

**B-5.1 Summarize the process of natural selection.**

**Biological evolution** describes all of the changes that have transformed life on Earth from the earliest beginnings to the diversity of organisms in the world today. Biological evolution is the unifying theme of biology. Biological evolution can occur on a small scale affecting a single population (*microevolution*) or on a large scale affecting changes in species across populations (*macroevolution*).

One way to explain how biological evolution occurs is through natural selection.

**Natural selection** occurs because the individual members of a population have different traits which allow them to interact with the environment either more or less effectively than the other members of the population. Natural selection results in changes in the inherited traits of a population over time. These changes often increase a species' fitness in its environment.

**There are four main principles to natural selection.****Overproduction of Offspring**

- The ability of a population to have many offspring raises the chance that some will survive but also increases the competition for resources.

**Variation**

- Within every population, variation exists within the *inherited traits* of the individuals.
- Variation exists in the phenotypes (body structures and characteristics) of the individuals within every population.
- An organism's phenotype may influence its ability to find, obtain, or utilize its resources (food, water, shelter, and oxygen) and also might affect the organism's ability to reproduce.
- Phenotypic variation is controlled by the organism's genotype and the environment.
  - Those individuals with phenotypes that do not interact well with the environment are more likely to either die or produce fewer offspring than those that can interact well with the environment.

**Adaptation**

- The process of *adaptation* leads to the increase in frequency of a particular structure, physiological process, or behavior in a population of organisms that makes the organisms better able to survive and reproduce.
  - With every generation, organisms with specific beneficial inherited traits (that arose in a previous generation due to genetic variation) become more prevalent.
  - As each generation progresses, those organisms that carry genes that hinder their ability to meet day to day needs become less and less prevalent in the population.
    - ◆ Organisms that have a harder time finding, obtaining, or utilizing, food, water, shelter, or oxygen will be less healthy and more likely to die before they reproduce or produce less viable or fewer offspring.
  - In this manner, the gene pool of a population can change over time.
- The concept of *fitness* is used to measure how a particular trait contributes to reproductive success in a given environment and results from adaptations.
  - Natural selection has sometimes been popularized under the term *survival of the fittest*.

**Descent with modification**

- As the environment of a population changes, the entire process of natural selection can yield populations with new phenotypes adapted to new conditions.
- Natural selection can produce populations that have different structures, live in different niches or habitats from their ancestors. Each successive living species will have descended, with adaptations or other modifications, from previous generations.
- More individuals will have the successful traits in successive generations, as long as those traits are beneficial to the environmental conditions of the organism.

**B-5.2 Explain how genetic processes result in the continuity of life-forms over time.**

The continuity of life-forms on Earth is based on an organism's success in passing genes to the next generation. Many organisms that lived long ago resemble those still alive today because the same genetic processes have passed along the genetic material of life. Based on scientific evidence, most scientists attribute the continuity of life-forms over time to the genetic processes that all organisms share.

- All life that has ever existed on Earth, share at least the same two structures:
  - (1) Nucleic acids (RNA or DNA) that carry the code for the synthesis of the organism's proteins (see B-4.1)
  - (2) Proteins (composed of the same twenty amino acids in all life forms on Earth)

- The process by which nucleic acids code for proteins (transcription and translation) is the same in all life forms on Earth. The same sequences of nucleotides code for the same specific amino acids. (see B-4.4)

All organisms have reliable means of passing genetic information to offspring through reproduction. The reproductive processes of organisms, whether sexual or asexual, result in offspring receiving essentially the same genetic information as the parent or parents, though there may be some genetic variability.

### ***Sexual Reproduction***

*Sexual reproduction* uses the process of meiosis to create gametes. (see B-4.5) Fertilization results in the embryo receiving alleles from each parent for each trait. The new individual will express a combination of traits allowing for variation within the offspring. (see B-4.7)

- Genetic variability may also be due to gene shuffling, crossing-over, recombination of DNA, or mutations. (see B-4.7 and B-4.8) When gametes are produced, each parent's alleles may be arranged in new ways in the offspring.
- Genetic changes or variability result in the transcription and translation of new or different proteins that will result in changes in the phenotype of an individual organism.
- Reproduction that results in allele combinations producing traits that improve an individual's chance of survival ensures the continuity of that life form over time.

### ***Asexual Reproduction***

*Asexual reproduction* involves only one parent that produces the offspring that are for the most part genetically identical to that parent.

- Genetic variability can only occur through mutations in the DNA passed from parent to offspring, which is another way these organisms achieve variations as the populations continue over time.
- This may be accomplished by cell division: binary fission (reproduction of single-celled organisms) or mitosis (reproduction in multi-celled organisms).
- Examples of asexual reproduction are budding, fragmentation, and vegetative propagation.
- The asexual reproduction rate is much higher than sexual reproduction and produces many offspring that are suited to continuing life in the present environment.
- Asexual reproduction may have a disadvantage in changing conditions because genetically identical offspring respond to the environment in the same way. If a population lacks traits that enable them to survive and reproduce, the entire population could die off.

The genetic view of evolution includes the transfer of the genetic material through these processes of reproduction. The continuity of a species is contingent upon these genetic processes. If an organism can reproduce both sexually and asexually, they have an adaptive advantage for survival.

### B-5.3 Explain how diversity within a species increases the chances of its survival.

A **species** is a group of organisms that share similar characteristics and can interbreed with one another to produce fertile offspring.

- Species that interbreed share a common *gene pool* (all genes, including all the different alleles, of all of the individuals in a population).
- Because of the shared gene pool, a genetic change that occurs in one individual can spread through the population as that individual and its offspring mate with other individuals.
- If the genetic change increases fitness, it will eventually be found in many individuals in the population.

Within a species there is a variability of phenotypic traits leading to diversity among the organisms of the species. The greater the diversity, the greater the chances are for that species to survive during environmental changes.

If an environment changes, organisms that have phenotypes which are well-suited to the new environment will be able to survive and reproduce at higher rates than those with less favorable phenotypes. Therefore, the alleles associated with favorable phenotypes increase in frequency and become more common and increase the chances of survival of the species.

- Favorable traits (such as coloration or odors in plants and animals, competitive strength, courting behaviors) in male and female organisms will enhance their reproductive success. Non-random mating results in the gene pool of a population that can change over time and a species that can become increasingly adapted to its environment.
- Organisms with inherited traits that are beneficial to survival in its environment become more prevalent. For example, resistance of the organism to diseases or ability of the organism to obtain nutrients from a wide variety of foods or from new foods.
- Organisms with inherited traits that are detrimental to survival in its environment become less prevalent.

**B-5.4 Explain how genetic variability and environmental factors lead to biological evolution.**

Genetic variation is random and ensures that each new generation results in individuals with unique genotypes and phenotypes. This **genetic variability** leads to biological evolution.

Factors that influence genetic variability within a population may be:

- **Genetic drift** is the random change in the frequency of alleles of a population over time. Due to chance, rare alleles in a population will decrease in frequency and become eliminated; other alleles will increase in frequency and become fixed. The phenotypic changes may be more apparent in smaller populations than in larger ones.
- **Gene flow** is the movement of genes into or out of a population. This occurs during the movement of individuals between populations (such as migration) thus increasing the genetic variability of the receiving population.
- **Non-random mating** limits the frequency of the expression of certain alleles. (see B-5.3)
- **Mutations** increase the frequencies and types of allele changes within the population. (see B-5.2)
- **Natural selection allows** for the most favorable phenotypes to survive and thus be passed on to future generations. (see B-5.1)

When there is no change in the allele frequencies within a species, the population is said to be in **genetic equilibrium**. This concept is known as the **Hardy-Weinberg principle**. Five conditions that are required to maintain genetic equilibrium are:

- **The population must be very large, no genetic drift occurs**
- **There must be no movement into or out of a population**
- **There must be random mating**
- **There must be no mutations within the gene pool**
- **There must be no natural selection**

**Speciation** is the process of forming of a new species (or other taxonomic groups) by biological evolution from a preexisting species.

- New species usually form when organisms in the population are isolated or separated so that the new population is prevented from reproducing with the original population, and its gene pools cease to blend.
- Once isolation (reproductive or temporal, behavioral, geographic) occurs, genetic variation and natural selection increase the differences between the separated populations.

- As different traits are favored in the two populations (original and new) because of isolation, the gene pools gradually become so different that they are no longer able to reproduce. At this point the two groups are by definition different species.

**Environmental factors (such as catastrophic events, climatic changes, continental drift) can also lead to biological evolution.**

Results from environmental factors may affect biological evolution on a grand scale over many generations (macroevolution). Some *patterns of evolution* are:

*Gradualism*

- Gradual changes of a species in a particular way over long periods of time, such as a gradual trend toward larger or smaller body size.

*Punctuated equilibrium*

- Periods of abrupt changes in a species after long periods of little change within the species over time, such as sudden change in species size or shape due to environmental factors.

*Adaptive radiation/Divergent evolution*

- In adaptive radiation (divergent evolution), a number of different species diverge (split-off) from a common ancestor.
- This occurs when, over many generations, organisms (whose ancestors were all of the same species) evolve a variety of characteristics which allow them to survive in different niches.

*Convergent evolution*

- In convergent evolution, evolution among different groups of organisms living in similar environments produces species that are similar in appearance and behavior.
- Convergent evolution has produced many of the *analogous structures* in organisms today. Analogous structures are similar in appearance and function, but have different evolutionary origins.

*Coevolution*

- With coevolution, when two or more species living in close proximity change in response to each other. The evolution of one species may affect the evolution of the other.

*Extinction*

- Extinction is the elimination of a species often occurring when a species as a whole cannot adapt to a change in its environment. This elimination can be gradual or rapid.
- *Gradual extinction* usually occurs at a slow rate and may be due to other organisms, changes in climate, or natural disasters. Speciation and gradual extinction occur at approximately the same rate.



- *Mass extinction* usually occurs when a catastrophic event changes the environment very suddenly (such as a massive volcanic eruption, or a meteor hitting the earth causing massive climatic changes). It is often impossible for a species to adapt to rapid and extreme environmental changes.

**B-5.5 Exemplify scientific evidence in the fields of anatomy, embryology, biochemistry, and paleontology that underlies the theory of biological evolution.**

Scientific studies in the fields of anatomy, embryology, biochemistry, and paleontology have contributed scientific evidence for the theory of evolution.

*Field of Anatomy*

The field of *anatomy* (the study of the structures of organisms) provides one type of data for the support of biological evolution.

- Scientists study homologous structures as one form of evidence to determine the possible relationship between the evolutionary paths of two species. (see B-5.4)
  - Organisms which have diverged from a common ancestor often have *homologous structures* (similar characteristics resulting from common ancestry). The greater the numbers of shared structures between two species, the more closely the species are related.
  - Many species have *vestigial organs* (structures with little or no function to the organism) that are remnants of structures that had important functions in ancestors of the species. The vestigial organs of one species are often homologous with structures in related species where the structure has remained functional.
- Also, the study of the anatomy of species located in different geographical locations reveals that species living in different locations under similar ecological conditions developed similar structures and behaviors.
- If a species encountered a different ecosystem due to a change in geographical location, favorable anatomical traits become established. A new species evolves with a shared common ancestor from the original population.

*Field of Embryology*

The field of *embryology* (the study of the embryonic development of organisms) provides another type of data for the support of biological evolution by comparing the anatomies of embryos (an early stage—pre-birth, pre-hatching, or pre-germination—of organism development).

- Sometimes similarities in patterns of development or structures that are not obvious in adult organisms become evident when embryonic development is observed.
- The embryos of vertebrates are very similar in appearance early in development but may grow into different structures in the adult form.
- These similar structures of these embryos may suggest that these species evolved from common ancestors.

### *Field of Biochemistry*

The field of **biochemistry** (the study of the chemical processes in organisms) studies genes and proteins to provide support for biological evolution.

- The more similar the DNA and amino acid sequences in proteins of two species, the more likely they are to have diverged from a common ancestor.
- Biochemistry provides evidence of evolutionary relationships among species when anatomical structures may be hard to use. For example,
  - when species are so closely related that they do not appear to be different, or
  - when species are so diverse that they share few similar structures.

### *Field of Paleontology*

**Paleontology** (the study of prehistoric life) is another tool that scientists use to provide support for biological evolution.

- The fossil record provides valid evidence of life forms and environments along a timeline and supports evolutionary relationships by showing the similarities between current species and ancient species.
- Comparing current and ancient species shows a pattern of gradual change from the past to the present.
- Examining the fossil record of Earth reveals a history that tells a story of the types of organisms that have lived on Earth (including those that are extinct) and the relative ages of those fossils.
- The fossil record is not complete because most organisms do not form fossils. Many of the gaps in the fossil record have been filled in as more fossils have been discovered.
- The older the fossils, the less resemblance there is to modern species.

**B-5.6 Summarize ways that scientists use data from a variety of sources to investigate and critically analyze aspects of evolutionary theory.**



Scientists study data to trace the **phylogeny (evolutionary history)** of a species or a group of related species. Based on this study of data, an evolutionary theory has been developed that states all forms of life on Earth are related because the ancestry of organisms can be traced back to a common origin. Evidence of the shared history is found in all aspects of living and fossil organisms (physical features, structures of proteins, sequences found in RNA and DNA). Scientists must use multiple sources of evidence in drawing conclusions concerning the evolutionary relationship among groups of organisms. For example:

### *Field of Anatomy:*

- Phylogenies can be constructed by assuming that anatomical differences increase with time. The greater the anatomical similarity, the more recently a pair of species shares a common ancestor.
  - The accumulation of evolutionary differences over time is called divergence. (see B-5.7)
  - Anatomical structures that share a common evolutionary history but not necessarily the same function are termed homologous. (see B-5.5)
- Evolutionary biologists make observations on as many anatomical structures as possible to construct phylogenies.
- Sometimes individual structures may suggest evolutionary relationships that differ from the bulk of the evidence. This may result from *convergence*, structures becoming more similar with time.
  - Convergence occurs when organisms with different evolutionary histories adapt to similar environments.
  - Anatomical structures that have different evolutionary origins but similar functions are said to be analogous. (see B-5.4)

### *Field of Embryology:*

- Characters of embryonic development allow scientists to reconstruct the phylogenies of highly divergent taxa, such as phyla and classes, that may have evolved so many anatomical differences that they are difficult to compare otherwise.
- One mechanism by which evolution may have proceeded is by selection for successive new stages at the end of embryonic development. If this has been the case, ontogeny (growth and development of an individual organism) will recapitulate phylogeny.

***Field of Paleontology:***

- The fossil record provides information regarding the dates and order of divergence for phylogenies.
- *Transitional fossils* (fossils that show links in traits between groups of organisms used to document intermediate stages in the evolution of a species) confirm evolutionary relationships.
- The primary challenge for using the fossil record as a map of evolutionary history is that the record is incomplete.
  - Even though millions of fossils have been discovered by scientists, many environmental conditions must be met in order for a fossil to form, and the chance of all of these conditions coming together at one time is rare.
  - The fossil record favors the preservation of species that existed for a long time, were abundant and widespread, and had hard shells or skeletons.
  - Gaps do not indicate weakness in the evolutionary theory, but rather point out opportunities for additional research. Fossils that allow scientists to fill gaps in the record are continually being discovered.

***Field of Biochemistry:***

- Phylogenies can be constructed by assuming that differences in DNA, proteins, and other molecules increase over time. The greater the overall genetic similarity, the more recently a pair of species shares a common ancestor.
- The time since a pair of species has diverged can be estimated under the assumptions of a "molecular clock."
- Even though a comparison of the DNA sequences of two species provides some of the most reliable evidence, there are challenges inherent in this approach as well.
  - Because genes evolve at different rates, it may be difficult for scientists to identify the molecules that yield information about the group of organisms at the scale under study.
  - Insertions and deletions result in homologous genes of different lengths, which may introduce difficulties in aligning them for comparison. (see B-4.8)
  - Different assumptions about the details of molecular evolution can yield different phylogenetic trees. (see B-5.7)
  - Natural selection can cause convergence in molecules, just as it causes convergence in anatomical structures. (see B-5.1)

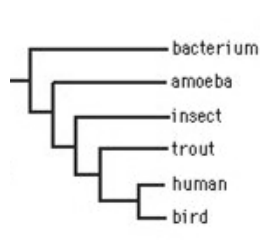
**One piece of evidence does not ensure an accurate picture of the history of the evolution of a particular group of organisms, but as scientists collect many pieces of evidence from many fields, the reliability of a particular hypothesis becomes greater and greater.**

The more evidence scientists can gather from different fields of science, the more reliable their information becomes in regards to evolutionary relationships. The evolutionary theory is a well-tested explanation that accounts for a wide range of observations made by scientists in many fields of science. No scientist suggests that all evolutionary processes are understood; many unanswered questions remain to be studied and analyzed.

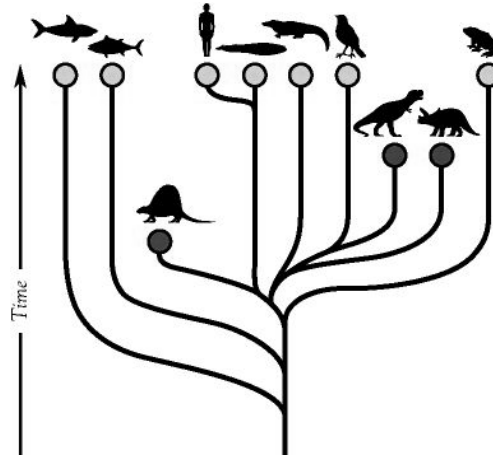
**B-5.7 Use a phylogenetic tree to identify the evolutionary relationships among different groups of organisms.**

A **phylogenetic tree** is a scientific diagram that biologists use to represent the phylogeny (evolutionary history of a species) of organisms. It classifies organisms into major *taxa* (groups) based on evolutionary relationships. Phylogenetic trees are used to classify species in the order in which they descended from a common ancestor using physical characteristics. Speciation could be thought of as a branching of a family tree then extinction is like the loss of one of the branches.

- Some phylogenetic trees only express the order of divergence of a species. They do not attempt to show relative or absolute time frames.



- Some phylogenetic trees indicate an estimated time of divergence. The tree below shows the relative time that species diverged.
  - The branch between humans and whales is almost at the top of the line, while the branch between birds and tyrannosaurs happens about midway up the line, indicating that birds and tyrannosaurs diverged much sooner than humans and whales diverged.



From phylogenetic trees, the following information can be determined:

- Which groups are most closely related?
- Which groups are least closely related?
- Which group diverged first (longest ago) in the lineage?

One of the main challenges that biologists concerned with biodiversity have recently face is in classifying organisms because species are becoming extinct at an increasing pace. As knowledge of biodiversity increases, revisions to taxonomic systems are continually being proposed. Biologists regularly revise the many branches of the phylogenetic tree to reflect current hypotheses of the evolutionary relationships between groups. The most recent classification scheme includes

- three domains (Bacteria, Archaea, and Eukarya)
- six kingdoms (Eubacteria, Archaeobacteria, Protista, Fungi, Plantae, and Animalia).