Evolution

I. In modern terms, we can define **evolution** as a change over time in the genetic composition of a population. Evolution also refers to the gradual appearance of all biological diversity.
  A. Evolution is such a fundamental concept that its study is relevant to biology at every level, from molecules to ecosystems. Our increasing understanding of evolution is changing practices in medicine, agriculture, biotechnology, and conservation biology.
  B. Evolution theory began major steps forward because of the publication of the book *On the Origin of Species* by Charles Darwin. Darwin made two major points in the book:
    1. Today's organisms are descended from ancestral species that were different from modern species.
    2. Natural selection provided a mechanism for this evolutionary change.
      a. The basic idea of natural selection is that a population can change over time if individuals that possess certain heritable traits leave more offspring than other individuals.
      b. Natural selection results in evolutionary adaptation, an accumulation of inherited characteristics that increase the ability of an organism to survive and reproduce in its environment.

II. Contributing ideas to the development of evolution theory
  A. Darwin's views were influenced by **fossils,** remains or traces of organisms from the past mineralized in **sedimentary rocks.**
    1. Sedimentary rocks form when mud and sand settle to the bottom of seas, lakes, and marshes. New layers of sediment cover older ones, creating layers of rock called **strata**.
    2. Erosion may later carve through sedimentary rock to expose older strata at the surface.
    3. Fossils within layers of sedimentary rock show that a succession of organisms have populated Earth throughout time.
    4. Fossils can be used to construct family histories of species if we can arrange them in chronological order but a few problems exist:
      a. The majority of living things were not captured as fossils upon their death.
      b. Of those that formed fossils, later geological processes destroyed many.
      c. Only a fraction of existing fossils has been discovered.
      d. The fossil record is biased in favor of species that existed for a long time, were abundant and widespread, and had hard shells or skeletons that fossilized readily.
    5. The fossil record showed Darwin that species have changed over time and that there used to be species on the planet that are no longer here.
  B. **Paleontology** is the study of fossils.
    1. Examining rock strata, we notice that the older the strata, the more dissimilar the fossils from modern life. This suggests that species have become more complex over time.
    2. We also notice that all species did not exist at the same time. Species appear suddenly in the fossil record and they disappear suddenly from it. This means extinctions has been a common occurrence in the history of life.
  C. The theory of **gradualism** assumes that large changes happen (*e.g.*, geological changes) took place through the cumulative effect of slow but continuous processes identical to those currently operating, rather than all at once.

1. Thus, valleys were formed by rivers flowing through rocks and sedimentary rocks were formed from soil particles that eroded from land and were carried by rivers to the sea. Mountains were formed as rock material is pushed upward as tectonic plates collide.
2. This would explain the presence of fossils of marine organisms on mountain sides.
3. Darwin realized that, if geologic changes result from slow, continuous processes then the Earth must be far older than the 6,000 years estimated by theologians from biblical inference.
4. Second, from this Darwin reasoned that slow and subtle processes persisting for long periods of time can also act on living organisms, producing substantial change over a long period of time.

D. Darwin’s time on the Beagle

1. The five-year voyage of the *Beagle* included exploring long stretches of the South American coastline. As he collected thousands of specimens, Darwin noted that the plants and animals of South America were very distinct from those of Europe.
    a. Organisms from temperate regions of South America more closely resembled those from the tropics of South America than those from temperate regions of Europe.
    b. Further, South American fossils, though different from modern species, more closely resembled modern species from South America than those from Europe.
2. Darwin became even more interested in the geographic distribution of species when the *Beagle* visited the Galapagos, a group of young volcanic islands 900 km west of the South American coast.
    a. After his return to England, Darwin noted that while most of the animal species on the Galapagos lived nowhere else, they resembled species living on the South American mainland.
    b. He hypothesized that the islands had been colonized by plants and animals from the mainland that had subsequently diversified on the different islands.
3. After his return to Great Britain in 1836, Darwin began to perceive that the origin of new species and adaptation of species to their environment were closely related processes.
    a. For example, clear differences in the beaks among the 13 species of finches that Darwin collected in the Galapagos are adaptations to the specific foods available on their home islands.

E. Darwin realized that **artificial selection** had been used by humans to modify a variety of domesticated plants and animals over many generations by selecting individuals with the desired traits and breeding them. The hope is that some offspring will possess an “improved” version of the trait. Darwin thought it was reasonable to think the same process might occur naturally over much longer periods of time - thousands of generations - and he called this process **natural selection**.

F. In June 1858, Alfred Russel Wallace (1823B1913), a young naturalist working in the East Indies, sent Darwin a manuscript containing a theory of natural selection essentially identical to Darwin’s.

1. Darwin published *On the Origin of Species by Means of Natural Selection* in 1859.
    a. The theory of evolution by natural selection was presented in the book with immaculate logic and an avalanche of supporting evidence.
    b. Within a decade, *The Origin of Species* had convinced most biologists that biological diversity was the product of evolution.

III. The Origin of Species developed two main ideas: that evolution explains the similarity between and diversity among all living things and that natural selection is the mechanism of evolution.

A. In his book, Darwin used the phrase **descent with modification** instead of evolution.

1. All organisms are related through descent from a common ancestor that lived in the remote past.
2. Over evolutionary time, the descendants of that common ancestor have accumulated diverse modifications, or **adaptations,** that allow them to survive and reproduce in specific habitats.

B. Viewed from the perspective of descent with modification, the history of life is like a tree with many branches from a common trunk. Closely related species, the twigs on a common branch of the tree, shared the same line of descent until their recent divergence from a common ancestor.

C. The logic of Darwin's theory can be divided into three inferences based on five observations.

1. Observation #1: Most species produce way too many offspring but only a few survive.
2. Observation #2: Populations tend to stay about the same size.
3. Observation #3: Resources like food are limited.
   a. <u>Conclusion #1:</u> In order to survive, individuals struggle in a competition for resources.
4. Observation #4: No two individuals are exactly alike.
5. Observation #5: Most of the variation can be inherited.
   a. <u>Conclusion #2:</u> Individuals having traits that are advantageous in an environment produce more offspring than do organisms without those traits. This is called **differential reproductive success**.
   b. <u>Conclusion #3:</u> Favorable traits will accumulate over time.

D. In each generation, environmental factors act like a filter for heritable variations, favoring some over others. The increase in the occurrence of favored traits in a population is evolutionary change. Darwin envisioned the diversity of life as evolving by a gradual accumulation of minute changes through the actions of natural selection operating over a huge length of time.

E. Natural selection is the primary mechanism of adaptive evolution by accumulating and maintaining favorable gene combinations (*i.e.*, traits) in a population.

1. Natural selection is based on differential reproductive success and that success depends on factors other than battle for mates.
   a. Individuals in a population vary in their heritable traits.
   b. Fitness can be thought of as the number of offspring that an individual produces compared to the number left by other individuals.
2. It is important to remember that the whole organism is subjected to natural selection. This means that even detrimental genes can be passed on if the organism's genetic package is better as a whole.

F. Three important points need to be emphasized about evolution through natural selection.

1. Although natural selection does act on individuals, individuals do not evolve. Each individual's combination of inherited traits affects its survival and its reproductive success relative to other individuals in the population. A population (a group of interbreeding individuals of a single species that share a common geographic area) is the smallest group that can evolve. Evolutionary change is measured as changes in relative proportions of heritable traits in a population over successive generations.

2. Natural selection can act only on heritable traits, traits that are passed from organisms to their offspring. Characteristics acquired by an organism during its lifetime may enhance its survival and reproductive success, but there is no evidence that such characteristics can be inherited by offspring.
3. Environmental factors vary from place to place and from time to time. A trait that is favorable in one environment may be useless or even detrimental in another environment.

IV. Mutation and Sexual Recombination Produce Genetic Variation
- A. New genes and new versions of genes originate only by mutation.
  1. A **mutation** is a change in the sequence of an organism's DNA.
  2. A new mutation that is carried by a gamete to an offspring can immediately change the gene pool of a population by introducing a new version of a gene.
  3. On rare occasions, a mutant gene may actually make its possessor better suited to the environment, increasing reproductive success.
     - a. This is more likely when the environment is changing.
  4. The process is slow because mutation rates are low in animals and plants, averaging about 1 mutation in every 100,000 genes per generation.
- B. Sexual recombination also produces genetic variation.
  1. On a generation-to-generation timescale, sexual recombination is far more important than mutation in producing the genetic differences that make adaptation possible, because it happens much more quickly.
  2. Sexual reproduction rearranges genes into novel combinations every generation.

V. If two populations are unable to share genes, eventually, a population may accumulate enough change that it constitutes a new species. This can happen in one of two ways.
- A. In **allopatric speciation**, geographic barriers can lead to the origin of species.
  1. Mountain ranges, glaciers, land bridges, or splintering of lakes may divide one population into isolated groups.
  2. Alternatively, some individuals may colonize a new, geographically remote area and become isolated from the parent population.
     - a. For example, mainland organisms that colonized the Galapagos Islands were isolated from mainland populations.
  3. Once geographic separation is established, the separated gene pools may begin to diverge through a number of mechanisms.
     - a. Mutations arise.
     - b. Sexual selection favors different traits in the two populations.
     - c. Different selective pressures in differing environments act on the two populations.
     - d. Particular versions of genes could be lost in one population.
- B. In **sympatric speciation,** speciation occurs in geographically overlapping populations when biological factors, such as chromosomal changes and nonrandom mating, reduce the exchange of genes between the two groups.
- C. Speciation marks the boundary between microevolution and macroevolution.
  1. Microevolution is a generation-to-generation change in the frequency of various genes in a population. This can be a result of natural selection.
  2. Speciation occurs when a population's genetic change from its ancestral population results in a reproductive barrier.

3. While the changes after any speciation event may be subtle, the cumulative change over millions of speciation episodes must account for macroevolution, the scale of changes seen in the fossil record.

D. Mechanisms of isolation include:
   1. Habitat isolation - a population begins to occupy a different habitat.
   2. Temporal isolation - a population mates at a different time.
   3. Behavioral isolation - a courtship ritual might be unique to a population.
   4. Mechanical isolation - physical differences prevent mating.
   5. Gametic isolation - sperm from one population is unable to fertilize the egg of another.
   6. Reduced hybrid fertility - hybrid offspring are sterile.

VI. Evidence of evolution is found throughout biology.

A. When two organisms from different evolutionary histories experience similar environmental pressures, natural selection may result in **convergent evolution** (*i.e.*, the organisms become more similar). Similarity in structures which may result is called **analogy**. Analogies are not due to shared ancestry.
   1. For example, both birds and bats have adaptations that allow them to fly.
   2. However, a close examination of a bat's wing shows a greater similarity to a cat's forelimb than to a bird's wing.
   3. Fossil evidence also documents that bat and bird wings arose independently from walking forelimbs of different ancestors.

B. Similarity in characteristic traits from common ancestry is known as **homology.**
   1. For example, the forelimbs of humans, cats, whales, and bats share the same skeletal structure, even though the appendages have very different functions.
   2. These forelimbs are **homologous structures** that represent variations on the ancestral tetrapod forelimb.
   3. As another example, all tetrapods (amphibians, reptiles, birds, and mammals) share the same five-digit limb structure.
   4. Embryology of animals shows homologous structures. All vertebrate embryos have a post-anal tail and pharyngeal gill slits.
   5. Some of the most interesting homologous structures are **vestigial structures,** structures that have minimal, if any, importance to a living organism, but which had important functions in the organism's ancestors.

C. Comparative anatomy confirms that evolution is a remodeling process, an alteration of existing structures.
   1. Because evolution can only modify existing structures and functions, it may produce structures that are less than perfect. For example, the back and knee problems of bipedal humans are an unsurprising outcome of adapting structures originally evolved to support four-legged mammals.
   2. As another example, the skulls of a human and a chimpanzee are formed by the fusion of many bones.
      a. The two skulls match almost perfectly, bone for bone.
      b. It is highly unlikely that such complex structures have separate origins.
      c. More likely, the genes involved in the development of both skulls were inherited from a common ancestor.

D. Similarities among organisms can also be seen at the molecular level.
   1. For example, all species of life have the same basic genetic machinery of RNA and DNA, and the genetic code is essentially universal. This suggests a single origin of life.

2. It is likely that the language of the genetic code has been passed along through all the branches of the tree of life ever since its inception in an early life form.
3. For many genes, the DNA sequence is more similar in closely related species.

E. The geographical distribution of species - **biogeography** - first suggested evolution to Darwin.
1. Species tend to be more closely related to other species from the same area than to species with the same way of life that live in different areas.
2. Islands and island archipelagos have provided strong evidence of evolution.
   a. Islands generally have many species of plants and animals that are **endemic,** found nowhere else in the world.
   b. These species are typically more closely related to species living on the nearest mainland (despite different environments) than to species from other island groups even if those groups have similar environments.
3. In island chains, or archipelagos, individual islands may have different, but related, species. The first mainland invaders reached one island and then evolved into several new species as they colonized other islands in the archipelago.

F. The succession of fossil forms is consistent with what is known from other types of evidence about the major branches of descent in the tree of life.
1. For example, considerable evidence suggests that prokaryotes are the ancestors of all life and should precede all eukaryotes in the fossil record. In fact, the oldest known fossils are prokaryotes.
2. Fossil fishes predate all other vertebrates, with amphibians next, followed by reptiles, then mammals and birds.

G. The Darwinian view of life also predicts that evolutionary transitions should leave signs in the fossil record and paleontologists have indeed discovered fossils of many such transitional forms that link ancient organisms to modern species.
1. For example, fossil evidence documents the origin of birds from one branch of dinosaurs.
2. Recent discoveries include fossilized whales that link these aquatic mammals to their terrestrial ancestors.