

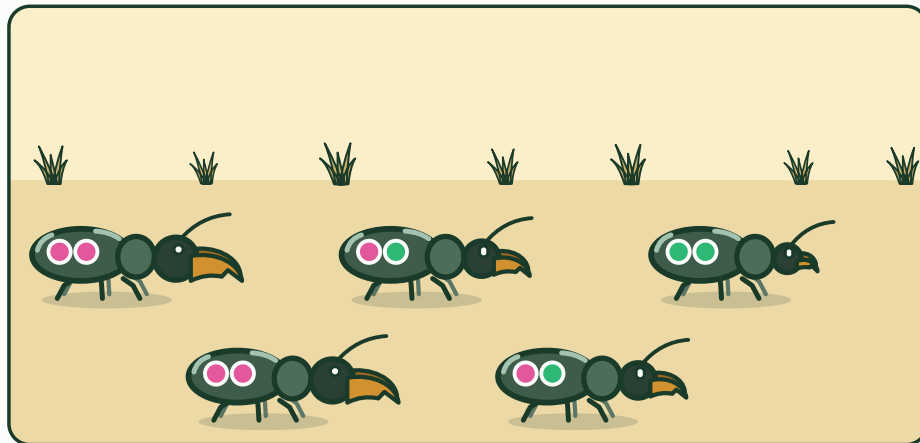
REVISION GUIDE

How *selection* changes a population

Natural selection

Nobody plans evolution, and nothing has to try. Here is how variation, too many young and a changing world add up to a population that is different a few generations later, and how a pond of guppies shows the tug of war between surviving and finding a mate.

The next generation: more large jaws



before

J 40%

j 60%

after

J 60%

j 40%



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By the end you can

- ☐ Explain natural selection as the mechanism of evolution, and why Darwin's explanation replacing Lamarck's was a paradigm shift D4.1.1
- ☐ Explain how mutation makes new alleles and sexual reproduction makes new combinations of them D4.1.2
- ☐ Explain how overproduction of offspring and competition for limited resources promote natural selection D4.1.3
- ☐ Explain how abiotic factors such as a hard frost act as density-independent selection pressures D4.1.4
- ☐ Use fitness, adaptation, survival and reproduction to explain why some individuals leave more offspring than others D4.1.5
- ☐ Explain why only heritable traits can be selected, and why traits acquired in a lifetime cannot D4.1.6
- ☐ Explain how competing for mates and being chosen drive the evolution of traits such as the plumage of birds of paradise D4.1.7
- ☐ Interpret data from Endler's guppy experiments, and explain how controlling the predator separates sexual from natural selection D4.1.8
- ☐ Describe a gene pool, and calculate and compare allele frequencies in a population, using a database for a human example D4.1.9, D4.1.10
- ☐ Explain neo-Darwinism: how selection between individuals changes allele frequencies in the gene pool D4.1.11
- ☐ Distinguish directional, stabilising and disruptive selection, and explain why all three change allele frequencies D4.1.12
- ☐ Use the Hardy-Weinberg equation to calculate allele and genotype frequencies, and say what its five conditions tell you D4.1.13, D4.1.14
- ☐ Distinguish artificial selection from natural selection, and explain antibiotic resistance as natural selection D4.1.15

Tick each one when you can do it without the book.

01 Evolution has a *mechanism*

D4.1.1 NATURAL SELECTION DRIVES EVOLUTION

Long before Darwin, many naturalists suspected that species change over time. What nobody had was a convincing explanation of how. Jean-Baptiste Lamarck, in the early 1800s, suggested that animals change by using or not using their parts, and pass those changes on. A giraffe stretches for leaves, its neck lengthens, and its calf is born with a longer neck. It sounds sensible, and it is wrong (chapter 4 shows why).

In 1859 Charles Darwin published a different mechanism, **natural selection**. Individuals in a population differ. More young are born than can survive. The ones whose traits suit the conditions leave more offspring, and the traits they carry become commoner. Nothing has to try, and nothing is planned.

The process never stops. Every generation of every population is being sorted, over billions of years, and the accumulated result is the biodiversity of life on Earth.

Darwin's idea replacing Lamarck's is a classic **paradigm shift**. That is the nature of science: an explanation is kept while it fits the evidence, and replaced when a better one arrives.

To keep the logic of natural selection in order, use the mnemonic below. ICE AGE is a teaching aid, not an IB term. The next three chapters take its letters one at a time.

Four claims about natural selection. Each one is a common slip. Decide, then check.

KEY TERMS

natural selection

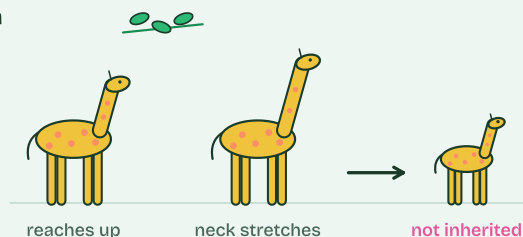
The process by which individuals whose heritable traits suit their environment survive and reproduce more than others, so those traits become more common in the population.

paradigm shift

A change in the basic framework scientists use to explain a whole area of knowledge, when a new theory that explains more replaces the old one.

Lamarck's idea

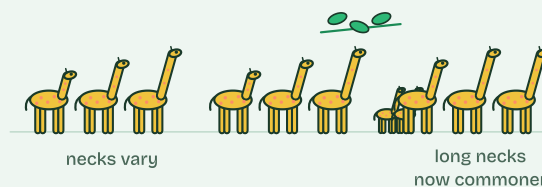
early 1800s
use and disuse



Darwin's idea

1859
natural selection

replaced Lamarck
a paradigm shift



STEP BY STEP

5 STEPS

1

Lamarck's idea
early 1800s
use and disuse

reaches up neck stretches → inherited, he said

Lamarck's idea: a giraffe stretches for leaves, its **neck lengthens**, and it passes the change on.

2

Lamarck's idea
early 1800s
use and disuse

reaches up neck stretches → not inherited

In fact the calf hatches with an ordinary neck: a change gained in life is **not inherited** (chapter 4).

3

Lamarck's idea
early 1800s
use and disuse

reaches up neck stretches → not inherited

Darwin's idea
1859
natural selection

necks vary

Darwin's idea starts with **variation**: the necks in a population are not all the same.

4

Lamarck's idea
early 1800s
use and disuse

reaches up neck stretches → not inherited

Darwin's idea
1859
natural selection

necks vary long necks feed best and leave more young

Long necks feed best in the lean season and **leave more young**. The alleles go with them.

5

Lamarck's idea
early 1800s
use and disuse

reaches up neck stretches → not inherited

Darwin's idea
1859
natural selection

replaced Lamarck a paradigm shift

necks vary long necks now commoner

Generations later, long necks are commoner. The explanation was **replaced**: a paradigm shift.

ANIMATION · WATCH IT HAPPEN: ICE AGE IN ONE POPULATION

6 MOMENTS

1 GENERATION 1

I Inherited **C Competition** **E Environment** **A Adaptation** **G Genotype** **E Evolution**

a wet year

Large jaws slender jaws

How common each version of the jaw gene is

■ large-jaw version ■ slender-jaw version generation 1

generation 1
generation 2
generation 3
generation 4
generation 5

2 36 YOUNG, FOOD FOR 12

I Inherited **C Competition** **E Environment** **A Adaptation** **G Genotype** **E Evolution**

a wet year

How common each version of the jaw gene is

■ large-jaw version ■ slender-jaw version generation 1

generation 1
generation 2
generation 3
generation 4
generation 5

Inherited variation. Jaws differ, set by the two versions of a jaw gene that each beetle carries (the pips): pink large, green slender.

Competition. Twelve beetles leave thirty-six young, three times as many as the ground can feed.

3 36 YOUNG, FOOD FOR 12

I Inherited **C Competition** **E Environment** **A Adaptation** **G Genotype** **E Evolution**

drought: only tough seeds

cracks it cannot crack it

How common each version of the jaw gene is

■ large-jaw version ■ slender-jaw version generation 1

generation 1
generation 2
generation 3
generation 4
generation 5

4 12 OF 36 SURVIVE

I Inherited **C Competition** **E Environment** **A Adaptation** **G Genotype** **E Evolution**

drought: only tough seeds

How common each version of the jaw gene is

■ large-jaw version ■ slender-jaw version generation 1

generation 1
generation 2
generation 3
generation 4
generation 5

Environmental pressure. A drought leaves only tough seeds. Large jaws crack them; slender jaws cannot, and those beetles starve.

Adaptation. The twelve survivors all have large or medium jaws, the trait that suits a dry year. Every one carries the large-jaw version.

5 GENERATION 2

I Inherited **C Competition** **E Environment** **A Adaptation** **G Genotype** **E Evolution**

dry years go on

How common each version of the jaw gene is

■ large-jaw version ■ slender-jaw version generation 1

generation 1
generation 2
generation 3
generation 4
generation 5

6 GENERATION 5

I Inherited **C Competition** **E Environment** **A Adaptation** **G Genotype** **E Evolution**

dry years go on

How common each version of the jaw gene is

■ large-jaw version ■ slender-jaw version generation 1

generation 1
generation 2
generation 3
generation 4
generation 5

Genotype frequencies change. Only survivors breed, so the large-jaw version of the gene is more common in generation 2.

Evolution. The dry years go on. By generation 5 nearly every beetle has large jaws: no beetle changed, the population did.

Watch it move, and change it as it runs: biologybybradford.com/guides/ib-biology-d4-1-natural-selection#mechanism

REMEMBER IT

The logic of natural selection: ICE AGE

I Icy	C Cubs	E Eat	A Anything	G Growing	E Enormous
Inherited variation the population varies, and the variation is heritable	Competition more young are born than resources can support	Environmental pressure some survive and breed more than others	Adaptations helpful traits are selected for	Genes (alleles) allele frequencies change from one generation to the next	Evolution the population has changed

PREDICT

Claim 1: "Natural selection gives organisms what they need to survive."

- (A) True: when a population needs a trait badly enough, selection supplies it over the generations
- (B) False: it favours only variation that already exists, and it cannot know what is needed
- (C) Partly: it gives each individual what it needs, but only when the need is urgent enough

Decide before you look. Answer on page 40.

PREDICT

Claim 3: "Organisms adapt to their surroundings by trying to."

- (A) False: the variation arises by chance, and the surroundings then sort it out
- (B) True: an animal that works hard at surviving gradually changes its body to suit its home
- (C) True: a strong enough need makes the right mutations more likely to happen in the next young

Decide before you look. Answer on page 40.

PREDICT

Claim 2: "Natural selection acts for the good of the species."

- (A) True: a trait spreads only if it helps the whole species to survive in the long run, as a rule
- (B) True: traits that harm the species are always removed before they can spread very far
- (C) False: a trait spreads if its bearers leave more offspring, even if it harms the species

Decide before you look. Answer on page 40.

PREDICT

Claim 4: "The fittest are the strongest, healthiest and fastest."

- (A) True: strength decides who wins every contest, and so who gets to breed at all
- (B) True: the healthiest animals live longest, so they always leave the most young of all
- (C) False: the fittest are those that leave the most offspring that themselves breed

Decide before you look. Answer on page 40.

WATCH OUT

Three more slips. **Individuals do not evolve:** a population does, across generations. **Mutations do not happen because they are needed:** they are chance changes (chapter 2). **Natural selection does not make perfect organisms:** it sorts what variation is on offer, under today's conditions, so every organism is a compromise.

02

D4.1.2 WHERE VARIATION COMES FROM (I IN ICE AGE)

Variation to *select from*

Selection can only choose between things that differ. In any sexually reproducing population, individuals differ in their heritable traits because they differ in their alleles. Two processes keep supplying them.

Mutation is the only source of brand new alleles. A copying slip, or damage to DNA, changes the base sequence of a gene, and the changed version is a new allele. Mutations happen by chance, with no regard for need. Most do nothing noticeable, some are harmful, and a few turn out to be useful under some conditions. Only a mutation in the cells that make gametes can be passed on.

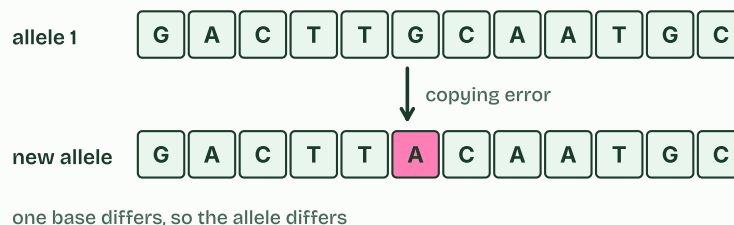
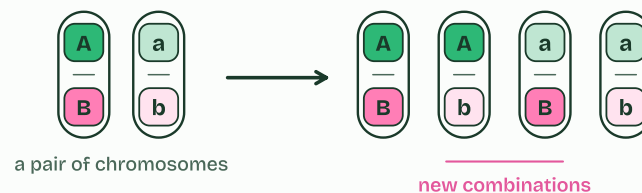
Sexual reproduction makes **new combinations** of the alleles that already exist. In meiosis, crossing over swaps pieces between a pair of chromosomes, and independent assortment sends each pair's chromosomes to the gametes at random (a person can make more than eight million different chromosome mixes this way alone, before any crossing over). Fertilisation then joins two gametes that met by chance. So no two siblings, apart from identical twins, have the same set of alleles.

Put the two together. Mutation adds alleles to the population's stock. Sexual reproduction shuffles that stock into endless new individuals. Without both, there would be nothing for selection to act on, and no change.

KEY TERMS

mutation

A random change in the base sequence of DNA. A mutation in a gene can make a new allele.

Mutation: a new allele**Sexual reproduction: new combinations**

STEP BY STEP

4 STEPS

1 Mutation: a new allele

allele 1 G A C T T G C A A T G C

Sexual reproduction: new combinations

A gene is a sequence of **bases**. This version is one allele of the gene.

2 Mutation: a new allele

allele 1 G A C T T G C A A T G C

↓ copying error

new allele G A C T T A C A A T G C

one base differs, so the allele differs

Sexual reproduction: new combinations

A copying error changes **one base**. The changed sequence is a **new allele**: mutation makes new alleles.

3 Mutation: a new allele

allele 1 G A C T T G C A A T G C

↓ copying error

new allele G A C T T A C A A T G C

one base differs, so the allele differs

Sexual reproduction: new combinations



a pair of chromosomes crossing over swaps pieces

In meiosis, **crossing over** swaps pieces between a pair of chromosomes that carry the alleles A, B and a, b.

4 Mutation: a new allele

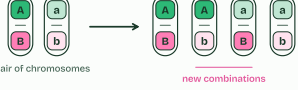
allele 1 G A C T T G C A A T G C

↓ copying error

new allele G A C T T A C A A T G C

one base differs, so the allele differs

Sexual reproduction: new combinations



a pair of chromosomes

new combinations

The gametes carry **combinations** that neither chromosome had before: sexual reproduction makes new combinations of alleles.

WATCH OUT

A mutation is not a response to a problem. A bacterium does not mutate because an antibiotic is near, and a beetle does not mutate because the winter is cold. The mutation arrives by chance, and the environment decides whether it helps.

PREDICT

Where does the very first copy of a new allele come from?

- (A) Crossing over during meiosis, which shuffles the alleles each parent already has
- (B) A mutation in the DNA of a cell that goes on to make gametes
- (C) Natural selection, which builds the alleles that the population needs most

Decide before you look. Answer on page 40.

03

D4.1.3 D4.1.4 OVERPRODUCTION AND PRESSURES (C AND E IN ICE AGE)

More offspring than the world can *feed*

Most species make far more offspring than ever survive. A frog lays hundreds or thousands of eggs, and an oak drops thousands of acorns. If every one grew up and bred, the population would explode. It does not, because the place where it lives can support only so many.

The **carrying capacity** is that limit. It is set by whatever runs short first: food, water, shelter or nesting sites, space, and for plants light and mineral nutrients. When there are more young than the resources can supply, they **compete**. Individuals of the same species need the same things, so competition within a species is especially sharp, and the ones that win leave more offspring.

Not every pressure is about running short. An **abiotic factor** such as a heat-wave, a hard frost, a drought or a flood can kill or spare individuals according to their traits. These are **density-independent** factors: a frost that kills half of a sparse patch of seedlings kills about half of a crowded patch too. A seedling with an allele that lets it tolerate cold has a better chance of surviving the frost and setting seed.

Any factor that makes some individuals more likely to survive and reproduce than others is a **selection pressure**. Food, water, nest sites and cold are all selection pressures. In ICE AGE this chapter is C, for competition, and E, for the environmental pressure that sorts the winners from the rest.

KEY TERMS

carrying capacity

The largest population an environment can support for a long time, set by the resources that run short first.

compete

To use or try to win the same limited resource, such as food, a territory or a mate.

abiotic factor

A non-living part of the environment, such as temperature, water, light, pH or salinity.

density-independent

Affecting a population in the same way whatever its density, so the same share of individuals is hit whether it is crowded or sparse.

selection pressure

An environmental factor that makes individuals with some heritable traits more likely to survive and reproduce than others.

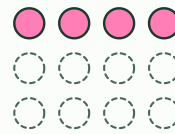
More young than places

4 places with food



4 adults, one to a place

12 young



4 find a place

8 find none

Food sets the limit, not the number born.

Two patches of seedlings, then a cold snap

sparse patch



2 of 4 die

the same share in each patch

crowded patch



6 of 12 die



frost

STEP BY STEP

5 STEPS

1

More young than places

4 places with food



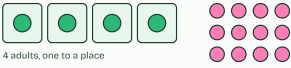
4 adults, one to a place

A habitat has **four places** with enough food, and four adults hold them.

2

More young than places

4 places with food



4 adults, one to a place

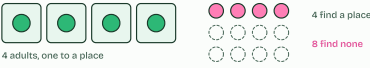
12 young

The adults raise **twelve young**: far more than the places can hold.

3

More young than places

4 places with food



4 adults, one to a place

12 young

4 find a place

8 find none

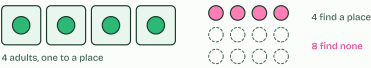
Food sets the limit, not the number born.

The young **compete**. Only four find a place; eight find none. The limit is the food, not the number born.

4

More young than places

4 places with food



4 adults, one to a place

12 young

4 find a place

8 find none

Food sets the limit, not the number born.

Two patches of seedlings, then a cold snap

sparse patch



crowded patch



A different pressure: two patches of seedlings, one **sparse** and one **crowded**.

5

More young than places

4 places with food



4 adults, one to a place

12 young

4 find a place

8 find none

Food sets the limit, not the number born.

Two patches of seedlings, then a cold snap

sparse patch



2 of 4 die
the same share in each patch

crowded patch



6 of 12 die

✱ frost

A cold snap kills half of each. It is **density-independent**: the share lost does not depend on the crowd.

LINKING QUESTION

What mechanisms minimise competition? Species can share a place without fighting over everything: one feeds high in the tree and one low, one by day and one by night, young and adults eat different foods (tadpoles and frogs), territories space individuals out, and seeds are carried away from the parent plant. Sharing out resources like this is the subject of B4.2 (ecological niches).

PREDICT

A late frost kills 60% of the seedlings in a sparse patch. How will a crowded patch of the same plant fare?

- (A) A larger share will die, because crowded seedlings are weaker and the cold finishes them
- (B) A smaller share will die, because the crowd shelters each seedling from the cold
- (C) About the same share will die: the frost does not count heads

Decide before you look. Answer on page 40.

04

Who survives, who *breeds*

D4.1.5

D4.1.6

FITNESS AND HEREDITY (A, G AND E IN ICE AGE)

Look closely at any population and the individuals differ in how well they are suited to their surroundings. Each of these helpful differences is an **adaptation**. In a crowd competing for the same limited food, the individuals with the better adaptations are more likely to survive, and to breed. That is natural selection through competition within a species, which is the case you are asked to study.

What selection really measures is **fitness**. Fitness has two parts: the **survival value** of a genotype (how likely it is to live long enough to breed) and its **reproductive potential** (how many offspring it tends to leave). An animal that lives to a great age but leaves no young has fitness of zero, because none of its alleles reach the next generation.

One more condition has to hold. The trait must be **heritable**. Only differences in alleles are handed down. A body-builder's muscles, a scar, a clipped hedge or a bird that grew large on extra food all arise from what happened in life, and are not encoded in the base sequence of the genes in the gametes. They die with the individual and are not evolution.

Put the pieces in ICE AGE order. Adaptations help some individuals survive and breed (A). Their alleles become commoner in the next generation (G). The population has changed (E). Then the whole cycle starts again with the new generation.

KEY TERMS

adaptation

A heritable feature that makes an organism better suited to its environment, so it survives and reproduces better.

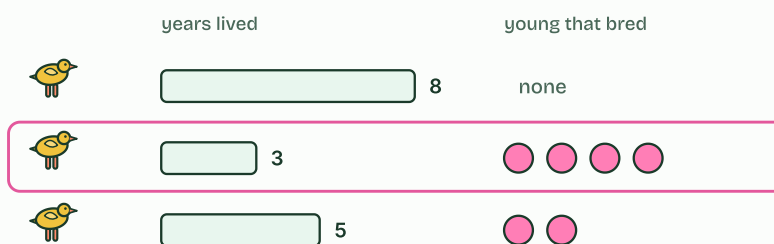
fitness

How well an individual or genotype does at surviving and at leaving offspring that survive to breed. It combines survival value and reproductive potential.

heritable

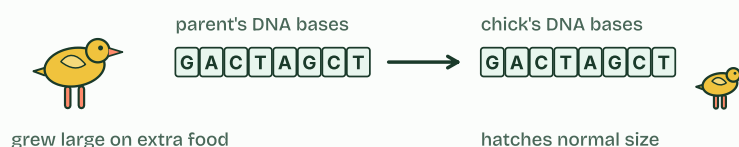
Passed from parents to offspring in the base sequence of their genes.

Fitness counts young that breed



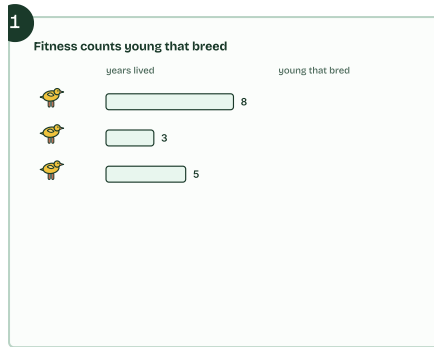
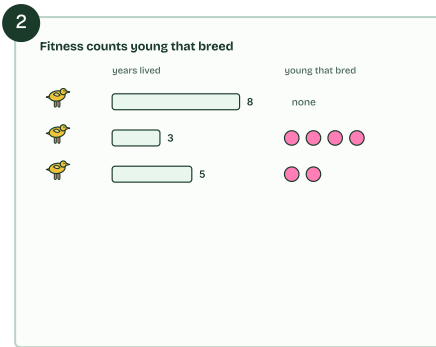
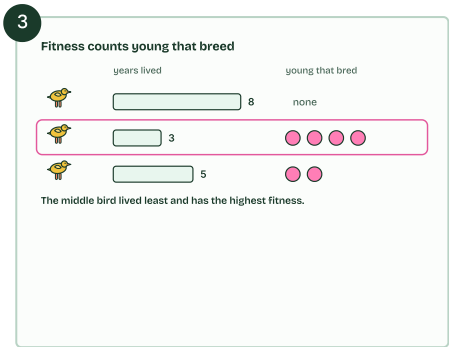
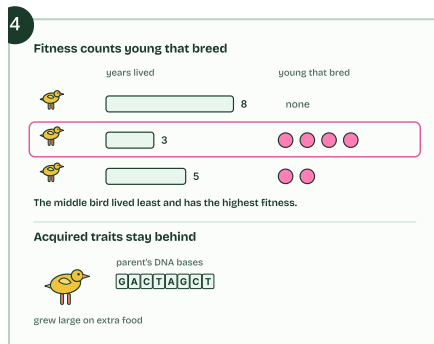
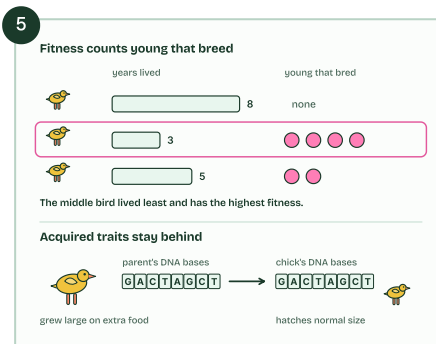
The middle bird lived least and has the highest fitness.

Acquired traits stay behind



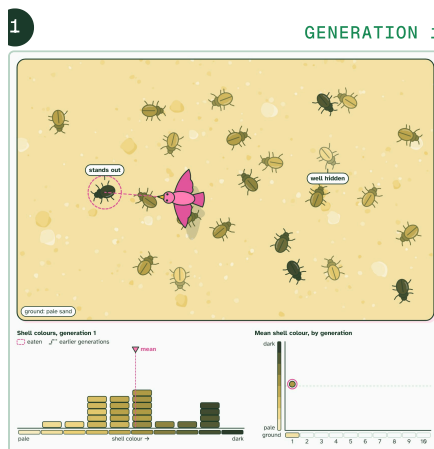
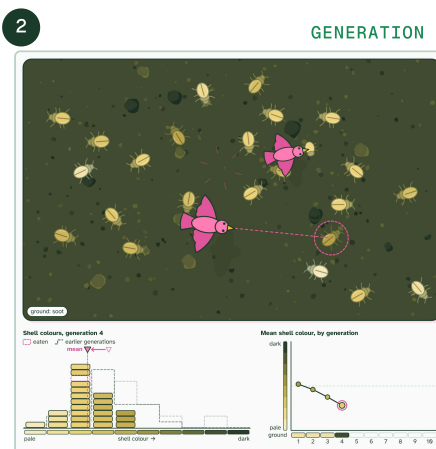
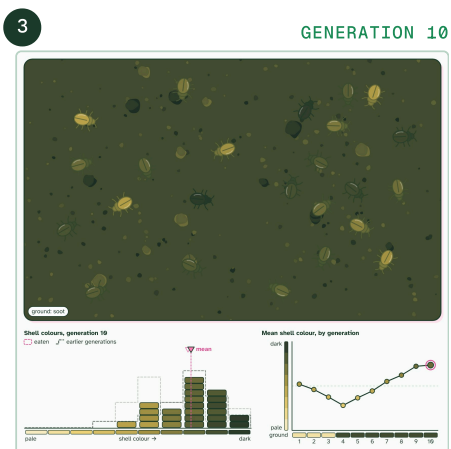
STEP BY STEP

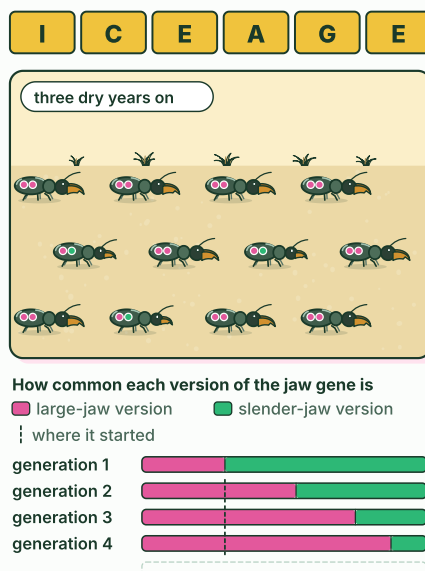
5 STEPS

Three birds, and how many years each **lived**.And how many young each raised that reached **breeding age**.The bird that lived least has the **highest fitness**. Survival matters only because it lets an animal reproduce.A parent grew large on extra food. Its DNA bases are the same as before: the size was **acquired**.The chick inherits the same bases and hatches a normal size: an acquired trait is **not heritable**.

ANIMATION · WATCH IT HAPPEN: A POPULATION CHANGES

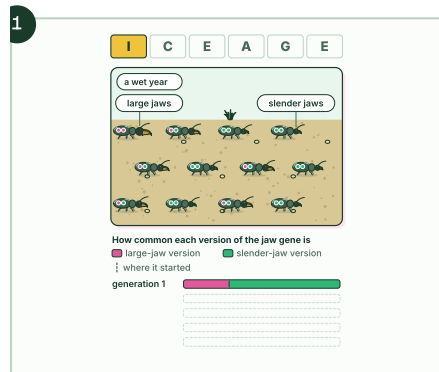
3 MOMENTS

Birds spot the beetles that stand out. The **best hidden** survive and breed.Then soot from a fire darkens the ground. Now the **pale** beetles stand out.No beetle ever changed its shell. The **population** changed: that is evolution.Watch it move, and change it as it runs: biologybybradford.com/guides/ib-biology-d4-1-natural-selection#fitness

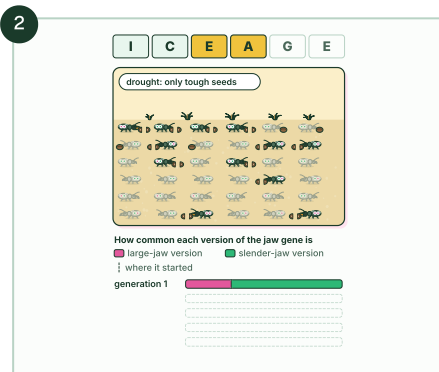


STEP BY STEP

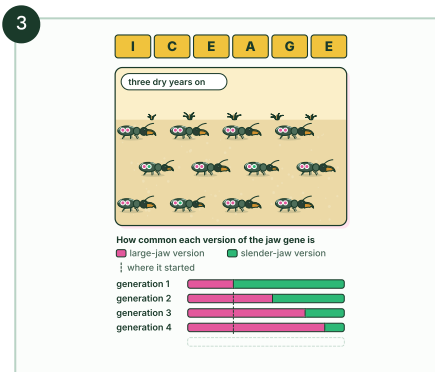
3 STEPS



Generation 1: the beetles' jaws vary, slender to large, and each carries two copies of the jaw gene (the pips: pink for large, green for slender). Which letter is this?



A drought leaves only tough seeds: who cracks them, and who starves? Predict before you run it.



Three dry years on. What has happened to the population, and to any one beetle?

WATCH OUT

Fitness is not fitness training. Nothing you gain by exercise, diet or injury changes the alleles you pass on, and a long life is worth nothing to evolution unless it comes with offspring.

LINKING QUESTION

How do intraspecific interactions differ from interspecific interactions? Intraspecific interactions are between individuals of one species, such as competing for the same food or mates, and they drive selection between the alleles in one gene pool. Interspecific interactions are between different species: predation, parasitism, mutualism and competition between species. Each can act as a selection pressure on the other species. C4.1 (populations and communities) takes both further.

PREDICT

A cat lives 15 years but raises no surviving kittens. A second cat lives 6 years and raises 8 kittens that all breed. Which has the higher fitness?

- ☐ (A) The second, because it left more offspring that went on to breed
- ☐ (B) The first, because it lived longer and so had more chances to pass on its alleles
- ☐ (C) Neither, because fitness describes a whole population and not single animals

Decide before you look. Answer on page 40.

PREDICT

A weight-lifter trains for years and builds large muscles. Her child is born. What can you say about the child's muscles?

- ☐ (A) They will be larger than average, because training changes the alleles she passes on
- ☐ (B) They will be slightly larger at first, then fade if the child does not train
- ☐ (C) They will be as large as the child's own alleles and own training allow

Decide before you look. Answer on page 40.

05

D4.1.7 SEXUAL SELECTION

Choosing a *mate*

Surviving is not enough: an animal has to find a mate. In many animals that is a contest of its own, and the traits that win it can be different from the ones that help you survive. **Sexual selection** is selection for success in getting mates.

It comes in two forms. In **intrasexual selection** members of one sex, usually males, compete with each other for access to mates: stags fight, and males display at one another. In **intersexual selection** one sex, usually females, chooses among the other.

A trait that wins mates is often a sign of overall fitness. A glossy coat, bright colour, loud call or large antler is hard to grow and keep up without good health and a good diet. A chooser that prefers it is, in effect, choosing a mate in good condition, and her offspring inherit the alleles that built the display and the allele for choosing it.

The male birds of paradise show it best. In many species the males have spectacular plumage, and perform elaborate displays and dances to the females that come to watch and pick. Each generation, the males with the finest displays leave the most young, and the plumage gets more extreme.

But the display has costs. Long feathers hinder flight, bright colour is easier for predators to see, and displaying takes energy and time that could go into feeding. A trait of this kind spreads only while the extra young it brings outweigh the extra risk. Natural selection and sexual selection can pull in opposite directions, and the next chapter is a real experiment on that tug of war.

KEY TERMS

sexual selection

Selection for traits that improve an animal's success in getting mates, even where the trait does nothing for survival or makes it harder.

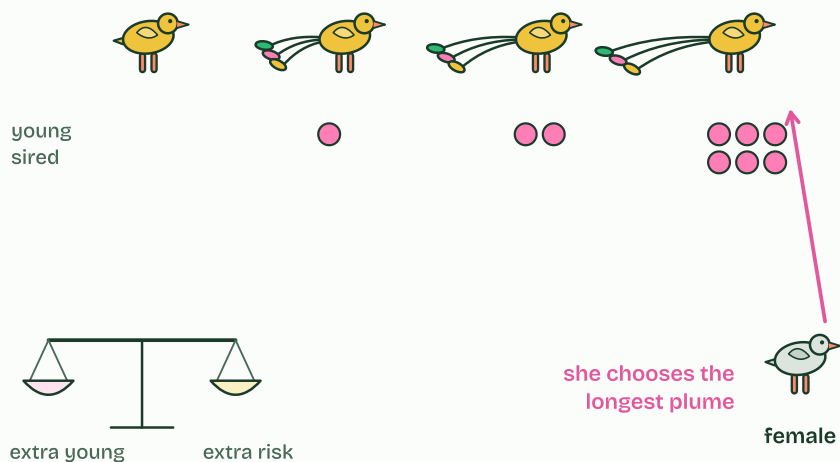
intrasexual selection

Competition between members of the same sex, usually males, for access to mates, as when stags fight with their antlers.

intersexual selection

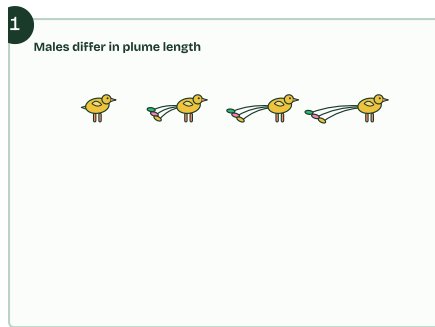
Choice of a mate by members of one sex, usually females, among the members of the other sex, based on their traits.

Males differ in plume length

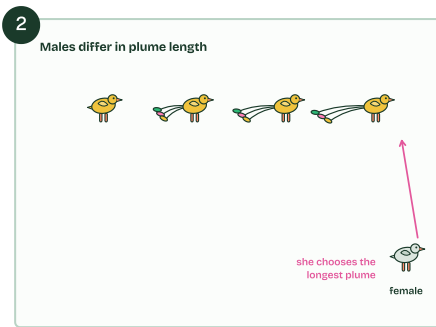


STEP BY STEP

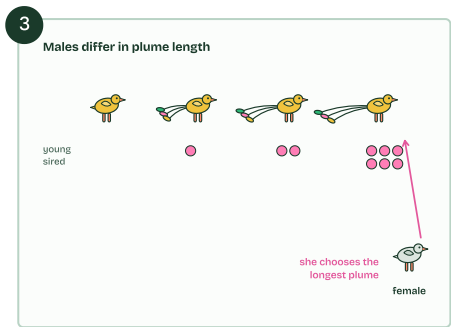
4 STEPS



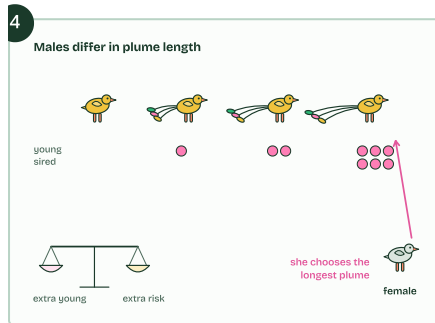
Four males of one species, with **plumes** of different lengths.



A female looks them over, and **chooses** the longest plume.



The male she chooses sires the **most young**, and they inherit his alleles for a long plume.



But a long plume has a **cost**: it spreads only while the extra young outweigh the extra risk.

EXAMPLE

Frogs. In many species the males call to attract females, and females tend to be drawn to louder calls. Calling costs energy, and it also tells predators where the caller is.

WATCH OUT

Sexual selection is not "survival of the fittest" in the sense of the strongest staying alive. A male that is eaten the day after mating has still passed on his alleles, and one that lives for years but never mates has not.

PREDICT

A male's bright tail makes him easier for predators to catch. How can the trait still spread through the population?

- (A) It cannot, because any trait that lowers survival is always removed
- (B) Only if the extra matings it brings outweigh the extra risk of being caught
- (C) It will, because bright males live longer when predators learn to avoid them

Decide before you look. Answer on page 41.

06

D4.1.8 MODELLING SELECTION: ENDLER'S GUPPIES

Two pressures, *tested*

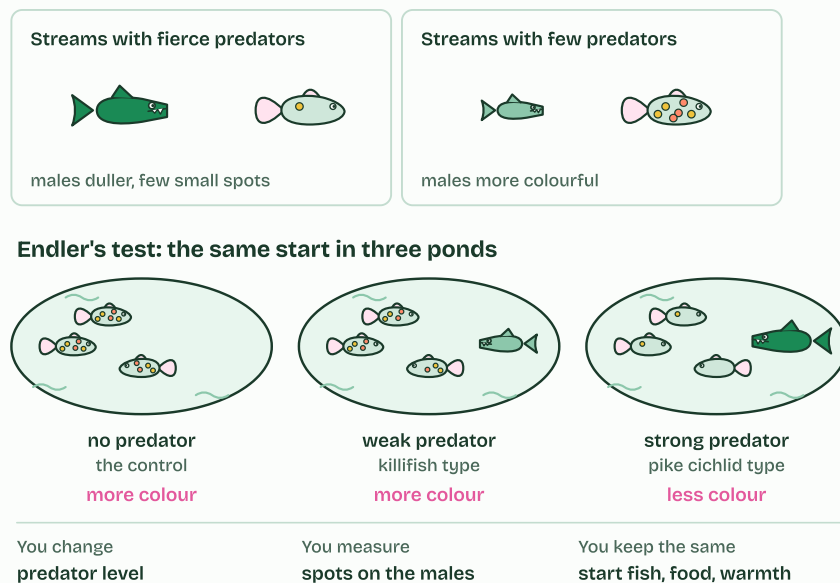
Wild guppies (*Poecilia reticulata*) live in streams in Trinidad. The males carry spots of orange, black and shimmering colours, and the females are plain. Females tend to prefer the more colourful males, which is sexual selection pushing towards brighter males. But a bright male is also easier for a predator to see, which is natural selection pushing towards duller males.

The balance depends on the predators. Streams with dangerous predators have duller males, and streams with few predators have more colourful ones. That is a pattern, not a proof: streams differ in many other ways too.

John Endler tested it as a scientist should, by controlling everything except the thing he suspected. He set up ponds with the same starting guppies, the same food and the same conditions, and changed one thing, the predator: none, a weak predator, or a dangerous one. Then he followed the males' spots over many generations. The experiment **models** the streams: it is simpler than nature, so one pressure can be isolated and measured.

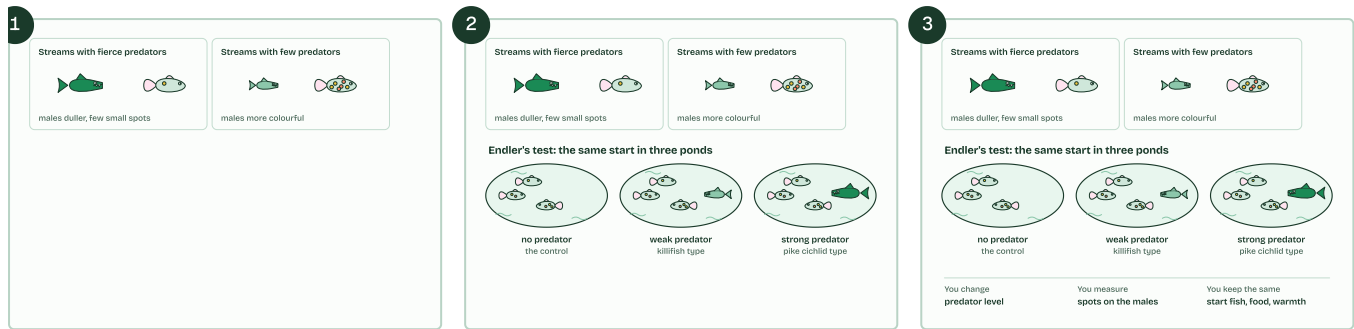
His result, in the direction that matters: where the predator was dangerous, the males came to have fewer and duller spots. Where there was no predator, or only a weak one, they ended up more colourful than they started. Predation is a strong selection pressure, strong enough to reverse what sexual selection builds.

The dry lab at the end of this guide lets you run the ponds yourself, then change the predator, the strength of mate choice and the number of generations.



STEP BY STEP

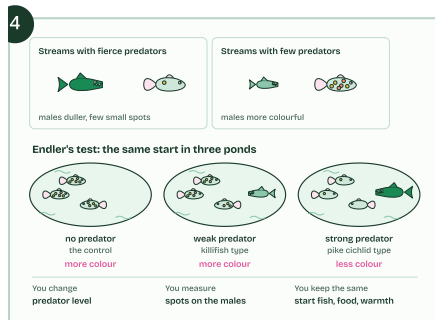
4 STEPS



In the wild, males in streams with **fierce predators** are duller than males in streams with few.

Endler set up **three ponds** with the same starting guppies: no predator, a weak predator and a dangerous one.

He changed **one thing**, the predator, measured the males' spots, and kept everything else the same.



After the generations: more colour with no or a weak predator, **less colour** with the dangerous one.

READING DATA LIKE THIS

Ask four questions of any graph of mean spots per male against generations. Where does each pond **start** (the same place, if the start was controlled)? Which way does each line **move**? Do the lines **separate** as the generations pass? And which pond is the **control**, the baseline the others are compared with? Differences between ponds, not changes inside one, are what show selection.

WATCH OUT

A single male does not change colour in response to the predator. The change is in the population, across generations, as males with some alleles leave more young than others. Check which one a result is claiming.

PREDICT

In the pond with the dangerous predator, males end up with fewer spots. What is the best explanation?

- (A) Males that show a lot of colour are caught more often, so duller males leave more offspring
- (B) Each male gradually loses its spots when it is hunted, and keeps them when it is safe
- (C) Females in the dangerous ponds stop preferring bright males, so the males stop growing spots

Decide before you look. Answer on page 41.

07

The *gene pool*

D4.1.9 HL

D4.1.10 HL

THE GENE POOL AND ALLELE FREQUENCIES

Natural selection happens to individuals, but evolution is a change in the population. To describe that change you need a way to describe a whole population's genes at once. A **gene pool** is all the genes and their different alleles in a population. Picture every allele of every individual tipped into one bag.

The useful number to take from a gene pool is an **allele frequency**: how common each allele is. Count the copies of one allele, and divide by the total number of alleles of that gene in the population. A diploid individual has two alleles of each gene, so a population of 10 has 20. Frequencies of all the alleles of a gene add up to 1, or 100%.

Two populations that are geographically isolated, with few or no individuals breeding across the gap, build up different gene pools. Their allele frequencies differ, because the pressures on each side differ and no alleles pass between the two. Comparing allele frequencies between populations is a way to see how far apart their gene pools have become.

Real allele frequencies are stored in public databases of human populations, and you are asked to search one. Your teacher will name the database your class uses. A search like this works with any of them.

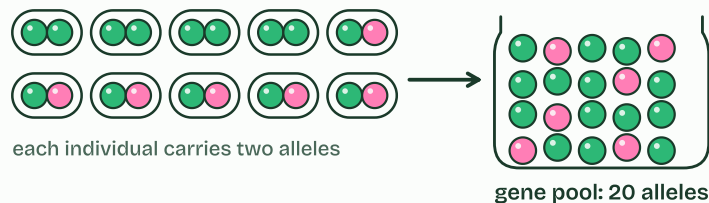
KEY TERMS

gene pool

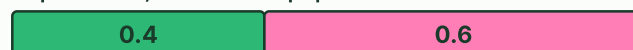
All the genes, and all the different alleles of them, present in a population.

allele frequency

The proportion of all the alleles of a gene in a gene pool that are one particular allele, as a decimal or a percentage.

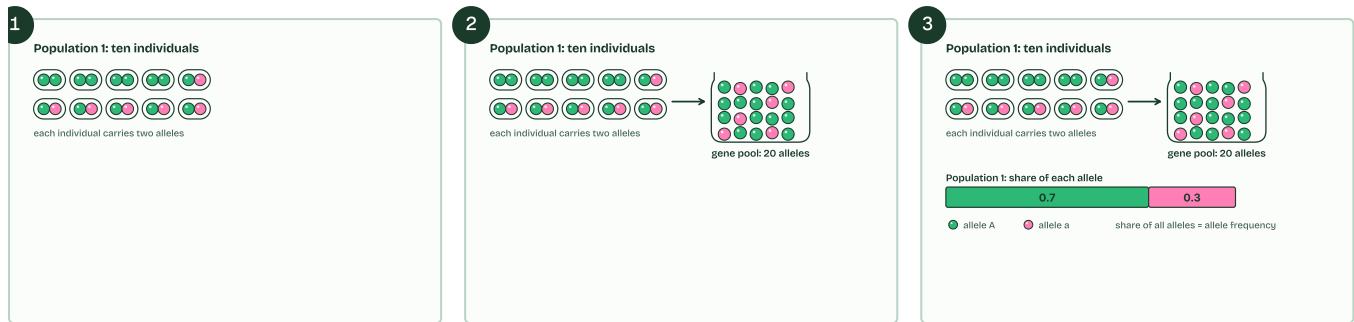
Population 1: ten individuals**Population 1: share of each allele**

sea

Population 2, cut off from population 1

STEP BY STEP

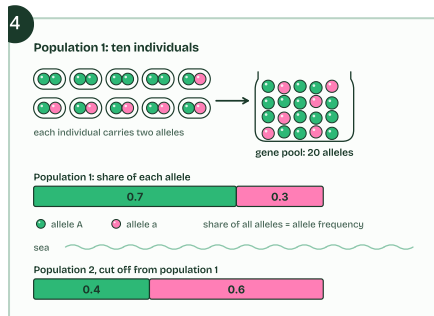
4 STEPS



Ten individuals, each carrying **two alleles** of one gene: allele A in green, allele a in pink.

Tip every allele into one jar: the **gene pool**, 20 alleles, 14 of them A and 6 of them a.

The **allele frequency** of A is 14 out of 20, which is 0.7. The frequencies of A and a add to 1.



A second population, cut off from the first, has **different** frequencies: 0.4 and 0.6.

YOUR SEARCH, IN SIX STEPS

1. Open the database your teacher names, and search for a gene or a variant. A good choice is the sickle-cell allele of the haemoglobin beta gene (*HBB*; the variant is called rs334).
2. Find the table of allele frequencies by population.
3. Choose two populations from different parts of the world, for instance one from West Africa and one from northern Europe.
4. Write down the frequency of the same allele in each.
5. Compare them. Which is higher, and by roughly how much?
6. Suggest a reason. The sickle allele protects heterozygotes against malaria, so where malaria has been common its frequency has been pushed up.

No database to hand? The pattern you should find is that the allele is absent or very rare in the northern European populations and common in several West African ones.

PREDICT

A population of 50 diploid individuals has 30 copies of allele B in its gene pool. What is the frequency of B?

- (A) 0.30, because 30 copies is the same as 30 out of every 100 individuals
- (B) 0.30, because there are 100 alleles in the pool and 30 are B
- (C) 0.60, because 30 of the 50 individuals in the population carry allele B

Decide before you look. Answer on page 41.

08

D4.1.11 HL SELECTION CHANGES ALLELE FREQUENCIES

Selection shifts *allele frequencies*

Darwin explained evolution without knowing how traits are inherited. The missing piece came later, with the study of genes: Mendel's results on inheritance were rediscovered in the early 1900s, and then DNA was found to carry the code. Biologists joined Darwin's natural selection to genetics in what is now called **neo-Darwinism**.

That gives a sharper definition. Evolution is a **change in the allele frequencies of a gene pool** over generations. Mutation adds new alleles, and natural selection is a process that changes how common each one is: individuals differ in their heritable traits, so they differ in how many offspring they leave, and so the alleles that go with the successful traits become more common in the gene pool.

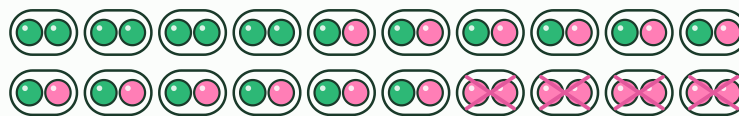
The figure runs one population by hand. Twenty beetles have two alleles for jaw strength: J (the dominant one) lets a beetle crack tough seeds, and j does not. A drought leaves only tough seeds. Beetles with two j alleles cannot feed and do not breed. The survivors carry 20 J out of 32 alleles, so the frequency of J has risen from 0.5 to 0.625. No beetle changed. The gene pool did.

Two points to carry away. Selection acts on **phenotypes**, the traits that individuals show, but evolution is read in **alleles**, in the population. And an allele does not vanish just because the trait it causes is disadvantageous: here j is still carried by the surviving Jj beetles.

KEY TERMS

neo-Darwinism

The modern theory of evolution, combining Darwin's natural selection with genetics: evolution is a change in the allele frequencies of a gene pool.

Generation 0: twenty beetles

Drought: only tough seeds are left. The four jj beetles cannot crack them and starve.

Alleles in generation 0: 20 J and 20 j



Alleles in the 16 survivors: 20 J and 12 j



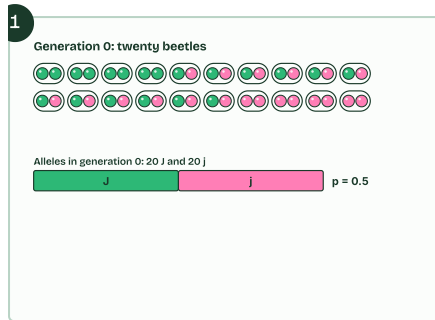
dashed line: where the J share started

The survivors breed, so the next generation inherits this pool:

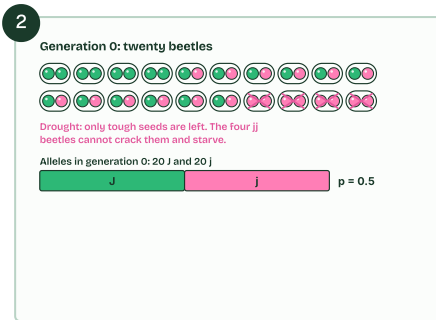
J has risen from 0.5 to 0.625. The population has evolved.

STEP BY STEP

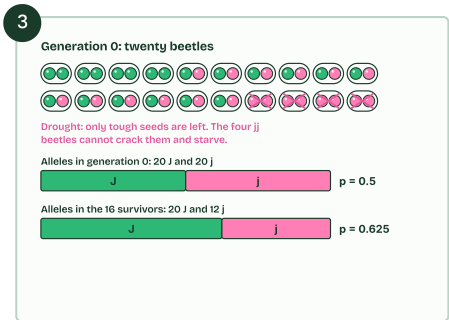
4 STEPS



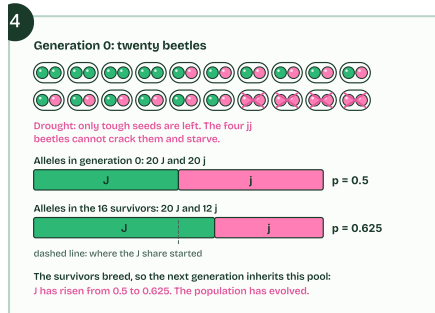
Twenty beetles, each with two alleles of a jaw gene. Across the population, J and j are equally common: $p = 0.5$.



A drought leaves only tough seeds. The four jj beetles cannot feed and do not breed.



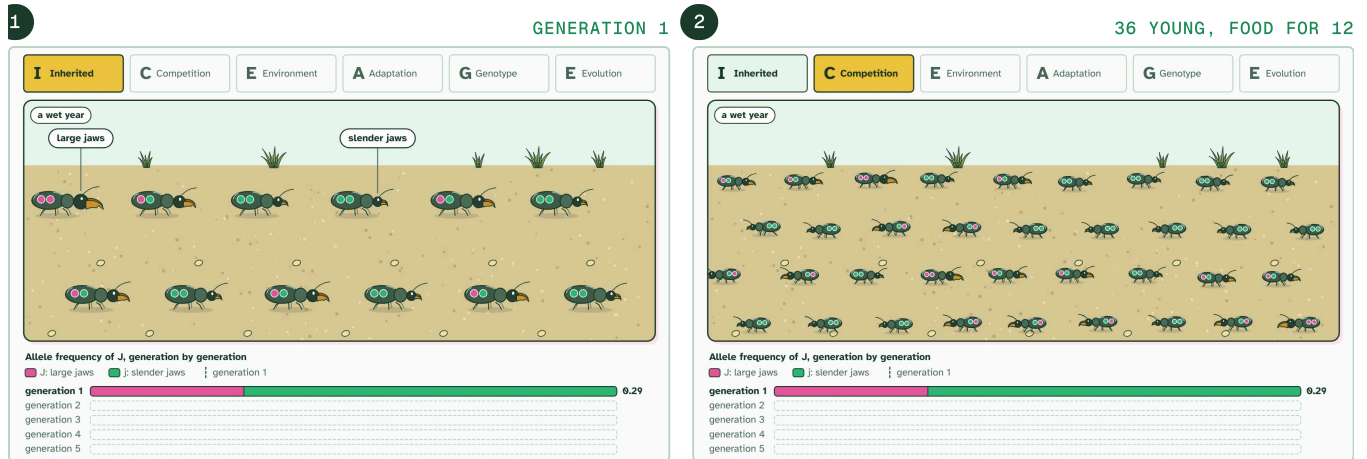
Count the alleles of the 16 survivors: 20 J and 12 j. The frequency of J is now **0.625**.



The survivors breed, so their gene pool is the next generation's. **The allele frequency has changed: evolution.**

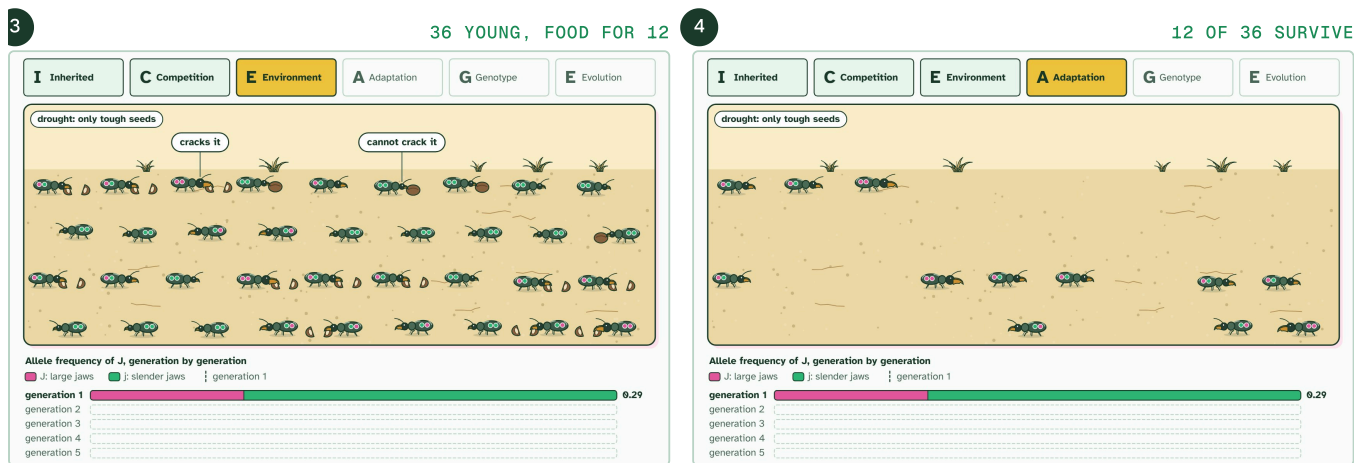
ANIMATION · WATCH IT HAPPEN: ALLELE FREQUENCIES SHIFT

6 MOMENTS



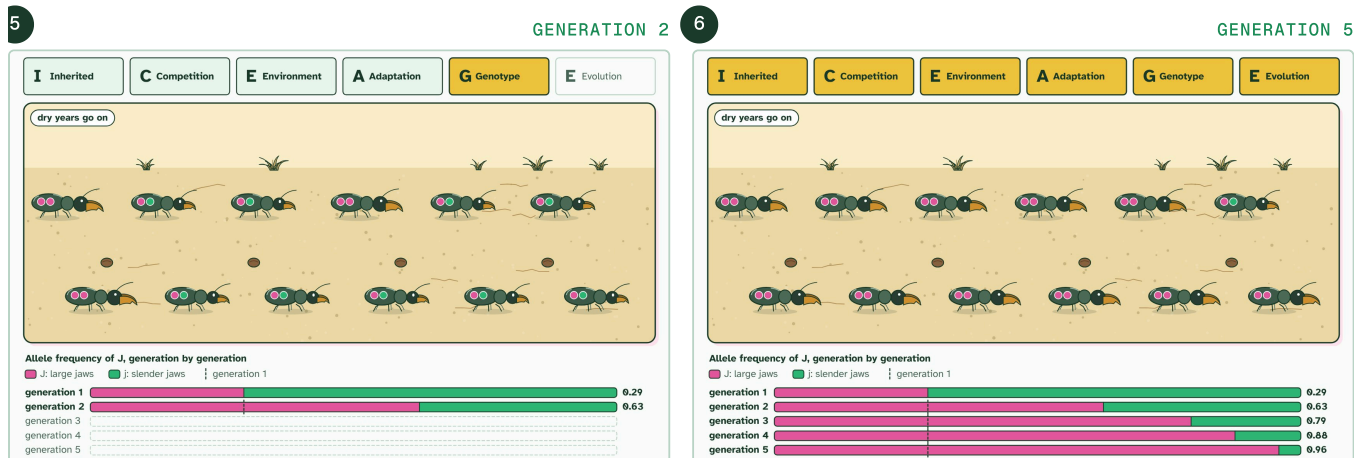
Inherited variation. Jaws differ, set by the two alleles of a jaw gene that each beetle carries (the pips): pink J large, green j slender.

Competition. Twelve beetles leave thirty-six young, three times as many as the ground can feed.



Environmental pressure. A drought leaves only tough seeds. Large jaws crack them; slender jaws cannot, and those beetles starve.

Adaptation. The twelve survivors all have large or medium jaws, the trait that suits a dry year. Every one carries J.



Genotype frequencies change. Only survivors breed, so the allele frequency of J rises in generation 2.

Evolution. The dry years go on. By generation 5 nearly every beetle has large jaws: no beetle changed, the population did.

Watch it move, and change it as it runs: biologybybradford.com/guides/ib-biology-d4-1-natural-selection#neodarwin

WATCH OUT

The frequency of an allele can change without any one individual changing at all. Do not write "the beetles evolved"; write "the allele frequency in the population changed".

PREDICT

In the beetle example, the J share of the gene pool was 0.5 before the drought and 20 of the 32 alleles of the survivors. What is it among the survivors?

- (A) 0.625, because 20 of the 32 surviving alleles are J
- (B) 0.5, because every J allele survived and none was lost
- (C) 0.75, because the four jj beetles carried no J alleles

Decide before you look. Answer on page 41.

09

D4.1.12 HL DIRECTIONAL, STABILISING AND DISRUPTIVE SELECTION

Three ways selection can *act*

A trait such as beak depth varies in a population, and most birds sit near the middle. Which individuals are favoured depends on the pressure, and the shape of the whole distribution shows which of three patterns is acting.

In **directional selection** one extreme is favoured, so the whole population shifts towards it. Antibiotic resistance in bacteria is the standard case: the resistant extreme survives, and resistance alleles become more common.

In **stabilising selection** the middle is favoured and both extremes are removed. Human birth weight is the classic example: very small and very large babies have lower survival than average ones, so the range narrows around the middle.

In **disruptive selection** both extremes are favoured and the middle is removed. Imagine a bird on an island with only very hard seeds and very soft seeds: deep beaks crack the hard, shallow beaks pick up the soft, and middling beaks do neither well. The population may split into two forms.

All three change allele frequencies. This is the point students most often miss for stabilising selection, because the average does not move. But the alleles that push the trait to the extremes are removed, so their frequencies fall, and the alleles for the middle form rise. Any selection that sorts individuals by a heritable trait leaves the gene pool changed.

KEY TERMS

directional selection

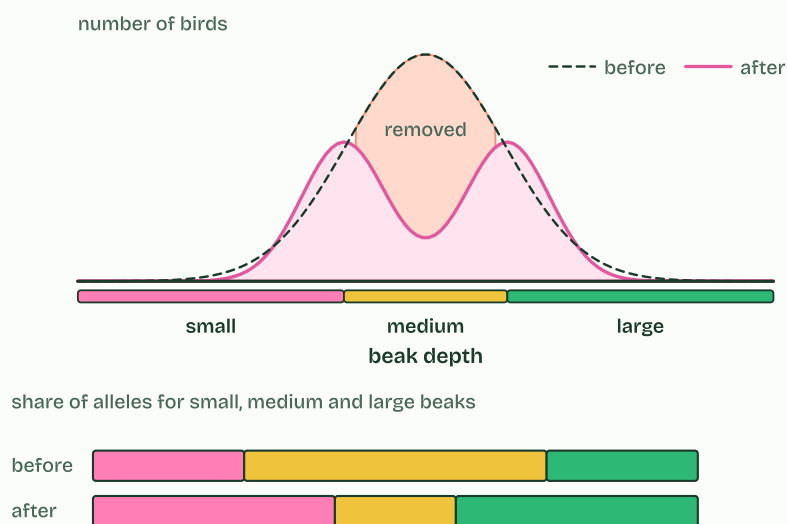
Selection that favours one extreme of a trait, so the population's average shifts in that direction.

stabilising selection

Selection that favours the intermediate form and removes both extremes, so the range narrows and the average stays put.

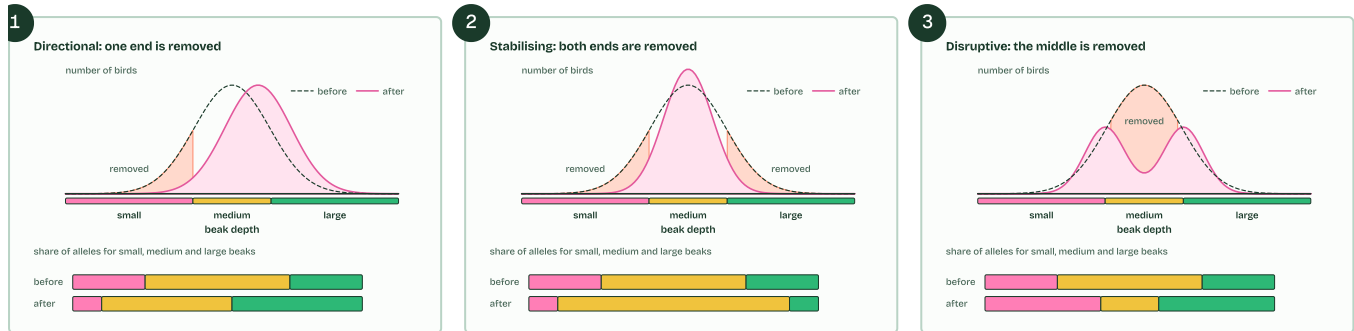
disruptive selection

Selection that favours both extremes and removes the intermediate form, so the population may split into two groups.

Disruptive: the middle is removed

STEP BY STEP

3 STEPS



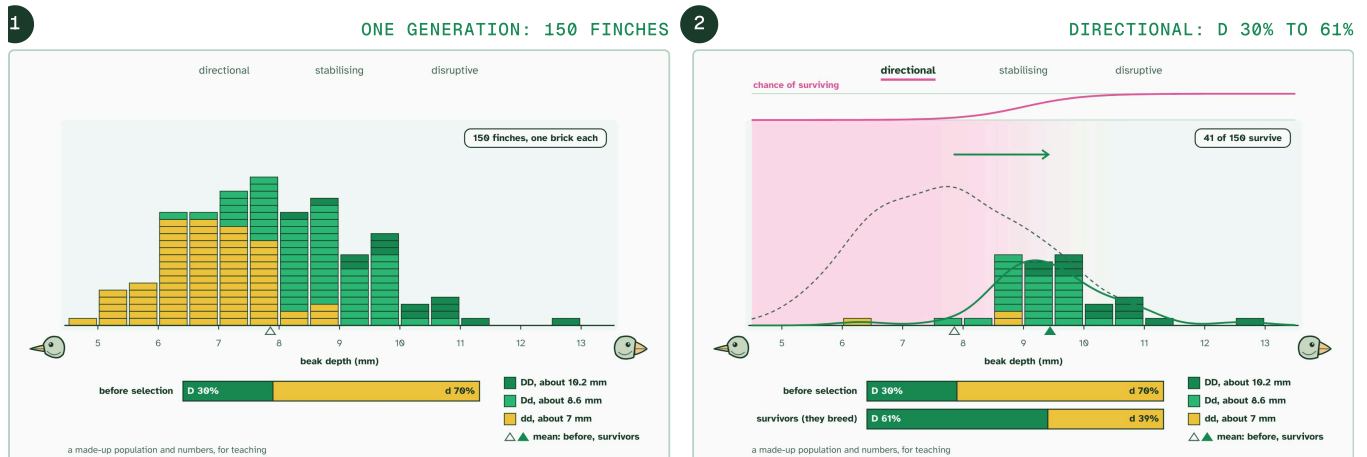
Directional: one tail of the curve is removed, and the whole curve shifts. Alleles for large beaks become commoner.

Stabilising: both tails are removed and the curve narrows. Alleles for the extremes become rarer.

Disruptive: the middle is removed and the curve splits in two. Alleles for both extremes become commoner.

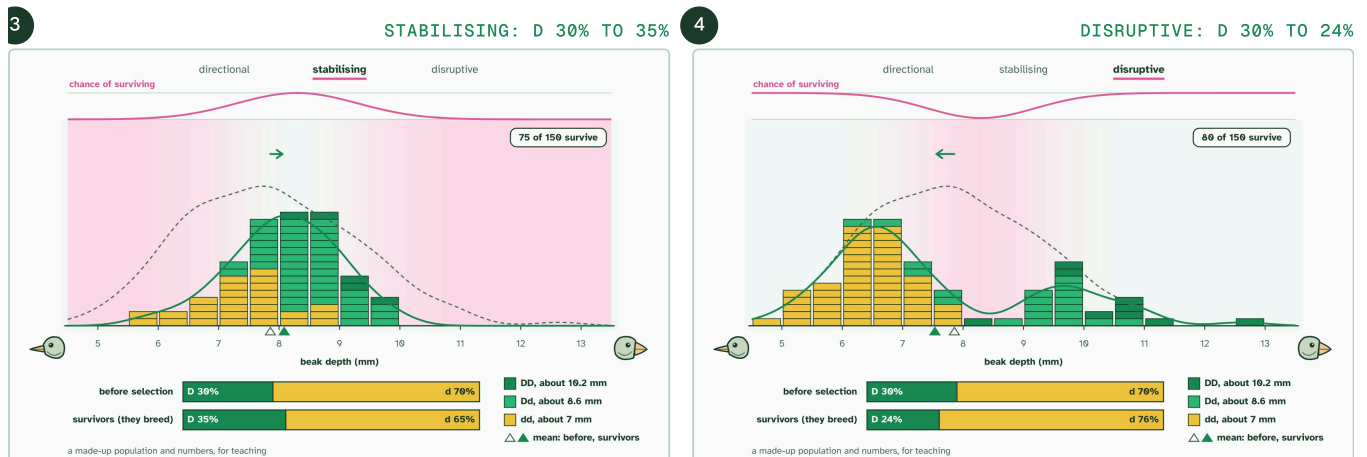
ANIMATION · WATCH IT HAPPEN: ONE POPULATION, THREE KINDS OF SELECTION

4 MOMENTS



One population of 150 finches: how deep each beak is. One gene adds about 1.6 mm for each **D** allele; other genes and food add the rest. **D** is 30% of the alleles.

The survivors breed. Their mean moves deeper, and **D** rises from 30% to 61% of the alleles they pass on.



The spread narrows. **D** still shifts, 30% to 35%: the favoured middle is mostly Dd, so more **D** is kept than before.

Two peaks are left. The middle was mostly Dd, so **D** falls, 30% to 24%. All three kinds change allele frequency.

Watch it move, and change it as it runs: biologybybradford.com/guides/ib-biology-d4-1-natural-selection#modes

REMEMBER IT

The three kinds of selection

D Drive	S Squeeze	D Divide
Directional one end is removed and the mean shifts	Stabilising both ends are removed and the range narrows	Disruptive the middle is removed and two groups emerge

WATCH OUT

Stabilising selection is not "no selection". The average stays the same because selection is at work: it keeps removing the extremes. Remember that all three kinds change allele frequencies.

PREDICT

Babies of very low and very high birth weight are less likely to survive than babies of average weight. Which kind of selection is this?

- (A) Directional selection, because birth weight is being pushed in one direction
- (B) Disruptive selection, because birth weights at both extremes are being favoured
- (C) Stabilising selection, because both extremes are removed

Decide before you look. Answer on page 41.

D4.1.13 HL

D4.1.14 HL

THE HARDY-WEINBERG EQUATION

10

What a population would be like if it were *not* evolving

To tell whether a population is evolving you need something to compare it with. The **Hardy-Weinberg equation** gives it: the genotype frequencies you would expect in a population in genetic equilibrium, where the allele frequencies stay the same from one generation to the next.

For a gene with two alleles, let p be the frequency of one (A) and q the frequency of the other (a). They are the only alleles, so $p + q = 1$. With random mating, any egg can meet any sperm, so the genotype frequencies are the square of that: $p^2 + 2pq + q^2 = 1$, where p^2 is AA, $2pq$ is Aa and q^2 is aa. The figure shows why the middle term is double: there are two ways to be a heterozygote.

You can use it two ways. From the allele frequencies, work out the genotypes. Or, if one genotype is known, work back to the alleles. The one you can usually see is the homozygous recessive, whose frequency is q^2 : take the square root to get q , then $p = 1 - q$.

The equation holds only if five conditions are met. If real data do not fit it, one of them is failing, and the population is evolving.

KEY TERMS

Hardy-Weinberg equation

For a gene with two alleles, $p + q = 1$ and $p^2 + 2pq + q^2 = 1$, which predict the genotype frequencies from the allele frequencies in a population in genetic equilibrium.

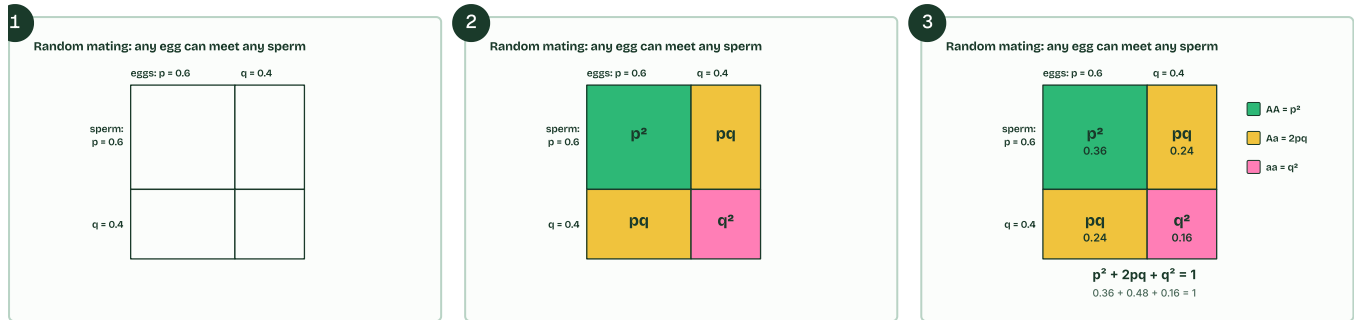
Random mating: any egg can meet any sperm



If 16% show the recessive trait, $q^2 = 0.16$,
so $q = 0.4$ and $p = 1 - 0.4 = 0.6$

STEP BY STEP

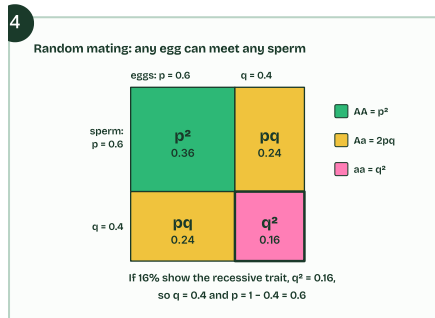
4 STEPS



Egg and sperm alleles meet at random. If the frequency of A is $p = 0.6$ and of a is $q = 0.4$, each edge of the square is split in those proportions.

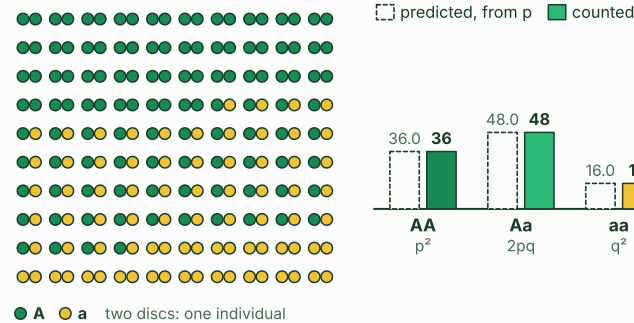
The four areas are the four ways eggs and sperm can combine: p^2 , pq , pq and q^2 .

AA is $p^2 = 0.36$, Aa is $2pq = 0.48$ and aa is $q^2 = 0.16$. Together they make 1.



Working back: if 16% show the recessive trait, $q^2 = 0.16$, so $q = 0.4$ and $p = 0.6$.

100 individuals: $p = 0.60$, $q = 0.40$



A recessive condition in 1 in 2500 people

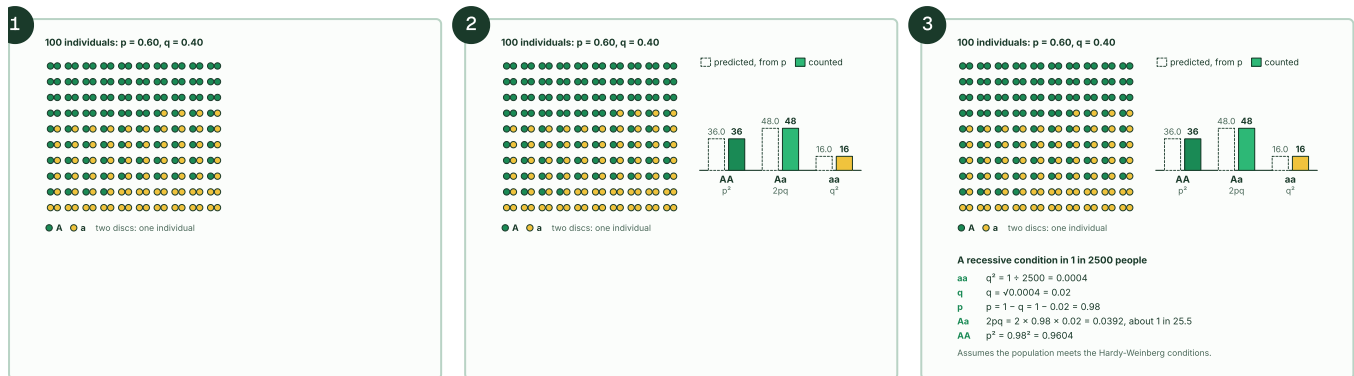
$$\begin{aligned}
 aa & q^2 = 1 \div 2500 = 0.0004 \\
 q & q = \sqrt{0.0004} = 0.02 \\
 p & p = 1 - q = 1 - 0.02 = 0.98 \\
 Aa & 2pq = 2 \times 0.98 \times 0.02 = 0.0392, \text{ about 1 in 25.5} \\
 AA & p^2 = 0.98^2 = 0.9604
 \end{aligned}$$

Assumes the population meets the Hardy-Weinberg conditions.

Move p and q , then switch off each condition in turn and see how the population compares with the prediction.

STEP BY STEP

3 STEPS



One gene, two alleles: p is the frequency of A, q of a, and $p + q = 1$. Here $p = 0.60$.

Hardy-Weinberg predicts the genotypes from p and q : $p^2 + 2pq + q^2 = 1$. When every condition is met, the counts fit.

It works backwards too. From the aa frequency, 1 in 2500: $q = 0.02$, $p = 0.98$, and carriers $2pq = 0.0392$, about 1 in 26.

REMEMBER IT

The five Hardy-Weinberg conditions

L Large	R Rats	M Make	M Most	S Spaghetti
Large population big enough that chance does not shift the frequencies	Random mating no mate choice by genotype, no inbreeding	Migration: none no alleles arrive or leave	Mutation: none no new alleles appear	Selection: none every genotype survives and breeds equally well

WORKED EXAMPLE

In a population of 200 beetles, 18 are green, which is a recessive trait. $q^2 = 18/200 = 0.09$, so $q = 0.3$ and $p = 0.7$. The heterozygotes are $2pq = 2 \times 0.7 \times 0.3 = 0.42$, which is 84 beetles. Check: AA = 0.49 (98 beetles), Aa = 0.42 (84), aa = 0.09 (18); $98 + 84 + 18 = 200$.

PREDICT

A recessive condition affects 1 person in 2500. Roughly how many people in the population are carriers (heterozygous)?

- (A) About 1 in 25, since $2pq$ is about 0.04
 (B) About 1 in 2500, the same as the number affected
 (C) About 1 in 50, since the frequency of the allele q is 0.02

Decide before you look. Answer on page 41.

PREDICT

In a population, the allele frequencies of A and a are both 0.5, but the genotypes seen are AA 0.40, Aa 0.20 and aa 0.40. What do you conclude?

- (A) Nothing is wrong: the equation allows any genotype frequencies if the alleles are 0.5 each
 (B) The population is in equilibrium, because AA and aa are equal and the alleles add to 1
 (C) A condition is failing: too few heterozygotes, so mating may not be random

Decide before you look. Answer on page 41.

11

D4.1.15 HL ARTIFICIAL SELECTION

Artificial selection and its *side effects*

Artificial selection is natural selection with a person choosing the parents. Farmers and breeders pick the individuals with the traits they want, the biggest cobs, the best milkers, the gentlest dogs, and let only those breed. The alleles that go with the chosen trait become commoner in each generation. It can change a population quickly, because a breeder's choice can be very strict. The A4.1 guide has the examples of crops and domestic animals, and its finches dry lab lets you try selection on a bench, so they are not repeated here.

The key word is **deliberate**. Humans sometimes change the environment without meaning to, and that can be a selection pressure too. Take an antibiotic. In a huge population of bacteria, mutation has by chance made a few cells resistant. The antibiotic kills the susceptible cells and leaves the resistant ones, which divide with no competitors. The resistance alleles go from rare to common.

Nobody chose the resistant bacteria for breeding, and nobody wanted the result. The antibiotic acted as a selection pressure on variation that already existed, so this is **natural selection**, an unintended consequence of a human action, not artificial selection. It matters in medicine: the more an antibiotic is used, the stronger the pressure, so using antibiotics only when they are needed slows the spread of resistance.

KEY TERMS

artificial selection

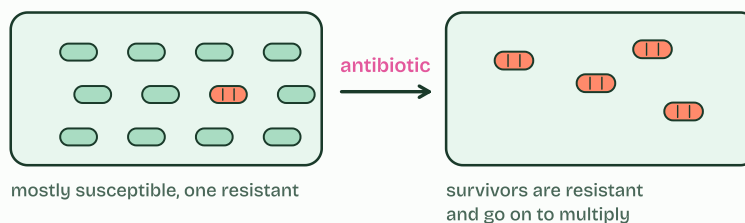
Breeding in which humans deliberately choose which individuals reproduce, according to traits they want, so those traits become commoner.

Artificial selection: people choose the parents



The breeder lets only the biggest cobs breed.

A dish of bacteria meets an antibiotic



STEP BY STEP

5 STEPS

1 Artificial selection: people choose the parents

generation 1

A crop varies in the size of its cobs. Each plant's size is partly **heritable**.

2 Artificial selection: people choose the parents

generation 1

The breeder lets only the biggest cobs breed.

The breeder picks the **largest** and lets only those breed.

3 Artificial selection: people choose the parents

generation 1 generation 2 generation 3

The breeder lets only the biggest cobs breed.

Repeat for a few generations: the cobs get steadily **bigger**, as the alleles for size become commoner.

4 Artificial selection: people choose the parents

generation 1 generation 2 generation 3

The breeder lets only the biggest cobs breed.

A dish of bacteria meets an antibiotic

mostly susceptible, one resistant

A dish of bacteria with **one** resistant cell among many susceptible ones.

5 Artificial selection: people choose the parents

generation 1 generation 2 generation 3

The breeder lets only the biggest cobs breed.

A dish of bacteria meets an antibiotic

mostly susceptible, one resistant survivors are resistant and go on to multiply

Add an antibiotic: the susceptible cells die, the resistant one multiplies. **Nobody chose it**, so this is natural selection.

COMPARE

Artificial selection: a person decides which individuals breed, for a trait they want, and the change is the aim. **Natural selection by a human action:** the environment decides who survives and breeds, nobody meant it, and the change is a side effect. The mechanism, heritable variation sorted by survival and reproduction, is the same in both.

WATCH OUT

The resistance did not appear "because" of the antibiotic, and the bacteria did not learn to resist. The mutation was already there, or arose by chance. The antibiotic only changed who survived.

PREDICT

Farmers spray a crop with an insecticide. After some years most of the pests resist it. Which kind of selection has taken place?

- (A) Artificial selection, because the farmers chose to use the insecticide on their crop
- (B) Natural selection, because the insecticide killed some pests and spared others
- (C) Neither, because the pests changed their bodies to cope with the poison they met

Decide before you look. Answer on page 41.

Key terms

Every term this guide defines, A to Z, with the chapter it is in. Cover the right-hand side and test yourself.

abiotic factor 03

A non-living part of the environment, such as temperature, water, light, pH or salinity.

adaptation 04

A heritable feature that makes an organism better suited to its environment, so it survives and reproduces better.

allele frequency 07

The proportion of all the alleles of a gene in a gene pool that are one particular allele, as a decimal or a percentage.

artificial selection 11

Breeding in which humans deliberately choose which individuals reproduce, according to traits they want, so those traits become commoner.

carrying capacity 03

The largest population an environment can support for a long time, set by the resources that run short first.

compete 03

To use or try to win the same limited resource, such as food, a territory or a mate.

density-independent 03

Affecting a population in the same way whatever its density, so the same share of individuals is hit whether it is crowded or sparse.

directional selection 09

Selection that favours one extreme of a trait, so the population's average shifts in that direction.

disruptive selection 09

Selection that favours both extremes and removes the intermediate form, so the population may split into two groups.

fitness 04

How well an individual or genotype does at surviving and at leaving offspring that survive to breed. It combines survival value and reproductive potential.

gene pool 07

All the genes, and all the different alleles of them, present in a population.

Hardy-Weinberg equation 10

For a gene with two alleles, $p + q = 1$ and $p^2 + 2pq + q^2 = 1$, which predict the genotype frequencies from the allele frequencies in a population in genetic equilibrium.

heritable 04

Passed from parents to offspring in the base sequence of their genes.

intersexual selection 05

Choice of a mate by members of one sex, usually females, among the members of the other sex, based on their traits.

intrasexual selection 05

Competition between members of the same sex, usually males, for access to mates, as when stags fight with their antlers.

mutation 02

A random change in the base sequence of DNA. A mutation in a gene can make a new allele.

natural selection 01

The process by which individuals whose heritable traits suit their environment survive and reproduce more than others, so those traits become more common in the population.

neo-Darwinism 08

The modern theory of evolution, combining Darwin's natural selection with genetics: evolution is a change in the allele frequencies of a gene pool.

paradigm shift 01

A change in the basic framework scientists use to explain a whole area of knowledge, when a new theory that explains more replaces the old one.

selection pressure 03

An environmental factor that makes individuals with some heritable traits more likely to survive and reproduce than others.

sexual selection 05

Selection for traits that improve an animal's success in getting mates, even where the trait does nothing for survival or makes it harder.

stabilising selection 09

Selection that favours the intermediate form and removes both extremes, so the range narrows and the average stays put.

Dry lab: *Endler's guppy ponds*

Four ponds of guppies side by side: no predator, a weak predator, a strong predator and a control. Choose how fussy the females are, run the generations, and watch the males' spots rise or fall as sexual selection and predation pull in opposite directions.

Pond A no predators

Pond B killifish

Pond C pike cichlid

Pond D control: random pairs

male (spots counted)
 female

pike cichlid, a strong predator
 killifish, a weak predator

Generation 0 of 20

The settings



Run it online: change the variables, run the trials, and the table and graph fill in as you go. biologybybradford.com/guides/ib-biology-d4-1-natural-selection#lab

Your question

What decides how colourful male guppies become? Do females choosing the brightest males always win, or does it depend on the predator? Start with one pond and one change, then compare it with a control pond.

What you can change

The predator in each pond (none, weak, strong, or the control, where mating is random and nothing is selected), how strongly the females prefer colourful males (none, weak, strong), the number of generations (10, 20 or 30) and the spots the males start with (6, 9 or 12). Change one thing at a time and keep the rest the same.

What to record

For each run: the settings, the mean number of spots per male each generation, the mean colour area, how many of the plainest and showiest males survived, and how many young each fathered. Repeat each set-up at least three times: the runs scatter, as real populations do. The coach under the bench helps you plan, process and evaluate.

Find out

- **What does mate choice do on its own?** Set strong mate choice and run the pond with no predator (A) beside the control pond (D, where nothing is selected) for 20 generations, three times. Which way does the mean number of spots move in each?
- **What does predation do?** Keep everything the same and compare ponds A, B and C: no predator, a weak one and a strong one. Run each three times. Where does each line end, and in what order?
- **Which pressure wins?** In the strong predator pond (C), change mate choice from none to weak to strong. At what point does colour stop falling, or start to rise?
- **Does the start matter?** Start the ponds with 6, then 9, then 12 spots per male. Do the strong predator ponds end up in the same place?
- **How hard does each pressure push?** Open the Two pushes graph. Which pressure pushes harder in each pond, and does the mean follow the stronger one?

Record

- For every run: the pond, the predator, the strength of mate choice, the starting spots and the number of generations.
- Each generation: the mean spots per male and the mean colour area. Note how many of the plainest and the showiest third of males survived, and how many young each fathered, when the bench shows them.
- Change one setting at a time, and read every pond against the control.
- Repeat each set-up at least three times and take a mean. Chance is part of the model, as it is of real ponds, so no two runs match exactly.
- Use the live graph to compare the ponds, or download the CSV and plot your own with error bars.

QUESTIONS ON THE LAB

QUESTION 1

Pond A has no predator, and the females strongly prefer colourful males. Which way should the mean number of spots per male move over the generations?

- (A) Down, because spots are costly to grow and nothing in the pond rewards them
- (B) Up: colourful males win more matings and nothing punishes them
- (C) It stays the same, because colour is not heritable in a pond of this size

Answer on page 42.

QUESTION 2

You keep the females' preference exactly as it was, but add a strong predator (pond C). The mean number of spots now falls. What does the difference between the two ponds show?

- (A) That the predator taught the males to lose their spots, one by one, during their lives
- (B) That females in the predator pond have changed what they like, as a result of the danger
- (C) That predation is a pressure strong enough to oppose sexual selection

Answer on page 42.

QUESTION 3

Why does the lab ask you to run each set-up at least three times, when one run already gives a line?

- (A) Because chance makes each run differ, so repeats show how much of a trend is real
- (B) Because the first run of any simulation is always wrong, and the later runs correct it
- (C) Because every repeat adds more generations to the run, which makes the result stronger

Answer on page 42.

WRITE IT UP AS AN INVESTIGATION

Your results from this dry lab can be written up the way an IB scientific investigation is: four criteria, each worth 6 marks. Tick each line as your write-up does it. The coach on the page checks these as you go; it never gives a mark.

1 Research design

A focused question set in its biology; your choices of what to measure, how, over what range and how often, explained rather than listed; what you kept the same and how; safety, ethics and the environment; a method someone else could follow and repeat.

- ☐ My question names what I changed.
- ☐ It gives the range I used, with units.
- ☐ It names what I measured and how.
- ☐ It names the organism or system.
- ☐ My background explains, with the biology, why the two should be linked.
- ☐ I cite my sources, and each reference can be traced.
- ☐ If I give a hypothesis, it predicts and explains.
- ☐ Every variable has its How, Why and Units.
- ☐ For each thing kept the same, I say how I kept it so.
- ☐ I list at least three things I kept the same.
- ☐ I name the apparatus that set what I changed, and the instrument that measured.
- ☐ I test enough values.
- ☐ My values spread wide enough.
- ☐ I run at least three trials at every value.
- ☐ I run a control.
- ☐ I explain why these values, this many and this often.
- ☐ Someone else could repeat my method.
- ☐ I deal with safety, ethics and the environment.

3 Conclusion

Your question answered from the processed data, with numbers quoted and the spread taken into account; the biology that explains the pattern; a comparison with published work; no claim bigger than the data.

- ☐ I answer my question in a sentence, naming both variables.
- ☐ I quote my processed numbers.
- ☐ I say how sure the spread lets me be.
- ☐ I say whether my hypothesis is supported.
- ☐ I explain the pattern with biology.
- ☐ I compare my result with published work, and cite it.
- ☐ I claim no more than my data show.

2 Data analysis

Raw data recorded clearly, with titles, units, uncertainties and the same decimal places down a column; what you saw as well as what you measured; processing that suits the question, shown with a worked example; the spread shown; a graph a reader can trust.

- ☐ Each table has a numbered title that says what it shows.
- ☐ Every heading has its quantity and its unit.
- ☐ Every raw data heading has its uncertainty.
- ☐ Each uncertainty is realistic for the instrument.
- ☐ Each uncertainty has the same decimal places as its readings.
- ☐ I record what I saw as well as what I measured.
- ☐ I show one worked example of my processing, and it is right.
- ☐ I say why I left out any trial.
- ☐ My error bars show a spread my repeats can support.
- ☐ My graph has a numbered title and labelled axes with units.
- ☐ I say what the error bars show.
- ☐ A straight line, if I draw one, has its R^2 .
- ☐ A statistical test, if I run one, has its hypotheses and suits the data.

4 Evaluation

Weaknesses and limitations of this method (not slips in carrying it out), with evidence from your own data, the effect each had on the results, which mattered most and why, and a realistic improvement for each.

- ☐ I give at least three weaknesses or limitations.
- ☐ Every row is filled in.
- ☐ No slips in carrying it out: weaknesses of the method itself.
- ☐ Each improvement is specific: which instrument, how many, what changes.
- ☐ Each effect says what it did to my data.
- ☐ At least two rows point to evidence in my own data.
- ☐ At least one limitation: what this experiment cannot tell me.
- ☐ I say which mattered most, and why.
- ☐ I deal with what stands out in my data.
- ☐ My improvements improve this investigation, not a new one.

Variables

Variable	How?	Why?	Units
Independent: predator in the pond			
Dependent: rate of change in mean spots per male			
Kept the same: strength of mate choice (how much females favour colourful males)			
Kept the same: starting mean spot number of the founders			
Kept the same: number of generations			
Kept the same: number of guppies each pond holds (200)			
Kept the same: the ponds: size, gravel, plants, light and food			
Kept the same: where the founders came from (one mixed stock)			

Evaluation

Weakness or limitation	Which?	Evidence in my data	Effect on my results	Improvement

Data generated with the guppy ponds dry lab, biologybybradford.com (a simulation; the values are illustrative). These checks catch what is missing. They cannot judge how good it is: that is what your teacher does.

**Check yourself**

The check for this guide is online: a fresh paper of past-paper style questions from the exam bank on D4.1 each time, marked as you go, and saved to your Exam practice progress when you are signed in. Scan the code, or type the link.

biologybybradford.com/exam-maker/sit?topics=D4.1&level=HL&paper=quiz&marks=15&src=ep

Answers

PREDICTIONS IN THE CHAPTERS

- 01** Claim 1: "Natural selection gives organisms what they need to survive."
B False: it favours only variation that already exists, and it cannot know what is needed
 False. Natural selection has no foresight. It can only favour versions of a trait that already exist in the population. If no individual happens to carry a helpful version, the population simply does badly.
-
- 01** Claim 2: "Natural selection acts for the good of the species."
C False: a trait spreads if its bearers leave more offspring, even if it harms the species
 False. Selection has no aims. A trait spreads if the individuals that carry it leave more offspring, even if it hurts the species later. A predator trait that is so good it wipes out the prey could spread for a while, then the predators starve.
-
- 01** Claim 3: "Organisms adapt to their surroundings by trying to."
A False: the variation arises by chance, and the surroundings then sort it out
 False. Variation arises by mutation and by the reshuffling of alleles, with no regard for need (chapter 2). Nothing an animal does in its life changes the alleles it passes on. The environment sorts the variation that chance has supplied.
-
- 01** Claim 4: "The fittest are the strongest, healthiest and fastest."
C False: the fittest are those that leave the most offspring that themselves breed
 False. In biology, fitness means success at passing on alleles: surviving and leaving offspring that survive to breed. A small, plain, well-hidden animal that raises six young is fitter than a powerful one that raises none.
-
- 02** Where does the very first copy of a new allele come from?
B A mutation in the DNA of a cell that goes on to make gametes
 A mutation. Crossing over and independent assortment only recombine alleles that are already in the population, and natural selection can only sort alleles that exist. A change in the base sequence is the one event that makes an allele that was not there before.
-
- 03** A late frost kills 60% of the seedlings in a sparse patch. How will a crowded patch of the same plant fare?
C About the same share will die: the frost does not count heads
 About the same share. A density-independent factor affects individuals in the same way whether they are crowded or sparse. The ones with a heritable tolerance of cold, in either patch, are the ones that survive. (Competition is different: it grows worse as the crowd grows.)
-
- 04** A cat lives 15 years but raises no surviving kittens. A second cat lives 6 years and raises 8 kittens that all breed. Which has the higher fitness?
A The second, because it left more offspring that went on to breed
 The second cat. Fitness is about the alleles that reach the next generation, so offspring that survive to breed are what count. The first cat survived well but its fitness, as far as evolution is concerned, is zero.
-
- 04** A weight-lifter trains for years and builds large muscles. Her child is born. What can you say about the child's muscles?
C They will be as large as the child's own alleles and own training allow
 The muscles will be as large as the child's own alleles and own training allow. Training changes her muscle cells, not the base sequence of the genes in her egg cells. A trait that is not encoded in the genes is not heritable, so it cannot be selected.
-

- 05** A male's bright tail makes him easier for predators to catch. How can the trait still spread through the population?

B Only if the extra matings it brings outweigh the extra risk of being caught

It can spread only if the extra matings it brings outweigh the extra risk. A trait that costs survival can still raise fitness if the males that carry it leave more offspring. Where the risk wins, the trait is selected against, which is what the next chapter shows.

- 06** In the pond with the dangerous predator, males end up with fewer spots. What is the best explanation?

A Males that show a lot of colour are caught more often, so duller males leave more offspring

Colourful males are caught more often, so duller males leave more young and the alleles for fewer spots become commoner. It is natural selection by predation against sexual selection by females. The change shows up between generations, not within one male's life.

- 07** A population of 50 diploid individuals has 30 copies of allele B in its gene pool. What is the frequency of B?

B 0.30, because there are 100 alleles in the pool and 30 are B

Frequency 0.30. Each of the 50 diploid individuals has two alleles of the gene, so the gene pool holds 100 alleles. The 30 copies of B are 30 out of 100, which is 0.30. Counting individuals instead of alleles is the usual slip.

- 08** In the beetle example, the J share of the gene pool was 0.5 before the drought and 20 of the 32 alleles of the survivors. What is it among the survivors?

A 0.625, because 20 of the 32 surviving alleles are J

0.625. After the drought the 16 survivors carry 32 alleles, 20 of them J. The frequency is 20 out of 32. Some j alleles were lost with the jj beetles but most survive in the Jj beetles, so the pool shifts toward J without j disappearing.

- 09** Babies of very low and very high birth weight are less likely to survive than babies of average weight. Which kind of selection is this?

C Stabilising selection, because both extremes are removed

Stabilising selection. Both the smallest and the largest are removed, so the range narrows around the average and the average itself stays the same. It still changes allele frequencies: the alleles that push weight to the extremes become rarer.

- 10** A recessive condition affects 1 person in 2500. Roughly how many people in the population are carriers (heterozygous)?

A About 1 in 25, since $2pq$ is about 0.04

About 1 in 25. $q^2 = 1/2500 = 0.0004$, so $q = 0.02$ and $p = 0.98$. The carriers are $2pq = 2 \times 0.98 \times 0.02 = 0.039$, which is about 1 in 25. Carriers are far commoner than affected people because most copies of a rare recessive allele sit hidden in heterozygotes.

- 10** In a population, the allele frequencies of A and a are both 0.5, but the genotypes seen are AA 0.40, Aa 0.20 and aa 0.40. What do you conclude?

C A condition is failing: too few heterozygotes, so mating may not be random

At least one condition is failing. With $p = q = 0.5$ the equation predicts AA 0.25, Aa 0.50, aa 0.25. There are far fewer heterozygotes than that, which fits non-random mating (like mating with like) or survival that differs between genotypes. A mismatch tells you the population is not in genetic equilibrium.

- 11** Farmers spray a crop with an insecticide. After some years most of the pests resist it. Which kind of selection has taken place?

B Natural selection, because the insecticide killed some pests and spared others

Natural selection. The farmers did not choose which pests would breed, and they did not mean to produce resistant ones. The insecticide was a selection pressure that spared the pests with a heritable resistance, and the resistance alleles became commoner. Artificial selection needs a deliberate choice of the parents.

QUESTIONS ON THE DRY LAB

Q1 Pond A has no predator, and the females strongly prefer colourful males. Which way should the mean number of spots per male move over the generations?

B Up: colourful males win more matings and nothing punishes them

Up. With no predator, sexual selection acts alone: colourful males leave more offspring, and the alleles for colour become commoner. It is the same direction as in Endler's ponds without a dangerous predator. Check that your repeats agree with each other before you trust the trend.

Q2 You keep the females' preference exactly as it was, but add a strong predator (pond C). The mean number of spots now falls. What does the difference between the two ponds show?

C That predation is a pressure strong enough to oppose sexual selection

The only thing you changed was the predator, so the predator is the cause. Colourful males are caught more often, so they leave fewer young, even though females favour them. It is natural selection pulling against sexual selection, the same tug of war Endler set up with a control, a weak predator and a dangerous one.

Q3 Why does the lab ask you to run each set-up at least three times, when one run already gives a line?

A Because chance makes each run differ, so repeats show how much of a trend is real

Chance affects who mates and who is eaten, so two runs with the same settings do not match. If three repeats all show the same direction, the trend is probably real; if they scatter across the control, it may be chance. That is why a mean and the spread of the repeats matter in any investigation.

How this was made. The course structure, the activities and the teaching choices come from my own classroom, my presentations and my years of teaching IB and AP Biology. I use Claude, an AI, to help write and build the interactive guides, lesson plans, slides and practice questions, and to draw the diagrams and code the interactives. I direct the work and review it against the IB and AP specifications before it goes live.

Written and drawn for Biology by Bradford, biologybybradford.com. Free to print and share with a class.