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The Theory of Evolution

A Level

Part A The theory

The theory of evolution is the theory that all life on Earth is descended from a single common ancestor, and that differences among species are due to gradual changes that have occurred over many generations.

Random [ ] can produce new [ ] of a gene, which may produce a different phenotype. If one phenotype is more beneficial for survival or reproduction than the other, then individuals with that phenotype will produce more offspring than those without. This means that the beneficial phenotype will, over time, increase in frequency in the population. This is the process of [ ]. Eventually, all individuals in the population will display the more beneficial phenotype.

Phenotypes may also change in population frequency due to random chance. This is the process of [ ].

As changes accumulate in a population, this population becomes different from other populations, until the two populations are different enough to be classified as two distinct species. This is the process of [ ]. Various forms of evidence support the theory that one original species produced all life on Earth by this process over billions of years.

Items:

genetic drift **natural selection** **alleles** **speciation** **mutations**

Part B The evidence

Which of the following features of life support the theory of evolution? Select all that apply.

- all life shares the same universal genetic code (i.e. each amino acid is coded for by the same codon(s))
- animal embryos within each phylum are very similar (e.g. human embryos have the same structures that in fish embryos develop into gills)
- the process of embryo development perfectly repeats the organism's evolutionary history
- some fossilised organisms represent "links" between groups of organisms (e.g. *Archaeopteryx*, which has a mixture of dinosaur features and bird features).
- evolutionary change can be observed in living organisms (e.g. bacterial strains evolving resistance to certain antibiotics)
- all life shares the exact same cell structure

Part C Fitness

In the context of evolutionary biology, **fitness** is defined as...

- the reproductive success of an individual, or of a particular genotype, within a population
- how attractive an individual is to other individuals in the population
- the athletic ability of an organism
- changes to an organism's genome that are the result of errors during DNA replication
- genetic differences between individuals in a population
- changes in trait/allele frequency over time (generations) due to random chance

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Home Gameboard Biology Evolution Theory Natural Selection vs Genetic Drift

Natural Selection vs Genetic Drift

A Level

P P P

Part A Natural selection

What is natural selection?

- changes in an organism's phenotype that are acquired during its lifetime and then passed on to the offspring
- changes to an organism's genome that are the result of errors during DNA replication
- the formation of a new species due to populations become reproductively isolated from each other
- genetic differences between individuals in a population that may affect survival and/or reproductive success
- changes in trait/allele frequency over time (generations) due to random chance
- changes in trait/allele frequency over time (generations) due to how beneficial the trait/allele is for survival and/or reproduction

Part B Genetic drift

What is genetic drift?

- changes in an organism's phenotype that are acquired during its lifetime and then passed on to the offspring
- the formation of a new species due to populations become reproductively isolated from each other
- changes in trait/allele frequency over time (generations) due to how beneficial the trait/allele is for survival and/or reproduction
- changes in trait/allele frequency over time (generations) due to random chance
- genetic differences between individuals in a population that may affect survival and/or reproductive success
- changes to an organism's genome that are the result of errors during DNA replication

Part C Population size

Why is genetic drift "stronger" in small populations than in large populations?

- mutation rates are higher in smaller populations, which results in more fluctuations in trait/allele frequency
- death rates are always higher in smaller populations
- natural selection only works in large populations, so genetic drift is the only process occurring in smaller populations
- large populations will not undergo any changes in trait/allele frequency, so genetic drift cannot act on large populations
- there is more variation in small populations than in large populations
- random fluctuations in trait/allele frequency will have a proportionally larger effect in smaller populations

Part D Selection vs drift

Examples of traits changing over time are given in the table below.

Example	Description
A	A population of birds has a mean beak length of $53\,\mathrm{mm}$. In this population, birds with larger beaks are able to eat a wider variety of seeds, and so their survival is improved. As a result of this, after a few generations, the mean beak length is $57\,\mathrm{mm}$
B	A plant population displays variation in leaf shape. $71\,\%$ of the population has smooth leaves, and $29\,\%$ of the population has serrated leaves. A disease that affects both types of plant equally wipes out most of the population, after which $94\,\%$ of the population has smooth leaves, and $6\,\%$ of the population has serrated leaves.
C	A particular plant species has red flowers. In one population, a recent mutation has occurred that causes yellow flowers to develop instead. The yellow flowers are less effective at attracting pollinators, and so this trait is quickly lost from the population.
D	In one narwhal population, the mean tusk length in males is $2.1\,\mathrm{m}$. Males with longer tusks are more successful at attracting females. As a result of this, after a few generations the mean tusk length in males is $2.2\,\mathrm{m}$
E	A synonymous mutation occurs in one bacterial cell within a population. After many generations, all of the cells within the population have this mutation.
F	A forest population of squirrels has two varieties of fur colour: brown or black. Those with black fur are more at risk of predation because they are less camouflaged in this forest. A forest fire kills all of the black squirrels, after which there are only brown squirrels in the population.

Match each example above to the process.

- **A**:
- **B**:
- **C**:
- **D**:
- **E**:
- **F**:

Items:

natural selection **genetic drift**

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Home Gameboard Biology Evolution Theory Selection Statements

Selection Statements

A Level

Part A Selection pressures

A selection pressure is a biological or physical factor in an environment that may result in evolution.

Which of the following situations results in selection pressures on one or more organisms?

- [ ] using an insecticide to kill the mosquitoes that spread malaria
- [ ] long-term use of antibiotics in hospital wards
- [ ] clearing rainforests to grow palm oil plantations
- [ ] introduction of a predator to islands with seabird colonies

Part B Pesticide resistance

Bt pesticide is used by farmers to kill insect pests. However, widespread use has resulted in the evolution of resistance to this pesticide. A recessive allele causes resistance.

Scientists have suggested that in areas where the Bt pesticide is used, a small number of fields are left untreated. These untreated fields are known as *refugia*. This method has been shown to slow down evolution of resistance to the pesticide.

Which of the following statements explain why refugia could slow down the evolution of resistance to Bt pesticide? Select all that apply.

- [ ] The refugia help to maintain genetic variation in the population of insect pests.
- [ ] Pesticide-resistant insects are only able to eat leaves of plants that have been treated with Bt pesticide, and so they will not survive in the refugia.
- [ ] When resistant insects breed with pesticide-sensitive insects that do not have the allele for resistance, the offspring produced will be sensitive to the pesticide.
- [ ] The resistance allele will mutate back to the original allele as a result of the insect eating the leaves of refugia plants.
- [ ] When fewer insects are exposed to pesticide, fewer mutations occur that produce alleles for resistance.

Part C Sickle cell anaemia

The table below shows information about a human genetic condition called sickle cell anaemia and an infection called malaria. Both sickle cell anaemia and malaria can be fatal.

genotype	phenotype	resistance to malaria
MM	does not show sickle cell anaemia	can be infected with malaria
Mm	does not show sickle cell anaemia	shows resistance to malaria
mm	shows sickle cell anaemia	shows more resistance to malaria than Mm

Which of the following statements are correct? Select all that apply.

- [ ] The presence of malaria has caused a mutation of the **M** allele to the **m** allele, leading to an increased chance of survival in the heterozygous state.
- [ ] In areas with malaria, sickle cell anaemia is less likely to be fatal.
- [ ] In areas with malaria, only those individuals that are heterozygous will be able to pass on their alleles to the next generation.
- [ ] In areas without malaria, human populations are likely to have a low number of people with the **m** allele.
- [ ] In areas with malaria, whether the **m** allele increases or decreases in frequency over time will depend on how common it is in the population.

Question elements adapted with permission from NSAA 2021 Section 1 Q61, NSAA 2018 Section 1 Q71, and NSAA 2020 Section 1 Q70

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Maize Grains

A Level

There is significant variation in the amount of oil present in maize grains.

In an experiment, maize grains were tested for their oil content and only those with either highest or lowest oil content were selected and planted. When this generation of plants matured and produced maize grains, these were tested for their oil content and the selection process was repeated. This was done over fifty generations of maize.

All plants were grown in the same conditions. The mean mass per maize grain was $0.4\,\mathrm{g}$ and did not change over the fifty generations. The results are shown in **Figure 1**.

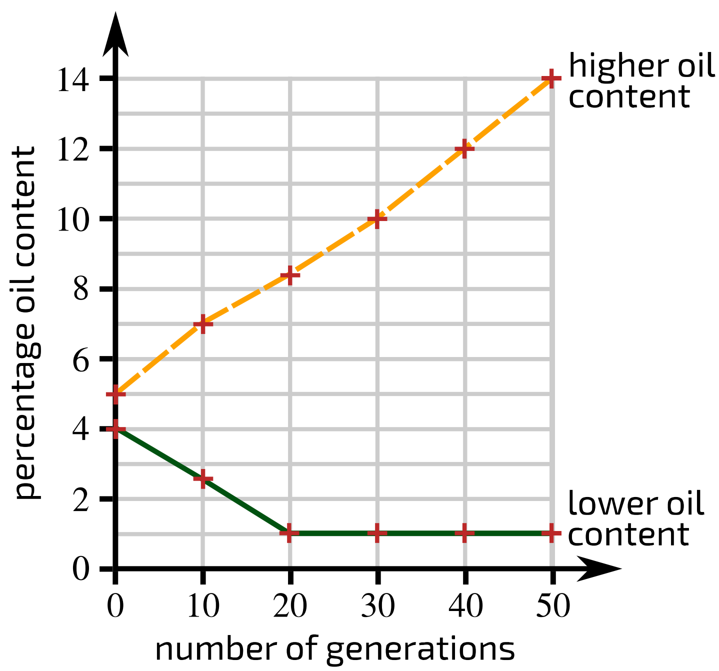

Figure 1: Percentage oil content of maize grains in two separate lineages over time. Within the higher oil content lineage, only grains with the highest oil content were planted each generation. Within the lower oil content lineage, only grains with the lowest oil content were planted each generation.

Part A Variation type

What type of variation is this?

Part B Selection type

What type of selection is this?

Part C Percentage changes

Calculate the percentage increase in the percentage oil content of the grains with a higher oil content over the fifty generations.

Calculate the percentage decrease in the percentage oil content of the grains with a lower oil content over the fifty generations.

Part D Absolute changes

Calculate the increase in mass of oil per grain in the higher oil content grains over the fifty generations.

Calculate the decrease in mass of oil per grain in the lower oil content grains over the fifty generations.

Adapted with permission from NSAA 2022 Specimen Paper Section 2 Q28

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Hardy-Weinberg Equilibrium

A Level

The Hardy-Weinberg principle states that, given certain conditions*, genotype frequencies will remain constant at

$$p^2 + 2pq + q^2 = 1$$

where

- p^2 is the proportion of homozygotes for the allele for which the proportion is given by p
- $2pq$ is the proportion of heterozygotes in the population
- q^2 is the proportion of homozygotes for the allele for which the proportion is given by q

Note that $p + q = 1$.

*These conditions are as follows:

- no mutations occur
- no natural selection occurs
- no genetic drift occurs (this requires the population to be infinitely large)
- no immigration into or emigration out of the population occurs
- mating within the population is random (i.e. individuals of each genotype mate with individuals of any genotype - not just their own)

Importantly, no population will meet all of these conditions - particularly the condition of being infinitely large! But the Hardy-Weinberg principle gives us the **expected** genotype frequencies to compare actual frequencies against. If genotype frequencies are close to the expected values ($p^2 + 2pq + q^2 = 1$), this suggests that at least some of the conditions are true. If genotype frequencies are very different from the expected values, this could suggest that natural selection and/or genetic drift are occurring.

Part A Equal proportions

A gene has two alleles (**A**, **a**) in a population. The proportion of allele **A** in the population (given by p) is 0.5.

Find q, the proportion of allele **a** in this population.

Assuming the population is in Hardy-Weinberg equilibrium, what percentage of individuals will be homozygous for allele **A**?

Part B Unequal proportions

A gene has two alleles (**A**, **a**) in a population. The proportion of allele **A** in the population (given by p) is 0.8.

Find q, the proportion of allele **a** in this population.

Assuming the population is in Hardy-Weinberg equilibrium, what percentage of individuals will be homozygous for allele **a**?

Part C How many heterozygotes?

A gene has two alleles (**A**, **a**) in a population of $2\,000$ individuals.

65% of the copies of this gene in this population are allele **A**.

How many individuals would you expect to be heterozygous in this population?

Part D Disequilibrium

A gene has two alleles (**A**, **a**) in a population. The proportion of allele **A** in the population (given by p) is 0.5.

The genotype frequencies are as follows:

- **AA**: 45% of individuals
- **Aa**: 10% of individuals
- **aa**: 45% of individuals

Which of the following reasons may explain why this population is not in Hardy-Weinberg equilibrium for this gene? Select all that apply.

- [ ] Homozygotes prefer to mate with individuals of the same genotype.
- [ ] Recent immigration into the population has occurred.
- [ ] Heterozygotes have a lower fitness than homozygotes.
- [ ] Heterozygotes have a higher fitness than homozygotes.
- [ ] The population is very large and so genotype frequencies are highly affected by genetic drift.
- [ ] The population is very small and so genotype frequencies are highly affected by genetic drift.
- [ ] Homozygotes prefer to mate with individuals of the opposite homozygote genotype.
- [ ] Recent emigration out of the population has occurred.

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Home Gameboard Biology Evolution Theory Flour Beetle Eye Colour

Flour Beetle Eye Colour

A Level

In flour beetles one gene controlling eye colour is located on chromosome 5. Flour beetles have two copies of chromosome 5 in each cell. One allele causes black eyes and a second allele causes red eyes.

The allele for black eye (B) is dominant over the allele for red eye (b).

$\frac{3}{4}$ of the alleles present in a population of 1600 flour beetles were the dominant B allele.

Part A Black eyes

What is the expected number of flour beetles with black eyes?

Part B Expected ratio of genotypes

What is the expected ratio of homozygous black eye beetles to heterozygous black eye beetles to red eye beetles? Express your answer as a ratio in its simplest form (e.g. 1 : 2 : 3)

Adapted with permission from NSAA 2022 Specimen Paper Section 2 Q30

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STEM SMART Biology Week 25

Predicting Allele Frequencies

A Level

The Hardy-Weinberg principle allows us to calculate expected genotype frequencies in the absence of natural selection when allele frequencies are constant. However, this is often not the case. Allele frequencies will change over time if they have different relative fitnesses.

In a population with two alleles of a particular gene (allele **A** and allele **B**), if we know the relative proportions and relative fitnesses of those two alleles, we can predict how allele frequencies will change over time using the following equation:

$$p' = \frac{pW_A}{\bar{W}}$$

where

- p' is the predicted relative proportion of allele **A** in the next generation
- p is the current relative proportion of allele **A**
- W_A is the relative fitness of allele **A** (i.e. the number of copies each **A** allele will contribute to the next generation, relative to the number of copies each **B** allele will contribute to the next generation)
- $\bar{W}$ is the average fitness of an individual in the population, which can be calculated using the equation below:

$$\bar{W} = pW_A + qW_B$$

where

- q is the current relative proportion of allele **B**
- W_B is the relative fitness of allele **B**

Note that

- $p + q = 1$
- one allele must have a relative fitness of 1 and the other allele must have a relative fitness that is less than or equal to 1

Part A Equal fitness

In one population, p is 0.25 and q is 0.75. The relative fitnesses of the two alleles are identical.

Calculate the predicted relative proportion of allele A in the next generation.

Part B Equal proportions

In one population, the relative proportions of allele A and allele B are equal in the current generation. However, allele **A** has a relative fitness of 1 and allele **B** has a relative fitness of 0.6.

Calculate the predicted relative proportion of allele **A** in the next generation.

Part C Unequal fitness and proportions

In one population, allele **A** has twice the relative fitness of allele **B**. The current relative proportion of allele **A** is 0.4.

Calculate the predicted relative proportion of allele **A** in the next generation. Give your answer to 3 significant figures.

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