

Natural selection and genetic modification revision notes

This topic explains how populations change over time by natural selection, and the evidence for evolution, including human evolution. It then covers the ways humans change organisms for their own use: selective breeding, tissue culture and genetic engineering.

For Edexcel GCSE Biology 1BI0 and Combined Science 1SC0. **Triple only** is not in Combined Science. **Higher tier** is only on the Higher paper.

1 Darwin, natural selection and antibiotic resistance Spec 4.1B-4.3

The work of Darwin and Wallace Spec 4.1B Triple only

The theory of **evolution by natural selection** was developed by two scientists working separately: Charles Darwin and Alfred Wallace.

Charles Darwin

- Darwin collected observations and specimens on a long sea voyage, including studying plants and animals in different places.
- He noticed that individuals of the same species show variation, and that organisms in different places are suited to their different environments.
- He spent many years collecting evidence and developing his ideas before publishing them in his book *On the Origin of Species* in 1859.

Alfred Wallace

- Wallace independently developed a very similar theory of evolution by natural selection.
- His ideas were based on his own observations and collections of plants and animals in different parts of the world.
- His work encouraged Darwin to publish, and the two men's ideas were presented together.

Impact on modern biology

- Natural selection gave a **unifying explanation** for the huge diversity of living things and how species are related.
- When combined with later knowledge of genes, it explains how **variation** arises (through mutation) and how characteristics are inherited.
- It helps us understand the emergence of resistant organisms, such as antibiotic-resistant bacteria.
- It supports the idea that living things can be classified according to how they are related.

Exam tip: If asked about Wallace, say he developed the theory independently of Darwin. Do not say he copied or helped Darwin write the book.

Evolution by natural selection Spec 4.2

Evolution is a change in the inherited characteristics of a population over many generations. Darwin explained how it happens using natural selection.

1. Individuals in a population show **variation**. Some of this is genetic, caused by differences in alleles, which arise by **mutation**.

2. More offspring are born than can survive, so individuals **compete** for resources such as food, space and mates, and some are eaten or die of disease.
3. Individuals with characteristics that suit their environment are more likely to **survive and reproduce**.
4. They **pass on the alleles** for those characteristics to their offspring.
5. Over many generations, the proportion of the population with the advantageous alleles increases.

Individuals with a characteristic that gives an advantage are sometimes described as the 'fittest'. This means best suited to their environment, not strongest.

Natural selection	The process by which organisms better adapted to their environment are more likely to survive, reproduce and pass on their alleles.
Evolution	A change in the inherited characteristics of a population over many generations.

Common mistake: Individuals do not change during their lives to cope with their environment. The advantageous allele has to be there already, and the proportion of individuals with it increases over generations.

Exam tip: Write the full chain in your answer: variation (from mutation), survival and reproduction of the better adapted, alleles passed on, proportion increases.

Resistant organisms and antibiotic resistance Spec 4.3

The emergence of **resistant organisms** is an example of natural selection that can be seen happening within a human lifetime. Bacteria reproduce very quickly, so changes in a population happen fast.

1. In a population of bacteria, a **mutation** produces an allele that makes one bacterium resistant to an antibiotic. This is variation.
2. The antibiotic is used. It kills the non-resistant bacteria, but the resistant bacterium survives. The antibiotic is the **selection pressure**.
3. The resistant bacterium reproduces with less competition, and passes the resistance allele on to its offspring.
4. Over time the population is mostly resistant bacteria, so the antibiotic no longer works against the infection.

This supports Darwin's theory because all the steps of natural selection can be observed: variation, a selection pressure, survival and reproduction of the better adapted, and inheritance of the useful allele.

Percentage of resistant bacteria (practice data)

In a lab, 300 bacteria were sampled before treatment and 12 were resistant to an antibiotic. After several rounds of treatment, 300 bacteria were sampled again and 192 were resistant. Calculate the percentage resistant at each time, and the change.

1. Before: $12 \div 300 \times 100 = 4\%$
2. After: $192 \div 300 \times 100 = 64\%$
3. Change: $64 - 4 = 60$ percentage points

Answer: 4% before, 64% after, an increase of 60 percentage points.

Maths skill: You may be asked to plot such data as a bar chart or line graph. Choose scales that use at least half the grid, label both axes with units, and plot the independent variable (time or treatment) on the x-axis.

Common mistake: Antibiotics do not cause the mutation, and bacteria do not 'get used to' antibiotics. The resistant bacteria were there by chance and are selected by the antibiotic.

Quick check

- 1 . What causes new alleles to appear in a population?
- 2 . Give the four main steps of natural selection in order.
- 3 . In antibiotic resistance, what is the selection pressure?
- 4 . Why do populations of bacteria change quickly?

2 Evidence for evolution and classification Spec 4.4-4.7

Fossil evidence for human evolution Spec 4.4

Fossils are the preserved remains or traces of organisms that lived long ago. By comparing fossils of different ages, scientists can see how early human ancestors changed over time. You need to know three important discoveries.

Fossil evidence for human evolution		
Fossil	Age	What it shows
Ardi	4.4 million years ago	Partial skeleton. A small brain and long arms. Could walk upright, but had a grasping big toe so could still climb trees.
Lucy	3.2 million years ago	Partial skeleton. Walked upright on two legs, with feet more like a human's, but still a small brain and some ape-like features.
Fossils found by Richard Leakey and his team	1.6 million years ago	Many fossils, including a nearly complete skeleton. A larger brain, longer legs and a body shape much more like a modern human.

Taken together, the fossils show a gradual change from ape-like ancestors towards modern humans. Walking upright came first, and larger brains came later.

The evidence has limits. Fossils are rare because most dead organisms decay before fossilising, and many fossils are incomplete. This is why scientists sometimes disagree, and why new discoveries can change ideas about human evolution.

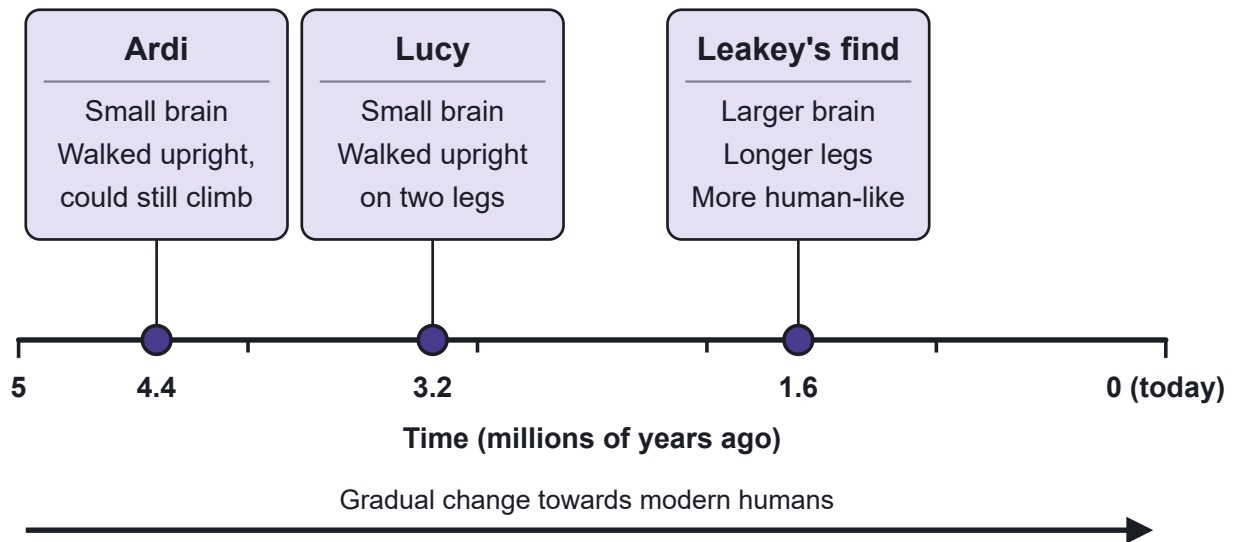
Working with large time spans

Ardi lived 4.4 million years ago and Lucy lived 3.2 million years ago. Write 4.4 million in standard form, and find how many years separate the two fossils.

1. $4.4 \text{ million} = 4\,400\,000 = 4.4 \times 10^6 \text{ years}$
2. $\text{Difference} = 4.4 - 3.2 = 1.2 \text{ million years}$
3. $1.2 \text{ million} = 1.2 \times 10^6 \text{ years}$

Answer: 4.4×10^6 years; the fossils are 1.2×10^6 years apart.

Exam tip: Learn the order, oldest first: Ardi (4.4), Lucy (3.2), Leakey's discovery (1.6). Questions often ask which is oldest or most like a modern human.



Oldest first: Ardi, Lucy, then Leakey's find. Walking upright came first; larger brains came later.

Stone tools Spec 4.5

Early humans made tools from stone. Stone tools survive for a very long time, so they give evidence about how early humans lived and how their skills developed.

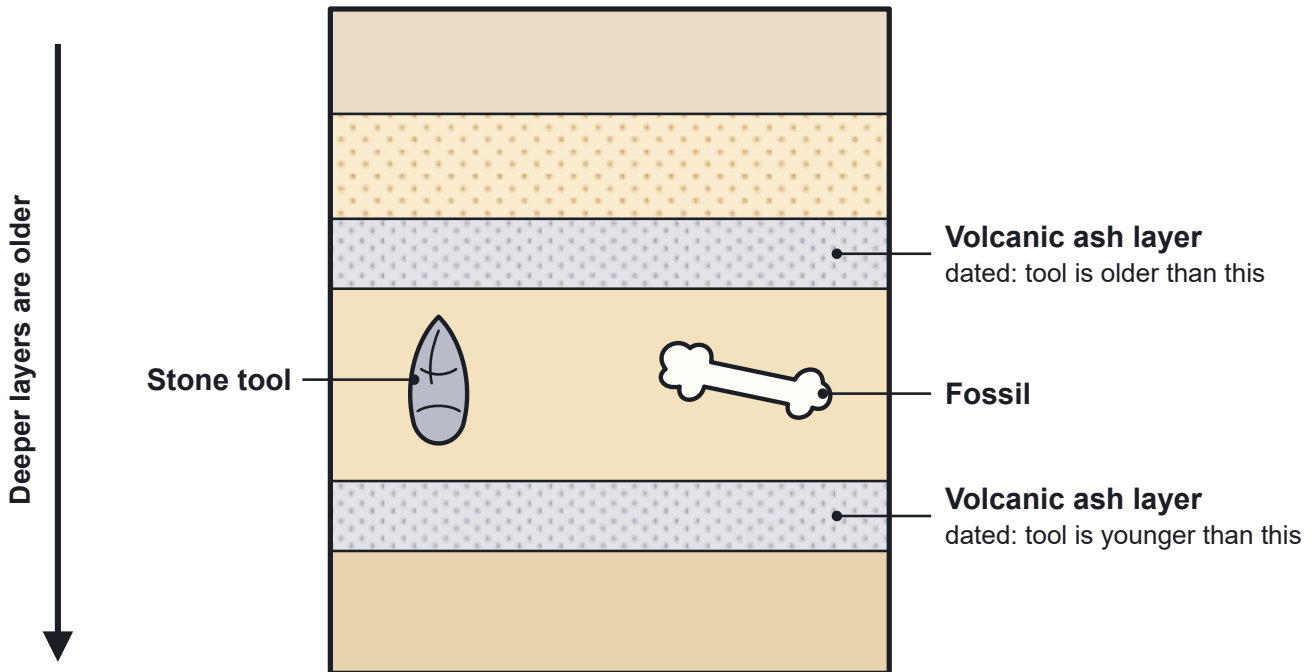
Development of stone tools over time

- The oldest tools are very simple, such as stones with a few chips knocked off to make a sharp edge.
- Over time tools became more **complex and better made**: more carefully shaped and more specialised for different jobs.
- This suggests that early humans developed greater skill and intelligence, which fits with fossil evidence of larger brains.

Dating stone tools

Scientists can date stone tools from their **environment**. A tool is found in a layer of rock or sediment. The age of that layer, or of materials found with the tool such as volcanic ash, can be worked out. The tool is then taken to be about the same age as the layer it was found in. Layers are laid down one on top of another, so deeper layers are usually older.

Exam tip: For 'how are tools dated', refer to the layer or materials around the tool, not to the tool itself.



The tool is dated from its **environment**: it must be younger than the ash below it and older than the ash above it.

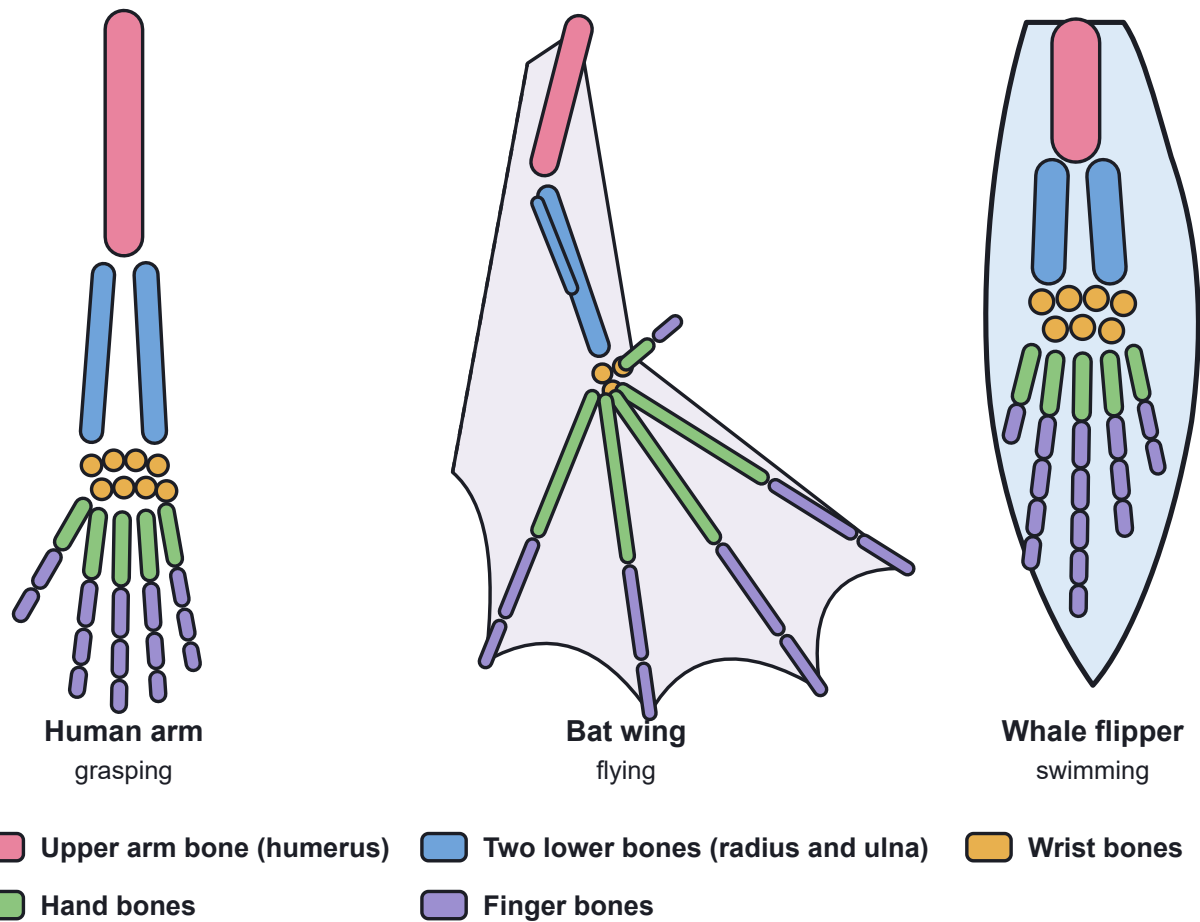
The pentadactyl limb Spec 4.6B Triple only

The **pentadactyl limb** is a limb with five digits. The same basic pattern of bones is found in the limbs of many vertebrates, including humans, bats, whales and frogs.

Although these limbs do different jobs (grasping, flying, swimming, jumping), they have the **same basic arrangement of bones**: one upper bone, two lower bones, then wrist, hand and finger bones. The size and shape of the bones differ to suit each function.

This provides evidence for evolution. The similar bone structure suggests the animals share a **common ancestor**, and natural selection has adapted the limb to different ways of life over time. If each animal had evolved separately, there would be no reason for the same bone pattern.

Exam tip: Use the two ideas together: same structure suggests a common ancestor; different functions are due to adaptation by natural selection.



Same **basic arrangement of bones**, different shapes for grasping, flying and swimming: evidence of a common ancestor.

Five kingdoms and three domains Spec 4.7

Living things were traditionally sorted into **five kingdoms**: animals, plants, fungi, protists and prokaryotes. This was based on the structure and features of organisms that could be observed.

Improved methods of **genetic analysis** (comparing the genetic material of different organisms) showed that the prokaryotes are not all closely related. This led to a new system of **three domains**, which sits above the kingdoms.

The three domains	
Domain	Organisms
Archaea	Prokaryotes that are genetically very different from bacteria
Bacteria	'True' bacteria (prokaryotes)
Eukarya	Organisms with a nucleus: protists, fungi, plants and animals

Exam tip: Explain the change using the key idea: genetic analysis revealed differences that observation of structure could not, so the prokaryotes were split into two domains.

Quick check

- 1 . Which is older, Ardi or Lucy?
- 2 . How are stone tools dated from their environment?
- 3 . Name the five kingdoms.
- 4 . What are the three domains?

3 Selective breeding and tissue culture Spec 4.8-4.9B

Selective breeding Spec 4.8

Selective breeding is when humans choose which organisms to breed so that the desired characteristics are passed on to the next generation. It has been used for thousands of years.

1. Decide which characteristic is wanted, for example high milk yield or disease resistance.
2. Choose parents that show the characteristic most strongly and breed them together.
3. From the offspring, select those with the characteristic and breed them together.
4. Repeat over many **generations** until the desired characteristic is strongly shown.

Examples of selective breeding

Organism type	Characteristics selected for
Food plants (crops)	Disease resistance, larger fruit or grains, better taste, higher yield
Domesticated animals	More milk, more meat, more eggs, a gentle nature, wool quality

Impact of selective breeding

- Food plants and animals give **higher yields**, so more food can be produced from the same land.
- Crops can be bred to resist disease, so less is lost.
- Breeding from only a few individuals reduces **genetic variation** in the population. If a new disease or a change in the environment appears, all individuals may be affected, and the population could die out.
- Closely related individuals are bred together (inbreeding), which can make harmful inherited conditions more common in domesticated animals.

Probability in a selective breeding cross

In a plant, disease resistance is controlled by a dominant allele R, and susceptibility by the recessive allele r. Two resistant plants with the genotype Rr are crossed. What is the probability that an offspring is susceptible to the disease?

1. Gametes from each parent: R or r
2. Possible offspring: RR, Rr, Rr, rr
3. Only rr is susceptible: 1 out of 4

Answer: The probability is 1/4 (25%). The ratio of resistant to susceptible offspring is 3 : 1.

Exam tip: Always say that selection is repeated over many generations. Mark schemes award a mark for this.

Tissue culture Spec 4.9B Triple only

Tissue culture is growing new cells or tissues from small pieces of tissue, using sterile conditions and a growth medium.

1. Take a small piece of tissue or a few cells from the parent plant.
2. Use **aseptic technique** so that bacteria and fungi do not contaminate the culture.
3. Place the tissue on a sterile **nutrient medium** (such as agar) containing nutrients and growth hormones.
4. The cells divide, forming a mass of cells that grow into small plants, which are genetically identical to the parent.

Advantages in plant breeding programmes

- Many identical plants can be produced **quickly**, from a very small amount of tissue.
- Plants with desirable characteristics, such as those produced by selective breeding or genetic engineering, can be copied exactly.
- Plants can be produced all year round, in a small space.
- Rare plants can be reproduced to help save them.

Advantages in medical research

- Large numbers of identical cells can be grown for research, so results are reliable.
- New drugs can be tested on cultured cells, reducing the need to test on animals or people.
- Cells can be used to study how diseases develop.

Exam tip: 'Identical' is the key word for plant breeding; tissue culture produces genetically identical offspring, so useful characteristics are kept.

Quick check

1. What is selective breeding?
2. Name two characteristics selected for in food plants.
3. Why can selective breeding be a risk to a population?

4 Genetic engineering Spec 4.10–4.12B

What is genetic engineering? Spec 4.10

Genetic engineering is a process which involves modifying the **genome** of an organism to introduce desirable characteristics.

Usually a gene for the characteristic is taken from one organism and inserted into another organism of a different species. The organism produced is called a genetically modified (GM) organism. It can now make the protein coded for by the new gene.

Examples of genetic engineering		
Organism	Gene inserted	Desirable characteristic
Bacteria	Human gene for insulin	Bacteria make human insulin, to treat diabetes
Crop plants	Gene for resistance to insect pests	Plants are not damaged by the pest

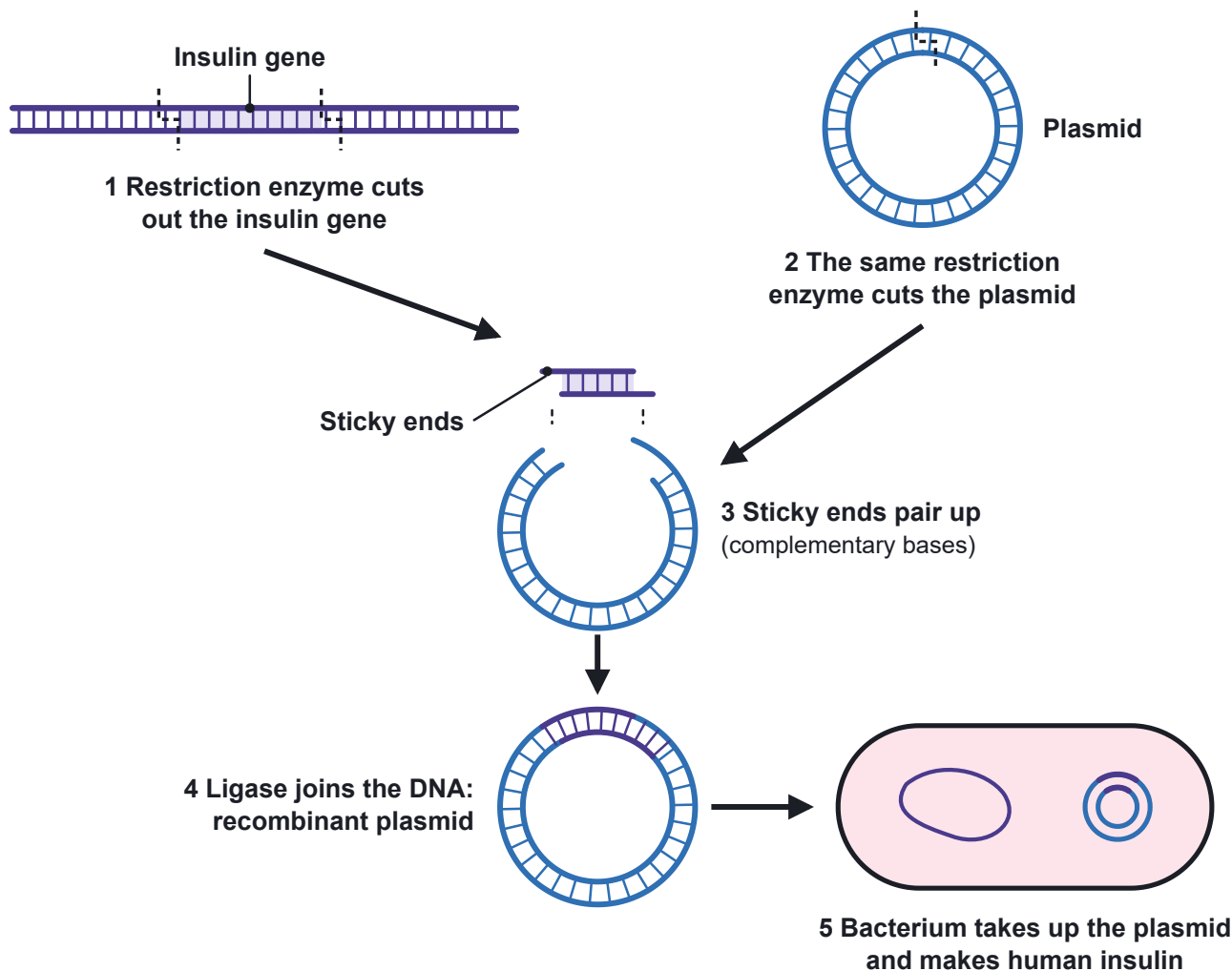
Common mistake: Genetic engineering is not the same as selective breeding. Selective breeding uses the genes already in a species; genetic engineering changes the genome directly.

The main stages of genetic engineering Spec 4.11 Higher tier

1. The gene for the desired characteristic is cut out of the chromosome of the donor organism using a **restriction enzyme**. Each restriction enzyme cuts DNA at a specific sequence of bases.
2. The cut leaves short, unpaired strands of DNA at each end. These are called **sticky ends**.
3. The **vector** is cut open using the same restriction enzyme, so it has matching sticky ends. A vector is something used to carry the gene into the new cell, such as a bacterial plasmid or a virus.
4. The gene and the vector are mixed. The sticky ends join by complementary base pairing, and the enzyme **ligase** joins the DNA strands together permanently. This makes recombinant DNA, for example a recombinant plasmid.
5. The vector is used to insert the gene into the cells of the target organism (for example a bacterium, or a plant or animal at an early stage of development). The organism's cells now make the protein.

Restriction enzyme	An enzyme that cuts DNA at a specific base sequence.
Sticky ends	Short, unpaired strands of DNA left at the ends of a cut, which can join with complementary sticky ends.
Ligase	An enzyme that joins pieces of DNA together.
Vector	A carrier, such as a plasmid or virus, used to insert a gene into another organism's cells.

Exam tip: Use the same enzyme to cut both the gene and the vector. That gives matching sticky ends. Ligase then does the joining.



Same **restriction enzyme** gives matching **sticky ends**; **ligase** joins them to make a recombinant plasmid.

GM organisms and crop plants Spec 4.12B Triple only

A well-known example is the introduction of a gene from the bacterium *Bacillus thuringiensis* (Bt) into crop plants. The gene codes for a **toxin** that kills many insect pests. Plants with the gene make the toxin themselves and so have **insect resistance**.

Advantages and disadvantages of GM crops	
Advantages	Disadvantages
Less crop is lost to pests, so yields are higher	Possible risk to human health, which some people worry about
Less insecticide needs to be sprayed, which saves money and reduces damage to other organisms	Genes may spread to wild plants, and the toxin might harm other insects
Crops can be given extra characteristics, such as greater nutritional value or resistance to disease	GM seeds can be expensive, and farmers may have to buy new seeds each year
More food can be produced for a growing population	Concerns that it is wrong or unnatural to change organisms' genes
Crops with a gene for herbicide resistance can be sprayed to kill weeds without harming the crop	Insect pests may evolve resistance to the Bt toxin by natural selection

Exam tip: Structure 'advantages and disadvantages' answers as a balanced argument, then add a conclusion. Link each point to the crop, the farmer, people or the environment.

Quick check

- 1 . What is genetic engineering?
- 2 . What does a GM organism contain that a normal organism does not?
- 3 . Give one example of a desirable characteristic introduced by genetic engineering.

5 Agriculture and evaluating biotechnology Spec 4.13B–4.14

Agricultural solutions for a growing population Spec 4.13B Triple only

The human population is growing, so more food is needed. Two agricultural solutions are the use of fertilisers and biological control.

Fertilisers

Fertilisers add mineral ions, such as nitrates, to the soil. Plants need these to grow well, so crop yields are higher.

- Advantage: increased growth and yield, so more food is produced from the same land.
- Disadvantage: fertilisers can be washed off fields into rivers and lakes, which can harm wildlife and pollute water.
- Disadvantage: they cost money, so the farmer's costs go up.

Biological control

Biological control is the use of living organisms to control pests. For example, ladybirds can be released to eat aphids.

- Advantage: no chemical residues are left on the food, and harmful chemical pesticides are not needed.
- Advantage: the control organism usually targets only the pest, and can keep working over a long time.
- Disadvantage: it is slower than pesticides and may not completely remove the pest.
- Disadvantage: the control organism might itself become a pest, or might eat other organisms, harming the ecosystem.

Exam tip: Questions about fertilisers or biological control need both sides. Give at least one advantage and one disadvantage, each explained, not just named.

Evaluating genetic engineering and selective breeding Spec 4.14

'Evaluate' means weigh up benefits and risks, including practical and ethical implications, and reach a judgement. Here are the main points for agriculture and medicine.

Benefits and risks		
	Benefits	Risks and implications
Selective breeding	Higher yields and better quality food; no special equipment needed; produces useful animals and plants	Takes many generations; reduces genetic variation; inbreeding can cause health problems in animals
Genetic engineering in agriculture	Crops with new characteristics such as insect resistance or greater nutritional value; quicker than selective breeding	Unknown effects on the environment and human health; genes may spread to wild species; some people think it is wrong to alter genes
Genetic engineering in medicine	Medicines such as human insulin can be made in large amounts from GM organisms	Possible unforeseen effects; ethical concerns about changing the genes of organisms, especially animals

Practical implications include time, cost, skill and the chance that it does not work. **Ethical** implications are about what people think is right or wrong, such as animal welfare and whether humans should change the genes of living things.

Interpreting yield data (practice data)

A farmer grows a non-GM crop with a yield of 4.0 tonnes per hectare, and a GM crop with a yield of 5.0 tonnes per hectare. Calculate the percentage increase in yield with the GM crop.

1. Increase = $5.0 - 4.0 = 1.0$ tonnes per hectare
2. Percentage increase = $\text{increase} \div \text{original} \times 100$
3. $1.0 \div 4.0 \times 100 = 25\%$

Answer: 25% increase.

Maths skill: When asked to plot or read data from graphs or tables, check the axis scales and units, and use values from the data in your evaluation.

Exam tip: In a 6-mark 'evaluate' answer, give benefits and risks, include both practical and ethical points, and finish with a clear conclusion that uses them.

Quick check

1. What does 'evaluate' require you to do in a question about genetic engineering?
2. Name one practical and one ethical implication of genetic engineering.
3. Give one risk of selective breeding.

Quick check answers

Darwin, natural selection and antibiotic resistance

1. Mutation.
2. Variation, competition so some survive and reproduce, alleles passed on, proportion with the useful allele increases.
3. The antibiotic.
4. Bacteria reproduce very rapidly, so the resistance allele spreads in a short time.

Evidence for evolution and classification

1. Ardi (4.4 million years ago; Lucy is 3.2 million years ago).
2. By finding the age of the rock layer, or materials found with them, in which they were buried.
3. Animals, plants, fungi, protists and prokaryotes.
4. Archaea, Bacteria and Eukarya.

Selective breeding and tissue culture

1. Choosing parents with desired characteristics to breed together, and repeating this over many generations.
2. Any two of: disease resistance, larger fruit or grains, better taste, higher yield.
3. It reduces genetic variation, so a new disease or change could affect all individuals.

Genetic engineering

1. Modifying the genome of an organism to introduce desirable characteristics.
2. A gene transferred from another organism.
3. For example, bacteria making human insulin, or crop plants resistant to insects.

Agriculture and evaluating biotechnology

1. Weigh up benefits and risks, including practical and ethical implications, and reach a judgement.
2. Practical: it is costly or may not work. Ethical: some think it is wrong to alter the genes of organisms.
3. It reduces genetic variation, or inbreeding causes health problems.