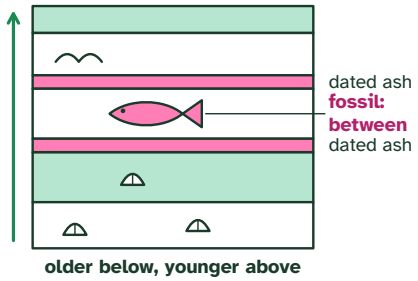
How we *know*

What to know, what to draw and what to say. Nothing else.

THE ONE IDEA

Rocks, bones and sequences, read apart, tell one story of common ancestry. A tree of it is a hypothesis, read at its nodes.



Date the ash, not the fossil. Sedimentary rock holds the fossils; volcanic layers hold the clock.

7.6.B START HERE

Reading the *rocks*

- A **fossil** is the preserved remains or traces of an organism from the past. In undisturbed sedimentary rock, **lower layers are older**: an order, not an age in years.
- For years, use a **radioactive isotope**, which decays at a fixed rate, its **half-life**. **Carbon-14** (about 5,730 years) dates once-living material up to about 50,000 years.
- Older rock needs slower isotopes. **Potassium-40** (half-life about 1.25 billion years; about a tenth decays to argon-40) is measured in **volcanic ash**, so a fossil between two dated ash layers gets an age between theirs.
- **Transitional forms** share features with extinct and extant groups: *Tiktaalik*, about 375 million years old, had gills and scales and limb-like fins.

½	¼	⅛
left after one half-life	after two: 11,460 years for carbon-14	after three

7.6.A EVIDENCE FROM MANY DISCIPLINES

Five kinds of data, one *story*

KIND	WHAT IT READS	ONE EXAMPLE
Geographical	Where species live, and where fossils are found.	Galápagos finches are most like birds of South America, the nearest mainland.
Geological	Rock layers and the fossils in them.	Fossils appear in a consistent order, layer on layer.
Physical	Radioactive decay at fixed rates.	Rocks and once-living material given ages in years.
Biochemical	DNA and protein sequences.	Close relatives have more similar sequences.
Mathematical	Counting.	Allele frequencies over generations; the changes a tree needs.

Methods that are independent and agree give strong support, not proof.

7.6.B ANATOMY

Same bones, *different jobs*

- **Homologous structures** share one plan from a **common ancestor**: the forelimbs of a human, bat, whale and horse.
- **Vestigial structures** are reduced remnants of structures fully formed in relatives: a whale's pelvis, a python's spurs. They are homologies too.
- Same job, different origin is **analogous**: a bird's wing and an insect's.
- **Vestigial is not useless:** a whale's pelvic bones anchor muscles used in mating. They are reduced from an ancestor's.



7.6.B MOLECULES

Sequences *remember* ancestors

- After two lineages split, mutations build up separately in each, so **fewer differences** means a **more recent common ancestor**.
- DNA changes faster than protein, so it separates close relatives. **Cytochrome c:** chimpanzee identical to human, rhesus 1 difference, yeast over 40.
- Nearly all life uses DNA and **the same genetic code**: evidence of one common ancestor of all of it.

human	A T G G C T A A G C T T	
chimpanzee	A T G G C T A A G C T T	0
mouse	A T G G C A A A G C T C	2
chicken	A T C G C A A G G C T A	4

Made-up sequence; pink bases differ from the human.

7.7.A CELLS AND GENOMES

What every *eukaryote* shares

- All eukaryotes share structural and functional features that point to **one common ancestor**.
- A complex feature built the same way in all of them was far more likely **inherited once** than evolved again and again.
- These are **typical of** eukaryotes, not found only in them.

MANY
Membrane-bound organelles
Nucleus, mitochondria, ER, Golgi.

LITTLE
Linear chromosomes
Strands with two ends.

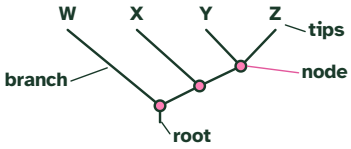
INTERRUPTIONS
Introns
Cut out of the RNA by a spliceosome.

Trees: read them, build them, *revise* them

7.9.A 7.9.B READING

Read a tree by its *nodes*

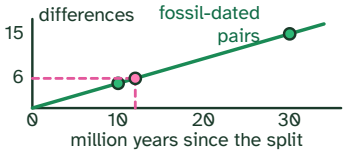
- Phylogenetic trees and cladograms show **hypothetical evolutionary relationships**, and can be tested.
- Each **node** is the **most recent common ancestor** of what branches from it: a speciation that has happened. The root is the ancestor of all.
- Follow two tips back to where they meet. Nodes **spin**, so tip order means nothing.



7.9.A CALIBRATING

Cladogram or tree, and *time*

- A **cladogram** shows **branching order only**; a **phylogenetic tree** also shows **change over time**.
- Time comes from **fossils** of known age and a **molecular clock**: differences build up at a roughly steady rate, so **time = differences ÷ rate**.
- It gives an estimate: generation time and selection change the rate.

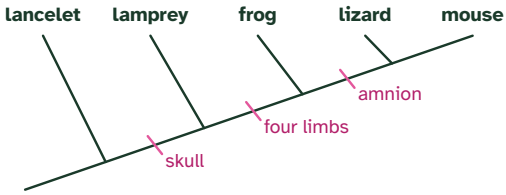


7.9.A BUILDING

From a table to a *cladogram*

	SKULL	LIMBS	AMNION
Lancelet			
Lamprey	✓		
Frog	✓	✓	
Lizard	✓	✓	✓
Mouse	✓	✓	✓

- The **out-group**, least related to the rest, shows the **ancestral** states.
- A **shared derived character** arose in a common ancestor and is in more than one descendant lineage. A trait everyone has groups no one.
- The trait most share is nearest the root. Where data clash, prefer the **fewest changes**.



7.9.B 7.8.A

Trees are *revised*, and evolution goes on

- Trees are built from **morphology** (living or fossil) and from **DNA and protein sequences**. **Molecular data** are typically **more accurate and reliable**: a character at every site, while similar body traits can evolve separately.
- Trees are **constantly revised**: in 2001 chloroplast DNA broke up the figwort family, grouped by its flowers.
- **All species continue to evolve.** Four kinds of evidence:

EVIDENCE	ONE CASE
Genomes	*E. coli* since 1988: 75,000 generations by 2022.
Fossils	Plankton shells change gradually, layer on layer.
Resistance	MRSA (1961), glyphosate (1996), tumor cells.
New diseases	2009 flu: pig, bird, human segments.

WATCH OUT

Five mistakes that *cost points*

- ✕ **Carbon-14 does not date dinosaurs.** They are 66 million years old; carbon-14 reaches 50,000.
- ✕ **Humans did not evolve from chimpanzees.** Both are living tips with a shared ancestor.
- ✕ **Read nodes, not neighbors.** Tips side by side need not be close relatives.
- ✕ **A cladogram's line lengths mean nothing.** Read time only on a tree with an axis.
- ✕ **Single-celled does not mean prokaryote.** Amoebas and yeasts are eukaryotes.

COVER THE SHEET

Can you *answer these?*

1. Calculate the age of a bone with ⅛ of its carbon-14.
2. Describe how a fossil in sedimentary rock is dated.
3. Explain why homologous limbs support common ancestry.
4. Identify three features shared by all eukaryotes.
5. Explain why a cladogram shows no time.
6. Calculate a split: 12 differences, 1 per 2 million years.
7. Justify using DNA over body traits to build a tree.
8. Describe one piece of evidence that evolution continues.

IN THE EXAM

Name the data and what it shows: "the same bones in the same order, so inherited from a common ancestor". On a tree, quote the node where two tips meet.

GO FURTHER

Animated figures, a dry lab and a marked Check are in the full guide online.