Evolution and speciation

A4.1 · SL and AHL

Which water-saving change is evolution?

Identify the population and evidence of inheritance

Afternoon stomatal closure is an individual response. An inherited population change across generations is a different claim.

A4.1 connects evidence for evolution with speciation. Prerequisites: inheritance, meiosis, variation and species concepts.

Numerical examples and chromosome models are invented. Named studies are identified in the handout.

Evolution concerns heritable population change

An individual need not change its alleles for frequencies to change

Evolution is change in a population's heritable characteristics across generations.

Growth, learning and temporary physiological adjustment do not by themselves establish evolution.

An adaptation is heritable and beneficial in particular conditions. A useful acclimatization response is not automatically a newly evolved inherited trait.

A water-saving feature can have a cost

Compare benefit and trade-off in the stated environment

A thick cuticle can reduce water loss. Reduced stomatal opening conserves water but can restrict carbon dioxide entry.

A benefit in dry conditions need not be best under every condition.

Test inheritance and reproductive success. A plausible functional story is a hypothesis, not sufficient evidence by itself.

Selection does not create variants because they are needed

Variation, inheritance and reproductive differences connect the mechanism

Mutation supplies new variants; inheritance passes variants on. Relevant variants must affect reproductive success for selection to change their representation.

No organism needs to know which mutation would help. Selection is not an intentional choice by a population.

Chance and other population processes also cause change; not every evolved difference is an adaptation.

Follow inherited forms into the next generation

1. **Invented start.** 100 A and 100 B: $f_A = 100/(100 + 100) = 0.50$.
2. **Invented offspring.** 300 A and 100 B: $f_A = 300/(300 + 100) = 0.75$.
3. **Interpret.** Increase: 25 percentage points; relative frequency increase $(0.75 - 0.50)/0.50 \times 100 = 50\%$.

Decision

Assume inherited forms, successive non-overlapping generations and no migration or mutation. B did not deliberately turn into A.

Compare homologous sequences, not just the same alphabet

Shared complex patterns support common ancestry

Homologous DNA, RNA and protein sequences provide evidence of common ancestry. Sharing four DNA base types alone is a weaker observation.

Align corresponding positions and check quality. Compare several genes and independent anatomical evidence.

A tree is inferred from evidence. Modern terminal species share ancestors; one is not automatically the other's ancestor.

Interpret a selected sequence alignment precisely

1. **Invented data.** Six differences among 40 homologous aligned sites.
2. **Calculate.** $d = 6/40 \times 100 = 15\%$ different; $34/40 \times 100 = 85\%$ matching.
3. **Limit.** These percentages describe this alignment, not the entire genomes. A date requires a rate/calibration model.

Selective breeding changes which inherited variants reproduce

Parent choice, inheritance and repeated selection

Breeders choose parents with desired heritable traits. Repeated selection can change trait frequency or average expression.

Dog breeds and crop varieties show substantial differences among related populations on observable timescales.

An acquired body change or training is not automatically transmitted as an inherited variant. Compare offspring under consistent conditions.

Natural selection has no breeder or planned goal

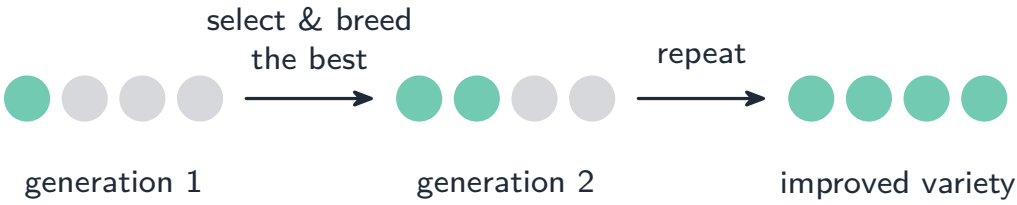
Artificial selection demonstrates possibility, not every past event

Strong selection and available variation can produce rapid population change in breeding programmes.

This supports the possibility of evolutionary change but does not recreate every historical event.

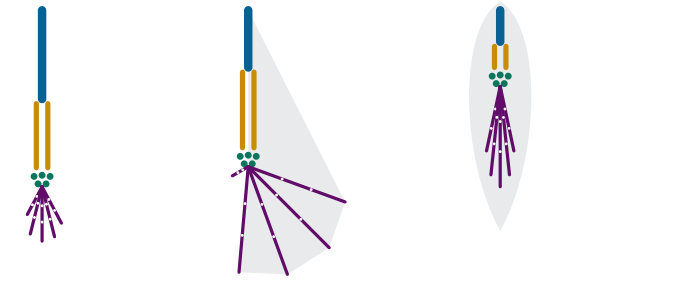
In natural selection, environmental conditions influence relative reproductive success; no breeder chooses a final form.

Selective breeding



Artificial selection shows heritable change

Compare the shared forelimb plan



the same bone plan with different proportions; schematic, not measured skeletons

The inherited bone plan can persist as proportions and functions change.

Trace corresponding structures before comparing functions

Region	Shared ancestral forelimb plan
Upper arm	One humerus
Forearm	Radius and ulna
Wrist / hand	Wrist bones and a hand region with digits
Digits	Ancestral five-digit plan; later reduction, loss or modification is possible

Different tasks do not remove homology

Corresponding positions matter more than equal lengths

Forelimbs can be modified for grasping, running, swimming and flying.

Molecular and developmental agreement strengthens an anatomical ancestry inference.

A modern arm did not have to become a different living species' flipper. Both lineages descend from ancestral populations.

A shared flight function can evolve independently

Specify the structure and comparison

Bird and insect wings both support flight, but an insect wing is not a bony vertebrate forelimb.

Bird and bat forelimb bones are homologous. Their powered flight and flight surfaces evolved separately: feathers versus a digit-supported skin membrane.

A streamlined shape in dolphins and sharks can reflect convergence. Compare independent features before assigning closest relatives.

Evolution of one population need not add a species

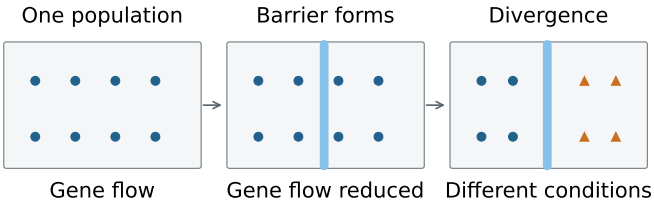
A split and an inherited average change are different claims

A population can change in heritable body size for generations while remaining one interbreeding group.

Speciation produces two or more species from pre-existing lineages; extinction removes species.

In the biological species framework, reproductive isolation limits gene flow. Appearance or distance alone does not prove a species boundary.

Trace separation, reduced gene flow and divergence



Invented history: separation need not create species immediately.
Test reproductive isolation using suitable evidence.

> A geographical barrier permits divergence; reproductive isolation still needs evidence.

Different selection pressures can strengthen divergence

Connect environment to inheritance and reproductive success

After gene flow is reduced, mutation, selection and other population processes can produce differences.

Inherited variants favoured under one set of conditions can be less successful in the other population.

Differences in mating signals, reproductive time or compatibility can strengthen reproductive isolation over generations.

Chimpanzees and bonobos illustrate a complex geographical history

The Congo River is a major barrier, not a complete historical explanation

Common chimpanzees and bonobos share ancestral populations. Much of their present ranges lies on different sides of the Congo River.

Reduced gene flow permitted divergence under different ecological and social conditions.

Genomic evidence also supports ancient episodes of gene flow after the main divergence. Neither a perfectly impermeable barrier nor one modern species as the other's ancestor follows.

Normalize water loss before comparing samples

1. **Invented measurements.** A loses 12 g; B loses 8 g. Each has area $0.20\,\mathrm{m}^2$ and duration 2 h.
2. **Relation.** $R = \text{mass lost}/(\text{area} \times \text{time})$. Then $R_A = 30$ and $R_B = 20\,\mathrm{g}/(\mathrm{m}^2\,\mathrm{h})$.
3. **Compare.** B is $(30 - 20)/30 \times 100 \approx 33.3\%$ lower relative to A.

Decision

The rate difference alone establishes neither inheritance nor a reproductive benefit.

Control conditions and test the evolutionary claim

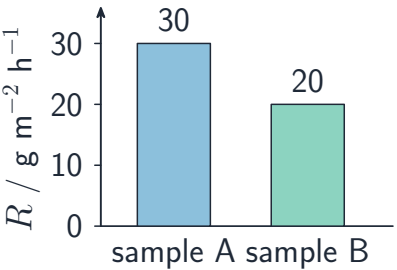
Repeat independent plants, not only one leaf measurement

Control humidity, temperature, airflow, light, leaf age and water supply. Record area and observation time consistently.

Use independent plants and repeated measurements. Common growth conditions and genetic evidence can test inheritance.

Measure survival or reproduction as well as water loss. Lower loss can restrict photosynthesis; a habitat correlation can be confounded.

Normalising before comparing



$$R = \frac{\text{mass lost}}{\text{leaf area} \times \text{time}}$$

A: $12/(0.20 \times 2) = 30$

B: $8/(0.20 \times 2) = 20$

B is about 33% lower (invented data)

Divide by area and time for a fair comparison

Compare the role of geography

Route	How gene flow can be reduced
Allopatric	Geographical separation limits contact; divergence and reproductive barriers can accumulate
Sympatric	Divergence without geographical separation; mating preferences, breeding times or chromosome-set changes can reduce gene flow

Both routes require more than different appearance

Identify the mechanism and persistence of isolation

A geographical barrier need not instantly make populations incompatible.

Populations in the same area may breed at different times or use different mating signals.

On secondary contact, evidence about mating and offspring viability/fertility helps evaluate reproductive isolation.

A common lineage can diversify into several ecological roles

Common ancestry, species boundaries and niche differences all matter

Ecological opportunities can arise in new habitats or around underused resources.

Invented birds exploit large seeds, small seeds and insects. Heritable feeding differences, selection and isolation can support diversification.

Resource partitioning can reduce competition without removing all competition. Individuals do not choose to evolve the needed beak.

Distinguish preventing a cross from reducing hybrid fertility

Mechanism	**How allele mixing is limited**
Courtship differences	Mating signals can prevent mating
Breeding seasons	Different reproductive times can prevent fertilization
Hybrid sterility	A surviving hybrid may produce few or no viable gametes; mules are generally sterile

A surviving hybrid does not establish free gene flow

Pairing and segregation matter in meiosis

Chromosome differences can disrupt regular meiotic pairing and gamete formation.

A mule can survive even though it is generally sterile. Adult viability and onward fertility are different properties.

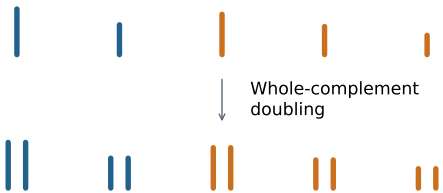
Some species hybridize occasionally. Evaluate frequency and reproductive success rather than treating isolation as universally absolute.

Combine invented parental chromosome sets

1. **Parents.** A has $2n_A = 4$: its gametes contain 2. B has $2n_B = 6$: its gametes contain 3.
2. **Hybrid.** Fusion produces AB with $2 + 3 = 5$ chromosomes. Assume A and B chromosomes do not pair effectively as homologues.
3. **Doubling.** AABB has ten chromosomes. Each of the five types now has a homologous partner; regular pairing can allow five-chromosome AB gametes.

Doubling supplies chromosome partners

AB: 5 chromosomes; partners absent



AABB: 10 chromosomes; 5 homologous pairs

Invented model: blue = A types; orange = B types.
Regular pairing can restore fertility; establishment still needs reproduction.

Invented AB $\rightarrow$ AABB: five chromosomes become ten, with five homologous pairs.

Restored fertility still needs a reproducing lineage

Abrupt isolation is possible, not guaranteed establishment

Compatible doubled plants, or a self-compatible plant, may reproduce while crosses with parental diploids give unbalanced complements.

This can establish reproductive isolation. Ordinary DNA copying followed by ordinary mitosis is not the same as doubling chromosome sets.

A hybrid does not automatically become an established new species. Fertility, compatible reproduction and persistence matter.

Persicaria provides molecular evidence of allopolyploid origins

A real study; our chromosome counts are invented

A 2008 study found different nuclear gene copies supporting contributions from different parental lineages in several *Persicaria* species.

For *P. punctata*, inferred contributors included *P. hydropiper* and a lineage related to *P. hirsuta* or *P. setacea*.

Some parental assignments remain uncertain. These historical crosses were inferred, not directly observed; the study is linked in the handout.

Try a frequency problem and an evidence decision

Keep percentage points distinct from relative change

Invented start: 80 inherited A and 120 B individuals. Next generation: 240 A and 160 B.

Find A's initial and final frequency, percentage-point change and relative percentage increase.

Separately, a plant closes its stomata on a dry afternoon. Explain why this observation alone does not show population evolution.

Reveal: changes in frequency require their denominators

1. **Start.** $f_A = 80/200 = 0.40$.
2. **Next generation.** $f_A = 240/400 = 0.60$: an increase of 20 percentage points.
3. **Relative change.** $(0.60 - 0.40)/0.40 \times 100 = 50\%$. Afternoon stomatal closure is an individual response, not evidence by itself of inherited population change.

Check yourself

Population, inheritance, structure and gene flow

Name the population and generations, and give evidence of inheritance. Explain benefits and trade-offs in a stated environment.

Specify the structure when distinguishing homology from analogous function.

For speciation, explain reduced gene flow and reproductive isolation. State denominators in frequencies and normalized rates.