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
  - Evolution occurs at the level of populations (not individual level); **Lamarckism** is a theory that falsely postulated that acquired characteristics throughout an individual's lifetime are inherited by offspring
- The **theory of evolution** was independently developed by Darwin and Wallace & attempts to explain how evolution occurs through **rigorous evidence**
- Evolutionary change can occur through **non-random** (i.e. selection) or **random mechanisms** (i.e. genetic drift, mutations, gene flow)

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** is a concept in modern evolutionary theory which states that all organisms on Earth are descendants from a single ancestral species
  - Differences in DNA or RNA or amino acid sequences are evidence for evolution because they show that organisms inherited their genetic material from a common ancestor but accumulated mutations over time after their lineages diverged
  - The more similar the base or amino acid 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 make desired traits more common in the population
  - For example, farmers propagate crop plants with high seed or oil production or only breed animals with certain aesthetic features for domestication
  - This causes the alleles associated with desirable phenotypes to increase in frequency within the population, which shows how rapidly evolutionary changes occur if selection pressures are strong

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** (e.g. 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** (e.g. 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 **d**ifferent (divergent) functions.
  - **Convergent evolution** occurs when heritable traits in species from unrelated lineages evolve to perform similar (convergent) functions.
- Divergent or convergent evolution can 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 (e.g. 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 rapidly they experience evolutionary change
  - The speed of evolution depends on the evolutionary pressures they experience
- Evolution is without direction or purpose; adaptations are not induced & 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**
  - Speciation requires that the two populations become **reproductively isolated** (i.e. individuals do not interbreed with the other population for a long time) in order to accumulate genetic differences
    - The longer two populations
  - 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** occurs when two populations are unable to interbreed and produce fertile offspring for a long period of time
  - Genetic differences accumulate between the two populations with time, eventually leading to the splitting of the two populations into 2 distinct species
  - **Additional higher level**: the **gene pools** of the two populations become isolated & sufficiently different to the point where if individuals were given a chance to reproduce with the other population, breeding may be unsuccessful or no fertile offspring are produced
  - There are different mechanisms of reproductive isolation, including geographic isolation
- **Geographical isolation** occurs two populations are separated geographically (e.g. by a mountain or river), greatly reducing gene flow & chances of interbreeding, which leads to reproductive isolation
  - Since each population lives in a different geographic location, they are likely going to experience different evolutionary pressures, leading to **differential selection** (different traits will be favored in each population)
  - With time, selection will cause sufficient genetic differences that prevent interbreeding & production of fertile offspring between the two populations, leading to speciation
  - 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**) 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 (e.g. anole lizards experienced adaptive radiation 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 (e.g. 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

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

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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.