACHER ACTIVITIES	LEARNER ACTIVITIES	RESOURCES	ASSESSMENT METHODS	TIME
Advance preparation Various activities may require the preparation of materials (paper – various colours shapes quantities), magazine articles, obtaining video material, photocopying, etc. **Overview** Create the opportunity for the learners to explore the concepts of mutations, adaptations and variation, including genetic drift and inbreeding.	Learners able to demonstrate an understanding of the meaning of the concepts mutation, population, adaptation and variation, and how it contributes to our understanding of evolutionary mechanisms.	Textbook, printed notes, video clips, slides, work book, writing implements.	Informal baseline (what do learners know about the concepts).	2 hrs
Setting the scene/Context Explanation of the outcomes of the activities **Main activity** Bring the meanings of the concepts out using any number of teaching and educational aids. Create opportunities for discussion, debates, research activities, etc. Interventions: Keep learners focussed Summary on writing board, OHP during	Study the notes and articles. Clarify the concepts through activities, eg. Poster making, mind maps on mutations, research on adaptations of animals (local or national), evolutionary trends in bird populations on Galapagos, variation in humans, drug resistance, etc. Reasoning, views and opinions to be summarised on the worksheet.	Hand out notes & worksheets on activities.	Informal diagnostic (explore ideas on the concepts), formative (worksheets, activities, etc), summative (enrichment questions, formal assessment activities, tests).	8-10 notional hours

feedback by teacher	Feedback – whether the concepts are clearly understood. **Follow-up/Homework** Each individual completes assigned tasks, projects.			

Expanded opportunities / Special needs Learners who have difficulty expressing themselves in written form, may prefer to give an oral presentation. Assist learners who have problems obtaining resources for research, etc.
Reflection by teachers and learners Clear up any misconceptions about the concepts.

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LESSON PLAN: **Micro-evolution and speciation**

To describe the formation of species at an ecological, reproductive and genetic level.

<table>
<tr><td>Educators:</td><td>Grade: Grade 12</td><td>School:</td></tr>
<tr><td>Learning outcomes</td><td colspan="2">LO 1: Scientific inquiry and problem-solving skills
LO 2: Construction and application of Life Sciences knowledge
LO 3: Life Sciences, Technology, Environment and Society</td></tr>
<tr><td>Focus assessment standards</td><td colspan="2">LO 2, AS 1: Accessing knowledge
LO 2, AS 2: Interpreting and making meaning of knowledge
LO 2, AS 3: Showing an understanding of the application of knowledge in everyday life.
LO 3, AS 1: Exploring and evaluating scientific ideas past & present.</td></tr>
<tr><td>Integrated Life Science learning outcomes</td><td colspan="2">LO 1
LO 3</td></tr>
<tr><td>Learning outcomes and assessment standards</td><td colspan="2"><table><tr><td>LO 1</td><td>AS1</td><td>AS2</td><td>AS3</td></tr><tr><td>LO 2</td><td>AS1</td><td>AS2</td><td>AS3</td></tr><tr><td>LO 3</td><td>AS1</td><td>AS2</td><td>AS3</td></tr></table></td></tr>
<tr><td>Integrated learning outcomes from other subjects</td><td colspan="2">Physical Sciences: LO 1, AS 3

Languages: LO 2, 3</td></tr>
<tr><td>Knowledge area</td><td colspan="2">Diversity, Change & Continuity</td></tr>
<tr><td>Prior learning</td><td colspan="2">GET Natural Sciences knowledge
FET Grade 10 & 11 Life Sciences knowledge (Genetics, Nucleic acids).
Concepts such as analysis, evaluating, inferences.</td></tr>
<tr><td>Where the lesson fits in</td><td colspan="2">➢ This lesson builds on natural selection and mutations and explores further mechanisms of micro-evolution.</td></tr>
</table>

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TEACHER ACTIVITIES	LEARNER ACTIVITIES	RESOURCES	ASSESSMENT METHODS	TIME
Advance preparation Various activities may require the preparation of materials (paper – various colours shapes quantities), magazine articles, obtaining video material, photocopying, etc. **Overview** Create the opportunity for the learners to explore the role of mutations and genetic drift as micro-evolutionary mechanisms in the formation of species. Examine different forms of speciation. Examine current thinking on evolution, eg evo-devo.	Learners able to demonstrate an understanding of the meaning of the concept of speciation, the mechanisms thereof and evolutionary impact.	Textbook, printed notes, video clips, slides, work book, writing implements.	Informal baseline (what do learners know about the concepts).	1 hour
Setting the scene/Context Explanation of the outcomes of the activities **Main activity** Bring the meanings of the concepts out using any number of teaching and educational aids. Create opportunities for discussion, debates, research	Study the notes and articles. Clarify the concepts through activities, eg. Interpret data on species on Galapagos islands, conducting research on sexual selection in a species of bird or other animal, exploring drug resistance, etc.	Hand out notes & worksheets on activities.	Informal diagnostic (explore ideas on the concepts), formative (worksheets, activities, etc), summative (enrichment questions, formal assessment activities, tests).	3-4 notional hours

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activities, etc. Interventions: Keep learners focussed Summary on writing board, OHP during feedback by teacher	Reasoning, views and opinions to be summarised on the worksheet. Feedback – whether the concepts are clearly understood. **Follow-up/Homework** Each individual completes assigned tasks, projects.			

Expanded opportunities / Special needs Learners who have difficulty expressing themselves in written form, may prefer to give an oral presentation. Assist learners who have problems obtaining resources for research, etc.
Reflection by teachers and learners Clear up any misconceptions about the concepts.

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LESSON PLAN: **Macroevolution and evolutionary trends in populations.**

Looking at macroevolution as patterns, trends and rates of change among lineages.

Educators:	**Grade: Grade 12**	**School:**
Learning outcomes	LO 1: Scientific inquiry and problem-solving skills LO 2: Construction and application of Life Sciences knowledge LO 3: Life Sciences, Technology, Environment and Society	
Focus assessment standards	LO 1, AS 1, 2 & 3 LO 2, AS 2 LO 3, AS 1 & 3	
Integrated Life Science learning outcomes	LO 1 LO 3	
Learning outcomes and assessment standards	LO 1 | AS1 | AS2 | AS3 LO 2 | AS1 | AS2 | AS3 LO 3 | AS1 | AS2 | AS3	
Integrated learning outcomes from other subjects	**Physical Sciences**: LO 1, 2 **Mathematical literacy:** LO 1, 2 & 4 **Languages:** LO 2, 3 & 4 *Social Sciences: **LO 1,2 & 3***	
Knowledge area	Diversity, Change & Continuity	
Prior learning	GET Natural Sciences knowledge FET Grade 10 & 11 Life Sciences knowledge (Genetics mutations, variation).	
Where the lesson fits in	➢ This lesson builds on microevolution and explores further trends in evolutionary development.	

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TEACHER ACTIVITIES	LEARNER ACTIVITIES	RESOURCES	ASSESSMENT METHODS	TIME
Advance preparation Various activities may require the preparation of materials (paper – various colours shapes quantities – magazine articles, obtaining video material, photocopying, etc. **Overview** Create the opportunity for the learners to explore the concepts of mutations, adaptations and variation.	Learners able to demonstrate an understanding of the meaning of the concepts mutation, population, adaptation and variation, and how it contributes to our understanding of evolutionary mechanisms.	Textbook, printed notes, video clips, slides, work book, writing implements.	Informal baseline (what do learners know about the concepts).	1 hour
Setting the scene/Context Explanation of the outcomes of the activities **Main activity** Bring the meanings of the concepts out using any number of teaching and educational aids. Create opportunities for discussion, debates, research activities, etc. Interventions: Keep learners focussed Summary on writing board, OHP during feedback by teacher	Study the notes and articles. Clarify the concepts through activities, eg. Poster making, mind maps, flow charts, case studies, investigate past evolutionary trends (fossil record – notes, magazines, etc) Predict current and future trends. Reasoning, views and opinions to be summarised on the worksheet. Feedback – whether the concepts are clearly understood.	Hand out notes & worksheets on activities.	Informal diagnostic (explore ideas on the concepts), formative (worksheets, activities, etc), summative (enrichment questions, formal assessment activities, tests).	8-10 notional hours

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	Follow-up/Homework Each individual completes assigned tasks, projects.			

Expanded opportunities / Special needs
Learners who have difficulty expressing themselves in written form, may prefer to give an oral presentation. Assist learners who have problems obtaining resources for research, etc.

Reflection by teachers and learners
Clear up any misconceptions about the concepts.

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