Early Ideas of Heredity

- traits, genetic material transmitted directly from two parents to offspring, “blending” together every generation
- BUT population would become uniform (contrary to everyday and experimental observations)

Modern Genetics

- the gene idea: discrete heritable units (genes) passed on from parents to offspring and retain separate identities
- documented by Gregor Mendel in experiments using garden peas
Gregor Mendel

- b. Czech Republic, 1822
- Augustinian monk
- careful experimentation and applied mathematics to study inheritance in garden pea plants
- laws of inheritance

Mendel and the Garden Pea

- Pea plants present several advantages
  - many varieties
  - distinct heritable features (characters)
  - different variants for each character (traits)
- small and easy to grow
- short generation time
- sexual organs enclosed in flower
- self-fertilization
- cross fertilization

Cross Fertilization

TECHNIQUE

Parental generation (P)
Stamens
Carpel

RESULTS
First filial generation of offspring (F1)
Mendel and the Garden Pea

- Mendel’s experimental design
  - allowed pea plants to self-fertilize for several generations
    - assured pure-breeding (true) traits
  - performed crosses between varieties exhibiting alternative character forms
    - Also used reciprocal crosses
  - permitted hybrid offspring to self-fertilize for several generations

Monohybrid Crosses

- Monohybrid cross - a cross that follows only 2 variations on a single trait (ie- white and purple colored flowers)

- Mendel studied 7 characteristics
  - each with 2 variants
What Mendel Found
• white flower and purple flower cross
  • F₁ Generation (first filial)
    - offspring flower color resembled one parent
      (no intermediate color)
  - all purple flowers
    (dominant trait) and
    none exhibited white
    flowers (recessive trait)

What Mendel Found
• F₂ Generation (second filial)
  • F₁ self-cross produced some
    plants exhibiting white flowers
    (recessive form reappeared)
    • 3:1 phenotypic ratio
      • Mendelian Ratio
        • ¼ of recessives
          always true breeding
        • disguised 1:2:1 ratio
          (geneotypic ratio)

F₂ Generation is a
Disguised 1:2:1 Ratio
• Alternative forms of each character (seed color) were segregating among the progeny

• ALLELES!

• This segregation of traits led Mendel to his understanding of heredity

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Mendel’s observations:

• Plants inherited intact traits (no intermediate appearance)

  - For each pair of alternative forms of a trait, one not expressed in F1 hybrids (latent), but reappeared in some F2 individuals

  - Pairs of trait segregated among progeny of cross (e.g. some flowers white, others purple)

  - Alternative traits expressed in F2 generation in 3:1 ratio (Mendelian ratio)

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Mendel’s Model

• alternative versions of genes account for variation

• for each character, offspring inherits two copies of gene, one from each parent

  • chromosomes, alleles
    • homozygous - same alleles
    • heterozygous - different alleles
Mendel’s Model

- expression of alleles dependent on dominance; only one allele expressed
- alleles for heritable character segregate during gamete formation (law of segregation)

Principle of Segregation

- Mendel’s first law of Heredity
  - The two alleles for a gene segregate during gamete (haploid) formation; rejoin at random, one from each parent, during fertilization
  - 2nd meiotic division produces gametes containing only one homologue for each chromosome
  - blending model would predict pale purple flowers.
  - Instead, F₁ hybrids all have purple flowers.

Using a Punnett Square

- Pp × Pp possible progeny genotype
- Called: monohybrid cross
- Results homozygous dominant or homozygous recessive or heterozygous
- F₁ and F₂ results
Punnett Square = Symbolic Analysis

- Uppercase = dominant allele (P = purple flowers)
- Lowercase = recessive allele (p = white flowers)
  - True breeding purple flowers: genotype = PP
  - True breeding white flowers: genotype = pp
  - Heterozygote (phenotype = purple flowers): genotype = Pp

- PP (homozygous dominant) → can produce only P gametes
- pp (homozygous recessive) → can produce only p gametes
  - Union (PP X pp) can only produce Pp (heterozygous) offspring in F1 generation
    - P dominant, so all have purple flowers

- F1 individuals (Pp) self-fertilize = produce BOTH P and p gametes
  - Visualize F2 possibilities using Punnett square → clearly predicts F2 generation has 3:1 phenotypic ratio = 1:2:1 genotypic ratio
    - 1 PP (purple)
    - 2 Pp (purple)
    - 1 pp (white)
Using a Punnett Square

Pp X Pp possible progeny genotypes
Called: monohybrid cross
Results homozygous dominant or homozygous recessive or heterozygous

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Dominant/Recessive Inheritance

<table>
<thead>
<tr>
<th>Table 12.1</th>
<th>Some Dominant and Recessive Traits in Humans</th>
</tr>
</thead>
<tbody>
<tr>
<td>Character</td>
<td>Phenotype</td>
</tr>
<tr>
<td>Baldness</td>
<td>Tall</td>
</tr>
<tr>
<td>Blue eyes</td>
<td>Blue-eyed</td>
</tr>
<tr>
<td>Collarollars</td>
<td>Collarollars</td>
</tr>
<tr>
<td>Facial hair</td>
<td>Facial hair</td>
</tr>
<tr>
<td>Fingers</td>
<td>Feathery</td>
</tr>
<tr>
<td>Fingerprints</td>
<td>Full prints</td>
</tr>
<tr>
<td>Freckles</td>
<td>Freckled</td>
</tr>
<tr>
<td>Hair color</td>
<td>Brown</td>
</tr>
<tr>
<td>Height</td>
<td>Tall</td>
</tr>
<tr>
<td>Hump</td>
<td>Humped</td>
</tr>
<tr>
<td>Ickles</td>
<td>Icky</td>
</tr>
<tr>
<td>Intelligence</td>
<td>Intelligent</td>
</tr>
<tr>
<td>Intelligence</td>
<td>Prepared</td>
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<tr>
<td>Intelligence</td>
<td>Rapid</td>
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<tr>
<td>Intelligence</td>
<td>Right</td>
</tr>
<tr>
<td>Intelligence</td>
<td>Smart</td>
</tr>
<tr>
<td>Intelligence</td>
<td>Strong</td>
</tr>
<tr>
<td>Intelligence</td>
<td>True</td>
</tr>
</tbody>
</table>

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Principle of Independent Assortment

- Are different traits inherited independently?
- Dihybrid Cross – follows behavior of 2 different characters in a single cross
  - Mendel followed characters of pea shape [round (R) & wrinkled (r)] and color [yellow (Y) vs green (y)]

RrYY X rryy → RrYy (dihybrid; round, yellow seeds)
Dihybrid Cross – Principle of Independent Assortment

- F1 dihybrids self-pollinated (RrYy X RrYy)
  - if alleles transmitted in same combination as parental cross (RY, ry), expect F2 to exhibit parental phenotypes, round yellow (R_Y_) and wrinkled green (rryy) in 3:1

- if traits independent, also expect to see round green (R_yy) and wrinkled yellow (rY_) seeds

Dihybrid Cross – Principle of Independent Assortment

- RrYy X RrYy
  possible gametes produced: RY, Ry, rY, ry

Make Punnett square with these gametes to generate all possible progeny.

4 X 4 square with 16 possible outcomes

- 9 round yellow
  - 3 wrinkled yellow
  - 3 round green
  - 1 wrinkled green

traits that behave independently have 9:3:3:1 phenotypic ratio
What did Mendel Observe?

- 9:3:3:1 phenotypic ratio

- Mendel called this **Independent Assortment (Mendel’s Second Law of Heredity)**
  - Genes that are located on different chromosomes assort independently of one another
  - This does not alter the segregation of individual pairs of alleles for each gene
  - Round vs Wrinkled still at 3:1 phenotypic ratio
  - Yellow vs Green still at 3:1 phenotypic ratio

---

**Mendel’s Laws of Heredity**

**Principle of Segregation** - the two alleles for a gene segregate during gamete (haploid) formation and are rejoined at “random” fertilization

**Independent Assortment**
- Genes that are located on different chromosomes assort independently of one another, one from each parent
Predicting the Result of a Cross: Probability

- 2 events *mutually exclusive* if both cannot happen at same time (i.e. – heads and tails on 1 coin flip)
- But with multiple coin flips, each flip represents an *independent event*.
- Rule of Addition:
  - For two mutually exclusive events, the probability of either event occurring is the sum of the individual probabilities.

Rule of Addition

- Ex- 6 sided die.
  - Probability of rolling each number (1-6) is 1/6; each outcome is mutually exclusive.
  - Probability of rolling either a 2 or a 6:
    \[ \frac{1}{6} + \frac{1}{6} = \frac{2}{6} = \frac{1}{3} \]

- Ex- heterozygous purple flower cross (Pp X Pp)
  - Probability of being heterozygous:
    \[ \frac{1}{4} + \frac{1}{4} = \frac{1}{2} \]

Rule of Multiplication

- States that probability of 2 independent events both occurring is the product of their individual probabilities.
  - Consider F1 progeny (Pp)
  - Probability that an F2 individual will be pp = prob of getting p from male *times* prob of getting p from female = \( \frac{1}{2} \times \frac{1}{2} = \frac{1}{4} \)
  - Basis for Punnett square
Dihybrid Cross Probabilities are Based on Monohybrid Cross Probabilities

- F1 X F1 cross = Pp X Pp
  - 4 possible outcomes, ¾ probability dominant phenotype, ¼ probability recessive phenotype
  - Use this and product rule to predict dihybrid cross outcome
  - Ex: probability of individual with wrinkled green (rryy) seeds in F2 generation = prob of getting wrinkled seeds (1/4) times prob of getting green seeds (1/4), or 1/16.

- Think of dihybrid cross as consisting of 2 monohybrid crosses!

Testcross = Revealing Unknown Genotypes

- Individual with unknown genotype crossed with homozygous recessive genotype.

![Diagram of Testcross]

Testcross

Technique

- Dominant phenotype, unknown genotype: PP or Pp
- Recessive phenotype, known genotype: pp

Predictions

- If purple-flowered parent is PP or Pp
- If purple-flowered parent is pp

Results

- All offspring purple
- ½ offspring purple and ½ offspring white
More on Testcross

- Recessive phenotype in offspring = test individual is heterozygote
- Also use with dominant dihybrids of unknown genotype

<table>
<thead>
<tr>
<th>TABLE 12.2 Dihybrid Testcross</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual Genotype</td>
</tr>
<tr>
<td>-----------------</td>
</tr>
<tr>
<td>A bb</td>
</tr>
<tr>
<td>AaBb</td>
</tr>
<tr>
<td>Aabb</td>
</tr>
<tr>
<td>Aabb</td>
</tr>
</tbody>
</table>

Test cross

- A ?_ B ?_

- a
- a
- b
- b

Extending Mendelian Genetics

- Mendel’s model oversimplified
  - assumed that each trait determined by a single gene, for which only 2 alternative alleles exist
  - alleles not always completely dominant or recessive
  - single gene might have > 2 alleles
  - single gene might produce multiple phenotypes
Extending Mendelian Genetics

- Phenotype considerations
  - Polygenic inheritance
    - More than 1 gene can affect a single trait
    - continuous variation
      - The greater the number of genes influencing a character, the more continuous the expected distribution of character variation will be.

- such characters are called quantitative traits

<table>
<thead>
<tr>
<th>Extending Mendelian Genetics</th>
</tr>
</thead>
<tbody>
<tr>
<td>pleiotropy</td>
</tr>
<tr>
<td>- most genes have multiple phenotypic effects</td>
</tr>
<tr>
<td>- pleiotropic allele may be dominant or recessive for different phenotypes</td>
</tr>
<tr>
<td>- effects are difficult to predict; a gene that affects 1 trait often performs other, unknown functions</td>
</tr>
<tr>
<td>- characteristic of many inherited disorders in humans (cystic fibrosis and sickle cell anemia)</td>
</tr>
<tr>
<td>- multiple symptoms (phenotypes) can be traced to a single gene defect</td>
</tr>
</tbody>
</table>
Dominance not always complete
- **Incomplete dominance** – heterozygote is intermediate in appearance between 2 homozygotes. Indicates neither appearance is dominant
  - When heterozygotes cross, progeny have 1:2:1 phenotypic ratio

**Codominance** – when 2 or more alleles of a gene are each dominant to other alleles but not to each other.
- Distinguished from incomplete dominance by appearance of heterozygote phenotype
- Phenotype of heterozygote for codominant alleles exhibit characteristics of both homozygous forms
- Ex – human blood types
  - Cross between AA individual and BB individual yields AB individuals

**Human ABO Blood Group System**
Different phenotypes of human blood groups based on response of immune system to proteins on surface of RBCs.
- Homozygotes = single type protein found on surface RBCs
- Heterozygotes = 2 types proteins found on surface RBCs, leading to codominance
  - human gene that encodes enzyme that adds sugar molecules to lipids on the surface of red blood cells
  - P adds galactose
  - P⁺ adds galactosamine
  - i adds no sugar
Extending Mendelian Genetics

- Environmental effects
  - degree of allele expression may depend on the environment
  - Not limited to external environment
    - i.e. – the ch allele in Siamese cats encodes heat sensitive version of enzyme tyrosinase (involved in albinism).
    - CH version inactivated at temp above 33C; surface of torso and head above 33C = whitish coat

- Genes may have more than 2 alleles
  - ABO blood types

- Epistasis
  - one gene interferes with the expression of another gene
    - Corn
      - Cross 2 true breeding white corn (lacking purple pigment anthocyanin) and get all purple corn!
      - Reason: 2 genes involved in producing pigment; lead to a modified 9:7 ratio instead of the usual F2 9:3:3:1 ratio

Epistatic Interactions

If the white hairs were due to a recessive allele for a single gene, expect white offspring

Means 2 genes encode for necessary enzyme in pigment production.

Unless both enzymes active
No pigment expressed
Epistatic Interactions Continued

- Epistasis in Labrador Retrievers
  - Coat color in labs due to interaction
  - 2 genes: \( E \) gene determines whether a dark pigment (eumelanin) will be deposited in fur.
  - Genotype \( ee \) = no dark pigment; yellow fur
  - \( EE \) or \( Ee \) a.k.a. \( (E_) \) had dark pigment deposited on fur

- Second gene \( B \), determines how dark pigment will be.
  - \( E_{bb} \) = chocolate lab
  - \( E_{B_}\) = black lab
  - \( ee_{bb} \) = yellow lab with brown nose, lips, eye rims
  - \( ee_{B_} \) = yellow lab with black nose, lips, eye rims

Sex Chromosomes and Sex Determination

Structure and # sex chromosomes vary in different species

In humans, Y chromosome determines “maleness”
- very condensed
Pedigrees
- Cannot perform controlled crosses on humans like plants
  - human inheritance use family histories
    - Pedigree – graphical representation of matings and offspring over multiple generations for a particular trait
- Geneticists can deduce model for mode of inheritance for trait

Dominant Pedigree: Juvenile Glaucoma
- One of most extensive pedigrees – 3 centuries
- Disease causes degeneration of nerve fibers in optic nerve (from eye to brain), leading to blindness.
  Dominant nature of trait obvious; every generation shows trait!

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Key
- Male
- Female
- Affected male
- Affected female
- Mating
- Offspring

1st generation
- Male
- Female
- Affected
- Mating
- Offspring

2nd generation
- Male
- Female
- Affected
- Mating
- Offspring

3rd generation
- Male
- Female
- Affected
- Mating
- Offspring

(x) Is a widow's peak a dominant or recessive trait?
(b) Is an attached earlobe a dominant or recessive trait?
Recessive Pedigree: Albinism

- Pigment melanin not produced
  - Multiple genes involved
  - Common feature = loss pigment from hair, skin, and eyes → sensitive to sun

- One example – due to nonfunctional allele of enzyme tyrosinase, required for formation of melanin pigment (tanning)
  - Female and males affected equally

Recessive Pedigree: Albinism

- Characteristics
  - Most affected individuals have unaffected parents
  - Single affected parent usually does not have affected offspring

  - Affected offspring are more frequent when parents related