Evolution IA

1. Introduction

Charles Darwin's ideas were published in "On the Origin of Species by Means of **Natural Selection** or the Preservation of Favoured Races in the Struggle for Life" in 1859. Darwin used this **concept of natural selection** to explain the **variation** he observed within and between species. It was clear to him that those adaptations which conferred survival advantages in a given environment would come to dominate a population, all else being equal.

Darwin never knew or mentioned anything about genes, alleles or mutations. Neo-Darwinism is the theory of **evolution** that represents a synthesis of Darwin's theory **in terms of natural selection and modern population genetics**. It supports natural selection as the major process that would account for biological evolution.

2. Learning Outcomes

(a) Explain why variation (as a result of mutation, meiosis and sexual reproduction) is important in natural selection
(b) Explain, with examples, how environmental factors act as forces of natural selection
(c) Explain the role of natural selection in evolution
(d) Explain why the population is the smallest unit that can evolve
(f) Define biological evolution as descent with modification and explain the link between micro-evolution and macro-evolution
(h) Explain the various concepts of the species (biological, ecological, morphological, genetic and phylogenetic concepts)
(j) Explain how new species are formed with respect to geographical isolation (allopatric speciation) and behavioural or physiological isolation within the same geographical location (sympatric speciation)

3. References

Campbell, N.A. and Reece, J.B. (2008). Biology, 9th edition. Pearson.

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4. Microevolution & Macroevolution

Broadly, biological **evolution** is defined as **descent with modification from a common ancestor**:

Notes to self

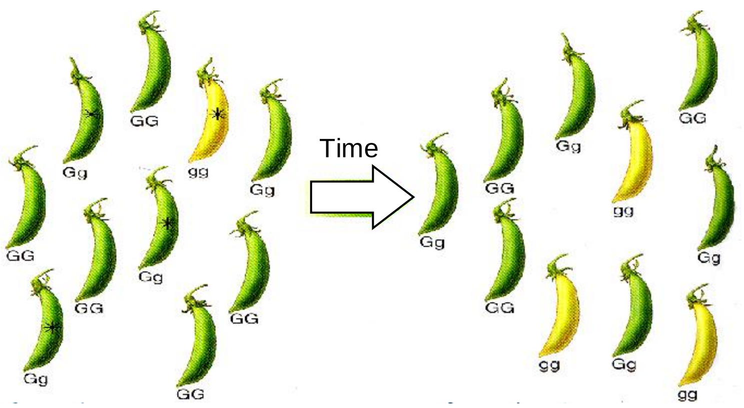
Modification: Evolution only occurs when there are **changes in allele frequency within a population over time**. (Allele frequency is a measure of the chances of finding a particular allele of a gene within the population.)

Descent: Evolution involves passing on of these **heritable genetic changes** to the next generation.

Common ancestor: Present day species are related through a common prehistoric ancestor that have changed and adapted over time. Therefore, all species come from pre-existing species.

Microevolution

Microevolution is the **change in allele frequency** within a population or species over time. This change is due to the “5 agents of evolutionary change” which we will discuss next.



Generation #1
Allele frequencies
G – Green pod color = 14/20 = 7/10 or 0.7
g – Yellow pod color = 6/20 = 3/10 or 0.3

Generation #2
Allele frequencies
G – Green pod color = 10/20 = 5/10
g – Yellow pod color = 10/20 = 5/10

Fig. 1: Changes in allele frequencies over time.

Macroevolution

Gradual changes in allele frequencies over many **thousands of years** may eventually give rise to a **new species**. This is macroevolution.

Microevolution and macroevolution are fundamentally identical processes but on a **different time scale**.

Microevolution may lead eventually to macroevolution, given enough time. The defining feature of macroevolution is **speciation**.

The **scale of changes** is also different between the two. **Microevolution** is concerned with **changes in allele frequencies within a species or population** while **macroevolution** focuses on changes that occur **at or above the level of species**.

Examples you will learn

Notes to self

- microevolution: antibiotic resistance in a bacteria and pigmentation of the peppered moth
- macroevolution at the level of the species: Darwin's Galapagos finches where new species of finches arise from an ancestral finch from South America
- macroevolution above the level of the species: mammals and birds diverged from reptiles, reptiles diverged from amphibians, and all tetrapods diverged from fish.

5. Five Agents of Evolutionary Change

The 5 agents of evolutionary change are **natural selection**, **disruption of gene flow**, **genetic drift**, **non-random mating** and **mutation**.

(a) Natural Selection

Natural selection results in the survival of individuals with the most favourable adaptations to a particular environment. This results in differential reproductive success in a population and, over many generations, can change the basic attributes of the population.

Principles of Natural Selection & How it Brings About Evolution:

(1) Overproduction of offspring

- All organisms produce large numbers of offspring. This can lead to an exponential increase in size of any population, if all offspring survive.

(2) Constancy of numbers

- Despite the tendency towards overpopulation, most populations remain relatively **stable in size**.
  This is because only a small fraction of the offspring population survives, matures and reproduces. Majority of offspring will die before reproductive age.

(3) Struggle for survival

- On the basis of points 1 and 2, individuals of a species constantly **struggle to survive**.
  Competition for finite resources such as food, soil nutrients, water, mates, habitats; and other factors such as disease and predators impose a limit on their number.

(4) Variation within a population

- Variation is the **differences between individuals of the same species** (due to the **presence of different alleles**).

- It includes morphological, physiological, biochemical and genetic differences.

- It is the raw material **for natural selection to act on**. If not for variation, **selection would not be possible as there would be no differences between individuals** of a population.

- Variations arise spontaneously and are not dictated by the need of organisms to survive better in the environment. Some variants are less adapted (due to the presence of unfavourable alleles) to survive in an environment compared to others. Other variants are better adapted to survive.

- Variation helps to ensure perpetuation of species and safeguard species from extinction when the environment changes.

- We have learnt earlier that **meiosis** and **sexual reproduction**, with the random fusion of male and female gametes, is a significant **source of variation**. A mating pair can give rise to offspring that are extremely varied. This is in contrast to asexual reproduction where the offspring are genetically identical to the parent.

- Meiosis and random fusion of gametes however **do not add new alleles to the population gene pool**. They merely reshuffle existing alleles among individuals, resulting in differences in phenotypes.

- **Mutations,** however, **introduce new alleles**, and enrich the gene pool. Because new alleles are introduced, there will be new phenotypes and hence increased variation.

(5) Survival of the fittest by natural selection

- When **environmental changes** such as a change in climate or an introduction of new predators occur, the variation allows some individuals with **selective advantage (i.e. those with favourable alleles that confer an advantage)** to **survive and reproduce more successfully than others**.

- These survivors have characteristics that are **selected/favoured by the environment**. The traits help them **adapt better** to the new environment.
- The organisms which survive get a chance to produce **viable and fertile offspring**.

- Any factor that reduces the reproductive success in a proportion of a population is called **selection pressure**. The intensity of environmental factors, biotic and abiotic, acting upon the survival and reproductive success of members of a population,

(6) Like produces like

- Those which survive breed to produce offspring **similar to themselves**.

- Advantageous characteristics (determined by **favourable alleles**) are more likely to be **passed on to the offspring**.

- For evolution to take place, the characteristics involved must be **heritable**.

(7) **Formation of a new species over a long period of time**

- Unequal ability of individuals to survive and reproduce will lead to a **gradual change** in a population.

- With each succeeding generation, the proportion of individuals having the advantageous characteristics (determined by **favourable alleles**) increases while those lacking the advantageous characteristics decreases. Favourable characteristics, and hence favourable genotypes accumulate over time, **changing allele frequency**.

- **Over hundreds and thousands** of **generations** spanning about 200,000 years, a **new species may form**. In organisms with a very short generation time, new species can be formed relatively faster.

The essential features of Darwin's theory describe how new species form (Fig.2.):

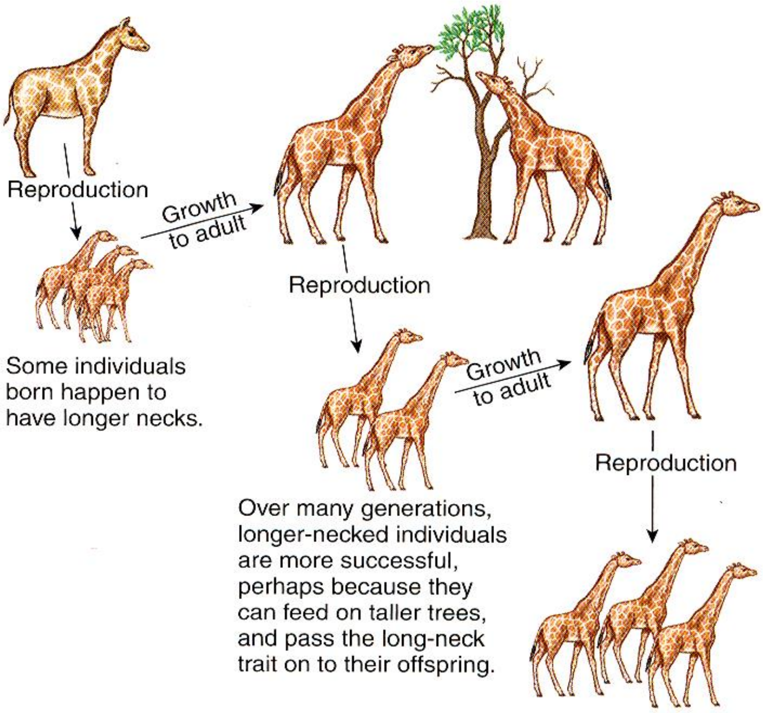


Fig. 2: Darwin's theory.

There is variation in neck length within the population of ancestor giraffes. Food availability becomes the selection pressure. Those with longer necks are more likely to survive and reproduce, passing on their genes for long necks to the next generation. Succeeding generations show an overall increase in number of

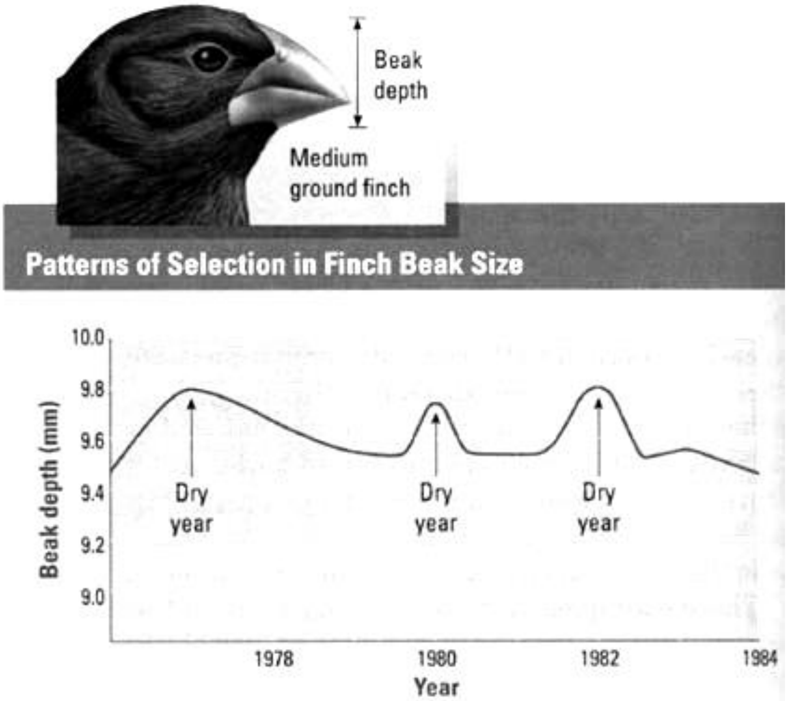


Fig. 3: Natural selection on Darwin's finches.

The graph record shows average beak size from *all* the finches captured over the years.

The medium ground finch, *Geospiza fortis*, feed preferentially on small, tender seeds produced in abundance in wet years. During droughts, plants produced few seeds and all available smaller, softer seeds were quickly eaten, leaving behind larger, harder seeds. The number of small-beaked finches declined correspondingly. Number of larger birds with more powerful beaks which can feed on the larger, harder seeds increases at the same time.

Types of Natural Selection:

Natural selection can affect the frequency of a heritable trait in a population in 3 different ways, depending on which phenotypes are favoured (Fig.4.):

Directional selection	Disruptive selection	Stabilising selection
▪ Phenotype at one extreme is repeatedly selected for. ▪ Favours what are initially relatively rare individuals. ▪ Once the new mean phenotype coincides with new optimum environmental conditions, stabilising selection takes over.	▪ Intermediate phenotypes are selected against. ▪ Favours individuals on both extremes of a phenotypic range. ▪ Possible to result in polymorphism, where two or more forms are found in one species.	▪ Extreme phenotypes are selected against. ▪ Favours the more common intermediate variants in a population. ▪ Does not promote evolutionary change but maintain phenotypic stability with a population over time.
Fig. 4A. Directional selection Melanic form of the peppered moth has selective advantage in polluted areas. Dark colour is due to a melanic allele, whose frequency increases in the population.	**Fig. 4B. Disruptive selection** Snails with pale shells are selected for in dry grasslands whereas those with dark broad bands are favoured in areas with leaf litter.	**Fig.** 4C. **Stabilising selection** Babies who are heavier than and lighter than optimum birth weight are at a selective disadvantage. Slightly increased mortality works against extremes of birth weight in humans.

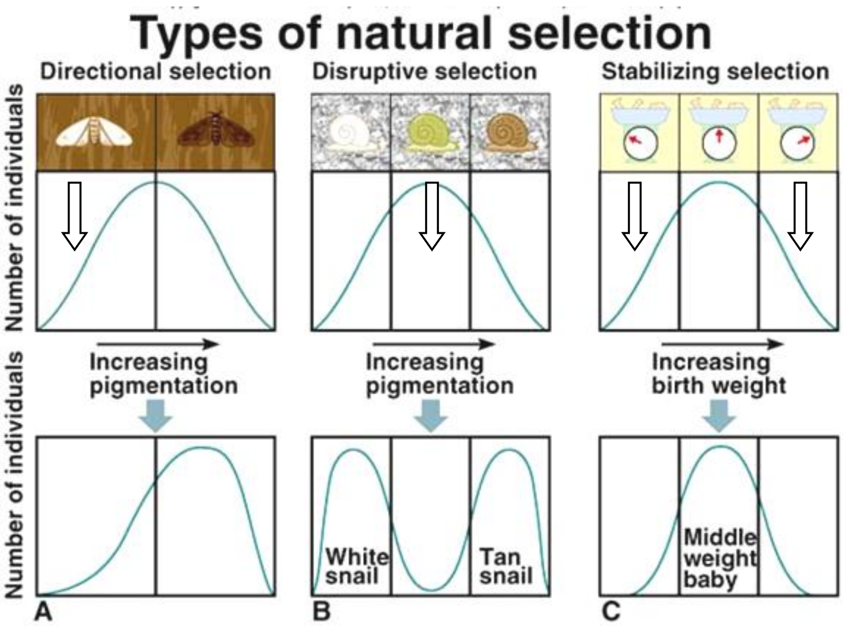


Fig. 4:

⇩ Show selection pressure working against certain phenotypes

Example 1: The peppered moth

- There are two types of **peppered moths (*Biston betularia*)** (Fig.5). The lighter form (white with black spots) and the melanic form (black with white spots). The black form arose from a **spontaneous mutation** in the lighter form.

  (Note: it is incorrect to imply that industrialization caused the melanic form of peppered moth to appear.)

- Before 1848, there was a greater proportion of the lighter form. This was because they were well-camouflaged from predators on light coloured, lichen-covered tree barks. The lighter form of moths had a **selective advantage** and were **better adapted** to the environment. Hence, they were **selected for** and hence they increased in frequency.
- With the industrial revolution the environment changed. **Lichens** on bark of trees, being pollution sensitive, were **killed** and the **dark coloured barks were exposed** and **soot** from industries made the barks **appear darker**. As a result, the **lighter form** of moth became **more visible** and **easy prey to birds.** Thus the lighter forms of moths were **selected against** & their numbers **declined**. The **darker forms** of moth however, were well camouflaged and thus **proliferated.**
- Hence there was **differential reproductive success** i.e. individuals with the favourable characteristic were more likely to **survive and reproduce** as compared to individuals with unfavourable characteristics.
- The human-induced change in which darker individuals predominate over lighter ones is known as "**industrial melanism**".
- The change in the numbers of the two types of moths is due to the **selection pressure exerted by the predatory birds** which can now more easily spot the lighter form of moths.

Q: what type of natural selection is shown by the example of the peppered moth?

Fig.5: Polymorphic forms of peppered moth.

Biston betularia typica (lighter form) has selective advantage in non-polluted areas compared to *B. betularia carbonaria* (melanic form).

Example 2: Antibiotic resistant bacteria

- Antibiotics are widely used to treat diseases caused by bacterial pathogens. Antibiotic resistance refers to the ability of a microorganism to withstand the effects of an antibiotic. An example of an antibiotic resistant bacterium: VRSA: vancomycin resistant *Staphylococcus aureus*
- Antibiotic resistant and non-resistant bacterial strains i.e. **variation,** exists naturally.
- Resistant strains usually arise by **spontaneous mutations.**
(Note: it is incorrect to imply that antibiotics caused the bacteria to mutate into resistant strains.)
- Antibiotics **kill most non-resistant bacteria**. Thus the non-resistant bacteria are **selected against** in the presence of antibiotics in the environment.
- Antibiotic resistant bacteria however have a **selective advantage** in the presence of antibiotics. They are said to be best **adapted to the environment** as they contain the antibiotic resistance allele. Thus they are **selected for** and more likely to **survive and reproduce**, **passing on the allele** for antibiotic resistance to subsequent generations. Hence the frequency of the antibiotic resistance allele increases in the population.
- Hence **differential reproductive success** occurs due to a **change in the environment.**
- The **selection pressure by antibiotics** can lead to the prevalence of antibiotic resistant bacteria.
- Thus new antibiotics have to be developed to eliminate the resistant bacteria. However, new resistant bacteria which are resistant to the new antibiotic will eventually become more commonly seen since they are selected for with the use of the new antibiotic.

Q: what type of natural selection is shown by the example 2?

Q: Antibiotics are essential in combating bacterial infection. Their use is therefore inevitable. Doctors always insist that we complete our course to prevent development of antibiotic resistance in the population. Explain how so?

Q: will stabilising selection result in evolutionary change?

(b) Disruption of Gene Flow

- Gene flow is the **transfer of alleles from one population to another**. This is achieved through to movement of fertile individuals or their gametes. (e.g. pollen being dispersed by the wind to another island or a bird flying to an island)

- Gene flow depends on geographical proximity, mobility of individuals, etc.

- In nature, individuals commonly migrate into or out of a locality.

- Gene flow tends to **reduce differences in allele frequencies between neighbouring populations**. Populations that mix their gene pools frequently tend to have similar allele frequencies.

- On the other hand, **disruption to gene flow** can **result in differences in allele frequencies** over time. Note: Disruption of gene flow is required for speciation to occur.

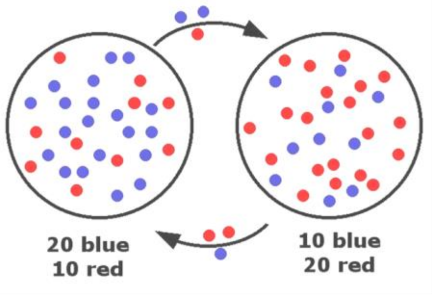


Fig. 6: Gene Flow.

(c) Genetic Drift

- A **change in allele frequency** due to **chance events** - chance because which allele ends up lost from the original gene pool is an **indiscriminate, random event**. This is different from natural selection as alleles in this case are lost from **random individuals** instead of from individuals with disadvantageous phenotypes.
- Genetic drift tends to **reduce genetic variation** in populations through such losses of alleles. The **smaller** the original population is, the **greater the impact of genetic drift.**
- The Founder effect and Bottleneck effect illustrate how genetic drift can affect allele frequency significantly.

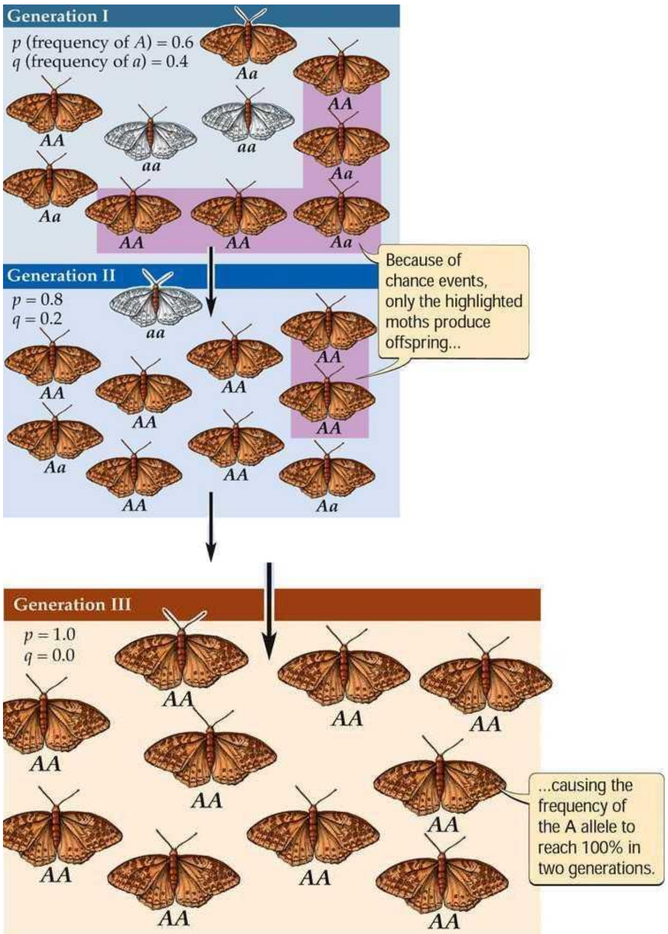


Fig. 7: Genetic Drift. Frequency of the alleles *A* and *a* are modified in the population of moths because only a sample of moths produces offspring by chance events.

(1) Founder effect

- A **few, random** individuals from a larger population became **pioneers** of a newly isolated population and are **not likely to carry all the alleles present in the original population.**
- The **new population** is usually **small and reproductively isolated**. If there is continuous breeding within this pioneer population, **rare alleles** may become more **common**.

  e.g.: The Amish community descended from a few founding individuals in 18th century; Darwin's finches on Galápagos descended from the distant mainland South American finches.

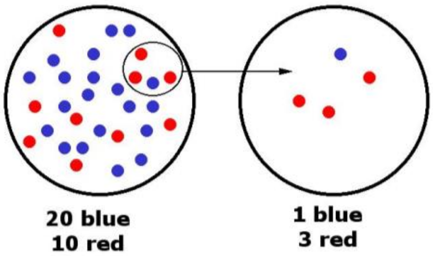


Fig. 8: Founder effect

(2) Bottleneck effect

- A catastrophic event leading to a **drastic reduction in population** results in the reduction of allele frequencies and even elimination of alleles in a random nature. E.g. disease epidemic, a natural disaster or any **unfavourable environmental change**.
- The **few, random surviving individuals** constitute a random genetic sample of the original pre-catastrophe population. Certain alleles may be **over-represented or under-represented** among the survivors.

  e.g.: Northern elephant seals were hunted till 20 remained. Even though the population has rebounded to tens of thousands, genetic variation has been lost.

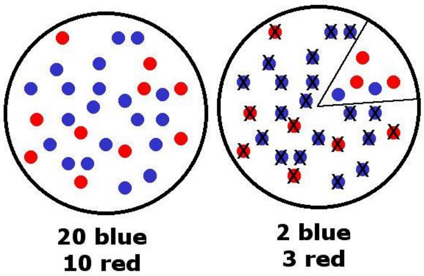
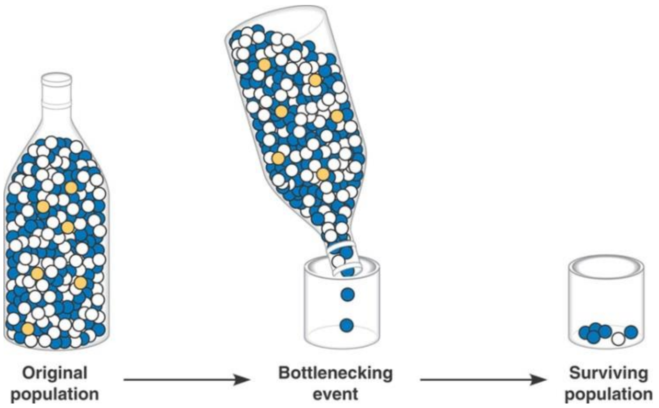


Fig. 9: Bottleneck effect



Q. Discuss if the following are examples of genetic drift.

1. *A global pandemic wipes out 90% of cheetah population.*
2. *Hunters hunting mink, for their fur, resulting in the decimation of their population.*
3. *Cheetahs hunting Thomson's gazelle.*
4. *The warming of the ocean resulting in the bleaching of the coral reefs.*
5. *Seasonal flu epidemic resulting in 30,000 worldwide fatalities.*
6. *Singaporeans setting up home in Australia.*
7. *Singaporeans setting up home on a deserted island.*

(d) Non-random Mating

- In many natural populations, individuals preferentially choose mates. Random mixing of gametes in natural populations therefore does not occur.
- e.g. presence of one or more inherited phenotype improves the chances of successful mating. This is also known as sexual selection. This allele may then be more prominent in the next generation.
- Artificial selection, where humans select the breeding pair, is a type of non-random mating.

(e) Mutation

- A mutation is a random change in an organism's DNA and are **a source of new alleles.**
- For mutations to have an impact on evolution, it must occur in gametes.

  Q. What happens if mutations occur in somatic (non-gametic) cells?

- Mutation rates are generally very low, odds of a gene mutating are in the order of 1 in 100,000 genes per generation. Although mutations at a particular gene locus are **rare**, **cumulative impact** of mutations at all loci over long periods of time can be **significant.**
- Mutation is unique amongst all the 5 agents of evolutionary change in that it is the only one that results in the **formation of new alleles**. It doesn't act directly on allele frequencies.
- Once a **mutation generates a new allele**, evolutionary forces like natural selection can take over and change the allele frequencies.
- Most mutations are deleterious, meaning that they are likely to confer a selective disadvantage. In a rare instance where a mutant emerges that possess a selective advantage (favorable adaptation), such individuals **survive and produce a disproportionate** number of offspring compared to less well adapted individuals. The mutated allele thus becomes more common.

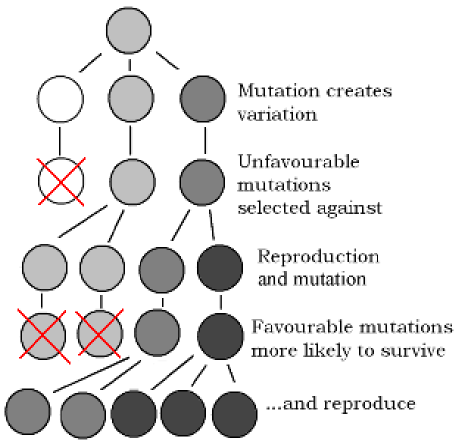


Fig. 10: Mutation

In Summary:

Notes to self

- There are **5 agents** of evolutionary change.
- The first 4 factors (natural selection, disruption of gene flow, genetic drift and non-random mating) result in **changes in allele frequencies**.
- ***Natural selection*** is one of the most powerful drivers of evolutionary change. It requires **variation** within a population and is influenced by the **organism's interaction with the environment**.
- ***Disruption of gene flow*** involves **isolating populations** through various isolating mechanisms which we will discuss later. This allows the isolated populations to **evolve independently** and over time the allele frequencies of the isolated populations will change. This concept is the key to explaining **speciation**.
- ***Genetic drift*** takes into account the **unpredictable, random events** that changes allele frequencies.
- ***Non-random mating*** takes into account **mate selection** which can influence evolution. It helps us explain why the peacock evolved to have such cumbersome tail feathers which may get in a way of a speedy escape from predators.
- ***Mutation*** is an important component for **speciation** to take place. It is the only one of the 5 agents that leads to the **formation of new alleles**.
- Changes in allele frequency alone cannot result in speciation. Two populations need to have sufficient **genetic differences** before they can be considered a separate species.

6. Populations Evolve, Not Individuals

- A population is a group of **interbreeding individuals belonging to a particular species** and sharing a common geographic area.
- Whilst natural selection occurs through interactions between individual organisms and their environment, it is the **collective genetic response of the population** that determines survival of the species and the formation of new species.
- Long-term effects of natural selection are at the level of the gene and the population rather than the individual. **Individuals don't change in their lifetimes**, no matter the selection pressure. Some individuals succumb to selection pressure while others thrive. Such survivors interbreed, thereby passing on favourable alleles to the next generation and over time, the allele frequencies change.
- **Microevolution** is a **measure of changes** in **allele frequencies** in a population over **successive generations**. The fate of an individual organism is relatively insignificant in the history of a species. Hence a population is the smallest unit that can evolve.