Non-Mendelian Modes of Inheritance

Multiple Allelic Inheritance

Multiple allelic inheritance is a type of inheritance where **a single gene** has **more than two possible versions** (*alleles*) in the **entire population**.
However, every person still inherits only **two alleles**—one from their **mother**, one from their **father**—because each person has two copies of every gene (one on each chromosome of a pair).

This type of inheritance allows for **more combinations** and **greater variation** in how traits appear among individuals. It is different from simple inheritance, where a gene usually has just two options: one dominant and one recessive.

How Alleles Are Inherited

Each person gets **two alleles** for every gene:

- One from the **mother** (egg)
- One from the **father** (sperm)

These two alleles form the person's **genotype**.
Depending on which alleles a person inherits, a certain version of the trait is shown as their **phenotype** (what is seen).

In multiple allelic systems, although the population may have **three or more alleles** for a gene, any **single individual** can only have **two** of them at a time.

Why Populations Have Multiple Alleles

Over time, **mutations** in genes can lead to the creation of new alleles. These mutations are passed on if they are not harmful. When people live in different environments or stay in isolated groups, **certain alleles become more common** in some regions and **less common** in others.

Processes such as:

- **Genetic drift** (random changes in gene frequency)
- **Natural selection**
- **Founder effect** (small groups starting a new population)
- **Migration and mixing of populations**

...all play a role in maintaining **many different alleles** in the population.

Key Example: ABO Blood Group System

One of the best-known examples of multiple allelic inheritance is the **ABO blood group system** in humans.

The Gene and Its Alleles

- The ABO blood group is controlled by **one gene** called **I (for isoagglutinogen)** on chromosome 9.
- This gene has **three alleles**:
    - **IA** → Produces **A antigen** on red blood cells
    - **IB** → Produces **B antigen**
    - **i** → Produces **no antigen**

Inheritance and Blood Types

Each person inherits **two alleles**. Depending on the combination, the blood type is determined:

Genotype	Blood Type	What's on Red Blood Cells
IAIA or IAi	A	A antigen
IBIB or IBi	B	B antigen
IAIB	AB	Both A and B antigens
ii	O	No antigens

Real-World Population Variation

The ABO alleles are **not evenly distributed** across all human populations:

- **O group**: Very common among **Native American** populations (up to 100% in some tribes).
- **B group**: More common in **South Asia**, **Central Asia**, and **northeastern China**.
- **A group**: Frequently found in **Northern and Central Europe** (e.g., Germany, Scandinavia).

Polygenic Inheritance

Polygenic inheritance refers to the inheritance of traits that are controlled by **multiple genes**, each making a small and often additive contribution to the **final observable trait** (called the phenotype). These are often **quantitative traits**—they don't appear in clear-cut categories like "tall" or "short", but instead vary across a continuous range, such as **blood pressure, intelligence, or facial morphology**.

Unlike single-gene (Mendelian) traits, polygenic traits are shaped by **the cumulative effect of many genes**, and they are also **influenced by environmental factors**, making them complex and variable within populations.

Key Characteristics of Polygenic Traits

1. Multiple Genes Control the Trait

- Polygenic traits are influenced by **many different genes**, often spread across different chromosomes.
- Each gene has **two or more alleles**, and each allele adds a small effect.
- No single gene dominates in determining the trait. Instead, **all genes contribute a bit** to the overall outcome.

2. Additive Effect of Alleles

- Each contributing allele adds a small **quantitative increase or decrease** in the trait.
- The more contributing alleles a person has, the more the trait is expressed.
- There is usually **no complete dominance or recessiveness**; instead, allele effects accumulate.
- For example, in a trait governed by five genes, a person can have **0 to 10 contributing alleles**, forming a spectrum of phenotypes.

3. Continuous Variation

- Polygenic traits show **a range of variation**, forming a **bell-shaped curve** or **normal distribution**.
- Most people fall around the **average or middle values**, while very high or very low values are rare.
- This variation is seen in traits like **IQ**, **cholesterol levels**, or **reaction time**.

4. Influenced by the Environment

- Polygenic traits are **multifactorial**: both genes and the environment affect their development.
- Even with the same genotype, **different environments can lead to different phenotypes**.
- For instance, people with a genetic tendency for high intelligence may not reach their potential if deprived of education, nutrition, or stimulation.

Mechanism: How Polygenic Inheritance Works

Example Model: Let's imagine a trait like **blood cholesterol level** is influenced by **three genes**, each with two alleles:

- Gene A: A (contributes to higher cholesterol), a (neutral)

- Gene B: B (contributes to higher cholesterol), b (neutral)
- Gene C: C (contributes to higher cholesterol), c (neutral)

A person's genotype might be:

- AABBCC (6 contributing alleles) → **Very high cholesterol**
- AaBbCc (3 contributing alleles) → **Moderate cholesterol**
- aabbcc (0 contributing alleles) → **Low cholesterol**

Thus, **the more contributing alleles** a person has, the higher the trait expression. This explains why traits like cholesterol or blood pressure vary **gradually** across a population rather than appearing in distinct categories.

Example: Intelligence (Cognitive Ability)

- Involves **hundreds of genes**, each contributing a small effect on aspects like memory, reasoning, and processing speed.
- Important genes include **CHRM2, NPTN, and FOXP2**, among many others.
- **Twin and family studies** show strong heritability, but expression is deeply influenced by:
    - Early childhood stimulation
    - Education access
    - Nutrition and health

Case Study: A longitudinal study in the UK (ALSPAC cohort) showed that **children with high genetic potential for cognitive performance scored very differently depending on parental income and educational support**, proving that environment plays a critical role in polygenic traits.

Multifactorial Inheritance

Multifactorial inheritance refers to the inheritance of traits that are controlled by a combination of **multiple genes** and **environmental influences**. These traits do **not follow classic Mendelian rules** (like dominant or recessive), and they usually show **continuous variation** in the population—such as height or skin colour—rather than existing in clear-cut categories.

What Does "Multifactorial" Mean?

- **"Multi"** means *many*
- **"Factorial"** refers to *factors*, both **genetic** and **environmental**

So, a **multifactorial trait** is one that results from the **interaction of numerous genes** and **external influences** like nutrition, climate, lifestyle, or exposure to sunlight.

How Multifactorial Inheritance Works

1. Many Genes Contribute Small, Additive Effects

- Traits like **height** and **skin colour** are not determined by a single gene.
- Instead, **dozens or even hundreds of genes** may each contribute a **small amount** to the overall trait.
- These effects are often **additive—**the more "height-increasing" or "melanin-increasing" gene variants you inherit, the taller or darker-skinned you are likely to be.

2. Environmental Factors Influence the Outcome

- Genetic potential does not act alone.
- The **environment modulates** how much of a gene's potential is expressed.
- For example:
  - Nutritional deficiencies during growth years may prevent a child from reaching their genetically determined height.
  - Degree of sunlight exposure can significantly affect actual skin colour due to melanin production.

3. Threshold Effect in Some Traits

- Though traits like height and skin colour are **gradual**, some multifactorial traits show a **threshold effect—**the trait appears only when combined genetic and environmental factors pass a certain limit.
- In the case of **height**, a child may carry many tallness genes but will not reach tall stature without adequate nutrition.

Example 1: Stature (Height)

Genes Involved:

- Height is influenced by **over 700 known genetic loci**, including those regulating **bone growth, growth hormone production, metabolism**, and **skeletal development**.
- Each gene may contribute a very **small fraction (often less than 0.5 cm)** to final height.

Environmental Influences:

- **Nutrition** (protein, calcium, vitamins)
- **Prenatal health**
- **Childhood illness**
- **Socioeconomic status**

- **Physical activity**

Example 2: Skin Colour

Genes Involved:

- Skin pigmentation is determined by **polygenes** affecting the **production, type, and distribution of melanin**.
- Major genes include **MC1R, SLC24A5, OCA2**, and others.
- These genes influence whether skin is rich in **eumelanin** (dark pigment) or **pheomelanin** (light pigment).

Environmental Influences:

- **Sunlight exposure (UV radiation)**
- **Latitude and climate**
- **Cultural practices** (e.g., clothing, outdoor work)
- **Nutritional factors** (like vitamin D synthesis)

PYQ Insights

1. Polygenic Inheritance

PYQ Gist: *"Which of the following is a polygenic trait?"*
(Options: Skin colour, ABO blood group, Sickle cell trait, Huntington's disease)

2. Multifactorial (Complex) Inheritance

PYQ Gist: *"Which trait shows multifactorial inheritance?"*
(Options: Intelligence, Blood group, Haemophilia, Muscular dystrophy)

3. Human Stature

PYQ Gist: *"Human height is best described as a trait that is:"*
(Options: Polygenic, Monogenic, Mitochondrial, Sex-limited)

4. Skin Colour

PYQ Gist: *"Which of the following is controlled by multiple genes and shows environmental influence?"*
(Options: Skin pigmentation, Eye colour, Blood group, Sickle cell anemia)