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Collegedunia NCERT Solutions

Step-by-step solutions, alternate methods & exam tips for Class 12th Biology, Chapter 6 (Coloured PDF, 2026-27 NCERT, Latest Edition)

Chapter 6: Evolution

About this Chapter

Chapter 6 *Evolution* traces the origin of life from chemical precursors through the diversification of species by natural selection. You will work with **Darwinian selection**, **adaptive radiation**, **Hardy–Weinberg equilibrium** and the fossil record of vertebrates and humans. These ten exercises test reasoning across observation, evidence and definition – not rote recall – so each solution names every concept it applies before using it.

Topics covered: Origin of life • Evidences of evolution • Darwinism • Adaptive radiation • Hardy–Weinberg • Geological time scale • Human evolution

Quick Formula Sheet

Hardy–Weinberg principle:
$p^2 + 2pq + q^2 = 1, p + q = 1$

Five disturbing forces:
Gene flow, genetic drift, mutation,
genetic recombination, natural selection

Darwin's two ideas:
Branching descent & *natural selection*

Adaptive radiation:
One ancestor $\rightarrow$ many forms in different habitats

Exercises

Q 6.1 **Explain antibiotic resistance observed in bacteria in light of Darwinian selection theory.**

SOLUTION

Concept used. **Darwinian natural selection** is the mechanism Charles Darwin proposed in 1859 (*On the Origin of Species*) to explain how populations change over time. It rests on four observable conditions:

- Within any population, individuals show heritable *variation*.

- More offspring are produced than the environment can support (*overproduction*).
- The resulting *struggle for existence* means not every individual survives or breeds.
- Variants whose traits raise their chance of survival and reproduction in that environment leave more offspring (*differential survival of the fittest*). Over generations these traits become more common in the population.

The phrase *"fitness"* here means reproductive success in a specific environment, not strength or speed.

> ☞ **Key Darwinian phrase**
> *"Survival of the fittest"* was coined by Herbert Spencer and borrowed by Darwin. "Fittest" is defined *relative* to the present environment, not as an absolute property.

Step 1. Pre-existing variation in the bacterial population.
A bacterial colony is not genetically uniform. Random mutations during DNA replication produce variants – some carry an altered enzyme, an efflux pump, or a modified cell wall that happens to weaken the binding of an antibiotic. These mutants exist *before* the antibiotic is ever applied, at frequencies of roughly 10^{-9} to 10^{-6} per cell per generation.

Step 2. Application of antibiotic creates a strong selective pressure.
When penicillin (or any antibiotic) is introduced, the environment changes drastically. Sensitive bacteria are killed; the rare resistant mutants survive. This is exactly Darwin's *struggle for existence*: the resource (antibiotic-free niche) is limited, and only a few variants can occupy it.

Step 3. Differential reproduction of the resistant variant.
Resistant bacteria reproduce rapidly (*E. coli* divides every ~ 20 min). Within hours the resistant genotype dominates the colony – a clear example of *differential survival and reproduction*. After a few generations the population is essentially all resistant.

Step 4. Inheritance of the resistance trait.
Resistance is encoded in DNA (often on plasmids), so it is passed to daughter cells. Plasmids can also move horizontally between species by conjugation, accelerating the spread – but the *Darwinian* core (variation + selection + inheritance) is intact.

Step 5. Outcome: rapid evolution of a resistant population.
Bacteria are a textbook demonstration of Darwinian selection because their short generation time makes the entire sequence visible within a single human lifetime. Hospitals now report MRSA (methicillin-resistant *Staphylococcus aureus*), VRE and XDR-TB – all evolved by the same logic.

Why this fits Darwin's theory perfectly. All four preconditions of natural selection are satisfied: heritable variation, overproduction (a single *E. coli* cell can yield 10^9

descendants overnight), differential survival under antibiotic pressure, and inheritance of the favourable trait. The antibiotic does not *create* resistance; it merely *selects for* pre-existing resistant variants. This is what Darwin meant by "nature selecting".

> **Final Answer:** Antibiotic resistance arises because rare pre-existing mutants in a bacterial population happen to be insensitive to the drug. When the antibiotic is applied, sensitive cells die while resistant cells survive and reproduce. Within a few generations the entire colony becomes resistant – a real-time demonstration of Darwinian natural selection (variation, struggle, survival of the fittest, inheritance).

✗ Common Mistake

Do **not** say "bacteria develop resistance because they are exposed to antibiotics." That is Lamarckism (inheritance of acquired characters), which is wrong. The mutation is *random* and *prior* to exposure; the antibiotic only selects among already existing variants.

EXPERT'S SOLUTION *: Aanya Iyer, M.Sc Microbiology, JNU*

Strategic angle: tell it as a Darwinian story. The cleanest way to handle this 5-mark question in the board is to recite Darwin's four conditions and tick each one against the bacterial example. Examiners reward that explicit mapping.
Concept used. The four pillars of Darwinian selection are (i) *variation*, (ii) *overproduction*, (iii) *struggle for existence*, and (iv) *differential survival of the fittest with inheritance*. A population evolves when an environmental change favours one heritable variant over another.

Step 1. **Variation.** Bacterial replication is high-fidelity but not perfect: mutation rate is roughly 10^{-9}–10^{-6} per base per generation. A culture of 10^8 cells therefore already contains several hundred random mutants, some of which alter the antibiotic's target (e.g. penicillin-binding protein, ribosome, gyrase) or activate a degradative enzyme (e.g. β-lactamase).

Step 2. **Overproduction.** An *E. coli* cell divides every ~ 20 minutes. Starting from one cell, after n generations the population is $N = 2^n$. In 10 hours ($n = 30$), $N \approx 10^9$. Resources, however, are limited, so all 10^9 cannot survive.

Step 3. **Struggle for existence.** When the antibiotic is added, the environment now defines a new "fitness". Cells with the wild-type target are killed; cells carrying the resistance mutation are not. The struggle is now between sensitive cells trying to grow in a hostile environment and resistant cells thriving in it.

Step 4. **Differential survival of the fittest with inheritance.** The resistant cells reproduce, passing the resistance allele to all daughters. Because each generation doubles the resistant population, a one-in-a-million mutant can dominate a 10^9-cell colony in roughly 30 generations.

Step 5. **Real-world consequence.** The same selection now plays out across hospitals: *Staphylococcus aureus* first met methicillin in the 1960s; MRSA was reported by 1961. Inappropriate antibiotic use simply accelerates the Darwinian inevitability.

Why this matters. Antibiotic resistance is the single most visible example of evolution in action that a school student can observe. The 2022 *Lancet* estimate attributes ~ 1.27 million human deaths a year directly to drug-resistant infections – the practical cost of misunderstanding Darwin.

> **Final Answer:** Resistance is the Darwinian outcome of pre-existing mutational *variation*, antibiotic-driven *differential survival*, and *inheritance* of the resistance allele across rapidly dividing generations. Bacteria do not "learn" resistance; the drug selects what was already there.

Q 6.2 **Find out from newspapers and popular science articles any new fossil discoveries or controversies about evolution.**

SOLUTION

Concept used. A fossil is any preserved remains, impression or trace of an organism that lived in the past, embedded in sedimentary rock. Fossils are dated by (i) *stratigraphy* (younger layers sit above older ones) and (ii) *radiometric dating* (^{14}C, $^{40}K/^{40}Ar$ etc.). Fossils give *direct* evidence of evolution: they show transitional forms, extinct groups and the geological order in which life diversified.

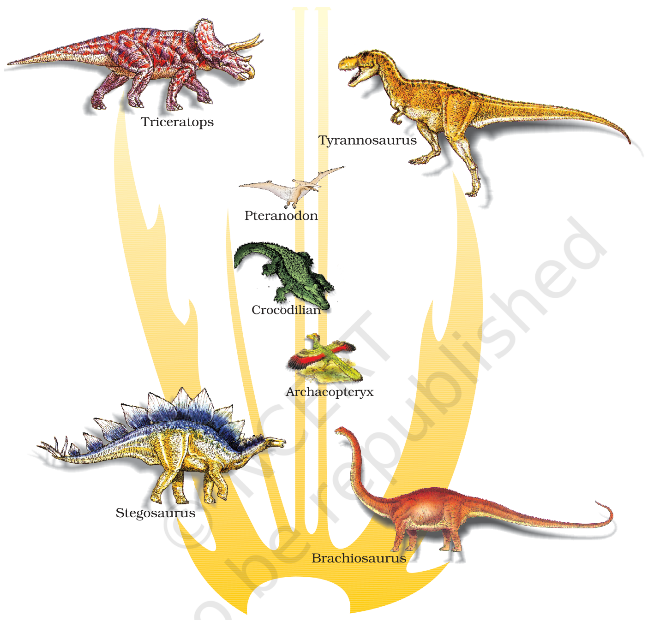


Figure 6.2 A family tree of dinosaurs and their living modern day counterpart organisms like crocodiles and birds

Fig. 6.2, NCERT Class 12 Biology, Chapter 6 – extinct organisms (dinosaurs) and their modern-day counterparts (crocodiles and birds). A standard fossil-to-living comparison.

Notable recent fossil discoveries (with sources students can look up).

Step 1. ***Tiktaalik roseae*** **(2006, Ellesmere Island, Canada).** A 375-million-year-old lobe-finned fish with a flat skull, neck, ribs and wrist-like fin bones – a clear *transitional fossil* between fish and tetrapods, bridging the water-to-land transition. Reported in *Nature* 440, 757 (Daeschler, Shubin & Jenkins, 2006) and covered widely in popular science press.

Step 2. ***Homo naledi*** **(2013–15, Rising Star cave, South Africa).** Over 1 500 hominin bones discovered by Lee Berger's team – a small-brained, ~ 1.5 m-tall hominin from $\sim 300\,000$ years ago, that may have deliberately deposited its dead. Controversy: *Did* a small-brained species practise mortuary behaviour, traditionally thought unique to *H. sapiens*?

Step 3. ***Australopithecus sediba*** **(2008, Malapa, South Africa).** ~ 2 million-year-old hominin with a mix of *Australopithecus* and *Homo* features. Reignited the debate about which australopithecine actually gave rise to *Homo*.

Step 4. **Feathered dinosaurs from Liaoning, China (1990s onward).** *Sinosauropteryx, Microraptor, Anchiornis*: theropod dinosaurs preserved with filamentous feathers in Yixian Formation lakes. They settled the question of bird origins in favour of a dinosaurian ancestry (Archaeopteryx was no longer an oddity).

Step 5. **Denisovans (2010, Denisova cave, Siberia).** An entire new hominin lineage identified from a finger bone, purely by ancient-DNA sequencing. Sparked a still-running controversy about how many hominin species coexisted in Asia and how much interbreeding occurred with *H. sapiens*.

Step 6. ***Dickinsonia* as the earliest animal (~ 558 Ma).** 2018 cholesterol-biomarker work (*Science* 361, 1246) showed Ediacaran *Dickinsonia* was an animal, not a fungus or lichen – pushing back the age of confirmed Metazoa.

Live evolution controversies in the press.

- *Where did Homo sapiens originate?* Single-origin (Africa, ~ 200 kya) vs. multi-regional models, complicated by new African finds at Jebel Irhoud (~ 315 kya).
- *Did Neanderthals and modern humans interbreed?* Confirmed by ancient-DNA work (Svante Pääbo, Nobel Prize 2022); ~ 1–4% Neanderthal DNA persists in non-African humans.
- *"Hobbit" Homo floresiensis* (2003, Flores Island): a tiny hominin alive until ~ 50 kya – species or pathological *H. sapiens*? Now widely accepted as a distinct species.

> **Final Answer:** Major recent fossil discoveries that reinforce evolutionary theory include *Tiktaalik* (fish $\rightarrow$ tetrapod transition, 2006), *Homo naledi* (small-brained hominin with possible mortuary behaviour, 2013), *A. sediba* (2008), feathered dinosaurs of Liaoning, the Denisovans (2010), and biomarker evidence that Ediacaran *Dickinsonia* was an animal (2018). Ongoing controversies concern human origins, Neanderthal introgression, and *Homo floresiensis*.

☞ Exam Tip

For "find out" questions, a board answer should still cite at least two specific named fossils and the years/locations of their discovery. Vague phrasing ("many new fossils have been found") fetches few marks.

EXPERT'S SOLUTION *: Pranav Sharma, M.Sc Biotechnology, AIIMS Delhi*

Strategic angle: a chronology with sources. The strongest answer organises discoveries by what they *settle* – i.e. which gap in the tree of life each closes – and pairs them with a citation a student can verify. Below is a worked map.

Concept used. *Transitional fossils* (forms with features of two related groups) are the gold-standard evidence for descent with modification. Each major group transition predicts a specific kind of fossil; finding one is a falsifiable test of Darwin's theory.

Step 1. **Fish-to-tetrapod gap.** *Tiktaalik roseae* (375 Ma, Devonian, Ellesmere Is., Canada) was predicted to exist in Late Devonian rocks of an exact age and was found there by Neil Shubin's team in 2004 (published 2006). It possesses a flat skull, a neck (free of the shoulder girdle, like a tetrapod), proto-wrist bones inside a fish's lobe fin, and ribs that could bear weight.

Step 2. **Dinosaur-to-bird gap.** *Anchiornis huxleyi* and *Microraptor* from Liaoning

(Yixian Fm, China, ∼ 160–120 Ma) preserve filamentous and pennaceous feathers on small theropod dinosaurs. Combined with Jurassic *Archaeopteryx* (1861, Solnhofen), they make the dinosaurian ancestry of birds the consensus view.

Step 3. **Ape-to-human gap.** *Sahelanthropus tchadensis* (2002, Chad; ∼ 7 Ma), *Ardipithecus ramidus* (1992, Ethiopia; ∼ 4.4 Ma), *Australopithecus sediba* (2008, S. Africa; ∼ 1.98 Ma), and *Homo naledi* (2013, S. Africa; ∼ 0.3 Ma) populate the bushy hominin tree.

Step 4. **Genus-level discoveries via ancient DNA.** The Denisovans (2010) were named entirely on the basis of a ∼ 40 kya finger-bone genome – a wholly new method that has since identified introgression from Denisovans into modern Papuans and Tibetans (the *EPAS1* high-altitude allele).

Step 5. **Earliest-animal gap.** 2018 biomarker work confirmed *Dickinsonia* (∼ 558 Ma) as a true metazoan, pushing the animal origin into the late Precambrian.

Why this matters. Every named fossil above was a *prediction* of evolutionary theory before it was found. The fact that they were found in the predicted rocks at the predicted ages is what Karl Popper would call “corroboration of a risky prediction” – the hallmark of a successful scientific theory.

Final Answer: From *Tiktaalik* (water-to-land) to feathered Liaoning dinosaurs (dinos-to-birds) to *Homo naledi* and the Denisovans (the bushy human tree), every major group transition predicted by Darwinian evolution has yielded a transitional fossil in the past 25 years. Current controversies concern the timing and geography of *H. sapiens* origins, Neanderthal and Denisovan introgression, and the species status of *H. floresiensis*.

Q 6.3 Attempt giving a clear definition of the term species.

SOLUTION

Concept used. A **species** is the basic unit of biological classification. Several non-equivalent definitions are in current use because no single criterion fits all life. The most widely taught is Ernst Mayr’s *biological species concept*, but students should know the alternatives because they apply to fossils, asexual organisms and bacteria.

Step 1. **Biological species concept (Ernst Mayr, 1942).** *A species is a group of actually or potentially interbreeding natural populations that are reproductively isolated from other such groups, and produce fertile offspring.* Key requirements:

- *Interbreeding* – members can mate and produce viable offspring.

- *Fertile offspring* – those offspring can themselves reproduce (this excludes mule, the infertile horse×donkey hybrid).
- *Reproductive isolation* from other species (pre-zygotic: behaviour, timing, habitat; post-zygotic: hybrid inviability or sterility).

Step 2. **Morphological species concept.** A species is a group of organisms sharing characteristic anatomical features distinct from other groups. Used for taxonomy when breeding cannot be observed (e.g. herbarium specimens, museum skeletons).

Step 3. **Phylogenetic species concept.** A species is the smallest monophyletic group descended from a common ancestor – diagnosable by at least one unique derived character. Useful for molecular-tree-based classification.

Step 4. **Ecological species concept.** A species is a lineage of populations that occupies a unique adaptive zone or niche. Useful when reproductive isolation is incomplete but ecological roles diverge.

Step 5. **Where Mayr's definition struggles.** It fails for (i) *asexual* organisms (bacteria, parthenogenetic lizards) where "interbreeding" is undefined, (ii) *fossil* species where mating cannot be tested, (iii) *ring species* (*Ensatina* salamanders) where adjacent populations interbreed but the end-of-ring populations do not.

> **Final Answer:** In NCERT terms: A *species* is a group of similar organisms that can interbreed in nature and produce fertile offspring, and that is reproductively isolated from all other such groups (biological species concept, after Ernst Mayr, 1942). Alternative definitions (morphological, phylogenetic, ecological) apply where reproductive isolation cannot be tested.

♥ Why so many definitions

A bacterial "species", a fossil "species" and a flowering-plant "species" are detected by very different criteria. The diversity of definitions reflects the diversity of life – not a failure of biology. JEE/NEET questions usually expect Mayr's wording; CBSE sometimes accepts the morphological definition too.

EXPERT'S SOLUTION *: Riya Mehta, M.Sc Botany, Delhi University*

Strategic angle: state Mayr first, then qualify. An examiner wants three things in a "define species" answer: (i) the biological species concept, in one accurate sentence; (ii) the three conditions (interbreeding, fertile offspring, reproductive isolation); (iii) at least one example showing why the definition matters.

Concept used. A *species* is the fundamental taxonomic unit. Below it lie subspecies, races and demes; above it lie genus, family etc. The biological species concept (BSC) defines a species by reproductive criteria; the morphological concept defines it by anatomy; the phylogenetic concept defines it by ancestry.

Step 1. **One-line Mayr definition.** "A species is a group of populations whose members can interbreed in nature and produce fertile offspring, and which is reproductively isolated from other such groups."

Step 2. **Decompose the three operative phrases.** *Interbreed in nature* excludes forced laboratory crosses. *Fertile offspring* excludes mules (donkey $\times$ horse) and ligers – those animals cannot found new populations. *Reproductively isolated* means no gene flow with other species in the wild.

Step 3. **Examples that test the definition.**

- *Same species, different appearance.* Domestic dogs (Chihuahua and Great Dane) belong to *Canis lupus familiaris*; despite their size difference, gene flow (via medium-sized breeds) keeps them one species.
- *Different species, similar appearance.* Lions and tigers can be crossed in zoos (liger, tigon) but ligers are usually sterile, and lions and tigers do not meet in the wild – so they are separate species *P. leo* vs *P. tigris*.

Step 4. **When BSC fails.** For bacteria (asexual), botanists often use $\geq 97\%$ 16S rRNA sequence identity as a species cutoff (phylogenetic concept). For fossils, morphology is the only available criterion (morphological concept).

Why this matters. Biodiversity counts, conservation priorities and patent law all depend on "how many species are there?". The answer is not absolute; it depends on which species concept is applied. The IUCN Red List, for instance, uses the phylogenetic species concept by default.

> **Final Answer:** A species is a group of organisms capable of interbreeding in nature to produce fertile offspring, and reproductively isolated from other groups (Mayr 1942). Where this fails – bacteria, fossils, asexual lineages – morphological, phylogenetic or ecological species concepts are used instead.

Q 6.4 **Try to trace the various components of human evolution (hint: brain size and function, skeletal structure, dietary preference, etc.).**

SOLUTION

Concept used. Human evolution is the gradual change, over ~ 7 million years, from a chimpanzee-like ancestor to modern *Homo sapiens*. It is documented by fossils, by comparative anatomy and by molecular data. The *trends* usually examined are: cranial capacity (brain size), skeletal structure (bipedalism, posture, hand), dentition and diet, and cultural artefacts (tools, fire, language).

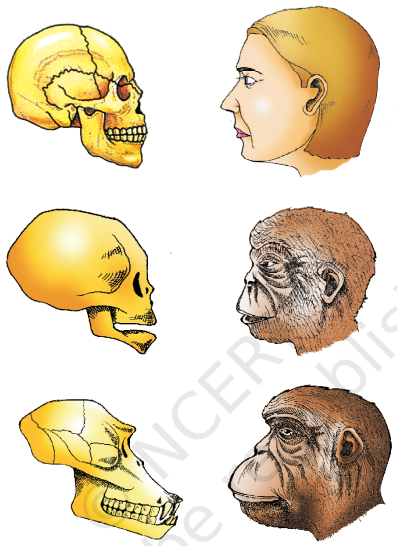


Figure 6.11 A comparison of the skulls of adult modern human being, baby chimpanzee and adult chimpanzee. The skull of baby chimpanzee is more like adult human skull than adult chimpanzee skull

Fig. 6.11, NCERT Class 12 Biology, Chapter 6 – comparison of the skulls of adult modern human, baby chimpanzee, and adult chimpanzee. Note the rounded vault and reduced brow ridge of the human skull.

Step 1. Brain size (cranial capacity). Hominid brains enlarged steadily:

- *Australopithecus* (~ 4 Ma) – ~ 400 cc (chimp-like).
- *Homo habilis* (~ 2 Ma) – ~ 650–800 cc; first stone tools.
- *Homo erectus* (~ 1.5 Ma) – ~ 900–1100 cc; controlled fire.
- Neanderthal man (~ 100 kya) – ~ 1400 cc; cared for sick, buried dead.
- *Homo sapiens* (modern) – ~ 1350 cc on average, but with cerebral re-organisation (large frontal lobes for planning and language).

Step 2. Skeletal structure – emergence of bipedalism. Walking on two legs was an early adaptation:

- *Foramen magnum* (the hole through which the spinal cord exits) shifted from the back of the skull (in apes) to directly below (in humans), consistent with an upright head balanced on the spine.
- *S-shaped vertebral column*, broad bowl-shaped *pelvis*, valgus (knock-knee) angle of the femur, longitudinal foot arch and a non-opposable big toe – all aligned for striding bipedal walk.
- *Free hand* from bipedalism enabled tool-making; opposable thumb refined for precision grip in *Homo*.
- Body size grew: *Australopithecus* ~ 1.0 m, *H. erectus* ~ 1.6 m, *H. sapiens* ~ 1.7 m.

Step 3. Dental and dietary changes.

- Earliest hominids (*Ardipithecus*, *Australopithecus*): mainly fruits and tubers, large molars, thick enamel.
- *Homo habilis*: *omnivorous* – scavenged meat, processed plant material; jaw shortens.
- *Homo erectus*: ate cooked meat, used fire (~ 0.5–1.0 Ma).
- Modern man: full omnivore; smaller jaw and teeth (cooking softened food, reducing the need for heavy chewing).

Step 4. Cultural and behavioural milestones. Tool-making (Oldowan flakes by *H. habilis*, ~ 2.5 Ma), control of fire (~ 1.5 Ma by *H. erectus*), burial of the dead (Neanderthals, ~ 0.1 Ma), cave painting (Bhimbetka, Chauvet, ~ 30 kya), agriculture (~ 10 kya), language (anatomically supported by the descended larynx and a modern hyoid, both present by ~ 0.1 Ma).

Step 5. Migration out of Africa. *Homo erectus* left Africa ~ 2 Ma (Java, Peking). *Homo sapiens* originated in Africa ~ 200 kya and migrated outward by ~ 60–75 kya, replacing or interbreeding with archaic populations such as Neanderthals and Denisovans.

> **Final Answer:** Human evolution can be traced along five interconnected components: (1) *steady increase in cranial capacity* ($400 \rightarrow 1400$ cc); (2) *skeletal adaptations for bipedalism* (repositioned foramen magnum, S-shaped spine, bowl-shaped pelvis, arched foot); (3) *dietary shift* from herbivory to omnivory with smaller teeth; (4) *cultural advances* (tools, fire, burial, art, language); and (5) *migration out of Africa* ~ 2 Ma and again ~ 60–75 kya.

☞ Exam Tip

A common NEET question asks for the cranial capacity of named hominids in increasing order. Memorise: *Australopithecus (400) < H. habilis (~ 750) < H. erectus (~ 1000) < H. sapiens (~ 1350) < Neanderthal (~ 1400).* Neanderthal had the largest brain.

EXPERT'S SOLUTION *: Aditya Reddy, Ph.D Molecular Biology, NCBS Bangalore*

Strategic angle: pair each "component" to its fossil-and-feature evidence. The clearest way to organise the answer is a table-like progression where every adaptive trend has a named fossil that first shows it.

Concept used. Each evolutionary innovation in the hominid line – bipedalism, brain expansion, tool use, fire, language – emerged at a different time and is fossilised in a specific way. Pairing trend $\leftrightarrow$ fossil makes the story examinable.

Step 1. Bipedalism (the foundational trait). First clear evidence at ~ 4 Ma in *Australopithecus*: the Laetoli footprints (Tanzania, 3.6 Ma) capture a strided walk identical to ours. Skeletal cues: angled femur, bowl-shaped pelvis, repositioned foramen magnum.

Step 2. Tool use. The Oldowan flake industry (~ 2.5 Ma, Gona, Ethiopia) coincides with *Homo habilis* ("handy man", 1964 discovery, L. Leakey). Brain size climbs to ~ 750 cc and the precision grip is now skeletally evident.

Step 3. Fire and migration. *Homo erectus* (~ 1.5 Ma): cranial capacity ~ 1000 cc, body size ~ 1.6 m, controlled fire (charred bones at Wonderwerk Cave, ~ 1.0 Ma), and migrates out of Africa (Java Man 1.7 Ma, Peking Man 0.7 Ma).

Step 4. Symbolic culture. Neanderthals (~ 200–30 kya), large brain (~ 1400 cc), care for the elderly (Shanidar 1, Iraq), deliberate burial with grave goods (Le Moustier), and pigment use (Maltravieso, Spain; ≥ 64 kya).

Step 5. Anatomically modern humans. *H. sapiens* in Africa ≥ 200 kya (Omo Kibish, Jebel Irhoud); cave art by ~ 35–40 kya (Chauvet, El Castillo); 18 kya cave paintings at Bhimbetka (India); agriculture ~ 10 kya; language by ~ 100 kya (descended larynx, modern hyoid).

Six-stage summary table – useful for revision.

- ~ 7 *Ma:* Last common ancestor with chimpanzee in African forest.
- ~ 4 *Ma: Australopithecus afarensis* (Lucy, 1974) – bipedal, ~ 400 cc brain.
- ~ 2.5 *Ma: Homo habilis* – first stone tools (Oldowan), ~ 750 cc.
- ~ 1.5 *Ma: Homo erectus* – controlled fire, migrated out of Africa, ~ 1000 cc.
- ~ 0.2 *Ma:* Neanderthals in Eurasia; modern humans in Africa; both with ≥ 1350 cc brains.
- ~ 0.04 *Ma: H. sapiens* dominant globally; cave art (Chauvet, Bhimbetka); language; symbolic culture.

Why this matters. Each "component" the question asks about is an evolutionary trend whose age can be pinned by a named fossil and a named site. Without that pairing the answer reads like a list; with it, the answer reads like science. Both NEET and CBSE board examiners specifically look for fossils and approximate ages.

> **Final Answer:** Trace human evolution through (1) *bipedalism* (*Australopithecus*, ~ 4 Ma; Laetoli prints), (2) *tool use* (*H. habilis*, 2.5 Ma; Oldowan), (3) *fire and migration* (*H. erectus*, 1.5 Ma; Java, Peking), (4) *symbolic burial* (Neanderthals, 0.1 Ma), and (5) *language and art* (*H. sapiens*, 0.1–0.04 Ma; Chauvet, Bhimbetka). Brain size climbed from ~ 400 to ~ 1400 cc across this progression.

Q 6.5 **Find out through internet and popular science articles whether animals other than man have self-consciousness.**

SOLUTION

Concept used. **Self-consciousness** (or *self-awareness*) is the ability of an organism to recognise itself as an individual separate from its environment and other individuals. The standard operational test in comparative psychology is the *Mirror Self-Recognition* (MSR) or *rouge test*, devised by Gordon Gallup in 1970: a coloured mark is placed on the animal's face where it can be seen only in a mirror, and the animal is observed for self-directed mark-investigating behaviour.

Step 1. **Animals that have passed the mirror test.**

- *Great apes* – chimpanzees (Gallup 1970), bonobos, orangutans, and gorillas. Among hominids only humans pass it consistently from ~ 18–24 months of age.
- *Cetaceans* – bottlenose dolphins (Reiss & Marino, 2001), Asian elephants (Plotnik, de Waal & Reiss, 2006), and orcas have shown mark-directed behaviour.
- *Birds* – Eurasian magpies (Prior, Schwarz & Güntürkün, 2008) pass the test, suggesting self-recognition evolved independently in birds (without a mammalian neocortex).
- *Fish* – the cleaner wrasse (*Labroides dimidiatus*) appears to pass the mark test (Kohda et al., 2019), though this remains controversial.

Step 2. **Other behavioural indicators.** Self-awareness is a spectrum, and the mirror test captures only one facet. Other indicators include:

- *Tool use with planning* (crows fashion hooks from twigs; chimps strip leaves; elephants throw debris with intent).
- *Theory of mind* – knowing that another agent has its own beliefs (chimps, scrub jays cache food differently if watched).
- *Metacognition* – "knowing what you know." Macaques and dolphins decline trials they judge hard, suggesting they recognise their own uncertainty.
- *Episodic-like memory* (western scrub jays remember *what, where, when* of cached food).
- *Cooperative problem-solving and altruism* in elephants and dolphins.

Step 3. **Brain correlates.** Most MSR-passing species have a high *encephalisation quotient* (brain mass relative to body mass), and many have von Economo (spindle) neurons in the anterior cingulate cortex – neurons earlier thought to be unique to humans but now described in great apes, cetaceans and elephants.

Step 4. **What this implies.** Self-consciousness is not uniquely human; it has evolved independently (*convergent evolution*) in several lineages whenever complex social or ecological cognition pays off. It exists on a continuum from minimal self-awareness (knowing one's body in space) to full reflective self-consciousness (humans).

> **Final Answer:** Yes – several non-human species pass the mirror self-recognition test and show other markers of self-awareness: chimpanzees, bonobos, orangutans, gorillas, dolphins, orcas, Asian elephants, Eurasian magpies, and (more controversially) cleaner wrasses. Self-consciousness is not unique to humans; it has evolved several times wherever complex social cognition is adaptive.

♥ Animal ethics

The list of species demonstrating self-awareness directly informs animal-welfare law. The EU prohibits great-ape research because their self-recognition implies a capacity for suffering similar to humans. India has banned dolphin captivity since 2013 on the same ground.

EXPERT'S SOLUTION : *Diya Banerjee, M.Sc Zoology, Banaras Hindu University*

Quick reading: a five-category cognitive ladder. Comparative psychologists test for self-consciousness on a graded ladder of behavioural markers; here are the five recognised rungs.

Concept used. The *rouge/mark test* is the strongest single operational test for self-recognition, but self-consciousness involves four further capacities – theory of mind, metacognition, episodic memory, and intentional deception – that together build the case.

Step 1. **Rung 1 – Mirror self-recognition.** Demonstrated in chimps, bonobos, orangutans, gorillas, dolphins, orcas, Asian elephants, Eurasian magpies, cleaner wrasse.

Step 2. **Rung 2 – Theory of mind.** Chimps modify their behaviour when another individual cannot see a hidden food item (Hare & Tomasello, 2001). Scrub jays re-cache food if a watcher was present.

Step 3. **Rung 3 – Metacognition.** Macaques and dolphins will press a "don't know" option when uncertain, instead of guessing – suggesting they monitor their own knowledge (Smith et al., 2003).

Step 4. **Rung 4 – Episodic-like memory.** Western scrub jays remember which food they cached, where, and when – and choose the freshest cache to retrieve (Clayton & Dickinson, 1998).

Step 5. **Rung 5 – Intentional deception.** Capuchins fake alarm calls to scare rivals off food; jays distract observers from real cache sites.

Why this matters. If self-awareness is a continuum across species (not a Boolean human privilege), then the moral status of animals must also be a continuum. Conservation and welfare priorities flow directly from that scientific evidence. The fact that magpies – birds without a mammalian neocortex – also pass the mirror test is especially important: it shows that self-consciousness has *converged* on multiple neural architectures, just as flight evolved independently in insects, pterosaurs, birds and bats.

Lab tests that demonstrate self-awareness – quick recap.

- *Mirror mark test (Gallup 1970).* Anaesthetised animal, dot of odourless dye on face. Awake, the animal is placed before a mirror. If it touches its *own* face (not the mirror), it has passed.
- *Body-as-obstacle test.* An elephant must step off a mat to retrieve a stick that is attached to it. Asian elephants pass (Dale & Plotnik 2017).
- *Mark recognition without mirror.* Cleaner wrasses rub the marked area on the substrate after seeing the mark in a reflective surface.
- *Cooperative problem-solving.* Two elephants pull opposite ends of a rope to deliver a shared food reward – each understands the partner's role.

> **Final Answer:** Animals other than man – at minimum great apes, dolphins, orcas, Asian elephants, magpies, and possibly cleaner wrasse – pass the mirror test of self-recognition. Many also demonstrate theory of mind, metacognition, episodic-like memory and intentional deception. Self-consciousness is therefore widespread in animals with rich social cognition, not unique to humans.

Q 6.6 **List 10 modern-day animals and using the internet resources link it to a corresponding ancient fossil. Name both.**

SOLUTION

Concept used. A living fossil is a modern species that closely resembles its fossil ancestors and has changed little over geological time. Even for animals that are *not* living fossils, palaeontology has often identified an extinct or near- ancestral form. The fossil ancestor proves *continuity* of lineage and lets us date when the group originated.

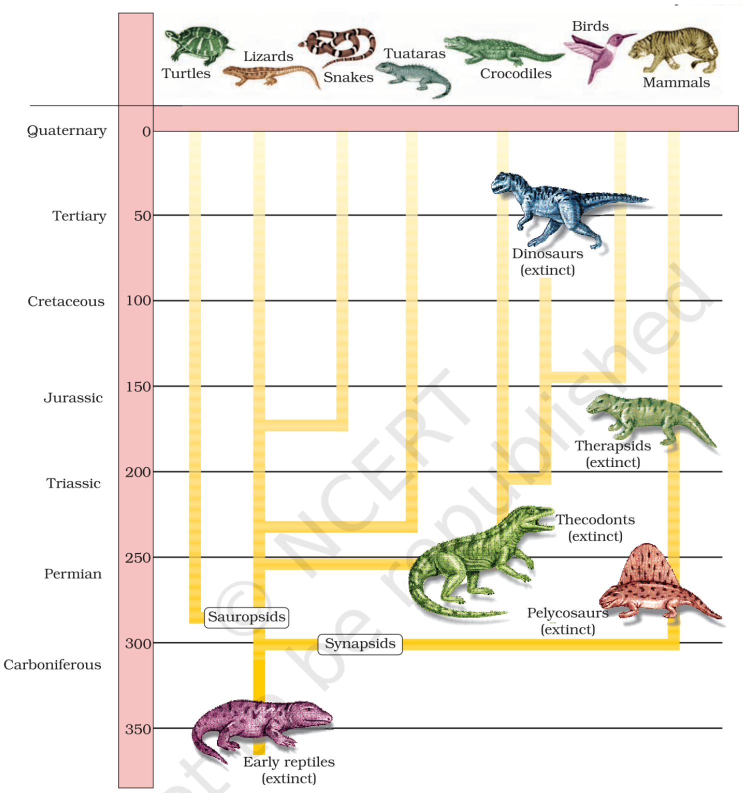


Figure 6.10 Representative evolutionary history of vertebrates through geological periods

Fig. 6.10, NCERT Class 12 Biology, Chapter 6 – evolutionary history of vertebrates across geological periods. Use this as the backbone for matching modern animals to ancestral fossils.

The table below lists ten modern animals paired with a named fossil/ancestor (period and approximate age in millions of years ago, Ma).

Modern animal	Ancient fossil / ancestor	Period	Approx age
1. Horse (*Equus*)	*Eohippus / Hyracotherium*	Eocene	$\sim$ 55 Ma
2. Elephant (*Elephas*)	*Moeritherium*	Eocene	$\sim$ 37 Ma
3. Whale (*Balaena*)	*Pakicetus*	Eocene	$\sim$ 50 Ma
4. Camel (*Camelus*)	*Protylopus*	Eocene	$\sim$ 40 Ma
5. Bird (modern)	*Archaeopteryx*	Late Jurassic	$\sim$ 150 Ma
6. Crocodile (*Crocodylus*)	*Protosuchus*	Late Triassic	$\sim$ 200 Ma
7. Coelacanth (*Latimeria*)	*Macropoma*	Cretaceous	$\sim$ 80 Ma
8. Horseshoe crab (*Limulus*)	*Mesolimulus*	Jurassic	$\sim$ 150 Ma
9. Lungfish (*Neoceratodus*)	*Dipnorhynchus*	Devonian	$\sim$ 400 Ma
10. Frog (*Rana*)	*Ichthyostega*	Late Devonian	$\sim$ 365 Ma

Step 1. **Five well-documented horse ancestors.** The horse line is one of the best-resolved fossil sequences in evolution: *Eohippus* (55 Ma, four-toed, dog-sized) $\rightarrow$ *Mesohippus* (38 Ma, three-toed) $\rightarrow$ *Merychippus* (25 Ma, grazing teeth) $\rightarrow$ *Pliohippus* (10 Ma, single-toed) $\rightarrow$ *Equus* (2 Ma, modern). Body size grew, the side toes vanished, and teeth became high-crowned for grass grazing.

Step 2. **Why *Archaeopteryx* is special.** Discovered in 1861 (Solnhofen limestone, Germany), it has feathered wings (bird-like) but teeth and a long bony tail (reptile-like). It bridges Reptilia and Aves and is usually the textbook example of a *transitional fossil*.

Step 3. **Living fossils.** *Coelacanth* (rediscovered alive in 1938 off South Africa; thought extinct for 65 Ma), *horseshoe crab* (almost unchanged for 200 Ma), *lungfish* and *tuatara* are textbook living fossils.

Final Answer: Ten modern animal–ancient fossil pairings: *Equus–Eohippus*; *Elephas–Moeritherium*; *Balaena–Pakicetus*; *Camelus–Protylopus*; modern bird–*Archaeopteryx*; *Crocodylus–Protosuchus*; *Latimeria–Macropoma*; *Limulus–Mesolimulus*; *Neoceratodus–Dipnorhynchus*; *Rana–Ichthyostega*. Each pair documents continuity across 40–400 million years.

☞ **Memory aid for the horse line**

Every Morning My Pony Eats: *Eohippus, Mesohippus, Merychippus, Pliohippus, Equus.* Five stages, in order.

EXPERT'S SOLUTION *: Karan Joshi, Ph.D Molecular Biology, NCBS Bangalore*

Structural observation: ten pairings, organised by class. A board answer wants ten clean pairings. Organise them by vertebrate class so you can quickly recover the list under exam pressure.

Concept used. *Phylogenetic continuity* predicts that every modern animal has identifiable fossil ancestors in older strata. The fossils need not be on the direct line of descent – a near-ancestral sister taxon (e.g. *Archaeopteryx* relative to modern birds) is enough to demonstrate the lineage.

Step 1. Mammals (4 examples).

- *Equus* (horse) – *Eohippus*, 55 Ma.
- *Elephas* (Asian elephant) – *Moeritherium*, 37 Ma.
- *Balaena* (whale) – *Pakicetus* (Pakistan, 50 Ma; four-legged, walked on land).
- *Camelus* (camel) – *Protylopus* (40 Ma, rabbit-sized).

Step 2. Birds (1 example). Any modern bird (sparrow, pigeon, eagle) – *Archaeopteryx* (150 Ma, Jurassic). It is the only Jurassic vertebrate with both feathers and teeth.

Step 3. Reptiles (1 example). *Crocodylus* (crocodile) – *Protosuchus* (200 Ma, Late Triassic). Crocodilians have remained morphologically conservative.

Step 4. Fishes (2 examples).

- *Latimeria* (coelacanth) – *Macropoma* (Cretaceous, ~ 80 Ma).
- *Neoceratodus* (Australian lungfish) – *Dipnorhynchus* (400 Ma, Devonian).

Step 5. Amphibians (1 example). Modern frogs and salamanders – *Ichthyostega* (365 Ma, Late Devonian; oldest known tetrapod with proper limbs).

Step 6. Invertebrate "living fossil" (1 example). *Limulus* (Atlantic horseshoe crab) – *Mesolimulus* (Solnhofen, 150 Ma); the body plan is ~ 200 Ma old.

Why this matters. Pairing each modern form with a fossil makes "descent with modification" concrete: the same body plan, modified over 10^8 years, is still recognisable. This is exactly what Darwin predicted in Chapter X of *Origin of Species*.

> **Final Answer:** Ten pairings (modern $\leftrightarrow$ fossil): horse $\leftrightarrow$ *Eohippus*, elephant $\leftrightarrow$ *Moeritherium*, whale $\leftrightarrow$ *Pakicetus*, camel $\leftrightarrow$ *Protylopus*, bird $\leftrightarrow$ *Archaeopteryx*, crocodile $\leftrightarrow$ *Protosuchus*, coelacanth $\leftrightarrow$ *Macropoma*, horseshoe crab $\leftrightarrow$ *Mesolimulus*, lungfish $\leftrightarrow$ *Dipnorhynchus*, frog $\leftrightarrow$ *Ichthyostega*.

Q 6.7 **Practise drawing various animals and plants.**

SOLUTION

Concept used. This question is a *skills exercise*, not a knowledge question. Comparative drawing of animals and plants trains the eye to spot **homologous** and **analogous** structures – a core method of evolutionary biology. Two structures are *homologous* if they share a common ancestor (same origin, possibly different functions); they are *analogous* if they perform the same function but evolved independently (different origins, similar form).

Homologous (same origin)	Analogous (different origin)
Forelimbs of whale, bat, cheetah, human	Wings of butterfly vs. wings of bird
Vertebrate hearts and brains	Eyes of octopus vs. eyes of mammal
Thorns of *Bougainvillea* and tendrils of *Cucurbita*	Flippers of dolphin vs. flippers of penguin

Step 1. What to draw and what to label. Practical suggestions for the student's notebook:

- *Forelimbs of frog, lizard, bird, bat, whale and human.* Label humerus, radius, ulna, carpals, metacarpals, phalanges in each. The same five bones occur in every case – proof of *homology*.
- *Wings of insect, bird and bat.* Insect wing is a chitinous membrane; bird wing has feathers on a modified forelimb; bat wing is a skin membrane stretched between elongated finger bones. Same function (flight), different origins – *analogy*.
- *Modified plant stems. Bougainvillea* thorn (axillary), *Cucurbita* tendril (axillary), *Opuntia* phylloclade (green, fleshy). Same axillary origin, different functions – *homology in plants*.
- *Modified plant leaves.* Tendril of pea, spine of cactus, scale of onion, insect-catching trap of pitcher plant. All are leaves – *homologous*; the spine of cactus and thorn of *Bougainvillea* are *analogous* (look alike, different origins).
- *Skulls of human, baby chimp and adult chimp.* Label the cranial vault, brow ridge, foramen magnum, jaw. The baby chimp skull resembles the human skull (*Bolk's neoteny hypothesis*).
- *Darwin's finch beaks.* Four beak shapes (seed-cracker, insectivore, woodpecker-like, cactus-eater) from the same ancestor – *adaptive radiation*.

Step 2. **How to label scientifically.** Use a sharp pencil, draw arrow leaders that do not cross, use *italic* for Latin binomials, and place a scale bar where applicable.

Step 3. **Why drawing helps.** Forcing your hand to copy a diagram forces your eye to register details a casual reader misses – the wrist bones of a bat wing, the leaf-origin of a cactus spine, the curvature of *Pakicetus*'s skull. Drawing is the cheapest tool in evolutionary biology.

> **Final Answer:** Practising drawings of homologous structures (forelimbs, plant leaves, hominid skulls, finch beaks) and analogous structures (insect/bird/bat wings, dolphin/penguin flippers) trains your eye to interpret *evolutionary* evidence in anatomy. Always label the constituent parts in italics and indicate whether the similarity is by descent (homologous) or by independent evolution (analogous).

☞ **Drawing checklist**

For every drawing: (1) sharp pencil, (2) unambiguous leader lines, (3) scale bar, (4) Latin name in italics, (5) mark whether the structure is homologous or analogous to the example beside it.

EXPERT'S SOLUTION *: Tara Pillai, M.Sc Botany, Delhi University*

Picture-first: a drawing curriculum for evolution. The question is open, but examiners reward students who use the drawings to *argue* for or against homology vs. analogy. Below is a 10-page notebook plan.

Concept used. *Homology* = same origin (different functions possible); *analogy* = same function (different origins). Drawing is the medium through which a biologist *shows* the evidence.

Step 1. **Page 1 – Vertebrate forelimbs.** Frog, lizard, bird, bat, whale, human side by side. Colour the humerus blue, radius–ulna green, carpals yellow, metacarpals orange, phalanges pink. The colour pattern proves the bones are the same.

Step 2. **Page 2 – Wings of insect, bird, bat.** Draw all three at the same scale. Annotate "chitin", "feathers", "skin membrane on elongated fingers". Same function, different origin = analogous.

Step 3. **Page 3 – Plant stems.** *Bougainvillea* thorn, *Cucurbita* tendril, *Opuntia* phylloclade – all axillary buds modified for different roles. Homologous.

Step 4. **Page 4 – Plant leaves.** Tendril of pea, spine of cactus, scale of onion, trap of pitcher plant – all are leaves. Homologous.

Step 5. **Page 5 – Darwin's finches.** Four beak shapes from Galápagos finches; label the diet beside each. Adaptive radiation.

Step 6. **Page 6 – Australian marsupials.** Tasmanian wolf, marsupial mole, koala, kangaroo, marsupial rat – all evolved from one ancestor by adaptive radiation.

Step 7. **Page 7 – Convergence.** Placental wolf vs. Tasmanian (marsupial) wolf. Same niche, different ancestors. Analogous.

Step 8. **Page 8 – Hominid skulls.** Adult human, baby chimp, adult chimp. Label brow ridge, cranial vault, foramen magnum.

Step 9. **Page 9 – Horse evolution.** *Eohippus* → *Mesohippus* → *Merychippus* → *Pliohippus* → *Equus*. Mark single-toe vs. multi-toe and tooth height in each.

Step 10. **Page 10 – Three industrial-melanism moths.** Pre-industrial light moth on bark, dark moth on soot-covered bark, post-clean-air light moth back on lichen. Pure Darwinian selection by colour.

What to revise before each drawing.

- *Forelimbs:* memorise the order humerus–radius–ulna–carpals–metacarpals–phalanges and the principle that the *same five bones in the same order* appear across vertebrates.
- *Wings:* insect (chitinous, no internal bones), bird (feathers on modified forelimb), bat (skin between elongated fingers). Same function, different origin.
- *Plant modifications:* every axillary thorn / tendril / phylloclade is a modified stem; every spine / scale / pitcher / tendril of leaf-origin is a modified leaf.
- *Skulls:* mark foramen magnum (centre in human, back in chimp), brow ridge (heavy in chimp, faint in human), cranial vault (rounded in human, sloping in chimp).

Why this matters. Every concept in this chapter can be *seen*. Once the diagrams are on the page, the verbal explanations become muscle memory. Drawings are also expected to appear in board diagrams (3–5 marks each). NEET diagram-based MCQs are answered fastest by students who have hand-drawn each diagram themselves; recognition is much faster after one's own hand has traced the lines.

> **Final Answer:** A focused drawing notebook with ten themed pages (vertebrate forelimbs, three wing types, plant stems and leaves, finch beaks, marsupials, convergent wolves, hominid skulls, horse line, melanic moths) covers every evolutionary mechanism in Chapter 6 and provides ready-made answer diagrams for the board.

Q 6.8 **Describe one example of adaptive radiation.**

SOLUTION

Concept used. Adaptive radiation is the evolutionary process in which an ancestral species, on entering a new geographical area or unoccupied set of niches, gives rise to several descendant species, each adapted to a different ecological role. The textbook examples are *Darwin's finches* of the Galápagos Islands and the *marsupials of Australia*. When more than one adaptive radiation appears to have occurred in an isolated geographical area (representing different habitats), the phenomenon is called *convergent evolution* – for example placental mammals in Australia exhibit adaptive radiation into forms remarkably similar to the corresponding marsupials (placental wolf vs. Tasmanian wolf-marsupial).

Figure 6.5 Variety of beaks of finches that Darwin found in Galapagos Island

Fig. 6.5, NCERT Class 12 Biology, Chapter 6 – Darwin's finches: four of the thirteen beak shapes that evolved from one ancestral seed-eating finch on the Galápagos Islands.

Step 1. **Geography.** The Galápagos Islands lie about 1000 km west of Ecuador in the Pacific Ocean. They are of volcanic origin (no land connection to South America) and harbour many endemic species.

Step 2. **Founding event.** A few seed-eating finches from South America were carried to the islands by storms, perhaps $\sim$ 2–3 million years ago. They found uncolonised niches – insects, seeds, fruit, cactus pulp, bark insects – and no avian competitors.

Step 3. **Diversification.** Over $\sim$ 2 Ma the founding population diversified into 13 (some say 15) species of finches, now collectively called *Darwin's finches*. Each species shows a beak modified for its diet:

- Heavy crushing beak for hard seeds (*Geospiza magnirostris*).
- Slender pointed beak for insects (*Certhidea olivacea*, the warbler-finch).
- Probing beak with a cactus-spine tool (*Camarhynchus pallidus*, the woodpecker-finch).
- Curved beak for cactus flowers (*Geospiza scandens*).

Step 4. **The Darwinian mechanism.** Random heritable variation in beak shape, combined with selection for whichever variant best exploited a particular food source on a particular island, drove the divergence. Peter and Rosemary Grant's 40-year fieldwork on Daphne Major showed that beak depth in *Geospiza fortis* measurably shifts in a single drought generation – adaptive radiation in real time.

Step 5. **Why finches are a textbook example.** They satisfy every requirement: (i) a single founding ancestor; (ii) unoccupied niches; (iii) heritable variation in beak shape; (iv) selection by diet; (v) reproductive isolation on different islands; (vi) documented divergence into many species.

A second adaptive radiation – Australian marsupials.

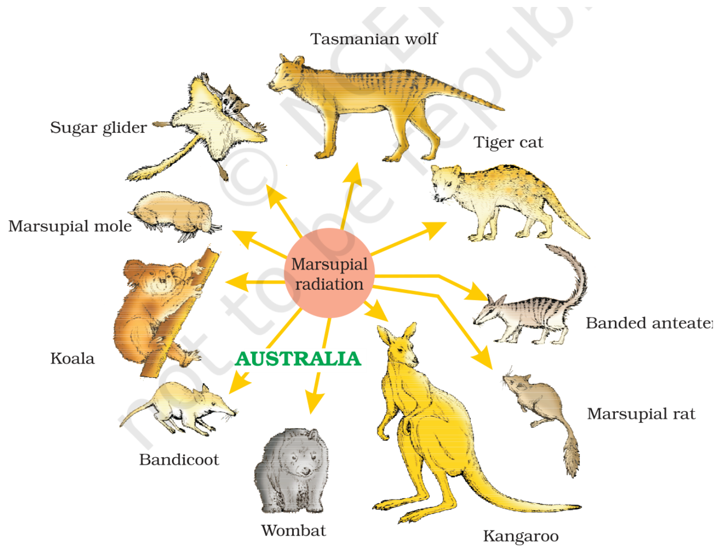


Figure 6.6 Adaptive radiation of marsupials of Australia

Fig. 6.6, NCERT Class 12 Biology, Chapter 6 – Australian marsupials. The single ancestral marsupial gave rise to forms occupying every major niche, from kangaroo (grazer) to Tasmanian wolf (carnivore) to marsupial mole (burrower).

When Australia drifted away from Gondwana (~ 50 Ma) it carried marsupials but very few placental mammals. The marsupial line then radiated into every niche the placentals fill elsewhere: kangaroos (grazers), Tasmanian wolves (carnivores), koalas (leaf eaters), marsupial moles (burrowers), wombats (rodent-like), gliders (gliding mammals). Many of these resemble unrelated placental mammals in other continents – a textbook case of both *adaptive radiation* (on Australia) and *convergent evolution* (with placentals).

Final Answer: The Galápagos finches are the cleanest example of adaptive radiation: a single seed-eating ancestor diversified into ~ 13 species in ~ 2 million years, each beak shape matched to its food source (seeds, insects, cactus pulp, woodpecker-like probing). Australian marsupials are a parallel continental-scale example.

♥ Two radiations, one principle

Both Darwin's finches and Australian marsupials illustrate the same logic: *one ancestor* + *empty niches* + *selection* → *diversification*. The same principle explains cichlid fish in Lake Victoria, lemurs in Madagascar, and silverswords in Hawaii. Pick the example you remember best in the exam.

EXPERT'S SOLUTION : *Vivaan Nair, Ph.D Molecular Biology, NCBS Bangalore*

Strategic angle: tell the finch story in five lines. For a 3-mark board answer you need: (i) the term, (ii) the location, (iii) the ancestor, (iv) the diversification, (v) the mechanism. The Galápagos finches deliver all five with a clean modern citation (the Grants).

Concept used. *Adaptive radiation* = "radiating" from one ancestor into many adaptive forms when ecological opportunity opens up. The signature pattern is many closely related species, each in a different niche, on a recently colonised area.

Step 1. Define the term. "The evolutionary diversification of an ancestral species into a number of new forms, each adapted to a particular niche, when the original population enters an unexploited area."

Step 2. Name the example. Galápagos finches, observed by Darwin in 1835 on H.M.S. Beagle.

Step 3. State the ancestor and outcome. A single seed-eating finch from South America $\rightarrow$ 13 species on the Galápagos, each with a beak suited to its food.

Step 4. State the mechanism. Heritable variation in beak depth + selection by available food $\rightarrow$ morphological divergence. Peter and Rosemary Grant (Princeton) documented this in real time on Daphne Major: in the 1977 drought, large-seeded plants survived and the finch population shifted to deeper beaks.

Step 5. Second example for the LA (long-answer) version. Australian marsupials radiated into 200+ species in the absence of placentals.

Other classical adaptive radiations a student should recognise.

- *Hawaiian silverswords* – descended from a single Californian tarweed; now ~ 28 plant species spanning desert, alpine and rainforest niches.
- *Hawaiian honeycreepers* – ~ 50 bird species from one finch-like ancestor, with beaks varying from seed-cracker to nectar-sipper.
- *Cichlid fishes of Lake Victoria / Malawi / Tanganyika* – over 1 500 species in ~ 5 Ma; the fastest radiation in vertebrates.
- *Lemurs of Madagascar* – ~ 100 species from a single ancestor that rafted from mainland Africa.

Why this matters. Adaptive radiation is the single most visual demonstration that evolution works. The 13 beaks of Darwin's finches are the icon of evolutionary biology because they make selection *paintable*. The same logic explains why islands are evolutionary laboratories: each island offers a fresh ecological canvas with few competitors, and natural selection quickly fills the empty niches with descendants of one founding species.

Final Answer: Adaptive radiation is the rapid diversification of a single ancestor into many forms suited to different niches. Darwin's finches (13 species on the Galápagos, all from one seed-eating ancestor, each with a beak matched to its diet) is the classic example; Australian marsupials, Hawaiian silverswords and honeycreepers, Madagascan lemurs and African cichlids are parallel cases on continental, archipelagic and lacustrine scales.

Q 6.9 Can we call human evolution as adaptive radiation?

SOLUTION

Concept used. Adaptive radiation requires *many descendant species*, each occupying a *different ecological niche*, arising from a single ancestor within a short geological time. The signature is a *branching* pattern of multiple coexisting forms (e.g. Darwin's finches). Human evolution must be tested against these criteria.

Step 1. **Did one ancestor give rise to many hominid species?** Yes – the fossil record shows several genera and species: *Sahelanthropus, Orrorin, Ardipithecus*, several *Australopithecus* (*A. afarensis, A. africanus, A. sediba, A. garhi*), *Paranthropus boisei*, and the *Homo* clade (*H. habilis, H. erectus, H. heidelbergensis, H. neanderthalensis, H. floresiensis, H. naledi, H. sapiens*). At several time points (e.g. ~ 2 Ma) three or four hominid species co-existed in Africa.

Step 2. **Did they occupy different niches?** Only weakly. *Paranthropus boisei* (the "robust" australopithecine) had massive jaws and ate hard plant food – clearly a different dietary niche. But most other hominids (gracile australopithecines, early *Homo*) overlapped substantially in diet and habitat. There is no "insectivore hominid" or "aquatic hominid" analogous to a woodpecker-finch vs. a vampire-finch.

Step 3. **Did they survive into the present?** *No* – and this is the decisive point. Of the dozen-plus hominid species, only one is alive today: *Homo sapiens*. Adaptive radiation, by contrast, produces a *persisting bush* of multiple coexisting forms (the 13 finches still all exist).

Step 4. **Verdict.** Human evolution shows the *branching* stage of an adaptive radiation but not the *persistence* stage. Most lineages went extinct; only one "radiated" lineage is left. Some authors therefore call it a *failed* or *partial* radiation. Strictly, by the conventional definition (multiple coexisting forms in different niches), human evolution is **not** a typical adaptive radiation.

Comparison with classical examples.

- *Darwin's finches.* 13 coexisting species, distinct beak-driven niches, descended from one ancestor. Persistent.
- *Australian marsupials.* 200+ coexisting species spanning every niche from herbivore to carnivore to burrower. Persistent.
- *Human evolution.* A dozen species over 7 Ma, but only *H. sapiens* remains. Not persistent.

Final Answer: Strictly speaking, *no* – human evolution is not a classical adaptive radiation. Although several hominid species branched from a common ancestor, they did not occupy distinctly different ecological niches, and all but *Homo sapiens* are extinct. A true adaptive radiation (e.g. Darwin's finches) produces a persisting bush of differentiated coexisting species. Some authors describe human evolution as a *branching* or *partial* radiation that was pruned by competition and climate.

✗ Common Mistake

A common error is to say "yes, because human evolution shows many ancestral forms". The presence of many ancestors is *branching descent*, not adaptive radiation. The defining feature of radiation is *coexisting* descendant species in *different niches* – and human evolution lacks both.

EXPERT'S SOLUTION *: Yash Verma, M.Sc Biotechnology, AIIMS Delhi*

Strategic angle: test the definition, then decide. For this kind of yes/no conceptual question the highest-scoring answer is one that lists the criteria for adaptive radiation, applies each to human evolution and concludes with reasoning.

Concept used. The four diagnostic features of adaptive radiation are: (1) *common ancestor*, (2) *multiple descendant species*, (3) *ecological diversification into distinct niches*, and (4) *persistent coexistence*.

Step 1. **Criterion 1 – common ancestor.** Yes. All hominids share a chimpanzee-like common ancestor $\sim$ 7 Ma ago.

Step 2. **Criterion 2 – multiple descendants.** Yes. At least 15 fossil hominid species are recognised (*Sahelanthropus, Orrorin, Ardipithecus*, *Australopithecus* (4 spp.), *Paranthropus* (3 spp.), *Homo* (8+ spp.)).

Step 3. **Criterion 3 – niche diversification.** *Partially. Paranthropus* robustus and *P. boisei* ate hard plant matter; gracile australopithecines were generalists; *Homo erectus* used fire and ate cooked meat. But these niches are *not* as separated as woodpecker-finch vs. ground-finch.

Step 4. **Criterion 4 – persistent coexistence.** No. Only *Homo sapiens* survives. Even Neanderthals and Denisovans went extinct ~ 30–40 kya, leaving us the sole surviving hominid.

Step 5. **Conclusion.** Three of four criteria are met weakly or partially; criterion 4 fails. Human evolution is therefore not a classical adaptive radiation. The better description is *phyletic evolution with branching* (anagenesis with cladogenesis), where most side branches went extinct.

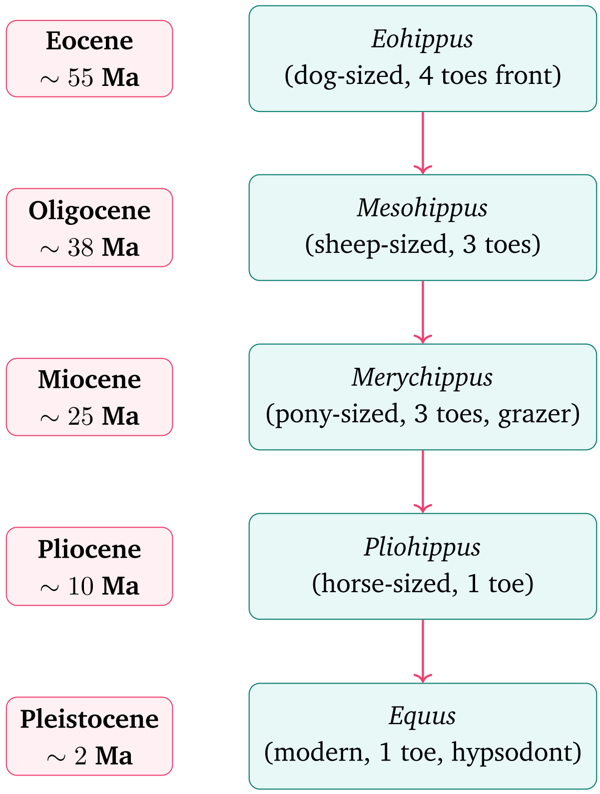
Why this matters. It highlights that not all diversification is adaptive radiation. Evolution can also produce many lineages most of which die out – humans are an example of this less glamorous pattern.

> **Final Answer:** No, human evolution does not satisfy the criterion of *persistent coexistence of multiple distinctly-niched descendants*. Although the hominid family did branch into many species, all but *Homo sapiens* are extinct, and the niche differences among hominids were modest. It is better described as branching descent (cladogenesis) under heavy extinction, not as a classical adaptive radiation.

Q 6.10 **Using various resources such as your school library or the internet and discussions with your teacher, trace the evolutionary stages of any one animal, say horse.**

SOLUTION

Concept used. The **horse lineage** (Family Equidae) is the most complete fossil sequence in vertebrate palaeontology, spanning ~ 55 million years from the Eocene to the present. The trends across this sequence are: (i) *increase in body size*, (ii) *progressive loss of side toes* (from four to one), (iii) *elongation of limbs*, (iv) *increase in tooth crown height* (hypsodonty) for grass grazing, and (v) *straightening of the back*. These changes track the planet's shift from forested to grassland environments during the Cenozoic.



Step 1. ***Eohippus / Hyracotherium* (Eocene, ~ 55 Ma).** The "dawn horse". Size of a fox (~ 0.4 m at the shoulder); four toes on the forefoot, three on the hindfoot; low-crowned teeth suited to soft browse; arched back. Forested habitat.

Step 2. ***Mesohippus* (Oligocene, ~ 38 Ma).** Sheep-sized (~ 0.6 m); three toes on each foot, the middle toe enlarged and weight-bearing; still a browser. Found in North America.

Step 3. ***Merychippus* (Miocene, ~ 25 Ma).** Pony-sized (~ 1.0 m); three toes, but only the middle toe touches the ground; high-crowned (hypsodont) teeth – the first grazer on the line, exploiting the Miocene grasslands. Long legs for fast running.

Step 4. ***Pliohippus* (Pliocene, ~ 10 Ma).** Horse-sized (~ 1.3 m); *single* weight-bearing toe on each foot, with the side toes reduced to splint bones; deep-rooted hypsodont teeth; long, slender legs for sustained galloping; open-plains grazer.

Step 5. ***Equus* (Pleistocene to Recent, ~ 2 Ma – 0).** The modern horse and zebra. ~ 1.6 m at the shoulder, one toe (hoof), with vestigial splint bones; permanently hypsodont molars; long mane; built for endurance running on open grassland. Domesticated by humans ~ 5500 years ago in the Eurasian steppe.

Underlying drivers. The horse line tracks the global climate shift from warm wet Eocene forests to dry Miocene grasslands. As grasses spread and forests retreated, selection favoured grazers with tougher teeth and faster gaits. Horses evolved in North America, dispersed to Eurasia via the Bering land bridge, went extinct in North America

~ 10 kya, and were re-introduced by Spanish settlers in the 1500s.

Final Answer: The horse evolved across five recognised stages from the forest-dwelling four-toed *Eohippus* (~ 55 Ma) through *Mesohippus, Merychippus, Pliohippus* to the modern single- toed *Equus*. Body size grew (from ~ 0.4 to ~ 1.6 m), the side toes were lost, the legs lengthened, and the teeth became high-crowned to handle abrasive grass – all in step with the spread of Miocene grasslands.

☞ **Exam Tip**

Memory aid: "**E**very **M**orning **M**y **P**ony **E**ats" – *Eohippus, Mesohippus, Merychippus, Pliohippus, Equus.* Memorise number of toes (4-3-3-1-1) and tooth type (browser-browser-grazer-grazer- grazer) along the same sequence.

EXPERT'S SOLUTION *: Sneha Kapoor, Ph.D Molecular Biology, NCBS Bangalore*

Strategic angle: pair every stage with the trend it shows. The horse line is celebrated because each stage exhibits a clear, named anatomical change. The cleanest board answer pairs the five genera with the five trends.

Concept used. *Orthogenesis* (directional evolution) once described the horse line, but modern interpretation is purely Darwinian – each stage is the heritable response to changing environments (forest → savanna → open grassland).

Step 1. **Stage 1: *Eohippus* (~ 55 Ma).** Trend baseline. Body ~ 0.4 m; *4* toes front; *3* toes hind; *low-crowned* teeth; *arched* back. Niche: forest browser.

Step 2. **Stage 2: *Mesohippus* (~ 38 Ma).** Trend: side-toe reduction. Body ~ 0.6 m; *3* toes on each foot; central toe enlarged; still low- crowned teeth.

Step 3. **Stage 3: *Merychippus* (~ 25 Ma).** Trend: hypsodonty (high-crowned teeth) and limb elongation. First grazer on the line. Body ~ 1.0 m; 3 toes but only the middle touches ground.

Step 4. **Stage 4: *Pliohippus* (~ 10 Ma).** Trend: monodactyly (single functional toe). Body ~ 1.3 m; side toes reduced to splint bones; deep- rooted molars; back straightened. Niche: open-plains sprinter.

Step 5. **Stage 5: *Equus* (~ 2 Ma – present).** Trend: completion. Body ~ 1.6 m; single hoof; permanently hypsodont molars; endurance runner; domesticated ~ 5.5 kya.

Trends summary in five lines.

- *Size:* 0.4 m → 1.6 m.
- *Toes:* 4/3 → 3/3 → 3/3 → 1/1 → 1/1.
- *Teeth:* brachydont (browser) → hypsodont (grazer).

- *Limbs:* short and bent $\rightarrow$ long and straight.
- *Back:* arched $\rightarrow$ straight.

Climatic backdrop – why these changes happened.

- *Eocene (55–40 Ma):* warm wet planet, dense forests, no grasslands $\rightarrow$ small browsers like *Eohippus* thrive.
- *Oligocene (40–25 Ma):* gradual cooling, savannas appear $\rightarrow$ *Mesohippus* loses one toe.
- *Miocene (25–5 Ma):* grass species explode globally; high silica content of grass abrades teeth $\rightarrow$ *Merychippus* evolves hypsodonty.
- *Pliocene (5–2 Ma):* dry, open plains dominate $\rightarrow$ *Pliohippus* sprints away from predators on a single toe.
- *Pleistocene (2 Ma–10 kya): Equus* diversifies into horses, zebras and asses; survives ice ages in Asia and Europe; extinct in North America ~ 10 kya; reintroduced by Spanish colonists, 16th century.

Why this matters. The horse line is the single most complete macroevolutionary fossil sequence we have. It shows unambiguously that the modern *Equus* did not appear suddenly but emerged through a documented chain of intermediate forms, each adapted to its contemporary environment. This is exactly the kind of evidence Darwin predicted in 1859 but did not yet have. Today every museum of natural history shows the horse sequence as the centrepiece evidence for evolution.

Final Answer: Horse evolution: *Eohippus* (Eocene, dog-sized, 4-toed browser) $\rightarrow$ *Mesohippus* (Oligocene, sheep-sized, 3-toed) $\rightarrow$ *Merychippus* (Miocene, pony-sized, first grazer) $\rightarrow$ *Pliohippus* (Pliocene, horse-sized, 1-toed) $\rightarrow$ *Equus* (Pleistocene–Recent, modern). Body size, limb length and tooth crown grew; side toes vanished; the back straightened – all driven by the spread of Miocene grasslands.

Key Takeaways

- *Darwinian natural selection* explains observable evolution – antibiotic resistance in bacteria is the clearest real-time example.
- Fossils provide *direct evidence* of evolution; named recent finds (*Tiktaalik*, *Homo naledi*, Denisovans) fill predicted gaps in the tree of life.
- A *species* is best defined as a group of interbreeding natural populations that produce fertile offspring and are reproductively isolated (Mayr, 1942).
- *Human evolution* traces increases in brain size ($400 \rightarrow 1400$ cc), bipedalism, omnivory and culture over ~ 7 Ma; only *Homo sapiens* survives.
- *Self-consciousness* is found in great apes, cetaceans, elephants and at least one bird (magpie) – it is not uniquely human.

- Every modern animal can be paired with a fossil ancestor; horses (*Eohippus* → *Equus*) and birds (*Archaeopteryx*) are the best-documented sequences.
- *Adaptive radiation* (Darwin's finches, Australian marsupials) is one ancestor diversifying into many niche- specialised forms; human evolution does not fully qualify because only one descendant lineage survives.
- The horse line documents five major trends – body size up, side toes lost, limbs lengthened, teeth made hypsodont, and back straightened – across 55 Ma of climatic change.

End of Exercises