isaac You work it out.

STEM SMART Biology Week 29 - Natural Selection & Genetic Drift

The Theory of Evolution

Subject & topics

Biology | Evolution | Theory

Status

Not started

Stage & difficulty

A Level Practice 2

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:

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

Part B

The evidence

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

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

Part C

Fitness

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

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

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STEM SMART Biology Week 29 - Natural Selection & Genetic Drift

Natural Selection vs Genetic Drift

Subject & topics

Biology | Evolution | Theory

Status

Not started

Stage & difficulty

A Level Practice 2

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
- the formation of a new species due to populations become reproductively isolated from each other
- changes to an organism's genome that are the result of errors during DNA replication
- 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 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 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
- changes to an organism's genome that are the result of errors during DNA replication
- 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
- genetic differences between individuals in a population that may affect survival and/or reproductive success

Part C

Population size

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

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

STEM SMART Biology Week 29 - Natural Selection & Genetic Drift

STEM SMART Biology Week 29 - Natural Selection & Genetic Drift

Selection Statements

Subject & topics

Biology | Evolution | Theory

Status

Not started

Stage & difficulty

A Level Challenge 2

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?

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

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.

- [ ] When fewer insects are exposed to pesticide, fewer mutations occur that produce alleles for resistance.
- [ ] 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.
- [ ] 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.

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.

- 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.
- 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, 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

Subject & topics

Biology | Evolution | Theory

Status

Not started

Stage & difficulty

A Level Challenge 2

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**.

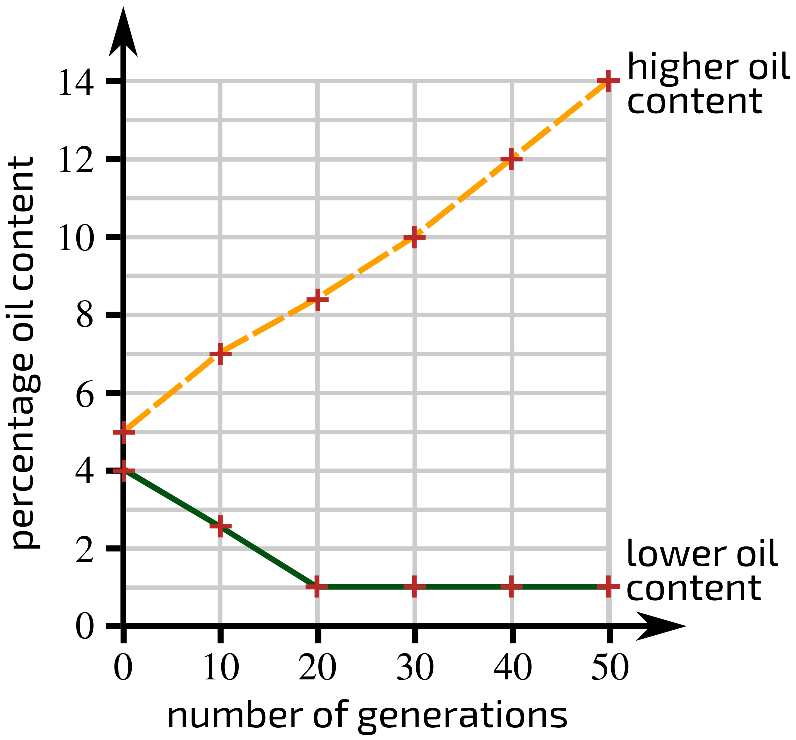

Figure 1: Percentage oil content of maize grains in two separate lineages over time. Within the higher oil content lineage, only grains with the highest oil content were planted each generation. Within the lower oil content lineage, only grains with the lowest oil content were planted each generation.

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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STEM SMART Biology Week 29 - Natural Selection & Genetic Drift

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STEM SMART Biology Week 29 - Natural Selection & Genetic Drift

Zebra Finch Clutch Size

Subject & topics

Biology | Evolution | Theory

Status

Not started

Stage & difficulty

A Level Challenge 1

The number of eggs a bird lays in its nest is called the clutch size.

The variation in clutch size was investigated in the zebra finch over several years.

The data are shown in **Figure 1**.

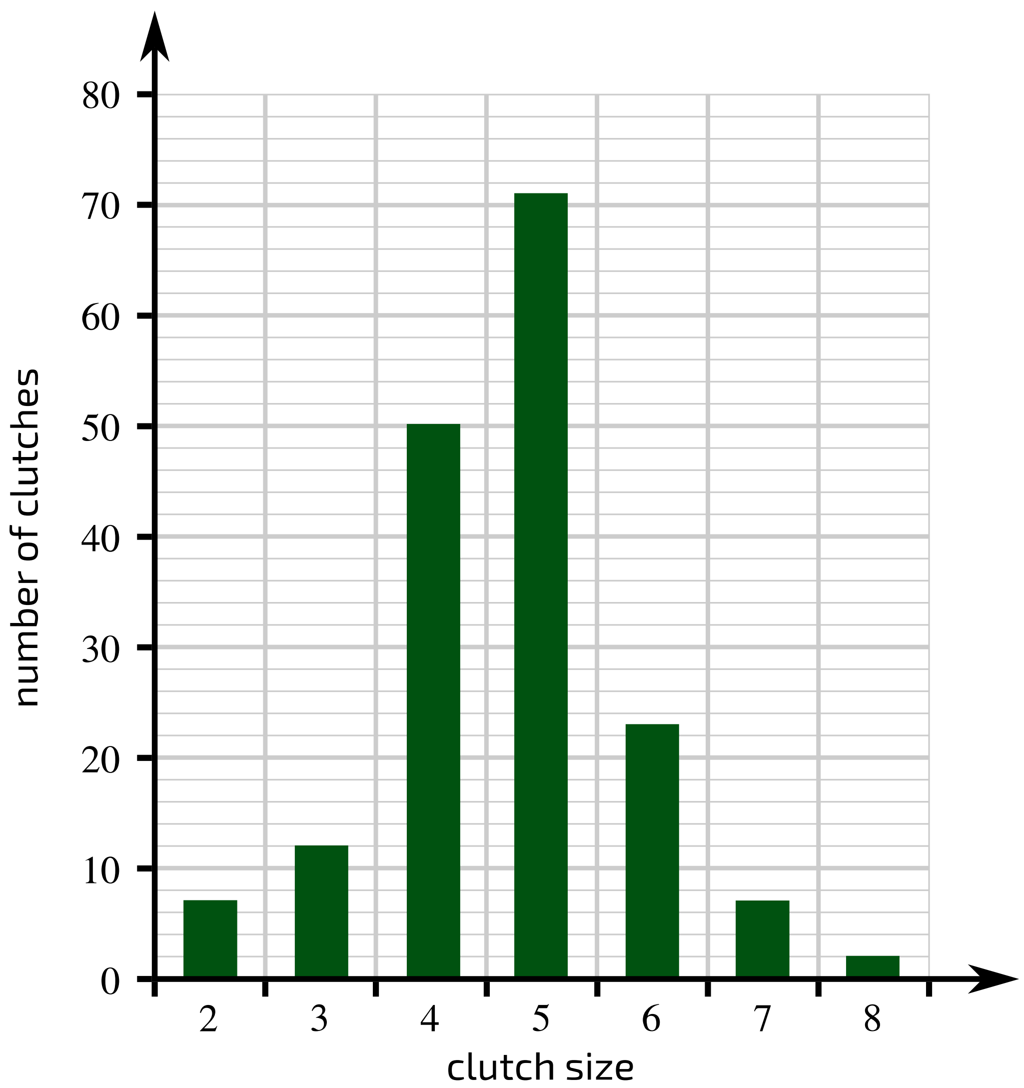

Figure 1: Zebra finch clutch size variation over several years.

Part A

Mean clutch size

Calculate the mean clutch size to 2 significant figures.

Part B

Selection

The data shown in **Figure 1** were collected over 60 years ago.

Scientists carried out a similar investigation recently and obtained very similar results (i.e. a similar mean clutch size and a similar spread of data).

What is the name given to the type of selection that is acting on clutch size in zebra finches?

Which of the following statements could explain why this form of selection is occurring?

- [ ] birds with small clutches (2 to 3 eggs) don't produce as many offspring as birds with intermediate clutches (4 to 6 eggs)
- [ ] birds with small clutches (2 to 3 eggs) are more likely to survive to the next mating season
- [ ] birds with intermediate clutches (4 to 6 eggs) struggle to feed all of their chicks, and so chicks from intermediate clutches have a lower survival rate than chicks from small clutches (2 to 3 eggs)
- [ ] birds with intermediate clutches (4 to 6 eggs) don't produce as many offspring as birds with large clutches (7 to 8 eggs)
- [ ] birds with large clutches (7 to 8 eggs) struggle to feed all of their chicks, and so chicks from large clutches have a lower survival rate than chicks from intermediate clutches (4 to 6 eggs)
- [ ] birds with large clutches (7 to 8 eggs) produce the largest number of offspring

Adapted with permission from CIE A Level Biology, June 2018, Paper 4, Question 2

Question deck:

STEM SMART Biology Week 29 - Natural Selection & Genetic Drift

STEM SMART Biology Week 29 - Natural Selection & Genetic Drift

Adaptation Examples

Subject & topics

Biology | Evolution | Theory

Status

All attempted (some errors)

Stage & difficulty

A Level Practice 2

An adaptation is a heritable trait that has evolved by natural selection. In other words, it is a trait that has increased in population frequency over time because it provides an advantage to individuals with the trait.

Adaptations can be anatomical, behavioural, or physiological.

Three examples are given below. For each example, you will need to explain how/why the adaptation evolved.

Part A

Antibiotic resistance

Antibiotics are substances that kill or inhibit the growth of bacteria. Some bacterial strains have evolved resistance to particular antibiotics e.g. methicillin-resistant *Staphylococcus aureus* (MRSA) is a strain of *Staphylococcus aureus* that has evolved resistance to the antibiotic methicillin.

Drag the items below into a logical order on the right to explain how a bacterial population could evolve resistance to a particular antibiotic (antibiotic X).

Note that not all of the statements below are correct, and so you should not use all of the items below. There may be more than one possible order of events.

Available items

- As a result of this, a greater proportion of cells in the next generation carry the new mutation.
- A new mutation randomly occurs in one cell that allows that cell to survive and reproduce in the presence of antibiotic X.
- Cells with the new mutation have increased survival and reproductive success (i.e. have a higher fitness) than cells without the new mutation.
- Exposure to antibiotic X causes a new mutation to occur in one cell that allows that cell to survive and reproduce in the presence of antibiotic X.
- Continued exposure to antibiotic X increases the rate of this particular mutation.
- The bacterial population is exposed to antibiotic X.
- After several generations, all cells contain the new mutation. The entire population is now resistant to antibiotic X

Part B

Lactase persistence

All mammals produce the lactase enzyme during infancy in order to digest the lactose in their mother's milk. In most mammals, lactase production stops once the animal stops drinking their mother's milk, as the LCT gene (which codes for lactase) is 'switched off'. However, in some humans, the LCT gene remains 'switched on' throughout childhood and adulthood due to mutations in the regulatory region of this gene. This allows them to drink milk (e.g. cow's milk) without suffering adverse effects such as diarrhoea and vomiting.

Drag the items below into a logical order on the right to explain how a human population could have evolved lactase persistence.

Note that not all of the statements below are correct, and so you should not use all of the items below. There may be more than one possible order of events.

Available items

- Individuals in the population begin to consume milk produced by farmed animals, perhaps due to famine/starvation.
- A new mutation randomly occurs in one human **small intestine cell** that stops the LCT gene being 'switched off' in these cells.
- Milk consumption causes a new mutation to occur that stops the LCT gene being 'switched off' in small intestine cells.
- If this continues over many generations, the frequency of this new mutation/allele will steadily increase until all/most individuals in the population have the lactase persistence phenotype.
- Individuals without the new mutation die in infancy because they cannot drink their mother's milk.
- A new mutation randomly occurs in one human **germline cell** that stops the LCT gene being 'switched off' in small intestine cells that are derived from this germline cell.
- As a result of this, individuals with the new mutation may have more offspring than those without the new mutation.
- Individuals with the new mutation suffer fewer adverse effects and gain more nutrients from milk consumption.

Part C

Long necks

Giraffes are the tallest living land animals, reaching heights of up to $5.7\,\mathrm{m}$, with necks as long as $2.4\,\mathrm{m}$. Their closest relatives, okapi, are less than $2\,\mathrm{m}$ tall with an approximate neck length of $0.5\,\mathrm{m}$. It is likely that the last common ancestor of giraffes and okapi, which lived approximately 12 million years ago, was more similar in height and neck length to okapi than to giraffes.

Drag the items below into a logical order on the right to explain how a giraffe necks could have become longer over evolutionary time.

Note that not all of the statements below are correct, and so you should not use all of the items below.

Available items

- The low availability of food increases the mutation rate in giraffes.
- A new mutation randomly occurs in one giraffe germline cell that results in the development of a slightly longer neck.
- If this continues over many generations, the frequency of this new mutation/allele will steadily increase, causing the average neck length of the population to increase.
- Individuals repeatedly stretch to reach higher leaves, causing an individual's neck to lengthen during their lifetime. This phenotype is then inherited by their offspring.
- As a result of this, individuals with the new mutation have more offspring than those without the mutation.
- Over millions of years, the steps above repeat several times (each time with a different mutation that slightly increases neck length).
- Individuals with the slightly longer neck are better at foraging and/or attracting mates than those with shorter necks.

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STEM SMART Biology Week 29 - Natural Selection & Genetic Drift

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Population Size and Allele Fixation

Subject & topics

Biology | Evolution | Theory

Status

Not started

Stage & difficulty

A Level Challenge 3

If more than one allele of a gene exists in a population, the relative frequencies of these alleles can change over time. The relative frequency of one allele may increase because it is more beneficial for the organism's survival/reproduction (i.e. due to natural selection) or because of random chance (i.e. due to genetic drift). Changes in allele frequencies can lead to **allele fixation**, which is when one allele becomes 'fixed' as the only allele of that gene in the population (meaning the other allele(s) has/have been lost from the population).

The degree to which genetic drift affects allele frequencies is related to the size of the population. One way of measuring the strength of this effect is to calculate the probability that allele fixation occurs due to genetic drift.

Consider a population that consists of N haploid individuals that reproduce asexually. In this population there exists two alleles, **A** and **B**, of a particular gene. The relative frequency of allele **A** is 0.2 and the relative frequency of allele **B** is 0.8. There is no selection acting on these two alleles.

Half of the individuals in the population successfully reproduce (each producing offspring that are clones of the parent). All of the original individuals die, and so the population now consists solely of those offspring.

Part A

$N = 10$

Calculate, for a population of $N = 10$, the probability that allele **B** has become fixed in the population by genetic drift. Give your answer as a decimal to 3 sf.

Part B

$N = 20$

Calculate, for a population of $N = 20$, the probability that allele **B** has become fixed in the population by genetic drift. Give your answer as a decimal to 3 sf.

Part C

$N = 40$

Calculate, for a population of $N = 40$, the probability that allele **B** has become fixed in the population by genetic drift. Give your answer as a decimal to 3 sf.

Part D

The effect of genetic drift

Which of the following statements correctly describes the relationship between population size and the strength of the effect of genetic drift on allele frequencies?

- Genetic drift has a stronger effect on allele frequencies in **large** populations.
- Genetic drift has a stronger effect on allele frequencies in **small** populations.

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