Evolution and Adaptations of Life

Although Louis Pasteur's work disproved spontaneous generation and fully cemented the notion of biogenesis, most people still believed in the idea of the *immutability of species.* Largely due to the literal belief in religious doctrine, people assumed that each species was created in its current form and wasn't capable of changing into new species.

All of that began to change when Charles Darwin shared his theory of evolution by means of natural selection with the world.
For a long time, fossils and biogeography provided the basis for most evolutionary evidence. Eventually, other techniques, including those involving comparing molecules or embryonic development, supported earlier evidence. Currently, evolution is understood on a small scope by examining allele frequencies in a population and on a large scope by the creation of new species from ancestral ones.

SECTION 1 - Evolution by Means of Natural Selection
Charles Darwin's voyage as a naturalist on the HMS *Beagle* from 1831 to 1836 allowed him to circumnavigate the globe and encounter all sorts of organisms in myriad ecosystems. He collected vast quantities of plant and animal specimens, recorded countless observations in his log, and even sketched the first phylogenetic tree that showed relatedness and divergence of organisms. It took Darwin more than 20 years, however, to refine his ideas and eventually publish his best-known work, *On the Origin of Species by Means of Natural Selection.*

1. ***Genetic Variation -*** Evolution ultimately depends on the existence of genetic variation within a population. Recall that genetic variation is introduced during meiosis among sexually reproducing organisms through the *processes* of crossing over and independent assortment. Genetic variation is also increased by the random fertilization of zygotes and the spontaneous mutation events that can occur.
2. ***Over reproduction -*** The creation of more offspring than are capable of surviving to maturity in a given environment is typical in nature. Consider the runt of a litter that wouldn't survive without human intervention, the egg in a clutch that won' t hatch (and might provide sustenance to its siblings), or the thousands of fertilized fish eggs that are consumed by other fish that are higher up in the food chain.
3. ***Struggle for Survival-*** Necessary resources are usually limited in a natural environment. These limiting factors — environmental factors that affect the survival and/or reproduction of a species play an important role in Evolution. They create an environment in which individual organisms compete with others for resources that affect their ability to survive and/or reproduce.
4. ***Differential Survival and Reproduction -*** Only organisms that possess a given collection of traits that makes them fit for survival in the environment will live. They will have the tendency to out compete other organisms whose traits are less fit evolutionarily when resources are limited. Those organisms that have certain genetic traits that enable them to survive longer and more easily will also tend to produce more offspring. Thus, the next generation will disproportionately resemble those organisms with the fittest genetic traits. This is evolution in action.

Although Darwin is credited with developing the theory of evolution by natural selection, it does not mean he was the first to conceptualize evolution or the only person to think of natural selection. His grandfather, Erasmus Darwin, believed in evolution, as did many others along the way, but Charles Darwin first developed the mechanism of natural selection to explain how evolution happens. In fact, another biologist and naturalist, Alfred Wallace, came up with an idea similar to Darwin's before Darwin actually published. Many people don't realize it, but Darwin and Wallace are jointly credited with developing the theory of evolution by means of natural selection.

SECTION 2 - Evidence *for* Evolutionary Theory

If asked to provide evidence for evolution, one might provide the fossil record as a wonderful example, and for good reason. Most of us conjure up images of imposing dinosaur fossils at a natural history museum, but fossils can provide an account of past life for only a small sampling of Earth's biodiverse organisms.

1. ***The Fossil Record -*** The fossil record is extensive and provides a thorough foundation for understanding the evolutionary history of life on Earth. A record of the planet in geologic time is preserved to a certain extent in the various strata (or layers) present in sedimentary rock. The farther down you dig into the strata, the older the layers and any fossils within them typically are; this describes the *Law of superposition.* The concept of determining a comparative fossil age based on superposition in strata is called *relative dating.* Fossils and the rocks in which they are embedded can also be tested for the presence of certain radioactive isotopes (such as carbon 14). Because a radioactive isotope decays at a predictable rate over time, the proportion of it to the more common, stable form allows biologists to determine the absolute age of a specimen. This provides the fossil's actual age in years.
2. ***Comparative Anatomy (Structural Homologies)-*** Not all species throughout history have been able to fossilize. Some are not constructed of hard enough body parts to preserve well, and others die in a region that does not produce sedimentary rock. Still, biologists want to understand evolutionary relationships between currently living organisms, so *comparative anatomy* is useful for such cases and can support other types of evolutionary evidence. *Homologous structures* are present in closely related species due to their shared genes that were inherited from a recent common ancestor. Such structures always share some underlying similarity, even when the current functions in related species are quite different. A classic example is the forelimb of mammals: a wing of a bat (used for flight), a flipper of a dolphin (used to swim), and a forearm of a chimpanzee (used to climb and manipulate tools). While these three structures seem strikingly different superficially, the underlying bone structure is actually quite similar.
3. ***Structural homologies in the forelimbs of vertebrates - Analogous structures*** are those that may look similar superficially, but the underlying structure is quite different and the genes responsible for the structure were not inherited from a recent common ancestor. Instead, the adaptations evolved independently in the two lineages, likely due to similar environmental pressures and limiting factors. Analogous structures do not provide evidence for relatedness. Finally, vestigial *structures* are those that persist in a diminished, nonfunctional form in a modern species. Examples of vestigial structures include a human's wisdom teeth and a whale's pelvis. A close relative of a species with a vestigial structure may still retain a fully functional form of the structure. For example, a whale's pelvis was derived from the pelvis of a terrestrial pig-like animal that inhabited the coasts. Modern pigs and other terrestrial mammals retain the functional pelvis necessary for coordinating movement of the lower limbs.
4. **Comparative Embryology -** With technological advances and the uncovering of the structure of DNA in the early 1950s, it was discovered that closely related species tend to share patterns of embryological development. This is due to a larger proportion of shared genes that are responsible for the early changes that take place in an embryo after fertilization to establish the body plan and develop the organ systems.
5. **Comparative Biochemistry -** Even more recently, over the past few decades, research on the structures and functions of nucleic acids and proteins has provided valuable insight into evolutionary history and relatedness among organisms. Given that DNA stores the genetic code in sequences of nucleotides called genes, and proteins result from decoding a gene into a sequence of amino acids within a polypeptide, comparing monomer sequences within either molecule can provide invaluable information regarding relatedness. Traits that increase in frequency in a population because they present an increase in fitness are called *adaptations.* Just as a population (rather than an individual) evolves, so too does it adapt. An individual contributes to this process by acting as the unit by which a unique collection of genes is tested out in the environment, but evolution and adaptation are truly population level characteristics. When an individual organism changes in the short term as a response to a significant environmental shift, this is called *acclimatization.* It is observed when the human body makes more red blood cells in response to a decrease in oxygen levels, as when hiking at high altitudes.

SECTION 3 - From Microevolution to Macroevolution

Evolution as conjured up by Charles Darwin is in modern times best under- stood using one of two lenses. M*icroevolution* explains evolution on the smallest scale, as a population of organisms passes on traits to subsequent generations. M*acroevolution* approaches evolution from the largest scope, focusing on the means by which new traits accumulate to create novel species and on understanding relatedness of all organisms over evolutionary time.

1. **Gene Pool -** It is important to realize that not all individuals in a population are capable of reproducing in their current state. If an organism cannot reproduce, then it cannot directly contribute to evolution in its population. Only individuals in a population that are capable of contributing their genes to the next generation are considered part of the *gene* pool. Frequencies of alleles present for a given gene can be calculated from the gene pool. Comparing allele frequencies over time can help to determine if the population is evolving for that particular gene.
2. **Genetic Equilibrium -** If allele frequencies for a particular gene remain stable from generation to generation, then the population is described as being in a state of genetic equilibrium. Two statisticians working independently in the early 20th century, Godfrey H. Hardy and Wilhelm Weinberg, contributed to a mathematical equation, now known as the *Hardy-Weinberg equilibrium,* that describes the numerical relationship between the alleles. Hardy and Weinberg also contributed to a set of assumptions that were used to describe a population that was not evolving for a given gene:
    - **a.** A large population
    - **b.** No selection
    - **c.** No mutat ion
    - **d.** No migration
    - **e.** Random mating

Often, biology students wonder how any population can exist in Hardy-Weinberg equilibrium in nature, given the seemingly extreme conditions that must be met. It is essential to remember that the assumptions established by the Hardy-Weinberg equilibrium are applied only to the gene in question, not to all genes within the genome simultaneously.

3. **Micro evolution -** When allele frequencies change over time, *microevolution* is occurring in that population. An allele frequency may increase due to a change in the environment that relates to an increase in the gene's evolutionary fitness; this breaks assumption a of the Hardy-Weinberg equilibrium. Or allele frequencies may change due to a disproportionate number of reproductively viable individuals that immigrate to the population (breaking assumption d)or because of random events that are usually significant only in a very small population (breaking assumption a).
4. **Geographic Isolation -** Whether it is in genetic equilibrium or not, a population may experience a major environmental change resulting in the population's being split into two smaller groups. If this geographic isolation is maintained for a long enough period of time, and if the now different environments experienced by the two populations place different pressures on the organisms, the populations can become genetically distinct as they accumulate adaptations and experience changes in allele frequencies.
5. **Speciation -** When a significant number of genetic differences accumulate, one or both of the populations may undergo *speciation„* in which a new species emerges that is no longer able to produce viable offspring with a member of the parental species. Speciation is considered *macroevolution,,* evolutionary change from the largest perspective. The type of speciation that results from geographic isolation is known as *allopatric speciation* and is the most common form *observed.* Plants have an uncanny ability to participate in a second type of speciation described as *sympatric.* Here, no physical barrier separates individuals; instead, an abrupt change in chromosome number during meiosis can create a new species. Animals are typically unable to tolerate such drastic genetic shifts.

It is helpful to consider the roots in the terms microevolution and macro-evolution. Recall that micro means "small" and macro means "large," so microevolution refers to genetic change from the smallest perspective possible – that of an individual gene and the frequencies of the possible alleles. Macroevolution, then, describes evolution from the largest perspective that of a species that is characterized by a certain set of genes composing its genome.

ASSESSMENT QUESTIONS

1. Which of the following is *not* an essential component of Darwin's theory of evolution by means of natural selection?

a. Overpopulation
b. Genetic variation
c. Predation
d. Differential reproduction

2. Which of the following could be a *biotic* (living) limiting factor in an aquatic ecosystem?

a. Availability of sunlight
b. Access to water
c. Levels of parasitic fungus present
d. Low temperature

3. Use the theme of continuity and variation to describe the concept of evolution in a population.

4. Which of the following is most useful in estimating the age of a fossil in years?

a. The law of superposition
b. The fossil's relative age
c. The presence of a radioactive isotope
d. All of the above

5. Which of the following would *not* be useful in providing evidence for relatedness between species?

a. Homologous structures
b. Analogous structures
c. Vestigial structures
d. Comparative embryology

3. Use the theme of the relationship between structure and function to describe the concept of homologous structures.

6. Which of the following could contribute to microevolution in a population?

a. Natural selection
b. A large population
c. Random mating
d. A lack of migration

7. Which of the following must be present to contribute to allopatric speciation?

a. Mutation
b. Interbreeding between populations
c. Extinction
d. A geographic barrier

8. Use the theme of the process and application of science to describe the concept of determination of allele frequencies in a gene pool.