A4.1 Evolution and speciation

Unity and diversity—Ecosystems

Standard level and higher level: 4 hours

Additional higher level: 1 hour

Guiding questions

• What is the evidence for evolution?

• How do analogous and homologous structures exemplify commonality and diversity?

SL and HL

A4.1.1—Evolution as change in the heritable characteristics of a population
This definition helps to distinguish Darwinian evolution from Lamarckism. Acquired changes that are not genetic in origin are not regarded as evolution.
Evolution is the change in the heritable characteristics of a population across time. The **theory of evolution** attempts to scientifically explain how evolution occurs through rigorous evidence. The **mechanism** for most but not all of evolutionary change is **natural selection**. Other equally important but non-deterministic (random) mechanisms include **genetic drift**, **mutations**, and **gene flow** (migration). While natural selection acts on existing variation to favor beneficial traits, other mechanisms may introduce new variation, redistribute existing variation, and can either promote or hinder the process of adaptation. Darwin and Wallace independently developed the theory of evolution based on natural selection, which replaced **Lamarckism** (a theory that falsely postulated that acquired characteristics throughout an individual's lifetime are inherited by offspring). Darwinian theory was revised as new evidence (especially genetic) was uncovered, leading to the now current **modern synthesis theory of evolution**.

A4.1.2—Evidence for evolution from base sequences in DNA or RNA and amino acid sequences in proteins
Sequence data gives powerful evidence of common ancestry.
Common ancestry/descent is a concept in modern evolutionary theory which states that all organisms on Earth are descendants from a single ancestral species. Biochemical evidence, which includes the fact that all organisms follow the same universal genetic code to synthesize proteins from DNA and RNA, supports universal common descent. DNA, RNA, and amino acid bases can be sequenced and analyzed in order to make comparisons between species. The more similar the sequences of two species are, the more likely that they recently branched off from a common ancestor.

A4.1.3—Evidence for evolution from selective breeding of domesticated animals and crop plants
Variation between different domesticated animal breeds and varieties of crop plant, and between them and the original wild species, shows how rapidly evolutionary changes can occur.
Selective breeding is a form of **artificial selection** whereby humans intervene with the breeding of species to produce desired traits in offspring (i.e. breeding the fastest horse or crops with the most starch). This shows how desired alleles increase in frequency in the gene pool of species over time, which is useful as it enables us to observe evolution at a faster pace than what normally occurs in nature.

A4.1.4—Evidence for evolution from homologous structures

Include the example of pentadactyl limbs.

Homologous structures are structurally similar body parts derived from a common ancestor with different functions. They are present in organisms that faced differential selective pressures but are descendent from a common ancestor (i.e. pentadactyl limbs function as arms for humans but fins for whales).

Analogous structures are structurally different body parts not derived from a common ancestor that share similar functions. They are present in organisms that do not share a common ancestor but faced similar selective pressures (i.e. birds and insects are unrelated but have wings for flight).

NOS: The theory of evolution by natural selection predicts and explains a broad range of observations and is unlikely ever to be falsified. However, the nature of science makes it impossible to formally prove that it is true by correspondence. It is a pragmatic truth and is therefore referred to as a theory, despite all the supporting evidence.

The evidence for evolution we have is but a fraction of what is available to us, since we have millions of undiscovered fossils and genomes waiting to be sequenced. This makes it impossible to explicitly say “we have all the possible evidence for evolution”, as it is beyond human capability to uncover all the evidence. However, it is still a very useful (**pragmatic**) theory, so it is treated like a truth in science as it is unlikely to ever be falsified.

A4.1.5—Convergent evolution as the origin of analogous structures

Students should understand that analogous structures have the same function but different evolutionary origins. Students should know at least one example of analogous features.

The context in which heritable changes occur in organisms (evolution) can be classified as divergent or convergent:

- **Divergent evolution** occurs when heritable traits from a common ancestor evolve to perform different (divergent) functions.
- **Convergent evolution** occurs when heritable traits in species from unrelated lineages evolve to perform similar (convergent) functions).

Divergent or convergent evolution both occur through the same mechanisms of change. It is important to distinguish between the two in order to correctly evaluate ancestral and evolutionary relationships (i.e. understanding divergence or convergence helps in tracing diseases and vaccine development).

A4.1.6—Speciation by splitting of pre-existing species

Students should appreciate that this is the only way in which new species have appeared. Students should also understand that speciation increases the total number of species on Earth, and extinction decreases it. Students should also understand that gradual evolutionary change in a species is not speciation.

The theory of evolution does **not** predict that species will constantly be evolving, or how fast they’ll change when they do; that depends on the evolutionary pressures they experience. Evolution is also without direction or purpose; adaptations are not induced and they do not arise with an intention.

Speciation is the process by which two populations of a single ancestor develop and evolve sufficient genetic differences that prevent interbreeding *and* the production of fertile offspring. Species do not necessarily have to split, some just go extinct and others do not split for many years.

A4.1.7—Roles of reproductive isolation and differential selection in speciation
Include geographical isolation as a means of achieving reproductive isolation. Use the separation of bonobos and common chimpanzees by the Congo River as a specific example of divergence due to differential selection.
Reproductive isolation is the phenomena by which two populations of the same species are unable to interbreed and produce fertile offspring. This leads to isolated gene pools that are more likely to differentiate and diverge with time, eventually leading to the splitting of the two populations into 2 distinct species. There are several mechanisms of reproductive isolation, including geographic isolation. **Geographical isolation** is the phenomena by which two populations of the same species are separated geographically (i.e. by a mountain or river), greatly reducing gene flow and leading to reproductive isolation. If their different habitats exert different selection pressures, **differential selection** will take place, which is a situation in which different traits are selected for in each population. For example, bonobos and chimpanzees are both primates that diverged from a common ancestor due to being separated by the Congo River, which acted as a geographical barrier given that both species are not proficient swimmers.

Additional higher level

A4.1.8—Differences and similarities between sympatric and allopatric speciation
Students should understand that reproductive isolation can be geographic, behavioural or temporal.
• **Allopatric** speciation = reproductive isolation due to physical (geographic barriers) factors • **Sympatric** speciation = reproductive isolation within the same geographic location due to genetic or ecological factors (i.e. non-random mating, different mating behaviors) Two types of sympatric speciation: • **Temporal**: different mating times of the year • **Behavioral**: different courtship behavior

A4.1.9—Adaptive radiation as a source of biodiversity
Adaptive radiation allows closely related species to coexist without competing, thereby increasing biodiversity in ecosystems where there are vacant niches.
Adaptive radiation is the divergent evolution of ecological and phenotypical diversity within a rapidly multiplying lineage (species), which results in an array of many species that adapt to a range of vacant niches. Ecological opportunity is the main driver of adaptive radiation. The absence (or reduction) of competition for resources promotes diversification in other species, which can occur via: 1. **Colonization** of competition-free regions (i.e. islands with vacant niches) 2. **Extinction** of other species, eliminating competitors or opening niches 3. **Key innovation**; evolution of a trait that provides access to new resources (i.e. anole lizards radiated after evolving toepads) Adaptive radiation increases biodiversity, which helps make ecosystems more resilient and less fragile to catastrophes like natural disasters, since there will be a sufficient number of species that are able to fill niches where other species failed to do so.

A4.1.10—Barriers to hybridization and sterility of interspecific hybrids as mechanisms for of preventing the mixing of alleles between species
Courtship behaviour often prevents hybridization in animal species. A mule is an example of a sterile hybrid.
Hybridization occurs when two different species crossbreed (i.e. a mule is produced when a horse and donkey crossbreed). Due to chromosomal differences in the two parents, the hybridized offspring, while containing useful traits from both parents (**hybrid vigor**), is sterile and unable to produce offspring. Breeding to produce infertile offspring is a waste of energy and resources, so species have developed **barriers to hybridization** through **distinct courtship behavior** to ensure their mate is of the same species. Thus, if mating occurs, the likelihood of producing a fertile offspring upon mating is high.

A4.1.11—Abrupt speciation in plants by hybridization and polyploidy
Use knotweed or smartweed (genus *Persicaria*) as an example because it contains many species that have been formed by these processes. *Note: When students are referring to organisms in an examination, either the common name or the scientific name is acceptable.*
Polyploidy results from non-disjunction during anaphase I (the homologous pairs do not separate), leading to an organism with a greater number of homologous chromosomes than the parent. In the case where the resultant diploid nucleus contains an even number of chromosomes, the species will usually be fertile, but if it is an odd number then the offspring may be able to survive, but it will be sterile. There are two types of polyploidies: • **Autopolyploidy** occurs when the extra homologous chromosome(s) are derived from the same species (both parents belong to the same species). • **Allopolyploidy** occurs when the extra homologous chromosome(s) are derived from different species (each parent is a different species). Plants belonging to the genus *Persicaria* commonly hybridize due to hybrid vigor.

Linking questions

• How does the theory of evolution by natural selection predict and explain the unity and diversity of life on Earth?

• What counts as strong evidence in biology?

Review questions

SL and HL

- Define evolution. [1]
- Distinguish between evolution and speciation. [1]
- Define differential selection. [1]
- Outline geographical isolation using an example. [2]
- Explain why the theory of evolution is considered a pragmatic truth in science. [2]
- Explain the significance of selective breeding as evidence for evolution. [3]
- Explain the implications of divergent and convergent evolution in determining evolutionary relationships. [4]
- Discuss the evidence for evolution. [7]

Additional Higher Level

- Outline how adaptive radiation can be a source of biodiversity. [2]
- Explain how speciation occurs. [3]
- Distinguish between allopatric and sympatric speciation. [3]
- Explain the role of polyploidy in speciation. [3]
- Explain why there are barriers to hybridization even though hybrid vigor exists. [3]
- Explain the advantages and disadvantages of hybridization. [4]
- Using an example for each, distinguish between divergent and convergent evolution. [4]
- Explain how the theory of evolution provides evidence for both unity and diversity within ecosystems. [5]

References

Ann Clark, Mary, et al. *Biology 2e*. E-book, OpenStax, 2018, https://openstax.org/books/biology-2e/pages/1-introduction. OpenStax.

Gordon Betts, J., et al. *Anatomy and Physiology 2e*. E-book, OpenStax, 2022, https://openstax.org/books/anatomy-and-physiology-2e/pages/1-introduction. OpenStax.

Takemoto, Hiroyuki et al. "How did bonobos come to range south of the congo river? Reconsideration of the divergence of Pan paniscus from other Pan populations." *Evolutionary anthropology* vol. 24,5 (2015): 170-84. doi:10.1002/evan.21456.