Big Idea 1:
The process of evolution drives the diversity and unity of life.

Enduring Understanding 1.A:
Change in the genetic makeup of a population over time is evolution.

Learning Objectives:
Essential Knowledge 1.A.1: Natural selection is a major mechanism of evolution.

(1.1) The student is able to convert a data set from a table of numbers that reflect a change in the genetic makeup of a population over time and to apply mathematical methods and conceptual understandings to investigate the cause(s) and effect(s) of this change.
(1.2) The student is able to evaluate evidence provided by data to qualitatively and quantitatively investigate the role of natural selection in evolution.
(1.3) The student is able to apply mathematical methods to data from real or simulated populations to predict what will happen to the population in the future.

Essential Knowledge 1.A.2: Natural selection acts on phenotypic variations in populations.

(1.4) The student is able to evaluate data-based evidence that describes evolutionary changes in the genetic makeup of a population over time.
(1.5) The student is able to connect evolutionary changes in a population over time to a change in the environment.

Essential Knowledge 1.A.3: Evolutionary change is also driven by random processes.

(1.6) The student is able to use data from mathematical models based on the Hardy-Weinberg equilibrium to analyze genetic drift and effects of selection in the evolution of specific populations.
(1.7) The student is able to justify data from mathematical models based on the Hardy-Weinberg equilibrium to analyze genetic drift and the effects of selection in the evolution of specific populations.
(1.8) The student is able to make predictions about the effects of genetic drift, migration and artificial selection on the genetic makeup of a population.

Essential Knowledge 1.A.4: Biological evolution is supported by scientific evidence from many disciplines, including mathematics.

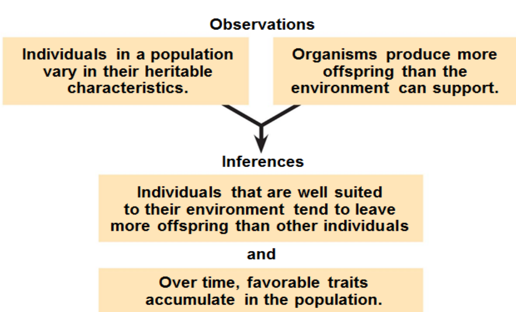
(1.9) The student is able to evaluate evidence provided by data from many scientific disciplines that support biological evolution.
(1.10) The student is able to refine evidence based on data from many scientific disciplines that support biological evolution.
(1.11) The student is able to design a plan to answer scientific questions regarding how organisms have changed over time using information from morphology, biochemistry and geology.
(1.12) The student is able to connect scientific evidence from many disciplines to support the modern concept of evolution.
(1.13) The student is able to construct and/or justify mathematical models, diagrams or simulations that represent processes of biological evolution.

Required Readings:
Textbook Ch. 22 & Textbook Ch. 23
Article: *The Exterminator - Pesticides & Resistance*
Article: *Heterozygous Advantage & Sickle Cell Anemia*

Practicing Biology Homework Questions:
Questions #1-19

Essential Knowledge 1.A.1: *Natural selection is a major mechanism of evolution.*

Natural selection is the major driving mechanism of evolution; the essential features of the mechanism contribute to the change in the genetic makeup of a population over time. Darwin's theory of natural selection states that inheritable variations occur in individuals in a population. Due to competition for resources that are often limited, individuals with more favorable variations or phenotypes are more likely to survive and produce more offspring, thus passing traits to subsequent generations. Fitness, the number of surviving offspring left to produce the next generation, is a measure of evolutionary success. Individuals do not evolve, but rather, populations evolve. Natural selection acts on phenotypes, not genotypes.



Natural selection results in ***adaptive evolution*** – accumulation of inherited characteristics that *enhance* organisms' ability to *survive and reproduce* in specific environments.

The Hardy-Weinberg equation can be used to test whether a population is evolving. Mathematical approaches are used by scientists to calculate changes in allele frequency, providing evidence for the occurrence of evolution in a population. A **population** is a localized group of individuals capable of interbreeding and producing fertile offspring. A **gene pool** consists of all the alleles for all loci in a population. A locus is **fixed** if all individuals in a population are homozygous for the same allele.

Hardy-Weinberg Theorem – states that allele frequencies tend to remain constant in populations unless something happens OTHER THAN Mendelian segregation and sexual recombination. This situation in which allele frequencies remain constant is called **genetic equilibrium**. If allele frequencies do not change, the population *will not evolve!* Hardy-Weinberg is a mathematical model that describes the changes in allele frequencies in a population: allows us to predict allele and genotype frequencies in subsequent generations (*testable*). It allows us to determine whether or not a population is evolving (*mathematically supported evidence of evolution*).

By convention, if there are 2 alleles at a locus, *p* and *q* are used to represent their frequencies

p = frequency of dominant allele in population
q = frequency of recessive allele in population

The frequency of all alleles in a population will add up to 1

For example, $p + q = 1$

Model Assumptions: conditions required to maintain genetic equilibrium from generation to generation:

Randomly Mating Population
Large Population Size (n>100)/No Genetic Drift
No Immigration or Emigration/Restrict Gene Flow
No Mutations
No Natural Selection

Note that all of these are conditions that can lead to evolution! If all 5 conditions are met, there should be NO EVOLUTION – no selection, no gene flow, no genetic drift, no mutation. Therefore, the Hardy-Weinberg theorem describes a NON-EVOLVING POPULATION!

Let p= frequency of allele A
Let q= frequency of allele a
Let p^2= frequency of genotype AA
Let 2pq= frequency of genotype Aa
Let q^2= frequency of genotype aa

Law says, given assumptions, that within 1 generation of random mating, the genotype frequencies are found to be in the binomial distribution $p^2+2pq+q^2=1$ (genotype frequencies) and $p+q=1$ (allele frequencies)

Practice Problem: The allele for the ability to roll one's tongue is dominant (R) over the allele for the lack of this ability (r).
In a population of 500 individuals, 25% show the *recessive* phenotype. How many individuals would you expect to be homozygous dominant and heterozygous?

Essential Knowledge 1.A.2: *Natural selection acts on phenotypic variations in populations.*

The environment is always changing, there is no "perfect" genome, and a diverse gene pool is important for the long-term survival of a species. Genetic variations within a population contribute to the diversity of the gene pool. Change in genetic information may be silent (with no observable phenotypic effects) or result in a new phenotype, which can be positive, negative or neutral to the organism. The interaction of the environment and the phenotype determines the fitness of the phenotype; thus, the environment does not direct the changes in DNA, but acts upon phenotypes that occur through random changes in DNA. These changes can involve alterations in DNA sequences, changes in gene combinations and/or the formation of new gene combinations.

While developing his theory of evolution, Darwin worked under a serious disadvantage – he did not know how heredity worked. Without understanding heredity, Darwin was unable to explain 2 important factors:

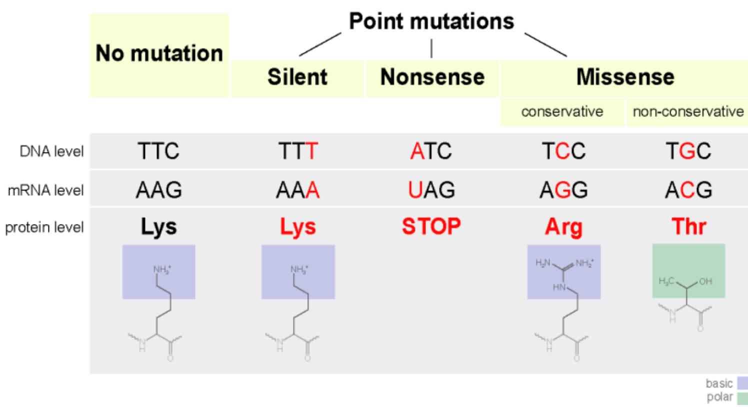
1. The source of variation central to his theory
2. How hereditable traits were passed from one generation to the next

Today, genetics, molecular biology, and evolutionary theory work together to explain how inheritable variation appears and how natural selection operates on that variation (i.e. how evolution takes place). Two processes, mutation and sexual reproduction, produce the variation in gene pools that contributes to differences among individuals:

- Variation in individual genotype leads to variation in individual phenotype
- Not all phenotypic variation is heritable
- Natural selection can only act on variation with a genetic component

Mutations are changes in the nucleotide sequence of DNA. Mutations cause new genes and alleles to arise. Only mutations in cells that produce gametes can be passed to offspring

- A *point mutation* is a change in one base in a gene. The effects of point mutations can vary. Mutations in noncoding regions of DNA are often harmless. Mutations in a gene might not affect protein production because of redundancy in the genetic code. Mutations that result in a change in protein production are often harmful. Mutations that result in a change in protein production can sometimes increase the fit between organism and environment.

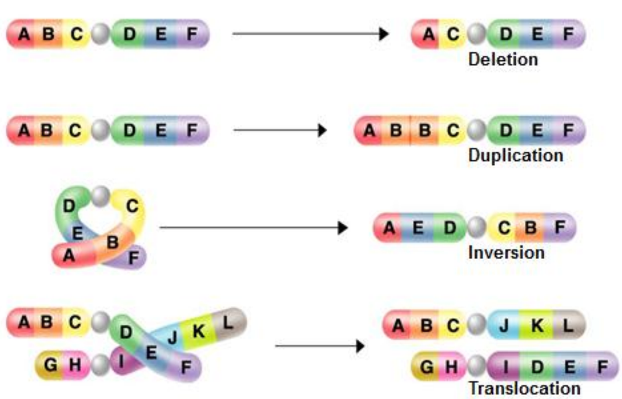


Silent Mutation: have no effect on encoded protein.

Nonsense Mutation: causes translation of protein to be terminated prematurely.

Missense Mutation: changes one amino acid for another.

Chromosomal mutations that delete, disrupt, or rearrange many loci are typically harmful. Duplication of large chromosome segments is usually harmful. Duplication of small pieces of DNA is sometimes less harmful and increases the genome size. Duplicated genes can take on new functions by further mutation.



Deletion: when an entire segment of chromosome is missing (several genes absent).
Duplication: when an entire segment of chromosome is duplicated (several genes duplicated).
Inversion: when the order of genes on a chromosome is inverted (causes proteins to be built incorrectly).
Translocation: when gene segments translocate to a new area of the chromosome (causes proteins to be built incorrectly).

Sexual reproduction can shuffle existing alleles into new combinations. In organisms that reproduce sexually, recombination of alleles is more important than mutation in producing the genetic differences that make adaptation possible. Three mechanisms contribute to the shuffling of alleles during sexual reproduction:

1. **Crossing Over:** creates variation as non-sister chromatids exchange portions of their genes during Meiosis I – recombinant chromosomes have a unique combination of maternal and paternal genes.
2. **Independent Assortment of Alleles:** because each homologous pair of chromosomes is positioned independently of the other pairs at metaphase I, the first meiotic division results in each pair sorting its maternal and paternal homologs into daughter cells independently of every other pair. In the case of humans (n=23), the number of possible combinations of maternal and paternal chromosomes in the resulting gametes is 223…each gamete produced during the lifetime has one of roughly 8.4 million possible combinations.
3. **Fertilization:** sexual reproduction mixes the genomes of two individuals – thus producing variation within the offspring.

A diverse gene pool is important for the survival of a species in a changing environment. Environments can be more or less stable or fluctuating, and this affects evolutionary rate and direction; different genetic variations can be selected in each generation. The interaction of the environment and the phenotype determines the ***fitness*** of the phenotype. Thus, ***the environment does NOT direct changes in DNA***, but acts upon existing that occur through random changes in DNA.

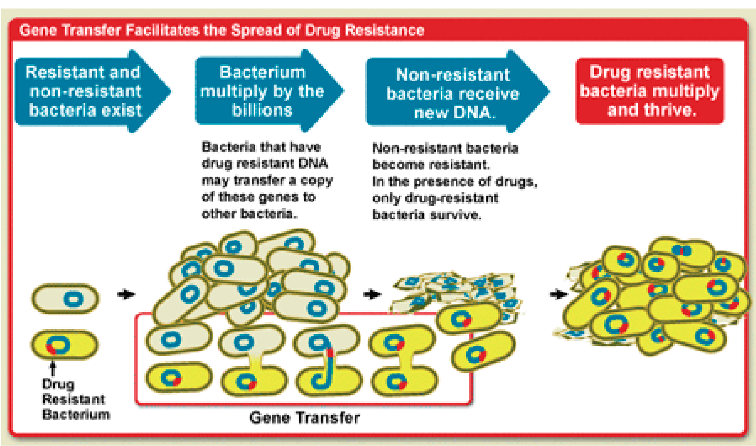
- Natural selection does not create new traits, but edits or selects for traits ***already present*** in the population
- The local environment determines which traits will be selected for or selected against in any specific population
- Because environments change, they act as selective mechanisms on populations. ***Illustrative Example:*** peppered moth…the **evolution of the peppered moth** over the last two hundred years has been studied in detail. Originally, the vast majority of peppered moths had light coloration, which effectively camouflaged them against the light-colored trees and lichens which they rested upon. However, because of widespread pollution during the Industrial Revolution in England, many of the lichens died out, and the trees that peppered moths rested on became blackened by soot, causing most of the light-colored moths to die off from predation. At the same time, the dark-colored moths flourished because of their ability to hide on the darkened trees.

Some phenotypic variations significantly increase or decrease fitness of the organism and the population. ***Illustrative Examples:***

- Peppered Moth (explained above)
- DDT Resistance in Insects (read article: The Exterminator - Pesticide Resistance)
- Sickle Cell Anemia (read article: Heterozygous Advantage & Sickle Cell Anemia)

Humans can impact variation in other species. ***Illustrative Examples:***

- Artificial Selection (modified other species by selecting and breeding individuals with desired traits – often leads to reduced genetic diversity).
- Overuse of Antibiotics



Antibiotic resistance in bacteria is a big problem

- Most bacteria isolated from clinical infection are resistant to multiple antibiotics
- Some are resistant to all antibiotics in routine use
- Some of what used to be the best antibiotics (very effective, few side effects) are now virtually useless
- MRSA
- Multi drug resistant TB.

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Essential Knowledge 1.A.3: *Evolutionary change is also driven by random processes.*

Although natural selection is usually the major mechanism for evolution, genetic variation in populations can occur through other processes, including mutation, genetic drift, sexual selection and artificial selection. Inbreeding, small population size, nonrandom mating, the absence of migration, and a net lack of mutations can lead to loss of genetic diversity. Human-directed processes such as genetic engineering can also result in new genes and combinations of alleles that confer new phenotypes.

Focusing on evolutionary change in populations, we can define evolution on its smallest scale, called *microevolution*. Microevolution involves evolutionary changes *below the species level*; changes in allele frequencies in a population over generations. Our focus in this section will be to understand that natural selection is not the only cause of microevolution. The other two mechanisms include genetic drift and gene flow.

The smaller a sample, the greater the chance of deviation from a predicted result. Genetic drift is a *nonselective* process occurring in small populations. **Genetic drift** describes how allele frequencies fluctuate unpredictably from one generation to the next. Genetic drift tends to reduce genetic variation through losses of alleles – and this reduction of genetic variation within a given population can increase the differences between populations of the same species.

- Example of Genetic Drift: **The founder effect** occurs when a few individuals become isolated from a larger population. Allele frequencies in the small founder population can be different from those in the larger parent population. Once isolated from the larger population, the new gene pools will likely evolve under their own environmental pressures.
- Example of Genetic Drift: **The bottleneck effect** is a sudden reduction in population size due to a change in the environment. The resulting gene pool may no longer be reflective of the original population's gene pool. If the population remains small, it may be further affected by genetic drift.

Effects of Genetic Drift on Populations in Nature:

1. Genetic drift is significant in small populations - Although chance events occur in populations of all sizes, they alter allele frequency substantially only in small populations.
2. Genetic drift causes allele frequencies to change at random - Because of genetic drift, an allele may increase in frequency one year, and decrease the next; thus causing an unpredictable change. Thus, unlike natural selection, which in a given environment consistently favors some alleles over others, genetic drift causes allele frequencies to change at random over time.
3. Genetic drift can lead to a loss of genetic variation within populations - By causing allele frequencies to fluctuate randomly over time, genetic drift can eliminate alleles from a population. Because evolution depends on genetic variation, such losses can further influence how a population can adapt to a change in environment.
4. Genetic drift can cause harmful alleles to become fixed - Alleles can be lost or become fixed entirely by chance through genetic drift. Alleles fixed by genetic drift are as likely to be harmful to the organism as to be beneficial or of no effect.
5. Genetic drift can facilitate inbreeding – which leads to further reduction in variation - Inbreeding is facilitated when mating partners are in short supply – inbreeding REDUCES heterozygocity in populations and therefore reduces genetic variation.

Natural selection and genetic drift are <u>not</u> the only phenomena affecting allele frequencies. Allele frequencies can also change by ***gene flow***, the transfer of alleles into or out of a population. This transfer of alleles is due to the movement of fertile individuals or their gametes (migration).

- Because alleles are exchanged among populations, gene flow tends to reduce the genetic differences between populations. If extensive enough, gene flow can result in neighboring populations combining into a single population with a common gene pool.
- Gene flow can increase the fitness of a population…insecticides have been used to target mosquitoes that carry West Nile virus and malaria. Alleles have evolved in some populations that confer insecticide resistance to these mosquitoes. The flow of insecticide resistance alleles into a population can cause an increase in fitness.

Comparing Genetic Drift and Gene Flow:

Genetic Drift: when <u>*chance*</u> events lead to <u>*unpredictable fluctuations*</u> in allele frequencies from one generation to the next.

- Effects are most pronounced in <u>*small populations*</u>.
- <u>*Reduces genetic variation*</u> through random loss of alleles.
- Illustrative Examples: Founder Effect/Darwin's Finches & Bottleneck Effect/Greater Prairie Chicken

Gene Flow: the transfer of alleles from one population to another.

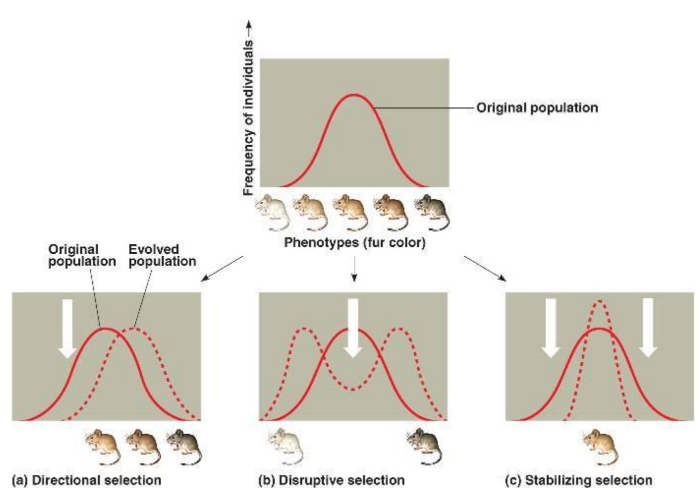
- Tends to <u>*reduce the genetic differences*</u> between populations.
- If extensive enough…can result in neighboring populations combining into a <u>*single common gene pool*</u>.
- Illustrative Examples: gene flow in humans; gene flow in bent grass near copper mines; insecticide resistance in mosquitos that transmit West Nile and malaria.

The Role of Natural Selection in Adaptive Evolution:

Natural selection is the only mechanism that consistently causes adaptive evolution. Differential success in reproduction results in certain alleles being passed to the next generation in greater proportions. Only natural selection <u>consistently</u> results in adaptive evolution - brings about adaptive evolution by acting on an organism's phenotype:

Three modes of natural selection:

(1. **Directional selection** favors individuals at one end of the phenotypic range (variation reduced and alleles can be lost from population)
(2. **Disruptive selection** favors individuals at both extremes of the phenotypic range (variation maintained in heterozygote)
(3. **Stabilizing selection** favors intermediate variants and acts against extreme phenotypes (phenotypic variation reduced)



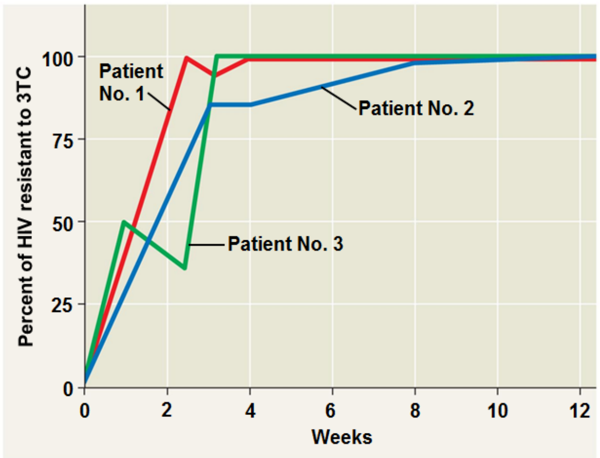
Natural selection increases the frequencies of alleles that enhance survival and reproduction. Adaptive evolution occurs as the match between an organism and its environment increases. Because the environment can change, adaptive evolution is a continuous process. Genetic drift and gene flow do not consistently lead to adaptive evolution as they can increase or decrease the match between an organism and its environment.

Essential Knowledge 1.A.4: *Biological evolution is supported by scientific evidence from many disciplines, including mathematics.*

Biological evolution driven by natural selection is supported by evidence from many scientific disciplines, including geology and physical science. In addition, biochemical, morphological, and genetic information from existing and extinct organisms support the concept of natural selection. Phylogenetic trees serve as dynamic models that show common ancestry, while geographical distribution and the fossil record link past and present organisms.

Direct Evidence of Evolution:

- The use of drugs to combat HIV selects for viruses resistant to these drugs
- HIV uses the enzyme reverse transcriptase to make a DNA version of its own RNA genome
- The drug 3TC is designed to interfere and cause errors in the manufacture of DNA from the virus
- Some individual HIV viruses have a variation that allows them to produce DNA without errors
- These viruses have a greater reproductive success and increase in number relative to the susceptible viruses
- The population of HIV viruses has therefore developed resistance to 3TC
- The ability of bacteria and viruses to evolve rapidly poses a challenge to our society



Other Evidence of Evolution:

- Fossils can be dated by a variety of methods that provide evidence for evolution. These include the age of the rocks where a fossil is found, the rate of decay of isotopes including carbon-14, the relationships within phylogenetic trees, and the mathematical calculations that take into account information from chemical properties and/or geographical data.
- Morphological homologies represent features shared by common ancestry. Vestigial structures are remnants of functional structures, which can be compared to fossils and provide evidence for evolution.
- Comparative embryology reveals anatomical homologies not visible in adult organisms. For example, at some stage in their embryonic development, all vertebrates have a tail located posterior to the anus, as well as pharyngeal pouches. Descent from a common ancestor can explain these similarities.
- Biochemical and genetic similarities, in particular DNA nucleotide and protein sequences, provide evidence for evolution and ancestry.
- Although organisms that are closely related share characteristics because of common descent, distantly related organisms can resemble one another for a different reason: **Convergent evolution** is the evolution of similar, or **analogous**, features in distantly related groups. Analogous traits arise when groups independently adapt to similar environments in similar ways. ***Convergent evolution does not provide information about ancestry!***