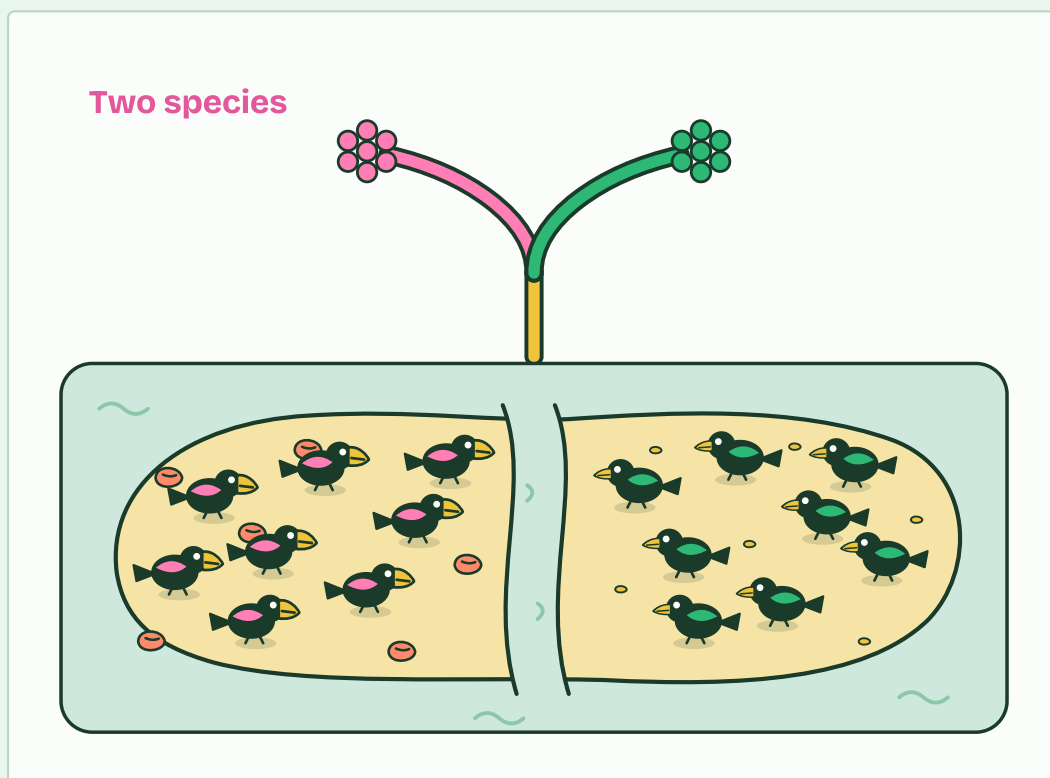


REVISION GUIDE

How one species becomes *two*

Evolution and speciation

Every species alive today began as part of another. Here is the evidence that life evolves, from DNA to the bones in your arm, and how a river, a season or a doubled set of chromosomes can split one species into two.



9 chapters · a dry lab

The interactive guide, with every animation:

biologybybradford.com/guides/ib-biology-a4-1-evolution-and-speciation



Contents

01	Evolution is a change in what a population inherits	3
02	Sequences remember common ancestors	6
03	Six vegetables, one wild weed	8
04	Same bones, different jobs, and the reverse	11
05	New species arise only by splitting	13
06	One river, two apes	17
07	Apart or together: two routes to a new species HL	19
08	One ancestor, many niches HL	22
09	The mule's dead end, the plant's way out HL	24
	Key terms	26
	Dry lab: Finches on islands	27
	Check yourself	28
	Answers	29

By the end you can

- ☐ Explain why evolution is a change in the heritable characteristics of a population, and why a change gained in one lifetime is not A4.1.1
- ☐ Use differences in base and amino acid sequences to judge which species share the most recent common ancestor A4.1.2
- ☐ Explain how crops and domestic animals show how quickly heritable characteristics can change A4.1.3
- ☐ Name the bones of the pentadactyl limb and tell homologous structures from analogous ones made by convergent evolution A4.1.4, A4.1.5
- ☐ Explain why splitting is the only way new species arise, and why gradual change in one line is not speciation A4.1.6
- ☐ Explain how reproductive isolation and differential selection split bonobos from common chimpanzees A4.1.7
- ☐ Compare allopatric and sympatric speciation, and explain how adaptive radiation fills vacant niches A4.1.8, A4.1.9
- ☐ Explain why a mule is sterile, and how hybridisation and polyploidy make a new plant species at once A4.1.10, A4.1.11

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

A4.1.1 WHAT EVOLUTION IS

01 Evolution is a change in what a population inherits

Evolution is not something one animal does in its lifetime. It is a change, over generations, in the **heritable characteristics** of a **population**. Genes carry those characteristics, so evolution shows up as some alleles becoming more common and others rarer.

The figure follows a real case. In 1977 a drought on Daphne Major, a tiny Galápagos island, left mostly big, hard seeds. Medium ground finches with deep beaks could crack them; many with shallow beaks starved. The survivors bred, their chicks inherited their alleles, and the next generation's beaks were about 4% deeper on average. No finch changed its own beak. The population changed, because some birds left more offspring than others.

KEY TERMS

heritable characteristics

Characteristics passed from parents to offspring in their genes, as alleles.

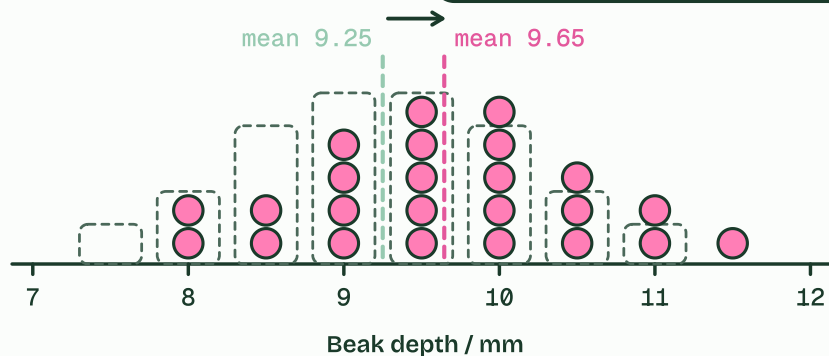
population

All the organisms of one species living in one area at the same time, able to breed with each other.

Generation 2

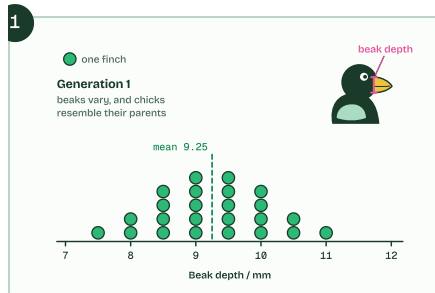
the population has changed:
beaks about 4% deeper on average

--- generation 1

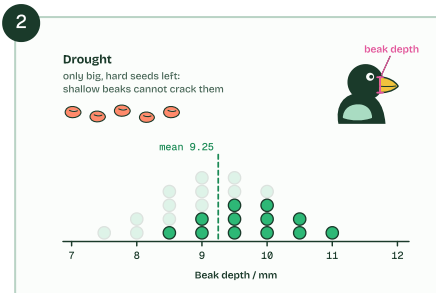


STEP BY STEP

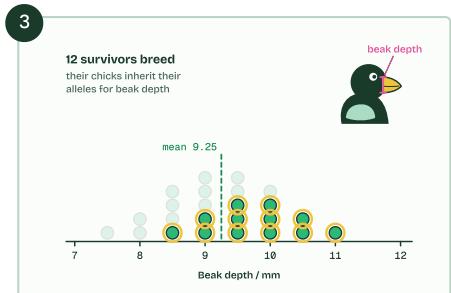
5 STEPS



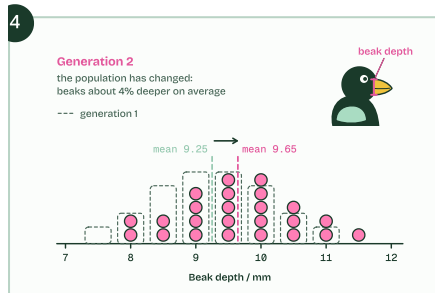
Each dot is one finch. Beak depth **varies**, and the variation is heritable: chicks resemble their parents.



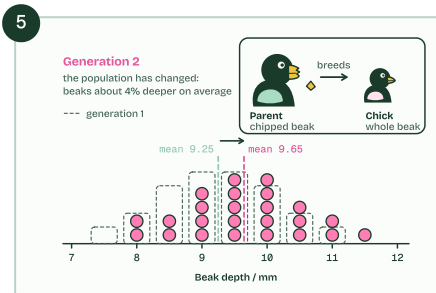
A drought leaves only big, hard seeds. Most finches with shallow beaks **starve**.



The survivors breed and pass on their **alleles**, deep-beak alleles included.



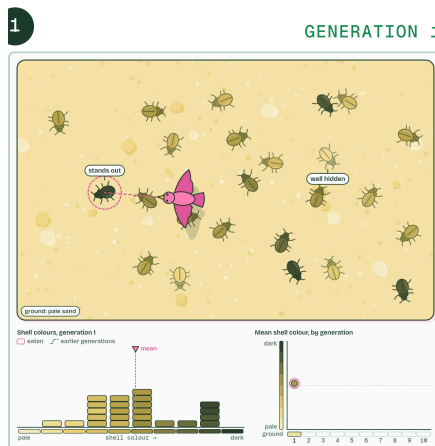
The next generation's beaks are deeper on average: the population has **evolved**.
(Numbers simplified from the real study.)



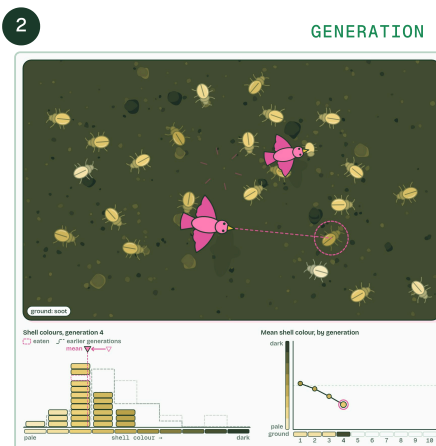
A beak chipped on a hard seed is not passed on: the chick hatches with a whole beak. An **acquired** change is not evolution.

ANIMATION · WATCH IT HAPPEN: A POPULATION CHANGES

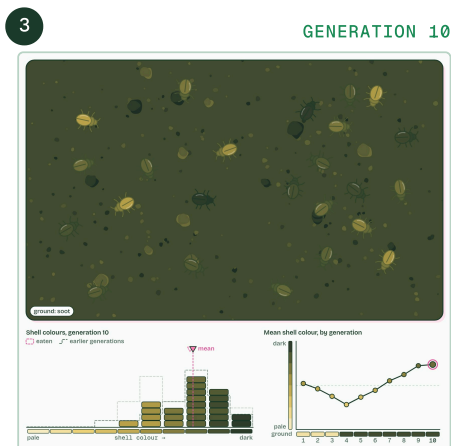
3 MOMENTS



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-a4-1-evolution-and-speciation#heritable

WATCH OUT

A change gained during a life is not passed on: a finch's chipped beak, a weightlifter's muscles, a giraffe stretching for leaves. None of these changes the alleles in eggs or sperm. Lamarck thought such changes were inherited; they are not, and they are not evolution.

WHY "THEORY"?

Evolution by natural selection explains and predicts a vast range of observations, and nothing found so far contradicts it. But science cannot prove an idea true by checking it against the whole world; it can only fail to disprove it. So it is called a theory: a pragmatic truth, true for every practical purpose and very unlikely ever to be overturned.

PREDICT

A gardener clips a hedge into a perfect cube every year for 40 years. Seeds from the hedge are sown. What shape do the seedlings grow into?

- ☐ (A) Cubes: forty years of clipping is long enough for the shape to be inherited
- ☐ (B) Slightly squarer than usual: a little of each year's change is passed on
- ☐ (C) The usual shape for the species: clipping never touched their alleles

Decide before you look. Answer on page 29.

02

A4.1.2 EVIDENCE FROM SEQUENCES

Sequences remember *common ancestors*

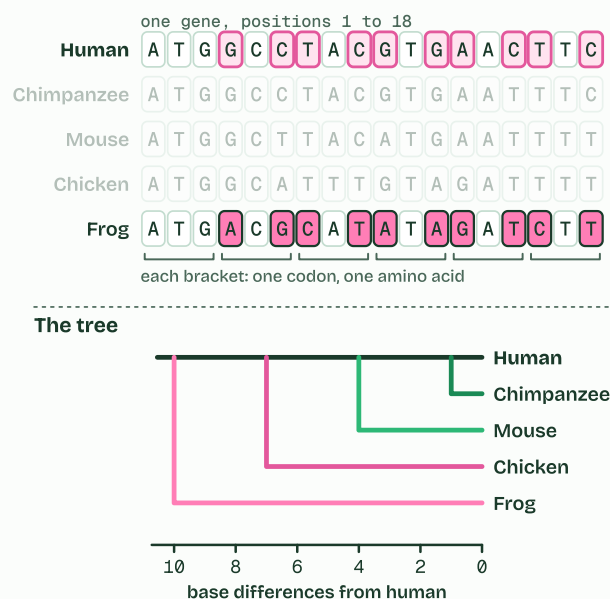
Every living thing keeps its genes in DNA, and almost all of them read it with the same genetic code. That shared machinery already points to one common ancestor. The sequences themselves hold the detail.

When a species splits in two, each new line copies its own DNA, and mutations build up separately in each. So the longer ago two species shared an ancestor, the more differences there are between the same gene in each. Compare one gene across species, count the differences, and the fewest differences mark the closest relatives.

Base sequences, in DNA or RNA, change faster than the amino acid sequences of the proteins they code for. Most amino acids have several codons, so many base changes leave the protein the same. Switch the figure to amino acids and some differences vanish: base sequences sort out close relatives, amino acid sequences reach further back.

KEY POINTS

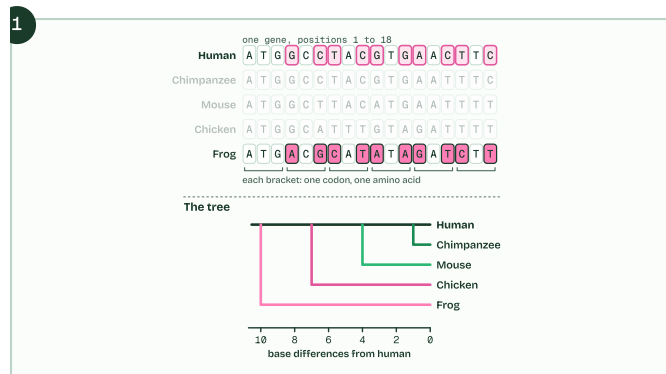
- Fewer differences: a more recent common ancestor.
- Different genes and different proteins give largely the same branching pattern, and so does the fossil record. Independent lines of evidence agreeing is what makes this powerful.



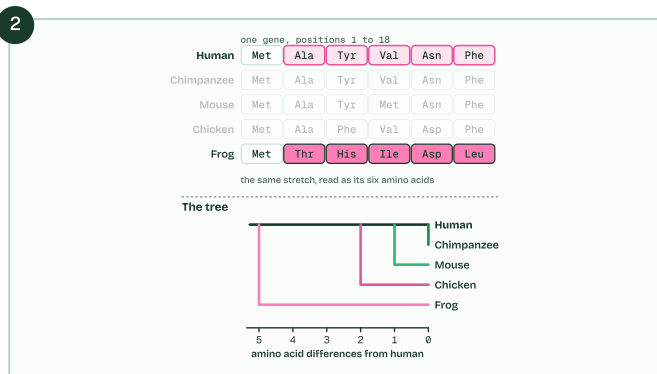
A made-up 18-base stretch of one gene, built the way real comparisons turn out. Real ones use thousands of bases and give the same pattern.

SWITCH IT

2 SETTINGS



Bases



Amino acids

EXAMPLE

Cytochrome c, a protein every aerobic cell uses, is 104 amino acids long in humans. A chimpanzee's is identical, a rhesus monkey's differs at one position, and a yeast's at more than 40.

WATCH OUT

Similar sequences do not mean one living species came from the other. Humans did not evolve from chimpanzees: both evolved from an ancestor that lived about 6 to 7 million years ago, and both lines have changed since.

PREDICT

Before you compare: which species' sequence will differ from the human one at the most positions?

- (A) Chimpanzee
- (B) Mouse
- (C) Chicken
- (D) Frog

Decide before you look. Answer on page 29.

03

A4.1.3 EVIDENCE FROM SELECTIVE BREEDING

Six vegetables, one wild *weed*

Wild cabbage grows on sea cliffs in western Europe: a straggly, leafy plant with yellow flowers. Over the last few thousand years, farmers kept seed only from the plants they liked best. This is **selective breeding**.

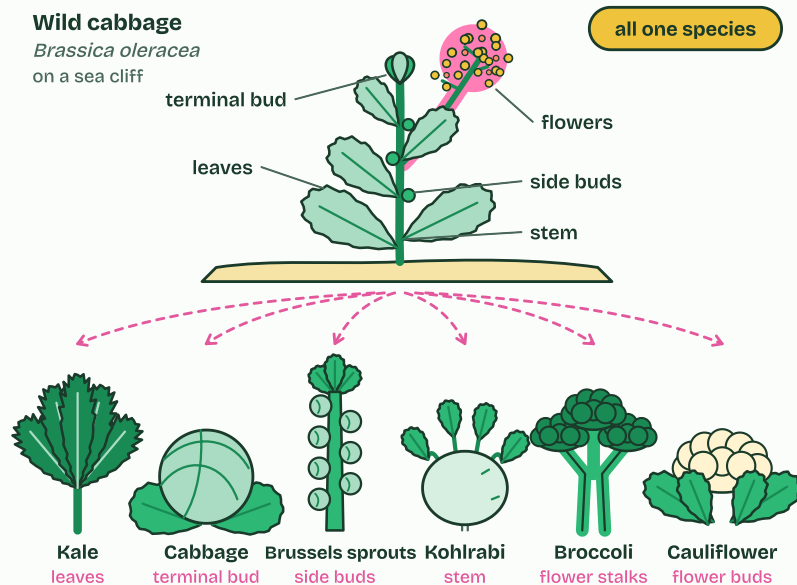
Choose the plants with the biggest leaves, generation after generation, and you get kale. Choose a fat terminal bud and you get cabbage; fat side buds, Brussels sprouts; a swollen stem, kohlrabi; thick flower stalks, broccoli; a dense mass of flower buds, cauliflower. Every one is still *Brassica oleracea*.

Why is this evidence for evolution? The cultivars differ from each other, and from wild cabbage, far more than the wild plant varies, and the changes are heritable: their seeds grow true. People choosing which plants breed changed a species this much in a few thousand years. Natural selection, choosing by survival and reproduction over millions of years, can change species far more.

KEY TERMS

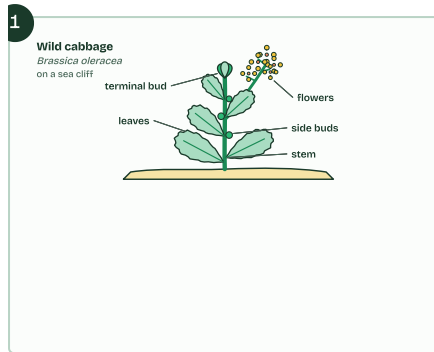
selective breeding

Humans choosing which plants or animals breed, so the characteristics they want become commoner in each generation. Also called artificial selection.

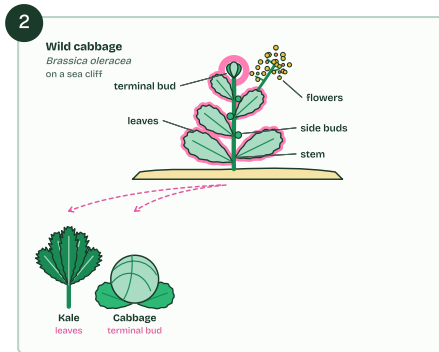


STEP BY STEP

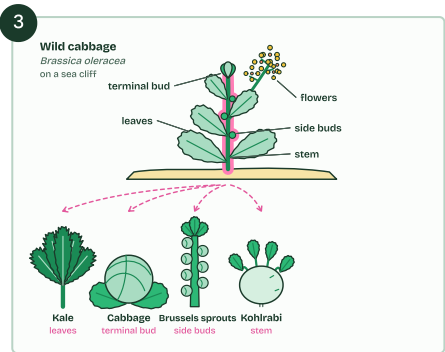
4 STEPS



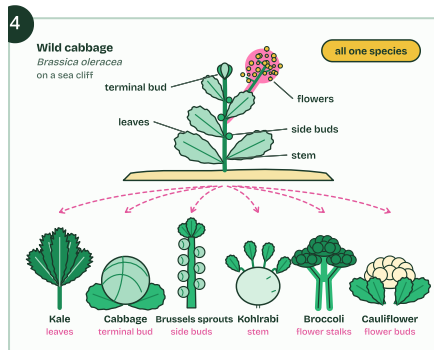
Wild cabbage: **leaves**, buds at the tip and along the stem, and yellow flowers.



Selected for **leaves**: kale. Selected for a big **terminal bud**: cabbage.



Selected for **side buds**: brussels sprouts. Selected for a swollen **stem**: kohlrabi.



Selected for **flower stalks and buds**: broccoli and cauliflower. All six can still interbreed: **one species**.

EXAMPLE

Maize was bred from teosinte, a wild grass of Mexico. A teosinte ear holds fewer than a dozen kernels, each in a stone-hard case; a cob of maize holds hundreds of soft ones. Dogs were domesticated from wolves more than 15,000 years ago, and most of today's breeds, from chihuahua to Great Dane, were bred in the last few hundred years.

WATCH OUT

Dog breeds and cabbage cultivars look like different species but are not: a chihuahua and a Great Dane share one gene pool, which their alleles can still cross through dogs of in-between sizes. Selective breeding shows how fast heritable characteristics can change. It is not an example of new species forming.

REMEMBER IT

The three lines of evidence for evolution in A4.1

D Darwin's DNA and protein sequences fewer differences, closer relatives	B Big Breeding big heritable changes, fast	H Hunch Homologous structures one bone plan, many jobs
---	---	---

PREDICT

Kohlrabi and Brussels sprouts look nothing alike. A grower lets them cross-pollinate. What happens?

- ☐ A No seeds form at all: by now they are different species
- ☐ B Seeds form and grow into fertile plants: one species
- ☐ C Seeds form but grow into sterile plants, like a mule

Decide before you look. Answer on page 29.

04

A4.1.4

A4.1.5

HOMOLOGOUS AND ANALOGOUS STRUCTURES

Same bones, different jobs, and the *reverse*

Your arm, a bat's wing, a whale's flipper and a horse's front leg do very different jobs. Inside, they are built from the same bones in the same order: one upper arm bone, two in the forearm, a block of wrist bones, a row of palm bones, then the digits. This shared plan is the **pentadactyl limb**, and structures built on a plan inherited from a common ancestor are **homologous structures**.

No engineer would build a wing, a paddle and a leg from the same parts. Evolution does not design from scratch: it modifies what an ancestor already had. The shared plan makes sense only if all four limbs were inherited from one common ancestor, an early four-legged vertebrate, and each line then modified it for its own way of life.

Now switch the figure. A bird's wing and an insect's wing both fly, but one is a forelimb full of bones and the other a thin fold of the body wall with no bones at all. Features with the same function but different evolutionary origins are **analogous structures**, and they arise by **convergent evolution**: unrelated lines meeting similar demands with similar solutions. The camera eyes of octopuses and vertebrates are another pair.

KEY TERMS

pentadactyl limb

The limb plan of amphibians, reptiles, birds and mammals: one upper bone, two lower bones, wrist or ankle bones, then up to five digits.

homologous structures

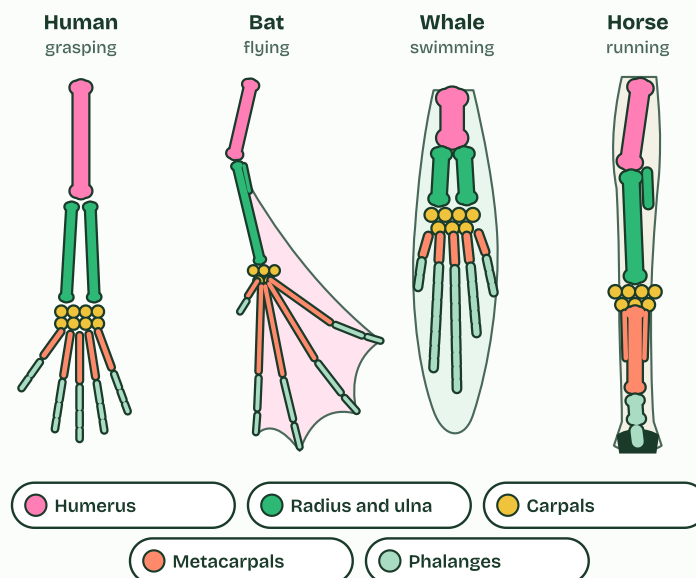
Structures built on one plan inherited from a common ancestor, whatever job each one now does.

analogous structures

Structures that do the same job but evolved separately in each line, so they were not inherited in that form from a common ancestor.

convergent evolution

Unrelated lines evolving similar features because they face similar demands, such as flight or swimming.



Humerus One upper arm bone, in every limb. Short and thick in the whale, a strut for the wing in the bat.

Carpals A block of small wrist bones: eight in your wrist. In the horse they make the joint people call its knee.

Radius and ulna Two forearm bones. In the horse they have fused into one strong support, with only the top of the ulna (the point of the elbow) still clear; in the bat the ulna is a thin splint.

Metacarpals The palm bones. Very long in the bat, holding the wing out. The horse stands on one, the cannon bone, with two thin splint bones beside it: what is left of two more.

Phalanges The finger bones. Long and spread in the bat, extra ones in the whale, and in the horse just three in a single digit, the last inside the hoof.

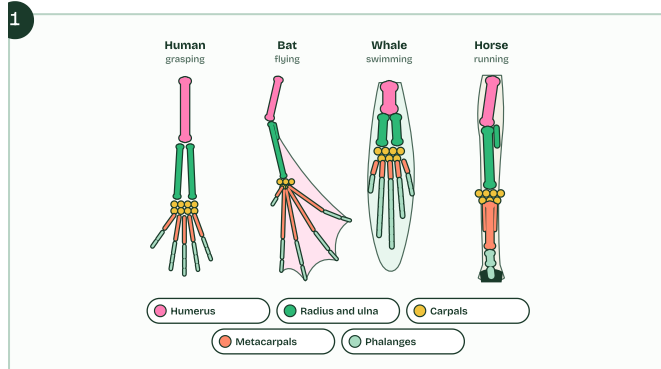
Insect wing No bones and no muscles inside: a thin double layer of cuticle, the insect's outer skeleton, stiffened by veins. Muscles in the thorax drive it.

Bird wing A forelimb: humerus, radius and ulna, wrist and hand bones (fewer digits, partly fused), with feathers for the flight surface. It is homologous with your arm.

Their last common ancestor A small animal living more than 550 million years ago, with no wings at all. Wings evolved separately in the two lines, from different starting parts: convergent evolution.

SWITCH IT

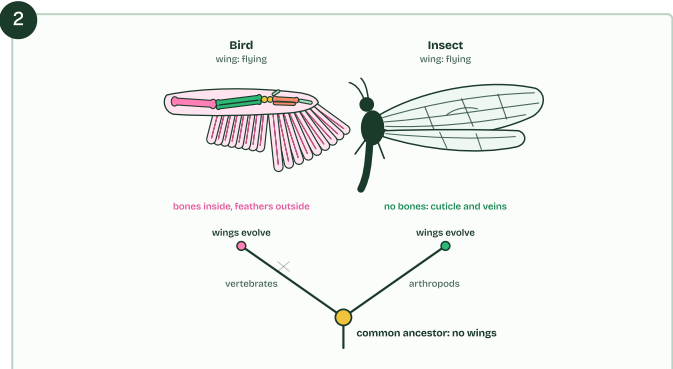
1



Homologous

2 SETTINGS

2



Analogous

WATCH OUT

Penguin, turtle and whale flippers are often given as analogous structures, but all three are forelimbs with the pentadactyl bones inside: homologous as limbs, with only the flipper shape converging. And "pentadactyl" names the plan, not a count: the horse has one digit left, on the same plan.

REMEMBER IT

The pentadactyl limb, shoulder to fingertip

H Hungry	R Rats	C Chew	M My	P Pencils
Humerus upper arm, one bone	Radius and ulna forearm, two bones	Carpals wrist	Metacarpals palm	Phalanges fingers

PREDICT

A bat's wing and a bird's wing: homologous or analogous?

- (A) Analogous only: they look different and are built differently
- (B) Homologous only: both are forelimbs, so nothing about them converged
- (C) Both: homologous as forelimbs, analogous as wings for flight

Decide before you look. Answer on page 29.

05

A4.1.6 SPECIATION

New species arise only by *splitting*

A **species**, in the definition biologists use most, is a group of organisms that can interbreed and produce fertile offspring. Its populations share one pool of alleles, because individuals move and mate between them.

Speciation happens when that sharing stops. Split a species into two populations that no longer interbreed and each changes in its own way: different mutations, different chance events, different selection. Given long enough, they differ so much that they could not interbreed even if they met again. One species has become two.

Every new species has appeared like this, by splitting from one that already existed. Speciation adds to the number of species on Earth and extinction takes species away; the diversity alive today is the balance of the two.

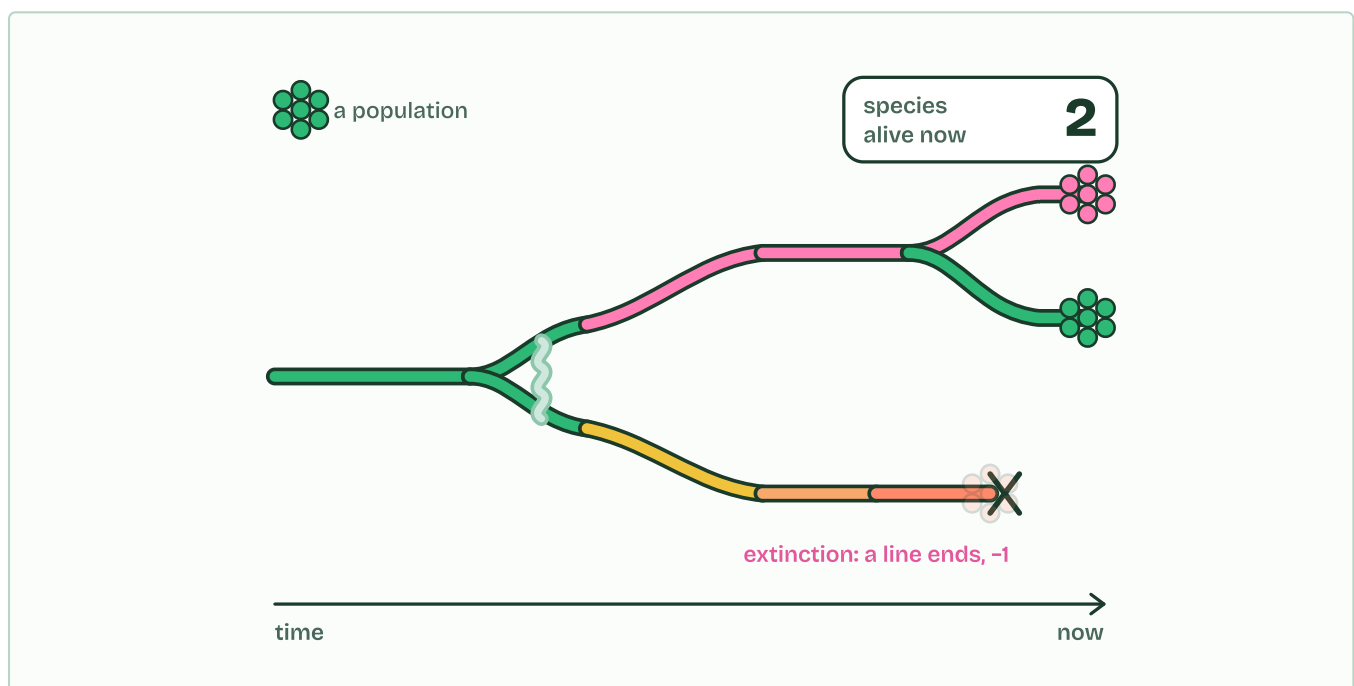
KEY TERMS

species

A group of organisms that can interbreed and produce fertile offspring. This is the biological species concept, the one used most.

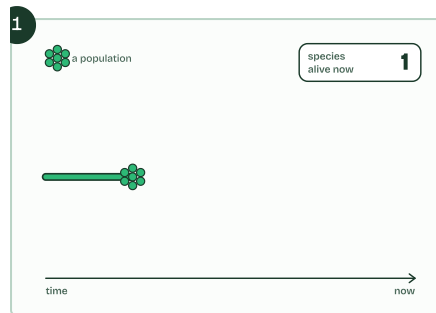
speciation

How new species arise: one existing species splits into two or more groups that can no longer interbreed.

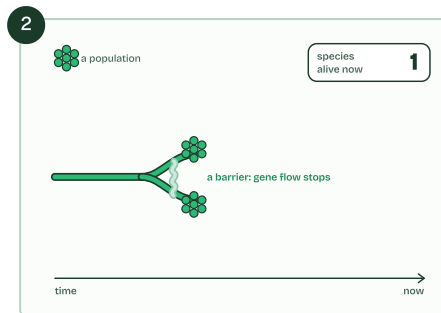


STEP BY STEP

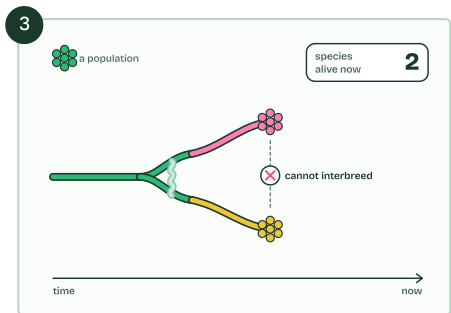
6 STEPS



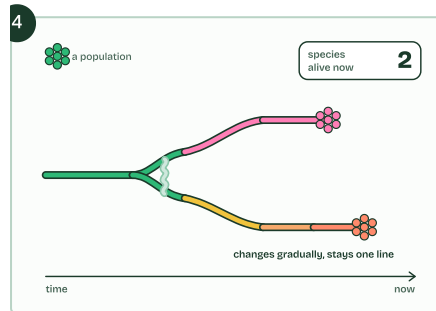
One species: every population can interbreed with every other.



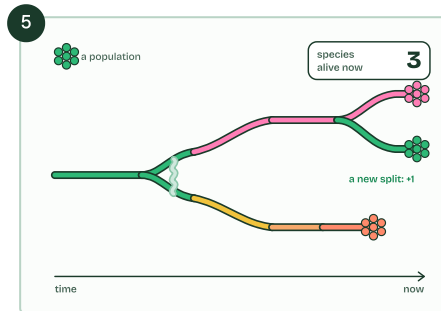
A barrier divides it into two populations.
Gene flow stops, but for now they are still one species.



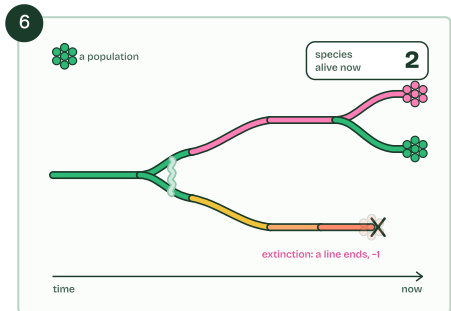
Each population changes separately until they **cannot interbreed**: two species.



The lower species changes **gradually** but never splits: still one species, so the count stays at two.



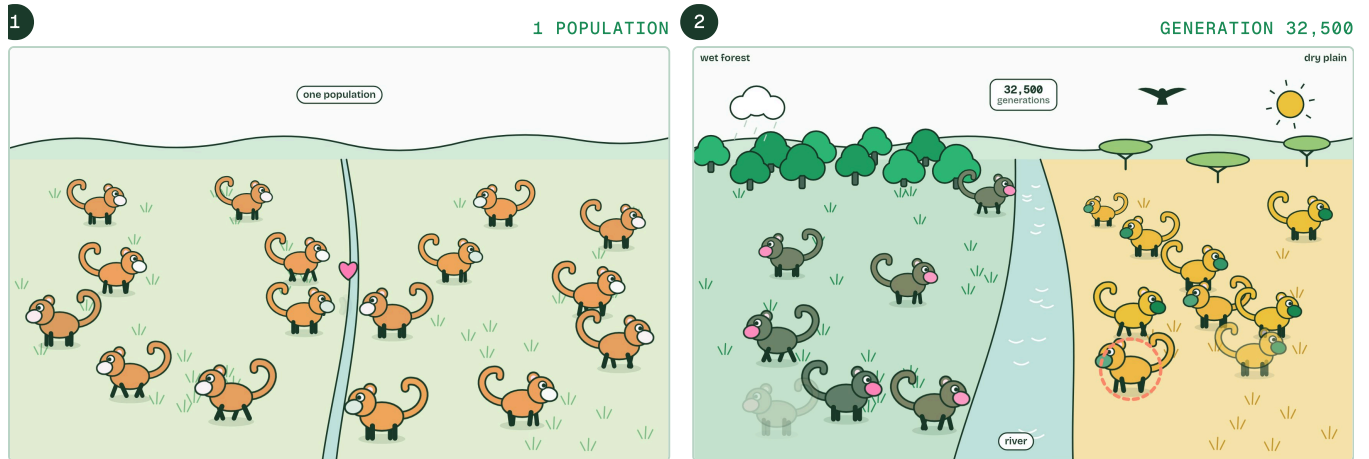
The upper species **splits** again: three.



The lower species dies out: **extinction** takes the count back to two.

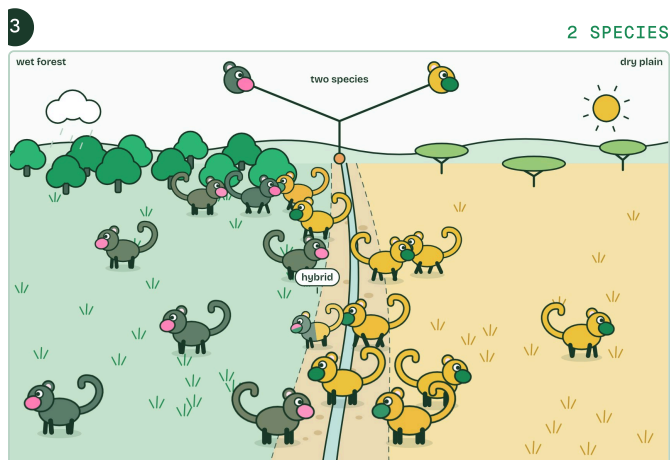
ANIMATION · WATCH IT HAPPEN: ONE POPULATION BECOMES TWO

3 MOMENTS



One population: any two can meet and mate, so genes flow across the valley.

Different selection each side: coats match the ground, displays drift apart.



Hybrids are rare, weak and often sterile, so the two never merge: **two species**.

Watch it move, and change it as it runs: biologybybradford.com/guides/ib-biology-a4-1-evolution-and-speciation#splitting

WATCH OUT

A species that changes gradually without splitting is still one line. It has evolved, but no species has been added, so that is not speciation. Play the figure to step 4.

WHERE THE DEFINITION STRUGGLES

Organisms that reproduce asexually, like bacteria, do not interbreed, and fossils cannot be tested, so these are grouped by their characteristics and sequences instead. And because splitting takes time, some pairs of populations are part-way: they interbreed a little where they meet, and whether they count as one species or two is a judgement.

PREDICT

A line of snails changes its shell shape steadily for two million years and never splits. The oldest and newest shells look so different that fossil experts give them different names. How many species has the line added to the Earth?

- ☐ (A) One: the oldest and newest shells now carry different names
- ☐ (B) None: at every moment there was still only one species
- ☐ (C) It depends on how different the oldest and newest shells look

Decide before you look. Answer on page 29.

06

A4.1.7

REPRODUCTIVE ISOLATION AND DIFFERENTIAL SELECTION

One river, two *apes*

Speciation needs two things. First, **reproductive isolation**: the populations must stop interbreeding, so alleles no longer pass between them. A sea, a mountain range or a river can do it: **geographical isolation**. Second, **differential selection**: different conditions on each side favour different characteristics, so the populations diverge. New mutations and chance (genetic drift), different on each side, add to it.

The Congo River is a real case. Common chimpanzees live north of it and beyond its upper reaches; bonobos live only in the forests south of its great bend. Neither ape can swim, and the river is wide and deep. Genetic evidence suggests their ancestors were divided roughly 1 to 2 million years ago, perhaps when a few reached the south bank during a dry spell and were then cut off.

South of the river there are no gorillas, and plants on the forest floor, which the apes eat when fruit is scarce, are plentiful. North of it, chimpanzees share the forest with gorillas and food is patchier. One widely held explanation is that these differences selected for different behaviour: bonobos live in large, calm groups in which females form strong alliances, while chimpanzee groups are led by males and compete more fiercely. Their bodies differ too: bonobos are more slender, with longer legs and smaller skulls.

KEY TERMS

reproductive isolation

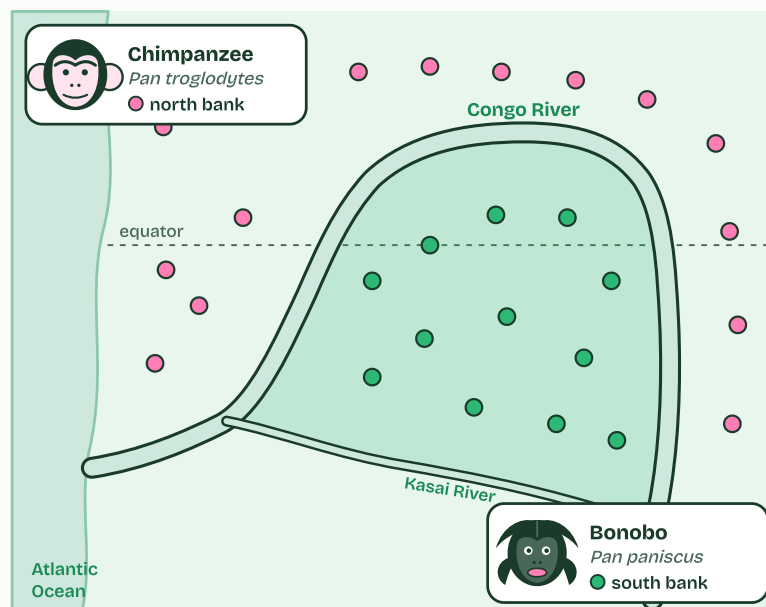
When two populations no longer interbreed, so no alleles pass between them.

geographical isolation

Reproductive isolation caused by a physical barrier, or distance, that keeps populations apart.

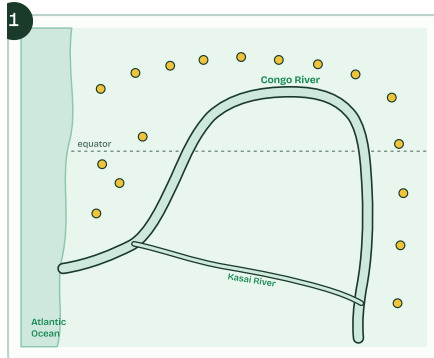
differential selection

Natural selection favouring different characteristics in different populations, because their environments differ.

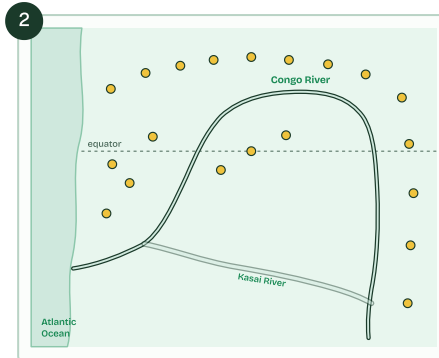


STEP BY STEP

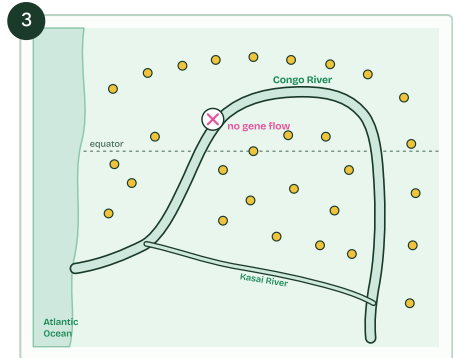
5 STEPS



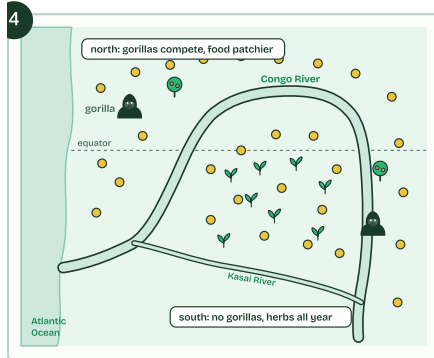
Long ago: one population of **ancestral apes**, north of the Congo River.



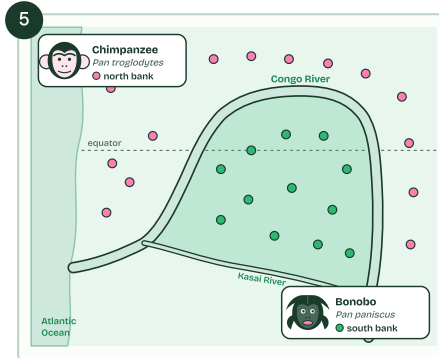
Perhaps in a dry spell, the river runs low and a few apes reach the **south bank**.



The water rises. Neither side can cross: **no gene flow** between the populations.



Different conditions on each bank: **differential selection** favours different behaviour and bodies.



Over about 1 to 2 million years they diverge into **two species**: chimpanzees north, bonobos south.

WATCH OUT

The river did not make the apes change. It stopped gene flow. Different selection on each side, with mutation and chance, did the changing.

HOW CLEAN WAS THE SPLIT?

Their genomes show that a few apes did cross the river long after the split, a few hundred thousand years ago, but too rarely to stop the two populations diverging.

PREDICT

Suppose the river had divided the apes but the forests on both banks were identical. What would you expect after a million years?

- (A) No differences at all: without selection, nothing in them would change
- (B) Some differences, from mutation and drift, but less divergence
- (C) Just as much divergence: isolation on its own does all the work

Decide before you look. Answer on page 29.

07

A4.1.8 HL ALLOPATRIC AND SYMPATRIC SPECIATION

Apart or together: *two routes* to a new species

Every speciation needs the same first step: gene flow between two groups has to stop, so they can change separately. The two routes differ in what stops it.

In **allopatric speciation** ("other homeland") a geographical barrier does it: a sea, a mountain range, or a river, as for the bonobos. In **sympatric speciation** ("same homeland") the groups live side by side, and something else keeps them from mating. They may breed at different times (**temporal isolation**) or choose mates differently (**behavioural isolation**).

Apple maggot flies in North America show it happening. They used to lay their eggs only in hawthorn fruit, and adults find mates on the kind of fruit they grew up in. After apple trees were planted in North America, some flies switched to apples; apple-infested fruit was first recorded in the 1860s. Apples ripen weeks before hawthorns, so apple flies now emerge, meet and mate earlier, on apples. The two groups share the same orchards, yet interbreed far less than they would by chance: they are on their way to becoming separate species.

KEY TERMS

allopatric speciation

Speciation in populations kept apart by geography: a sea, a mountain range, a river, or sheer distance.

sympatric speciation

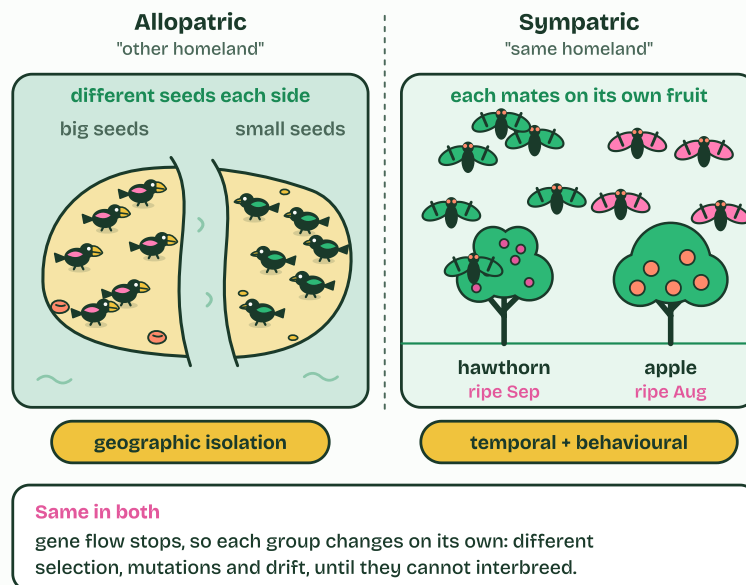
Speciation within one area: the groups could meet, but stop interbreeding, for example because they breed at different times, choose different mates or, in plants, have doubled their chromosomes.

temporal isolation

Isolation because populations breed at different times of day or year.

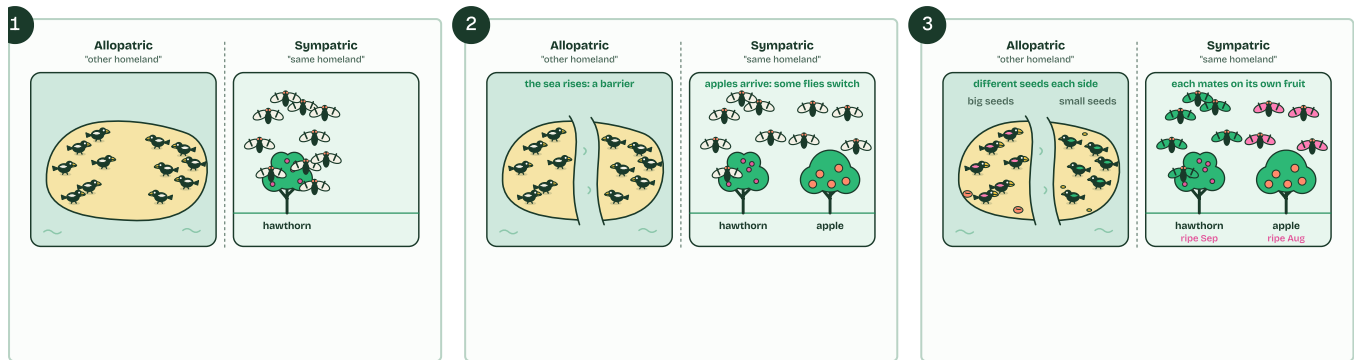
behavioural isolation

Isolation because populations court or choose mates differently, so they do not mate with each other.



STEP BY STEP

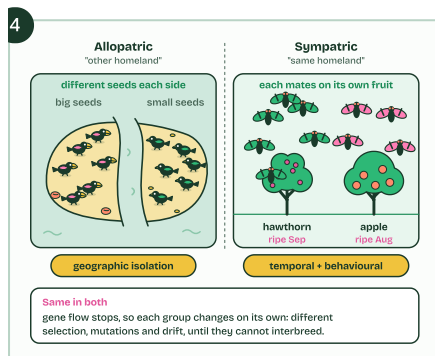
4 STEPS



Two populations, each of **one species**: finches on an island, flies on hawthorn trees.

Left: the sea rises and **splits** the island. Right: apple trees arrive and some flies **switch** to them; no barrier.

Left: different seeds each side select different beaks. Right: apple flies mate earlier, on apples. **Gene flow stops** in both.



Both groups diverge. What stopped gene flow differs: **geography**, or **timing and behaviour**.

WATCH OUT

Sympatric does not mean the groups never meet; it means they could meet and still do not mate. It is rarer than allopatric in animals, because any interbreeding mixes their alleles again. In plants it is common, by polyploidy (chapter 9).

REMEMBER IT

Three kinds of reproductive isolation

G Grumpy Geographic a barrier between them	B Birds Behavioural different courtship	T Tweet Temporal breed at different times
--	---	---

PREDICT

Two populations of a cricket share one meadow. One sings and mates in spring, the other in late summer. Which kind of isolation is this, and which route to speciation?

- ☐ (A) Geographic isolation: allopatric speciation
- ☐ (B) Temporal isolation: sympatric speciation
- ☐ (C) Behavioural isolation: allopatric speciation

Decide before you look. Answer on page 29.

08

A4.1.9 HL ADAPTIVE RADIATION

One ancestor, many *niches*

When a species reaches a place with food and ways of life that nothing else is using, its descendants can split again and again, each line adapting to a different way of life. This is **adaptive radiation**. The unused ways of life are **vacant niches**.

About 1 to 2 million years ago a few seed-eating finches reached the Galápagos from the American mainland. The islands had few other small birds, so niches stood empty: big seeds, small seeds, cactus flowers, buds and fruit, insects, grubs hidden in bark. Today about 18 species of Darwin's finches descend from that one ancestor, each with a beak suited to its food. The woodpecker finch even pries out grubs with a cactus spine held in its beak.

Because each species uses a different food, closely related species can live on the same island without competing much. That is why adaptive radiation raises biodiversity: one species has become many, living side by side. In Lake Malawi, cichlid fish have radiated into hundreds of species in one lake, scraping algae, crushing snails, eating scales or other fish.

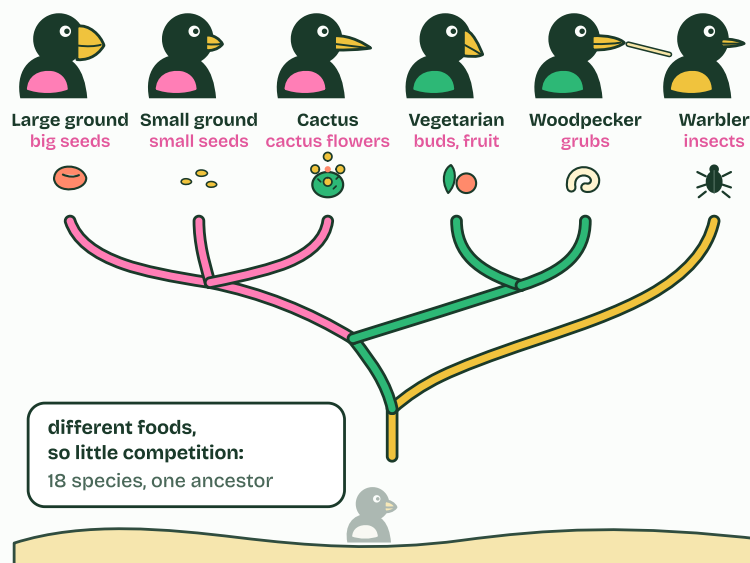
KEY TERMS

adaptive radiation

One ancestral species giving rise, fairly quickly, to many species, each suited to a different way of life (niche).

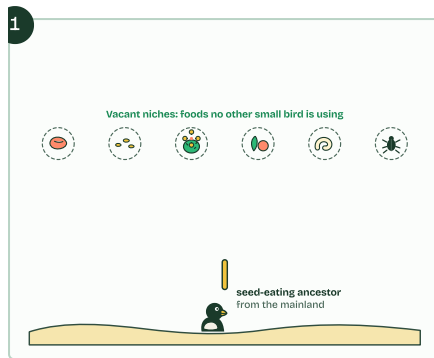
vacant niches

A niche is the role of a species in its ecosystem: what it eats, where and when it lives, how it interacts with others. A vacant niche is one no species is filling.

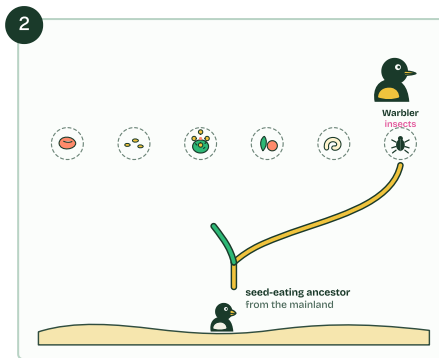


STEP BY STEP

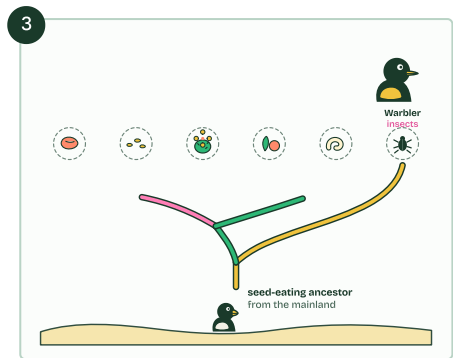
5 STEPS



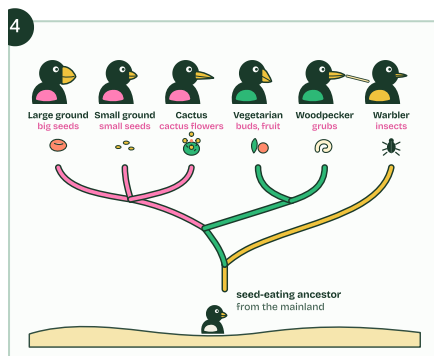
A seed-eating finch arrives on islands with **vacant niches**: foods no other small bird is using.



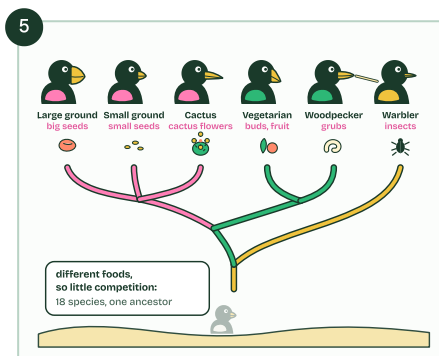
The first split: one line takes to eating **insects**, with a thin, pointed beak.



The rest split into **ground finches** and **tree finches**.



Each line splits again, each species with a beak **suited to its food**.



Different foods mean **little competition**: many related species live side by side.

WATCH OUT

The finches did not grow new beaks because they needed them. In each population, birds whose beaks happened to suit an unused food survived and bred better: natural selection acting on variation that was already there.

PREDICT

Suppose the first finches had landed on islands already full of small birds of many kinds. What would you expect?

- (A) Fewer finch species: most niches would already be filled
- (B) More finch species: competition makes new species faster
- (C) The same number: radiation depends only on the finches' genes

Decide before you look. Answer on page 30.

09

A4.1.10 HL

A4.1.11 HL

HYBRIDS AND POLYPLOIDY

The mule's *dead end*, the plant's way out

Even where two species meet, their alleles rarely mix. Barriers act before fertilisation and after it. Before, courtship usually prevents **hybridisation**: many animals choose mates by songs, dances, colours or scents that belong to their own species, and ignore the rest. Each firefly species flashes its own code, and a female answers only her own species' code.

After fertilisation, a hybrid may die young, or live but be sterile. A horse ($2n = 64$) and a donkey ($2n = 62$) can produce a mule, with 32 chromosomes from the horse and 31 from the donkey: 63. A mule is strong and healthy, but at meiosis its chromosomes cannot all pair up, because horse and donkey chromosomes differ in number and arrangement. Its gametes get unbalanced sets and almost never work, so horse and donkey alleles go no further.

Plants have a way out. A hybrid of two plant species is usually sterile for the same reason. But if its chromosome number doubles, every chromosome gains an identical partner, meiosis works, and the plant is fertile. It is a **polyploid**, and it cannot breed successfully with either parent: a new species in a generation or two. This is **abrupt speciation**.

The smartweeds and knotweeds, genus *Persicaria*, are full of examples: DNA studies show that several of their species, some of them common weeds, began as hybrids like this. Redshank, *Persicaria maculosa* ($2n = 44$), is one, with pale persicaria ($2n = 22$) as one of its parents.

KEY TERMS

hybridisation

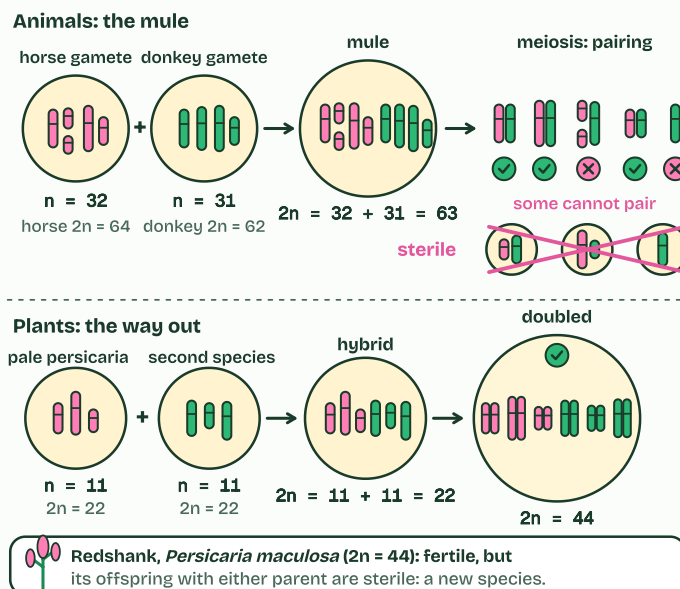
Mating between two different species, producing a hybrid.

polyploid

Having more than two complete sets of chromosomes.

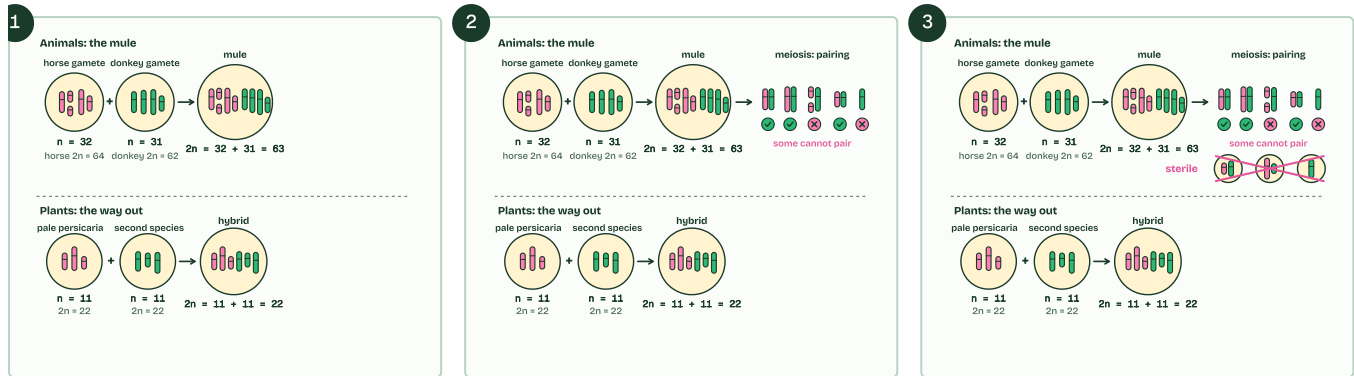
abrupt speciation

A new species formed in one or a few generations, as when a hybrid plant doubles its chromosomes, rather than by gradual divergence.



STEP BY STEP

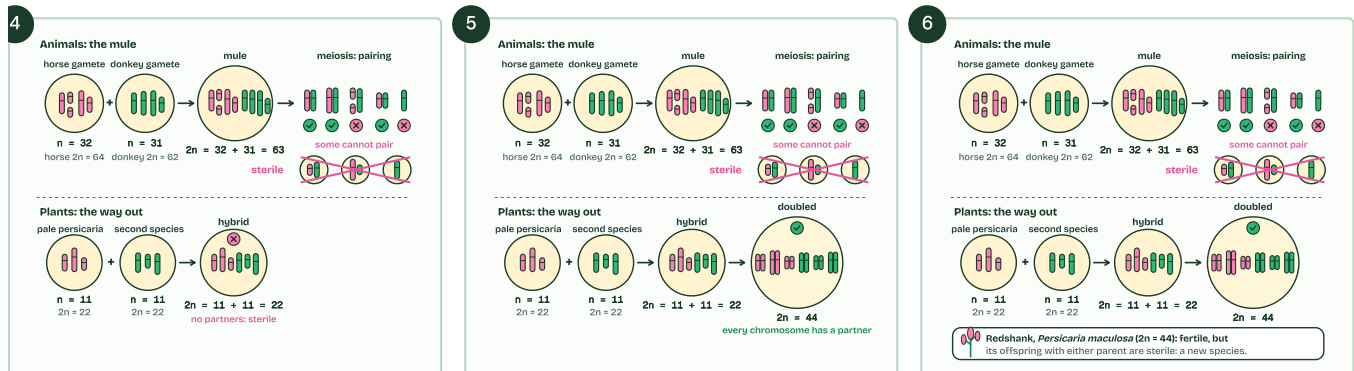
6 STEPS



A horse gamete (32 chromosomes) and a donkey gamete (31) make a **mule** with 63. A few of each set are drawn.

At meiosis, matching chromosomes pair up, but horse and donkey sets differ in **number and arrangement**: some cannot pair.

So the gametes get **unbalanced** sets and do not work: the mule is sterile.



Two smartweed species make a hybrid with 11 + 11 = 22. No chromosome has a matching partner: **sterile**, like the mule.

The chromosome number **doubles** to 44: every chromosome now has an identical partner, so meiosis works.

A fertile **polyploid** whose offspring with either parent are sterile: a new species, made in a generation or two.

WATCH OUT

The hybrid's number is the sum of the gametes, not of the parents: 32 + 31 = 63 for the mule, 11 + 11 = 22 for the smartweed hybrid. Doubling then gives 44. Japanese knotweed, the invasive garden weed, is a polyploid too, but it belongs to a different genus (*Reynoutria*, also called *Fallopia*); name a *Persicaria* for this example.

PREDICT

Redshank (2n = 44) is crossed with one of its parents, pale persicaria (2n = 22). How many chromosomes do the offspring have, and are they fertile?

- (A) 44: they take after redshank, so they are fertile
(B) 33: three sets that cannot pair evenly, so sterile
(C) 66: six sets, so fertile, like any polyploid

Decide before you look. Answer on page 30.

Key terms

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

abrupt speciation 09

A new species formed in one or a few generations, as when a hybrid plant doubles its chromosomes, rather than by gradual divergence.

adaptive radiation 08

One ancestral species giving rise, fairly quickly, to many species, each suited to a different way of life (niche).

allopatric speciation 07

Speciation in populations kept apart by geography: a sea, a mountain range, a river, or sheer distance.

analogous structures 04

Structures that do the same job but evolved separately in each line, so they were not inherited in that form from a common ancestor.

behavioural isolation 07

Isolation because populations court or choose mates differently, so they do not mate with each other.

convergent evolution 04

Unrelated lines evolving similar features because they face similar demands, such as flight or swimming.

differential selection 06

Natural selection favouring different characteristics in different populations, because their environments differ.

geographical isolation 06

Reproductive isolation caused by a physical barrier, or distance, that keeps populations apart.

heritable characteristics 01

Characteristics passed from parents to offspring in their genes, as alleles.

homologous structures 04

Structures built on one plan inherited from a common ancestor, whatever job each one now does.

hybridisation 09

Mating between two different species, producing a hybrid.

pentadactyl limb 04

The limb plan of amphibians, reptiles, birds and mammals: one upper bone, two lower bones, wrist or ankle bones, then up to five digits.

polyploid 09

Having more than two complete sets of chromosomes.

population 01

All the organisms of one species living in one area at the same time, able to breed with each other.

reproductive isolation 06

When two populations no longer interbreed, so no alleles pass between them.

selective breeding 03

Humans choosing which plants or animals breed, so the characteristics they want become commoner in each generation. Also called artificial selection.

speciation 05

How new species arise: one existing species splits into two or more groups that can no longer interbreed.

species 05

A group of organisms that can interbreed and produce fertile offspring. This is the biological species concept, the one used most.

sympatric speciation 07

Speciation within one area: the groups could meet, but stop interbreeding, for example because they breed at different times, choose different mates or, in plants, have doubled their chromosomes.

temporal isolation 07

Isolation because populations breed at different times of day or year.

vacant niches 08

A niche is the role of a species in its ecosystem: what it eats, where and when it lives, how it interacts with others. A vacant niche is one no species is filling.

Dry lab: *Finches on islands*

Split a population of finches, decide what acts on each side, run the generations, then bring them back together and test whether you have made a new species.



Run it online: change the variables, run the trials, and the table and graph fill in as you go. biologybybradford.com/guides/ib-biology-a4-1-evolution-and-speciation#lab

Your question

What does it take to turn one population into two species? Is cutting off gene flow enough, or do the two sides also need different selection? How much gene flow undoes it?

What you can change

The scenario (split by the sea, a control with the same food both sides, and at higher level one island with two foods), the difference in food, the number of birds, how many cross each generation, how strongly females choose mates by song, mutation, and how many generations to run.

What to record

For each run: the settings, the difference in mean beak depth when you stop, and the isolation index and verdict when you reunite them. Change one setting at a time and repeat each set-up at least three times: the runs scatter, as real populations do.

Find out

- **Is isolation alone enough?** Run the control (same food both sides) three times with no birds crossing, then the split with very different food three times. Reunite them after each run. Compare the isolation indexes.
- **How much gene flow undoes it?** Keep the food very different and raise the birds crossing each generation: 0, 1, 2, 4, 8. Three runs at each. At what rate does the verdict change from two species to one?
- **Small or large?** Run the control with 20 birds per island and with 300. Which pair of islands drifts further apart by chance alone?
- **Higher level: one island, two foods.** Set mate choice to none, then moderate, then very strong. When does the population split into two groups that do not interbreed?

Record

- For every run: the scenario, the settings you changed, the generations, the difference in mean beak depth, and the isolation index and verdict when you reunite or test them.
- Change one setting at a time and keep the rest fixed.
- Repeat each set-up at least three times and take a mean: no two runs are the same, because chance is part of the model, as it is of real populations.
- Use **Graph your results** under the lab to see the mean isolation index for each number of birds crossing each generation, or download the CSV and plot it yourself.

QUESTIONS ON THE LAB

QUESTION 1

In the control, the islands have the same food. After 200 generations the mean beaks usually differ a little, but the test says one species. Why?

- (A) With the same food on both islands, mutation stops, so nothing can change
- (B) Only drift and mutation differ, so the beaks wander slowly and at random
- (C) The sea between them is not a real barrier, so the birds still interbreed

Answer on page 30.

QUESTION 2

With very different food, a handful of birds crossing each generation is enough to keep the two islands one species. How?

- (A) The crossing birds eat the other island's seeds, so that island runs out of food
- (B) The crossing birds cannot survive on the other island, so nothing there changes
- (C) Each crossing bird brings its alleles, mixing the gene pools every generation

Answer on page 30.

QUESTION 3

Higher level. On one island with two foods, the population only splits into two groups when mate choice is strong. Why is mate choice needed here, but not when the sea splits the island?

- (A) On one island nothing else stops the two groups mating, so behaviour must
- (B) Mate choice causes the mutations that make beaks deeper or shallower
- (C) Strong mate choice makes the birds move to the other side of the island

Answer on page 30.



Check yourself

The check for this guide is online: a fresh paper of past-paper style questions from the exam bank on A4.1 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=A4.1&level=HL&paper=quiz&marks=15&src=ep](https://biologybybradford.com/exam-maker/sit?topics=A4.1&level=HL&paper=quiz&marks=15&src=ep)

Answers

PREDICTIONS IN THE CHAPTERS

- 01** A gardener clips a hedge into a perfect cube every year for 40 years. Seeds from the hedge are sown. What shape do the seedlings grow into?
- C The usual shape for the species: clipping never touched their alleles**
- The usual shape. Clipping changes the hedge's body, not the alleles in its pollen and ovules, so nothing about it reaches the seeds. Only changes to the alleles in gametes can be inherited, which is why only they count as evolution.
-
- 02** Before you compare: which species' sequence will differ from the human one at the most positions?
- D Frog**
- The frog. Our line split from the chimpanzee's about 6 to 7 million years ago, from the mouse's about 90 million, from the birds' about 310 million and from the amphibians' about 350 million. The frog's line has had longest for differences to build up.
-
- 03** Kohlrabi and Brussels sprouts look nothing alike. A grower lets them cross-pollinate. What happens?
- B Seeds form and grow into fertile plants: one species**
- They cross easily and the offspring are fertile, which is why seed growers keep the cultivars far apart. However different they look, they are still one species with one gene pool.
-
- 04** A bat's wing and a bird's wing: homologous or analogous?
- C Both: homologous as forelimbs, analogous as wings for flight**
- Both. As forelimbs they share the pentadactyl plan from a common ancestor: homologous. But that ancestor could not fly, so wings evolved separately in bats (skin stretched over long fingers) and birds (feathers on a shortened hand): as wings, analogous.
-
- 05** A line of snails changes its shell shape steadily for two million years and never splits. The oldest and newest shells look so different that fossil experts give them different names. How many species has the line added to the Earth?
- B None: at every moment there was still only one species**
- None. At every moment there was one species of these snails, so the count never went up. The two names are a convenience for describing change along one line. Gradual change within one line is evolution, but only a split adds a species.
-
- 06** Suppose the river had divided the apes but the forests on both banks were identical. What would you expect after a million years?
- B Some differences, from mutation and drift, but less divergence**
- Some differences. Mutations and drift still differ on each side, so the populations slowly drift apart, but with no differential selection nothing pushes them in different directions. Try it in the dry lab: the control has the same food on both islands.
-
- 07** Two populations of a cricket share one meadow. One sings and mates in spring, the other in late summer. Which kind of isolation is this, and which route to speciation?
- B Temporal isolation: sympatric speciation**
- Temporal isolation, and sympatric, because they live in the same place. Nothing separates them but the time of year when they breed, which is enough to stop gene flow.
-

- Q8** Suppose the first finches had landed on islands already full of small birds of many kinds. What would you expect?

A Fewer finch species: most niches would already be filled

Fewer. A finch with a beak suited to insects would compete with established insect-eaters, which already do that job well, so selection would not favour it. Vacant niches are what let a radiation happen.

- Q9** Redshank ($2n = 44$) is crossed with one of its parents, pale persicaria ($2n = 22$). How many chromosomes do the offspring have, and are they fertile?

B 33: three sets that cannot pair evenly, so sterile

33. A redshank gamete carries 22 and a pale persicaria gamete 11. The offspring have three sets of 11, and an odd number of sets cannot pair evenly at meiosis, so they are sterile. That is why the new polyploid is reproductively isolated from its parents straight away.

QUESTIONS ON THE DRY LAB

- Q1** In the control, the islands have the same food. After 200 generations the mean beaks usually differ a little, but the test says one species. Why?

B Only drift and mutation differ, so the beaks wander slowly and at random

Isolation stops gene flow, but with the same food there is no differential selection to push the two populations in different directions. Drift and new mutations still differ on each side, so the beaks wander apart a little, slowly and in no particular direction: far too little, in 200 generations, for the birds to prefer their own kind. It is the bonobos' lesson (A4.1.7): isolation lets populations diverge, and different selection drives them apart.

- Q2** With very different food, a handful of birds crossing each generation is enough to keep the two islands one species. How?

C Each crossing bird brings its alleles, mixing the gene pools every generation

Gene flow. Every bird that crosses and breeds carries its alleles into the other gene pool, undoing some of the divergence that selection builds. A few migrants each generation can hold two populations together as one species, even when selection on each side is strong. That is why reproductive isolation comes first in speciation (A4.1.6 and A4.1.7).

- Q3** Higher level. On one island with two foods, the population only splits into two groups when mate choice is strong. Why is mate choice needed here, but not when the sea splits the island?

A On one island nothing else stops the two groups mating, so behaviour must

Without a barrier, deep-beaked and shallow-beaked birds meet and mate, and their chicks have middling beaks, mixing the two groups back together every generation. Only behavioural isolation, choosing a mate that sounds like your own kind, stops that gene flow. With the sea, geography does that job. This is the difference between sympatric and allopatric speciation (A4.1.8).

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.