Inheritance
Inheritance

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- What is variation?
- Genes and alleles
- Patterns of inheritance
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- Summary activities
The population of the Earth is more than 6 billion people, and no two individuals (apart from identical twins) are genetically the same. Why?

People are different because they inherit different characteristics (or traits) from their parents.

Like all babies, this child carries a unique set of genes; half from his mother and half from his father.

A person’s unique characteristics are caused by:

- the set of **genes** they inherited from their parents (nature)
- the **environment** in which they developed (nurture).
Inherited and acquired characteristics

Some characteristics, such as eye colour and earlobe shape, are only determined by genes. These are called **inherited characteristics**.

Other types of characteristics, such as scars and hair length, are not inherited but depend on environmental factors. These are called **acquired characteristics**.

Differences in some characteristics are due to a combination of **both** inherited and environmental factors. In some cases, it can be difficult to say how much influence each factor has.
**Nature, nurture or both?**

What has caused variation in each of these characteristics?

<table>
<thead>
<tr>
<th>genes</th>
<th>environment</th>
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<tr>
<td></td>
<td>vegetarianism</td>
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<td>mass</td>
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<td>fingerprints</td>
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<td></td>
<td>blood group</td>
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<td>skin colour</td>
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<td>ear-lobe shape</td>
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</table>
The overall appearance of an organism depends on two things:

1. its genes (inherited characteristics)
2. the effects of the environment in which it lives.

All the observable characteristics of an organism are called its phenotype.

The full set of genes of an organism is called its genotype.

An organism’s phenotype therefore depends on its genotype plus environmental effects.

**phenotype = genotype + environmental effects**
Characteristics can be classified in different ways. How would you categorize variation in eye colour? Could height be categorized in the same way?

- A feature that can be measured and given a value from a range of values shows **continuous variation**.

- A feature that cannot be measured but is one of a few distinct options shows **discontinuous variation**.

Which type of variation are eye colour and height?
What is continuous variation?

Characteristics that show continuous variation cannot easily be placed into individual categories. They vary over a continuous range of values.

Continuous variation is caused by the combined effects of genes and the environment.

Examples of continuous variation include height, mass, skin colour, intelligence and leaf area.

Are characteristics that show continuous variation fixed, or can they change?
What is discontinuous variation?

Characteristics that show discontinuous variation can be placed into distinct categories – the organism either has a specific characteristic, or it does not.

Discontinuous variation is usually controlled by a small number of genes. The environment has little or no effect.

Examples of discontinuous variation include blood group and eye colour.

Are characteristics that show discontinuous variation fixed, or can they change?
What type of variation do these statements relate to?

- continuous
- discontinuous

an example is eye colour
Environmental causes of variation

The effects of the environment in which an organism lives can cause significant variation between individuals.

Plants are affected by water, sunlight, temperature and the availability of nutrients.

When these factors are plentiful the plants thrive. When these factors are scarce the plants wither.

Animals are similarly affected by water and nutrients.
Observing variation in humans

As well as environmental factors such as climate and diet, humans are affected by education, culture and lifestyle.

Because these factors change our phenotype, the effects of many environmental factors can be clearly seen.

Scientists often use identical twins to study the effects of environmental factors. Although the twins are genetically identical, each one will have been shaped differently by their environment and experiences.

For example, a bad diet may cause one twin to be larger and less healthy than the other twin.
Genetic causes of variation

Sexual reproduction is the most important cause of genetic variation because it mixes up genetic material.

How does it do this?

- During meiosis, homologous chromosomes exchange genetic material. They then line up and separate in different ways, producing a large variety of different gametes.

- At fertilization, any male gamete can combine with any female gamete.

All these events occur randomly and create new combinations of genetic material.
Mutation and genetic variation

Mutation is the change in the type or amount of DNA and is therefore another cause of genetic variation.

Mutations can arise spontaneously; for example, through the incorrect copying of base pairs during DNA replication, or the unequal distribution of chromosomes during cell division.

Mutations can also be caused by environmental factors, such as radiation and certain chemicals. These factors are called **mutagens**.

Some mutations may be beneficial, but many are harmful and increase the risk of diseases such as cancer.
<table>
<thead>
<tr>
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<th>True or false?</th>
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<tbody>
<tr>
<td>1.</td>
<td>A person's unique characteristics are caused by their genes and the environment in which they developed.</td>
</tr>
<tr>
<td>2.</td>
<td>Eye colour and earlobe shape are acquired characteristics.</td>
</tr>
<tr>
<td>3.</td>
<td>The full set of genes of an organism is called its phenotype.</td>
</tr>
<tr>
<td>4.</td>
<td>All the observable characteristics of an organism are called its genotype.</td>
</tr>
<tr>
<td>5.</td>
<td>A feature that can be measured and given a value from a range of values shows continuous variation.</td>
</tr>
<tr>
<td>6.</td>
<td>A feature that cannot be measured but is one of a few distinct options shows discontinuous variation.</td>
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</table>
Family resemblance

Members of the same family often look similar.

Which parent do these children look more like?

If the son and daughter have children of their own one day, will they also look like their parents?

Why do members of the same family look similar?

Humans, like all organisms, inherit characteristics from their parents. How are characteristics passed on?
Chromosomes in a homologous pair contain the same type of genes that code for the same characteristics, such as eye colour.

Each chromosome in the pair, however, may have a different version of the gene.

For example, the version of a gene on one chromosome may code for brown eyes, whereas the version of the gene on the other chromosome may code for blue eyes.

Each different version of a gene is called an allele.
Homozygous alleles

If the alleles for a characteristic in a homologous pair are the same, the organism is said to be **homozygous** for that characteristic.

What colour eyes will these homozygous pairs of alleles produce?

- allele for brown eyes
- allele for brown eyes
- allele for blue eyes
- allele for blue eyes

[Diagram of alleles and eye colors]
Heterozygous alleles

If the alleles for a characteristic in a homologous pair are different, the organism is said to be **heterozygous** for that characteristic.

What colour eyes will this heterozygous pair of alleles produce?

The characteristic expressed by heterozygous alleles will depend on which allele is **dominant** and which allele is **recessive**.
Dominant or recessive?

The phenotype for a particular characteristic depends on which allele is dominant and which allele is recessive.

- **Dominant** alleles are always expressed in a cell’s phenotype. Only one copy of the dominant allele needs to be inherited in order for it to be expressed. Dominant alleles (e.g. brown eyes) are represented by an upper case letter (e.g. ‘B’).

- **Recessive** alleles are only expressed in a cell’s phenotype if two copies of it are present. If only one copy is present, its effect is ‘masked’ by the dominant allele. Recessive alleles (e.g. blue eyes) are represented by a lower case letter (e.g. ‘b’).
What eye colour?

The allele for **brown** eyes is dominant over the allele for **blue** eyes.

So, what colour will the eyes be of an individual who is heterozygous for eye colour?

The individual will have **brown** eyes, because the allele for brown eyes masks the allele for **blue** eyes.
Inheritance terms

Match the term to its description

- **allele**: An allele that is only expressed if two versions of it are present in a cell.
- **homozygous**: Having two different alleles of a specific gene.
- **heterozygous**: One of two or more versions of a gene, found at a specific location on a chromosome.
- **dominant**: An allele that is always expressed, even if the cell only contains one copy.
- **recessive**: Having two identical alleles of a specific gene.
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Homozygous cross

Eye colour in the offspring of homozygous parents

The allele for brown eyes (B) is dominant over the allele for blue eyes (b).

If a homozygous brown-eyed person and a homozygous blue-eyed person reproduce, what are the possible eye colours of their offspring?

Click "start" to find out.
Eye colour in the offspring of heterozygous parents

The allele for brown eyes (B) is dominant over the allele for blue eyes (b).

If two F1 heterozygous brown-eyed parents reproduce, what are the possible eye colours of their offspring?

Click "start" to find out.
Finding the genotype

For some characteristics, the genotype of a homozygous recessive individual can be determined from their phenotype.

For example, the allele for brown fur (B) in mice is dominant over the allele for white fur (w). This means that all white mice must therefore have the genotype ww.

But what about individuals that have brown fur? Is their genotype BB or Bw?

A test cross can be used to determine whether an individual is homozygous or heterozygous for a dominant trait.
What is a test cross?

During a test cross, an individual with an unknown genotype is crossed with a homozygous recessive individual. The phenotype of the offspring will reveal the unknown genotype.

- If all the offspring display the dominant phenotype, then the parent of unknown genotype must be homozygous for the characteristic.

- If half the offspring show the dominant phenotype, and half show the recessive phenotype, then the parent must be heterozygous for the characteristic.
Using test crosses to find out genotype

The allele for brown fur (B) in mice is dominant over the allele for white fur (w).

The genotype of a white mouse is always WW, but the genotype of a brown mouse can be unknown.

Click "start" to find out how a test cross can determine the genotype of the brown mouse.
What is incomplete dominance?

Sometimes two different alleles are neither fully dominant or recessive to each other.

In heterozygous individuals, this creates a phenotype that is an intermediate mix of the other two. This is called incomplete dominance.

For example, when a red *Mirabilis jalapa* plant (also called the snapdragon or ‘Four o'clock flower’) is crossed with a white *Mirabilis jalapa* plant, all the offspring flowers are pink because both the red and white alleles are expressed.
What is co-dominance?

The human ABO blood group system is controlled by three alleles: A, B and o. A and B are dominant while o is recessive.

In heterozygous individuals who have both A and B alleles, both are fully expressed, creating an extra phenotype.

This is called co-dominance.

What is the pattern of inheritance of the ABO blood system?
Co-dominance in humans

Blood groups in the offspring of heterozygous parents

Humans have four different types of blood group, which are controlled by just three alleles ($A$, $B$ and $O$).

If a person who is heterozygous for blood group $A$ reproduces with someone who is heterozygous for blood group $B$, what are the possible blood groups of their offspring?

Click "start" to find out.
What are sex chromosomes?

Humans cells contain one pair of **sex chromosomes**, which control gender.

- Males have one **X** and one **Y** chromosome (**XY**).
- Females have two **X** chromosomes (**XX**).

**Y** chromosomes are very small and contain 78 genes, whereas **X** chromosomes are larger and contain a 900–1,200 genes.

Because females can only produce **X** gametes, it is the sperm that determine the sex of the offspring at fertilization.
How is sex inherited?

The combination of sex chromosomes that a baby inherits will determine whether it will develop into a boy or a girl.

Click "play" to find out more.
Gregor Johann Mendel (1822–1884) was an Austrian monk who closely studied the patterns of inheritance in pea plants.

Click "start" to find out more about Mendel, and how his discoveries lead to our understanding of modern genetics.
Mendel’s experiments

Over seven years, Mendel experimented on more than 28,000 pea plants! Why were his experiments so successful?

- Pea plants grow quickly.
- Pea plants are available in pure-breeding (homozygous) strains.
- Many pea plant characteristics show discontinuous variation; they are either one form or another, with no intermediates. This means that their phenotypes are easily distinguishable.
Mendel's early experiments

Experiment 1: Cross-pollination
First, Mendel cross-pollinated a homozygous (pure-bred) smooth pea plant and a homozygous wrinkly pea plant.

What type of peas were produced by this cross?
Monohybrid crosses

The type of experiment that Mendel carried out, investigating just a single characteristic, is called a **monohybrid cross**.

There are two alleles controlling pea shape. This means there are **three** possible genotypes that the F2 generation of plants could inherit, leading to **two** possible phenotypes.

<table>
<thead>
<tr>
<th>Genotype</th>
<th>Phenotype</th>
</tr>
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<tbody>
<tr>
<td>homozygous dominant</td>
<td>SS</td>
</tr>
<tr>
<td>homozygous recessive</td>
<td>ww</td>
</tr>
<tr>
<td>heterozygous</td>
<td>Sw</td>
</tr>
</tbody>
</table>

The likelihood of a trait being produced during a monohybrid cross can be mapped out using a **Punnett Square**.
What are Punnett Squares?

What do Punnett Squares show?

Punnett Squares show each of the possible outcomes of a monohybrid cross.

Click "play" to find out how Punnett Squares explain the 3:1 ratio of smooth to wrinkly peas.

smooth  x  wrinkly
Mendel’s laws of inheritance

After his research, Mendel proposed two laws of inheritance.

**Mendel’s first law: the law of segregation**

- Alternate versions of genes (alleles) cause variation in inherited characteristics.
- An organism inherits two alleles for each characteristic – one from each parent.
- Dominant alleles will always mask recessive alleles.
- The two alleles for each characteristic separate during gamete production.

**Mendel’s second law: the law of independent assortment**

- Genes for different characteristics are sorted independently during gamete production.
• **acquired** – A characteristic of an organism that depends on environmental factors.

• **allele** – One version of a gene, found at a specific location along a chromosome.

• **carrier** – An individual with a recessive allele, whose effect is masked by a dominant allele.

• **characteristic** – A specific feature of an organism, such as eye colour.

• **co-dominance** – A situation where two alleles are equally dominant.

• **continuous** – Variation represented by a continuous range of values and which can be measured.
discontinuous – Variation represented by discrete categories.

dominant – An allele that is always expressed, even if the cell only contains one copy.

gene – The unit of inheritance.

genotype – The full set of genes of an organism.

eheterozygous – Having two different alleles of a specific gene.

homologous chromosomes – A matched pair of chromosomes that carry genes for the same characteristics.

homozygous – Having two identical alleles of a specific gene.
- **incomplete dominance** – A situation where two alleles are both partially expressed, producing an intermediate phenotype.

- **inherited** – A characteristic of an organism that depends on its genes.

- **monohybrid cross** – A cross in which one pair of characteristics is studied.

- **phenotype** – All the observable characteristics of an organism.

- **recessive** – An allele that is only expressed if two versions of it are present in a cell.
- **test cross** – A situation where an individual with an unknown genotype is bred with a homozygous recessive individual to reveal the unknown genotype.

- **variation** – The difference between individuals within a population.
Anagrams

How quickly can you unscramble anagrams of words about inheritance?

start
How dominant is your knowledge of inheritance?

start