



Natural selection

Revision notes • IB Biology natural selection: variation, overproduction, selection pressures, fitness, sexual selection, Endler's guppies and Hardy-Weinberg (HL).

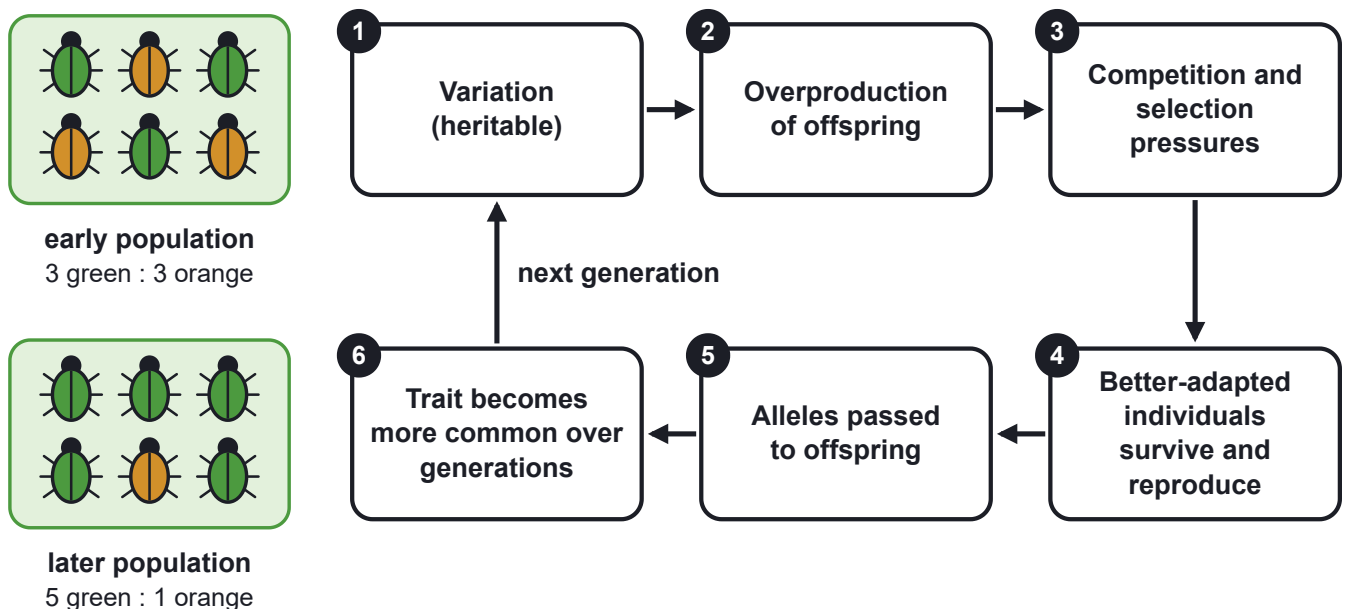
For IB Diploma Biology, Standard Level and Higher Level (first assessment 2025). **HL only** is additional higher level content, for HL students only.

Natural selection Spec D4.1

Natural selection as the mechanism of evolution Spec D4.1.1, D4.1.6

Natural selection is the mechanism driving evolutionary change. Evolution is a change in the heritable characteristics of a population over many generations. Natural selection operates continuously in every population, and it has done so for billions of years. Its accumulated effects have produced the biodiversity of life on Earth.

1. Individuals in a population vary, and much of this variation is heritable.
2. More offspring are produced than the environment can support.
3. Individuals compete for limited resources and face other selection pressures.
4. Individuals with traits better suited to the environment are more likely to survive and reproduce.
5. They pass the alleles for these traits to their offspring.
6. Over many generations, the frequency of these traits in the population rises.



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Natural selection: **heritable variation** plus overproduction and competition make better-adapted traits commoner over generations.

A paradigm shift

In Darwin's time it was widely understood that species evolved, but the mechanism was not clear. The leading idea was **Lamarckism**: organisms change during their lives through use and disuse, and pass these acquired changes on. Darwin's theory of natural selection gave a convincing mechanism and replaced Lamarckism. This is an example of a **paradigm shift**.

Paradigm shift	A fundamental change in the accepted theory and way of thinking in a field of science, when an old framework is replaced by a new one that explains the evidence better.
Lamarckism	The discarded idea that characteristics acquired during an organism's life, through use or disuse, are passed on to its offspring.

Traits must be heritable

Evolutionary change only happens if traits are **heritable**: coded in the base sequence of genes and passed on in gametes. Characteristics acquired during an individual's life due to environmental factors are not encoded in the base sequence of genes, so they are not heritable.

- Larger muscles built by training are not passed to offspring.
- A plant that grows tall in fertile soil does not produce taller offspring for that reason.
- A scar or a learned skill is not inherited.

Common mistake: Never write that organisms change 'because they need to'. Individuals do not evolve; populations do, as allele frequencies change over generations.

Mutation and sexual reproduction as sources of variation Spec D4.1.2

Natural selection can only act if individuals differ. Two processes generate the heritable variation it acts on.

Two sources of heritable variation		
Process	What it does	How
Mutation	Generates new alleles	A random change in the base sequence of DNA. Only mutations in cells that give rise to gametes are passed to offspring. Most are neutral or harmful; a few are beneficial.
Sexual reproduction	Generates new combinations of alleles	Crossing over in prophase I and random orientation of bivalents in metaphase I of meiosis give genetically different gametes. Random fertilisation of one gamete by another adds further combinations.

Mutation is the only source of genuinely new alleles. Sexual reproduction does not create alleles, but it shuffles existing ones into combinations that may never have existed before, so every offspring is genetically unique (apart from identical twins).

In asexual reproduction, offspring are genetically identical to the parent except where a mutation occurs, so variation is much more limited.

Exam tip: Keep the guide's distinction exact: mutation = new alleles; sexual reproduction = new combinations of alleles. Swapping them loses the mark.

Overproduction, competition and selection pressures Spec D4.1.3, D4.1.4, D4.1.5

Overproduction and competition

Most species produce far more offspring than can survive. The **carrying capacity** of an environment is the maximum population size it can support sustainably. Above it, there are not enough resources, so individuals of the same species compete: **intraspecific competition**.

- Animals: food (for example seeds for seed-eating birds), water, nesting or breeding sites, territory and shelter.
- Plants: light, water, mineral ions such as nitrate and phosphate, and space for roots.

Abiotic factors as selection pressures

A selection pressure is any factor that affects the chance of survival or reproduction differently depending on an individual's traits. Abiotic factors such as very high or very low temperatures, drought or flooding are **density-independent**: they affect survival whatever the population size. In a severe frost, for example, individuals with better insulation or more cold-tolerant tissues are more likely to survive.

Differences in adaptation, survival and reproduction

Individuals differ in how well adapted they are. Better-adapted individuals win more resources, survive longer and leave more offspring. This difference between individuals is the basis of natural selection.

Carrying capacity	The maximum population size of a species that an environment can support sustainably.
Density-independent factor	A factor, usually abiotic, that limits a population regardless of its density, such as a heatwave or a hard frost.
Fitness	The survival value and reproductive potential of a genotype: how many offspring it contributes to the next generation compared with other genotypes.

Exam tip: Survival alone earns no mark. Write 'survive and reproduce, passing on their alleles'.

Exam tip: Linking question: how do intraspecific interactions differ from interspecific interactions? Intraspecific competition is usually most intense because individuals of one species have identical resource needs.

Sexual selection and Endler's guppies Spec D4.1.7, D4.1.8

Sexual selection

Sexual selection is selection for traits that increase success in attracting a mate. Usually females choose between males, or males compete with each other. Differences in physical and behavioural traits can act as signs of overall fitness: only a healthy male in good condition can grow and display an elaborate ornament.

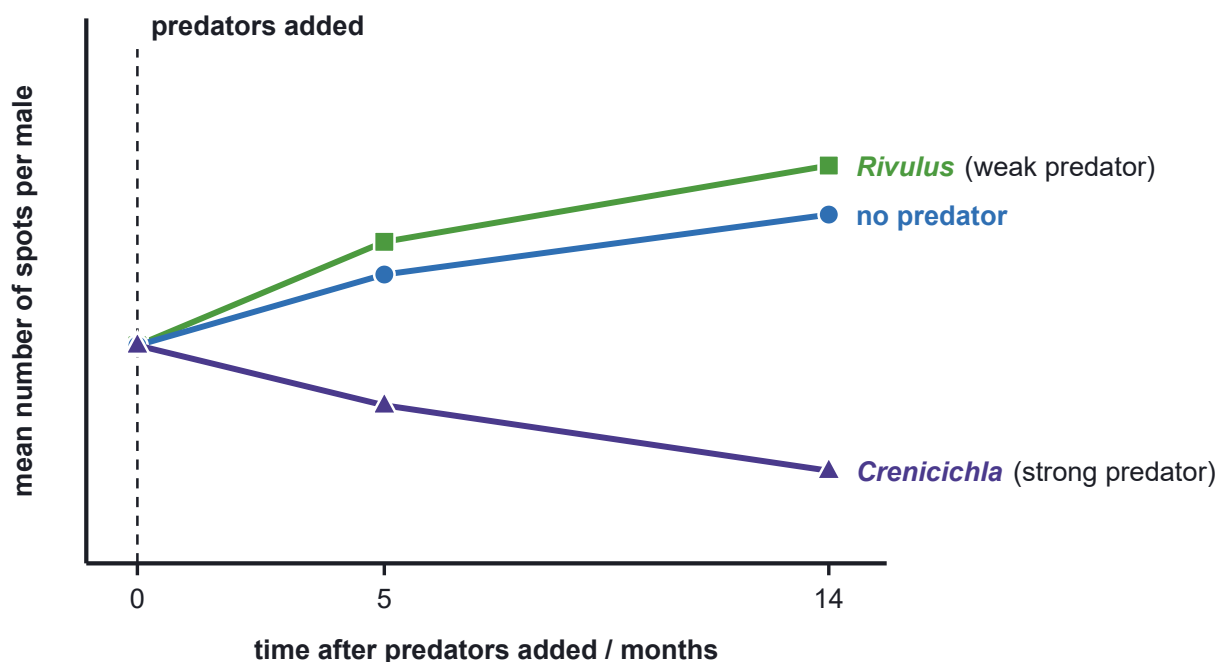
Male **birds of paradise** have brightly coloured plumage, long ornamental feathers and complex courtship displays, while females are dull brown. Females choose the males with the most impressive displays. Those males father more offspring, so alleles for elaborate plumage have increased in frequency, even though the plumage costs energy and makes the males more visible to predators.

Modelling selection: Endler's guppies

Guppies (*Poecilia reticulata*) live in streams in Trinidad. Males have coloured spots; females prefer more colourful males. In pools with a dangerous predator, the pike cichlid (*Crenicichla*), males are dull with

fewer spots. In pools with only a weak predator, *Rivulus*, which rarely eats adults, males are bright with many spots. Endler hypothesised that colour is a balance between sexual selection and predation.

1. Ten large ponds were set up in a greenhouse, five with coarse gravel and five with fine gravel, and stocked with guppies from many different streams.
2. The guppies bred freely for six months with no predators.
3. Predators were then added: two ponds had no predator, four had *Rivulus* and four had *Crenicichla*. The selection pressure was experimentally controlled.
4. The number and size of spots on males were recorded at the start, 5 months and 14 months after predators were added (about 10 generations).
5. Spot numbers rose in ponds with no predator or with *Rivulus*, and fell in ponds with *Crenicichla*, where the spots also became smaller.
6. In a field experiment, guppies moved from a high-predation site to a stream with only *Rivulus* had more colourful males within about two years (about 15 generations).



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Endler's ponds: spots increased without strong predation and decreased with *Crenicichla* (pattern only; values illustrative).

Practical skill: With Endler-style data, name the independent variable (predation pressure), the dependent variable (spot number or size), controlled variables (pond size, gravel, food) and the replicate ponds.

Gene pools and allele frequencies

Spec D4.1.9, D4.1.10, D4.1.11

HL only

Gene pool

All the genes and their different alleles present in a population.

Allele frequency

The proportion of all copies of a gene in a population that are a particular allele, given as a value from 0 to 1.

Geographically isolated populations

When populations are geographically isolated, alleles do not flow between them. Different mutations arise, selection pressures differ, and chance events change allele frequencies, so the gene pools

diverge.

- **Lactase persistence** (digesting lactose as an adult): over 90% of people in Sweden and Denmark have it, and it is common in some pastoralist groups in East Africa, but rare (5% or less) in most East Asian populations. Different lactase-persistence alleles (different mutations near the lactase gene) are responsible in Europe and in East Africa.
- **ABO blood groups**: the I^B allele is most frequent in Central and South Asia, while many Indigenous populations of South America have almost only the i allele (blood group O).

Practical skill: Use an allele frequency database (for example the Allele Frequency Net Database or gnomAD) to compare one human allele across populations, and record the population, sample size and frequency.

Natural selection changes allele frequencies

Individuals differ in their heritable traits. Those with traits giving higher fitness leave more offspring, so the alleles for those traits make up a larger share of the next generation's gene pool. Evolution can therefore be described as a **change in allele frequency** in a gene pool over time.

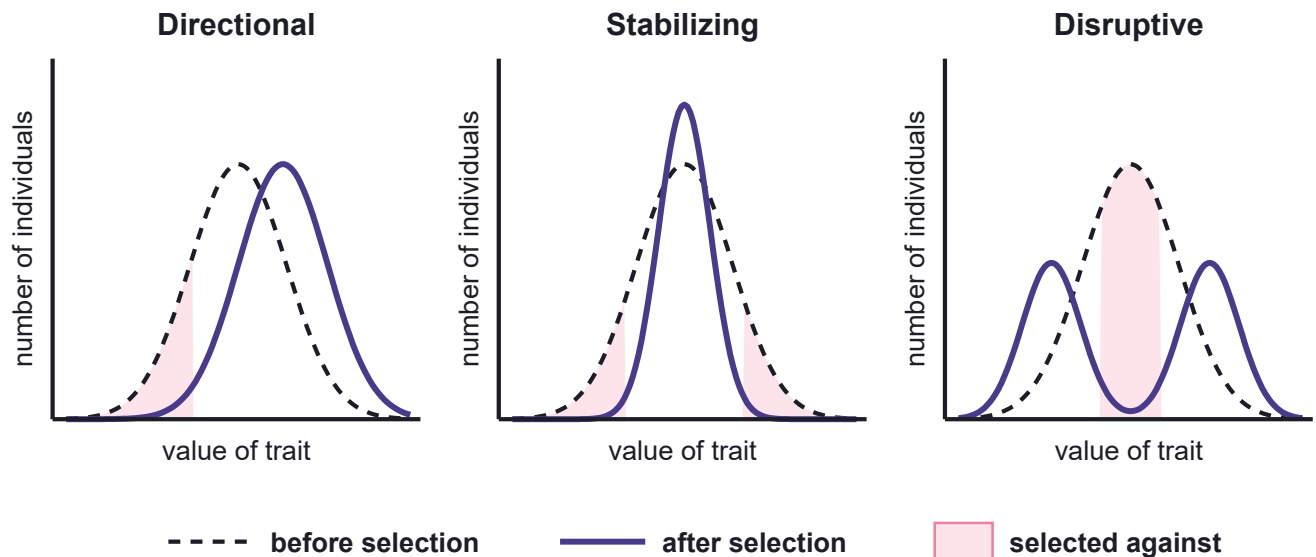
Darwin developed the theory of evolution by natural selection without knowing about genes. Biologists later integrated genetics with natural selection in what is now known as **neo-Darwinism**.

Directional, disruptive and stabilizing selection; artificial selection Spec D4.1.12, D4.1.15

HL only

Three patterns of natural selection on a continuously varying trait			
Type	Phenotypes favoured	Effect on the distribution	Example
Directional	One extreme	Mean shifts towards that extreme	Medium ground finches on the Galápagos after a drought: birds with deeper beaks could crack the large, hard seeds left, so mean beak depth increased.
Stabilizing	Intermediate values	Mean stays the same; variation decreases	Human birth mass: very light and very heavy babies historically had lower survival.
Disruptive	Both extremes	Variation increases; can split into two peaks	Black-bellied seedcrackers: small-billed birds feed well on soft seeds and large-billed birds on hard seeds; intermediates do neither well.

All three types result in a **change in allele frequency**, because individuals with some alleles leave more offspring than others.



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Directional, stabilizing and disruptive selection all change allele frequency.

Artificial selection

Artificial selection is carried out in crop plants and domesticated animals by choosing individuals with desirable traits for breeding, generation after generation.

- Wild cabbage (*Brassica oleracea*) has been bred into cabbage, kale, broccoli, cauliflower and Brussels sprouts by selecting for leaves, flower heads or buds.
- Dairy cattle have been selected for high milk yield.

Common mistake: Antibiotic resistance in bacteria is an unintended consequence of human action. Nobody chose which bacteria would breed, so it is natural selection, not artificial selection.

The Hardy-Weinberg equation and its conditions Spec D4.1.13, D4.1.14 HL only

For a gene with two alleles, **p** and **q** denote the two allele frequencies. Where one allele is dominant, p is usually the dominant allele and q the recessive allele. Every allele copy is one or the other, so $p + q = 1$, and with random combination of gametes the genotype frequencies are p^2 , $2pq$ and q^2 .

$$p + q = 1$$

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

What each term means

Term	Genotype frequency
p^2	Homozygous dominant (AA)
$2pq$	Heterozygous (Aa)
q^2	Homozygous recessive (aa)

Allele and carrier frequencies

In a population, 1 in 2500 people has a recessive genetic condition. Calculate the frequency of carriers (practice figures).

1. $q^2 = 1 \div 2500 = 0.0004$
2. $q = \sqrt{0.0004} = 0.02$
3. $p = 1 - q = 0.98$
4. $2pq = 2 \times 0.98 \times 0.02 = 0.0392$

Answer: Carrier frequency = 0.0392, about 3.9% or 1 in 26 people.

Maths skill: Start from q^2 , the homozygous recessive frequency, because it is the only genotype you can identify from the phenotype. Never take the square root of the dominant phenotype frequency.

Conditions for genetic equilibrium

- A very large population, so chance changes (genetic drift) are negligible.
- Random mating.
- No mutation.
- No migration into or out of the population (no gene flow).
- No natural selection: all genotypes survive and reproduce equally.

If observed genotype frequencies do not fit the Hardy-Weinberg equation, one or more conditions is not being met, for example **mating is non-random** or **survival rates vary between genotypes**.

Quick check

1. What generates new alleles?
2. Why are acquired characteristics not inherited?
3. What is fitness?
4. **HL only** What does $2pq$ represent in the Hardy-Weinberg equation?
5. **HL only** Is antibiotic resistance an example of artificial selection?

Quick check answers

Natural selection

1. Mutation: a random change in the base sequence of a gene.
2. They are not encoded in the base sequence of genes.
3. The survival value and reproductive potential of a genotype.
4. The frequency of heterozygotes.
5. No, it is natural selection; nobody chose which bacteria would reproduce.