Genetics and Evolution

Fundamental Concepts of Genetics

- **Genes** determine the physical and biochemical characteristics of every organism
    - Are DNA sequences that code for heritable traits
- **Chromosomes** are organized bundles of the entire genome in order to ensure that the all DNA can be passed on to daughter cells.
- **Alleles** are alternative forms of a single gene.
- **Genotype** is the genetic combination possessed by an individual and the manifestation of this genotype as an observable trait is known as a **phenotype**.
- Homologues: humans possess two copies of each chromosome except for male sex chromosome (one X and one Y)
- Locus: Each gene has a specified location on the chromosome.
- A person will inherit two alleles for all genes since each chromosome comes with a homologues pair.
- Dominant Allele: alleles where only one copy is needed to express the given phenotype
- Recessive: alleles where two copies are needed for phenotype to be expressed
- Homozygous means that both alleles are the same type, heterozygous means that the alleles are different, and hemizygous is when there is only one allele present

Patterns of Dominance

- Complete dominance: one dominant and one recessive allele for specific gene
- Codominance: when more than one dominant allele exists (blood types A & B)
- Incomplete Dominance: heterozygote expresses a phenotype that is intermediate between the two homozygous genotypes

Penetrance & Expressivity

- Penetrance: population measure which is the proportion of individuals in the population carrying the allele who express the phenotype of that allele.
- Expressivity: Varying phenotypes for an identical genotype
    - Can be constant or variable.

Mendelian Concepts

First Law: Law of Segregation

- Genes exist in alternative forms (alleles)
- Organism has two alleles for each gene, one from each parent
- Two alleles segregate during meiosis which results in gametes only having one allele.
- Only one allele will be fully expressed while other will be silent, except for when alleles are codominant or incomplete dominant.

Second Law: Law of Independent Assortment

- Inheritance of one gene does not affect the inheritance of another gene.
- Is due to recombination that occurs during prophase I of meiosis.

DNA as Genetic Material

Was initially thought that protein was the material that genes were inherited through.

- Griffith discovered the **transforming principle**, which was the principle that bacteria were able to acquire genetic material and alter their genomes
- At Rockfeller institute, 3 scientists noticed that if DNA was destroyed, rat would survive even after undergoing transformation principle, but rat would still die if protein was destroyed by an enzyme
    - Proved that genetic material was carried in DNA
- Hershey and Chase discovered that bacteriophages only injected DNA and protein through using radiolabeled sulfur and phosphorus.

Changes in the Gene Pool

Mutations

- A change in the DNA sequence which results in a mutant allele. Can be compared to their **wild-type** counterparts. These counterparts are the alleles which are considered normal or natural in the population
- Mutagens: are substances that can cause mutations (radiation, chemicals)
- Transposons: are elements that can insert and remove themselves from the genome. If inserted in the middle of a coding sequence, gene will be mutated.
- Can also arise during incorrect pairing of nucleotides during transcription/translation.

Nucleotide Level Mutations

- Point Mutations: when one nucleotide in DNA is swapped for another.
    - Silent: change in nucleotide has no effect on the final protein synthesized from the gene. Most commonly occurs when changed nucleotide is the third one because there is a **degeneracy** (wobble) In the genetic code.
    - Missense: Substituting one amino acid for another in the final protein
    - Nonsense: substituting a **stop codon** for an amino acid in the final protein
- Frameshift Mutations: when nucleotides are inserted or removed from the genome.
    - Can change the codon sequencing which would then shift the **reading frame**.

Chromosomal Mutations

Larger scale mutations where large segments of DNA are affected.

- Deletion Mutations: large segment of DNA is lost from a chromosome
- Duplication Mutation: Segment of DNA copied multiple times in the genome
- Inversion Mutations: Segment of DNA reversed in chromosome
- Insertion Mutation: Segment of DNA moved from one chromosome to another.
- Translocation Mutations: Segment of DNA from one chromosome is swapped with a segment of DNA from another chromosome.

Consequences of Mutations

- Can be **advantageous** like heterozygotic sickle cell anemia which prevents malaria and has only minor symptoms
- Can be **deleterious**
    - Inborn errors of metabolism: defects in genes required for metabolism.

Leakage

- The flow of genes between species.

- Can sometimes produce **hybrid** offspring if two species are closely related.
    - Usually cannot reproduce since they have odd number of chromosomes

Genetic Drift

- Changes in the composition of the gene pool due to chance.
- Founder Effect: extreme case where small population of species is in reproductive isolation as a result of natural barriers, catastrophic events or other **bottlenecks** that drastically and suddenly reduce the size of the population available for breeding.
    - **Inbreeding** may occur in later generations which encourages homozygosity which subsequently decreases genetic diversity.
- Loss of genetic variation may cause reduced fitness of the populations which is a condition known as **inbreeding depression**
- **Outbreeding/Outcrossing** is the introduction of unrelated individuals into a breeding group.

Analytical Approaches in Genetics

Punnett Squares

Diagrams that predict the relative genotypic and phenotypic frequencies that will result from the crossing of two individuals. Alleles of two parents are arranged on top and side of squares.

Monohybrid Cross

- **Monohybrid** is a cross in which only one trait is being studied. The **P generation** is the individuals being crossed and the offspring are the **filial generation.**

Test Cross

- Often called back crosses since they are used to determine the genotype of the parent based on the phenotype of its offspring
- Organism with an unknown genotype is crossed with an organism known to be homozygous recessive.

Dihybrid Cross

- Can extend Punnett square to account for two genes instead of one gene if the genes are **unlinked** (Mendel's 2nd law).

Sex-Linked Crosses

- Females have two X chromosomes and thus can be homozygous and heterozygous for a condition on the X chromosome. Males are usually hemizygous for genes carried on X chromosome since there is only one X chromosome.
- Use different notations for these chromosomes: X is for x chromosome and is usually given a subscript if a diseased allele is present. Y is for Y chromosome and rarely carries a sex-linked trait.
    - Heterozygous female means that one of her X chromosomes carries the recessive sex-linked trait
    - Hemophiliac male means that the male expresses the trait
    - Always assume that sex-linked traits are X-linked recessive

Gene Mapping

- The further apart two genes are, the more likely it is that there will be a point of crossing over (**chiasma**) between them.
- Recombination Frequency: likelihood of two alleles being separated from each other during crossing over. This is proportional to the distance between the genes on the chromosome.
    - Tightly linked genes have recombination frequencies close to 0 percent.
    - Weakly linked genes have recombination frequencies approaching 50%.
- A **genetic map** can be constructed using recombination frequencies. This represents the distance between genes on a chromosome
    - Unit of measurement is a **map unit** or **centimorgan** which corresponds to a 1 percent chance of recombination to occur between genes.

Hardy-Weinberg Principle

- Allele Frequency: how often an allele appears in a population. Evolution results from the change in these frequencies in reproducing populations over time
- If frequency is not changing, then evolution is not occurring.
    - Population needs to be very large so that there is no genetic drift.
    - There are no mutations that affect the gene pool
    - Mating between individuals in the population is random
    - There is no migration of individuals into or out of the population
    - The genes in the population are all equally successful at reproducing
- If these above conditions are met, the population is said to be in **Hardy-Weinberg Equilibrium**. Then you can use two equations to predict the allelic and phenotypic frequencies.

Freq of genotypes and phenotypes → $p^2 + 2pq + q^2 = 1$

Freq of alleles → $p + q = 1$

p = frequency of the dominant allele in a population

q = frequency of the recessive allele in a population

- These equations demonstrate that evolution is not occurring since parent allele frequencies go unchanged

Evolution

Natural Selection

- Termed survival of the fittest since it is the theory that certain characteristics or traits possessed by individuals may help them to have greater reproductive success.
    - Organisms produce offspring, few survive to reproductive maturity
    - Chance variation within individuals in a population are heritable, but if they give the organism a higher chance of survival, the variation is deemed **favorable**.
    - **Fitness** is the level of reproductive success. Individuals with more favorable variances are more likely to have a higher fitness

Modern Theories

- Modern Synthesis model or neo-Darwinism: when mutation or recombination results in a change that is favorable to the organism's reproductive success, then that change is more likely to pass on to the next generation.
    - Differential Reproduction: The traits passed on by the more successful organisms will become wide-spread
- Inclusive Fitness: measure of an organism's success in the population. Based on the number of offspring, success in supporting offspring and the ability of the offspring to support others.
    - Different from early descriptions since they were based solely on how many offspring could be created.
    - Promotes the idea that altruistic behavior improves the fitness and success of a species.
- Punctuated Equilibrium: changes in some species occur in rapid bursts rather than evenly over time

Modes of Natural Selection

- Stabilizing Selection: keeps phenotypes within a specific range by selecting against extremes. E.g- fetus weights
- Directional Selection: adaptive pressure leads to the emergence of extreme phenotype. E.g. – bacteria who are resistant to antibiotics
- Disruptive Selection: Two extreme phenotypes selected over the norm. E.g – Darwins birds with small and large beaks
    - Polymorphisms: naturally occurring differences between members of the same population. The driving force of this selection
    - Adaptive Radiation: rapid rise of a number of different species from a common ancestor. Allows for various species to occupy different niches.
        - Favored by environmental changes or isolation of small groups of the ancestral species.

Speciation

- Species: largest group of organisms capable of breeding to form fertile offspring.
- Speciation: formation of a new species through evolution
- Isolation: progeny of two once-similar populations are unable to interbreed.
- Prezygotic mechanisms: prevents the formation of a zygote between two species
    - Temporal isolation, ecological isolation, behavioral isolation, reproductive isolation or gametic isolation
- Postzygotic mechanisms: allows gametes to fuse but offspring is sterile.
    - Hybrid inviability, sterility, hybrid breakdown (first gen is viable but second gen is not)

Patterns of Evolution

- Divergent Evolution: development of different characteristics between two or more lineages sharing the same common ancestor.
- Parallel evolution: related species evolve in similar ways for a long period of time in response to similar environmental selection procedures.

- Convergent Evolution: independent development of similar characteristics in two or more lineages not sharing a recent common ancestor.

Measuring Evolutionary Time

- Rate is measured by the rate of change of a genotype over a period of time and is related to the severity of the evolutionary pressures put on species.
- **Molecular Clock model**: analyzing when two related species split from each other by seeing the correlation between their genomes.