Biology

Simple Inheritance: Who's queen bee?

A queen bee looks and behaves very differently from her daughters – the worker bees that swarm around her hive. This is because of a complex interaction between her genes and the environment in which she was raised. But some features of bees and other organisms – including us – are determined by a single gene.

In this lesson you'll investigate the following:

- Why do some traits skip a generation?
- What is the difference between your genotype and your phenotype?
- How do geneticists study inheritance patterns in humans?
- What does your genetic family tree look like?

So let's find out the latest buzz about bees!

Introduction: Simple inheritance

Who's queen bee?

From the colour of your eyes and skin to your risk of developing a serious illness, your genes have a huge impact on your life. Genes are the units of inheritance that allow all living things, from microbes to humans, to pass on features – known as *traits* – to their descendants.

Sometimes just a single gene can have a huge effect on an organism, like the Ivory gene that controls whether a bee's eyes are black or white. But genetics – like life – is not usually that simple. Most traits are determined by multiple genes or are influenced by an organism's particular environment, such as what they eat and how much sunlight they get.

One example is the Ultrabithorax (*Ubx*) gene in honey bees. This gene has a key role in modifying the legs of worker bees with special structures that allow them to carry pollen from flowers back to their hives. Curiously, the queen bee doesn't develop these structures even though her worker children must have inherited their genes from her. So what's going on?

Scientists recently discovered that the *Ubx* gene is somehow switched off by royal jelly. This is the milky, protein-rich substance that queen bees are fed in much larger amounts from birth. When researchers turned off *Ubx* in worker bees, their legs lost their pollen-gathering structures and looked far more queenly!

Discoveries such as this highlight how environmental factors – such as a diet of royal jelly – can have a big influence on the way genes operate. But we can understand the basic principles of genetics by looking at the simpler cases in which a trait is determined by a single gene.

Read the full *Cosmos* blog post here.

Some examples of heritable human traits: chin dimple, double-jointed thumb, red hair.

Question 1

Reflect: You resemble your parents because you inherited genetic information from them. Have you ever wondered how much of your appearance was determined in this way?

Use a camera to take a selfie and look closely at your features. Try to identify some distinctive traits that you can also recognize in other members of your family. Upload your selfie into a sketchpad in the project space and label the traits using the line and text tools. In a separate text space describe the distinctive traits you have and your relation to family members who share them.

Note: If you were adopted and don't know your birth family, identify traits that you think *might* be genetic and then indicate the ones that you'd like to pass on to any children you might have.

Gather: Simple inheritance

Simple inheritance

The basic principles of genetics – the science of inheritance – were discovered in the nineteenth century by a monk called Gregor Mendel.

By carrying out a large number of experiments in the gardens of his monastery, Mendel discovered that several traits of pea plants follow **simple inheritance** patterns. This is when the appearance or absence of a trait is controlled by a single unit of inheritance, or *gene*.
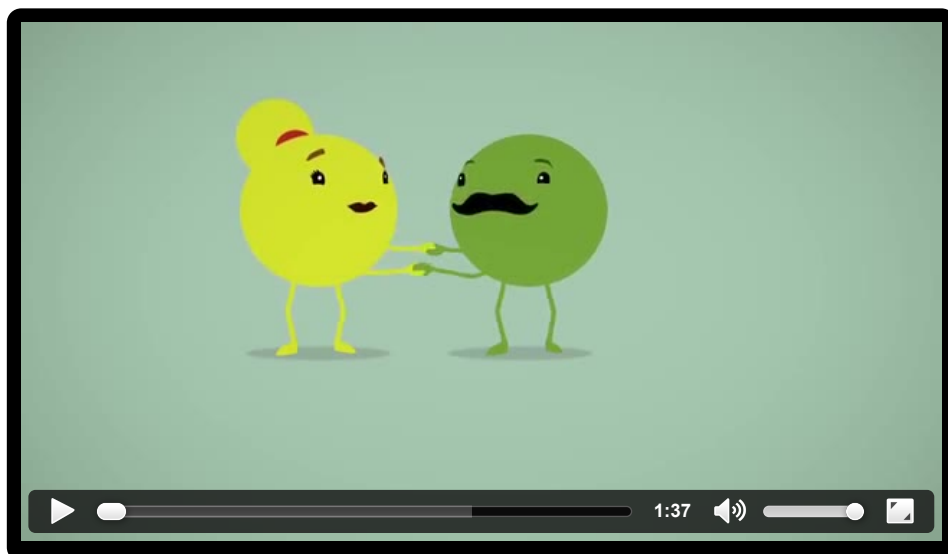
Question 1

Recall: When Mendel bred yellow-seeded pea plants with green-seeded plants the offspring were:

- [ ] all green-seeded.

- [ ] 50% yellow-seeded and 50% green-seeded.

- [ ] 75% yellow-seeded and 25% green-seeded.

- [ ] all yellow-seeded.

Question 2

Count: When Mendel then bred together these offspring, the next generation of plants were:

Hint: Count the "children" shown at 1:05 in the video and convert into percentages.

- [ ] all green-seeded.

- [ ] 50% yellow-seeded and 50% green-seeded.

- [ ] 75% yellow-seeded and 25% green-seeded.

- [ ] all yellow-seeded.

Dominant and recessive traits

The results of Mendel's breeding experiments were very strange. Why did the pairing of a yellow-seeded pea plant with a green-seeded plant produce only yellow-seeded plants? And how did the trait of green seeds skip a generation and reappear in the next one?

Mendel reasoned that the yellow-seeded plants in the middle generation must have been carrying two *different* copies of the gene for seed colour: one for yellow seeds and one for green seeds. As mentioned in the video, different versions of a gene are now known as *alleles*.

All of the plants in the middle generation must have had the allele for yellow seeds because they all "expressed" this trait in their appearance. Mendel called this the *dominant* trait. But the same plants must have also been carrying the allele for green seeds so that they could pass it on to some members of the next generation. Having green seeds is a *recessive* trait because it recedes – or goes into hiding – when the dominant allele for yellow seeds is present. It only comes out on display when a plant gets *two* alleles for green seeds, one from each parent.

Question 3

Define: Alleles are:

- [ ] traits that are controlled by a single gene.
- [ ] different versions of a gene.
- [ ] traits that are controlled by multiple genes.
- [ ] patterns of simple inheritance.

Question 4

Recall: The inheritance of a recessive trait occurs only when:

- [ ] the father contributes two alleles for the trait.
- [ ] the mother contributes two alleles for the trait.
- [ ] each parent contributes one allele for the trait.
- [ ] each parent contributes two alleles for the trait.

Phenotype and genotype

A particular organism's *phenotype* – its set of observable traits – is partly determined by its *genotype* – its set of genes.

The following diagram illustrates this for several of the single gene traits possessed by one particular pea plant. Obviously, many of its traits are also influenced by other factors such as the amount of light and water it receives.

The genotype for each gene is the combination of alleles it inherits from its parents. In this example, the plant has the genotype YY for seed colour because each of its parents gave it a dominant Y allele for yellow seeds. But it *might* have had one of the other possible genotypes shown: Yy or yy.

The dominant allele is always symbolized by a capital letter and the recessive allele is symbolized by the lower case form of the *same* letter. For example, in the genotype Pp, P is the dominant allele for purple flowers and p is the recessive allele for white flowers, whereas in the genotype rr, r is the recessive allele for wrinkled seeds and this plant lacks the dominant allele for round seeds, R.
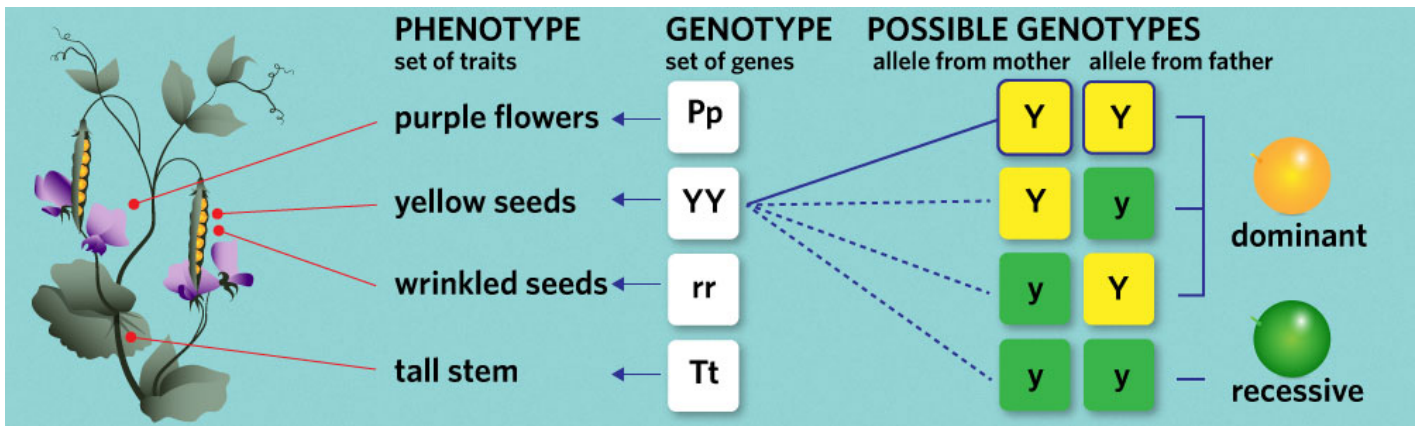
Another distinction raised in the video is between genotypes:

- A genotype in which the alleles are the same is called *homozygous*. For example, both YY and yy are homozygous genotypes although they result in different traits.
- A genotype in which the alleles are different is called *heterozygous*. So Yy is heterozygous and plants with this genotype are *carriers* of the recessive allele for green seeds but *express* the dominant allele for yellow seeds.

Question 5

Classify: An example of a homozygous genotype is:

- ☐ Bb
- ☐ yellow seed colour
- ☐ ss
- ☐ recessive

Question 6

Select: Pea plants that are heterozygous for the seed colour gene:

Hint: More than one answer may be correct.

- ☐ have green seeds but carry the recessive allele for yellow seeds.
- ☐ have yellow seeds but carry the recessive allele for green seeds.
- ☐ have two different seed colours – yellow and green.
- ☐ have two different alleles for seed colour.

As well as pea plants, Mendel tried to carry out controlled breeding among honey bees – but he found them far less cooperative! For one thing, it's hard to keep track of individual bees when they're swarming together in a hive.

And as highlighted by the *Cosmos* blog post, bee genetics turns out to be more complex than the workings of pea plants. Even when two female bees have exactly the same genotypes, a diet of royal jelly can turn one into a queen while the other is destined for a life as a worker.

Recent discoveries have shown how rare simple inheritance is. But geneticists still depend on the insights Mendel gained from his experiments on the humble pea.

⊞ Question 7

Summarize: Type the missing words into the table below.

When the alleles for a gene are the same the genotype is called _____.	
When the alleles for a gene are _____ the genotype is called heterozygous.	
If present, the _____ allele will always be expressed as the phenotype.	
The recessive trait will only be expressed as the phenotype when both of the alleles are _____.	

✏️ Question 8

Match: Mendel found that many traits of pea plants show the same simple inheritance pattern as seed colour. For example, flower colour is also controlled by a single gene. The dominant trait is purple flowers and the recessive trait is white flowers, so the possible genotypes are PP, Pp and pp.

1. Match the traits in the left hand column with their genotypes by drawing straight lines. If the trait can be produced by more than one genotype then draw more than one line.
2. Classify each of the genotypes as either homozygous or heterozygous in the right hand column.

One of the traits has been completed for you.

Process: Simple inheritance

Some of the heritable traits found in humans: curly hair, attached earlobes, green eyes.

Pedigrees

Mendel's experiments on pea plants allowed him to discover simple inheritance patterns because these plants have several single gene traits. Pea plants are also easy to observe and breed in a controlled way. Studying inheritance in humans is more challenging for several reasons: human genetics is enormously complex, we reproduce more slowly and our breeding can't be controlled by scientists in laboratories!

Instead, scientists study genetic patterns in human families by constructing *pedigrees* – family trees that show how a particular trait is passed down from one generation to the next.

In a pedigree, each person in a family tree is replaced by a symbol – a square if they're male and a circle if they're female. When someone has the trait we're interested, their symbol is filled in. When two people have children together, a horizontal line is drawn to connect the two symbols and their children are drawn in a separate row underneath.

The video below uses a pedigree to show how one type of deafness follows a recessive inheritance pattern.

Note that "wild type" just refers to the dominant phenotype. Also, someone who has a heterozygous genotype can be called a "heterozygote" or "carrier".
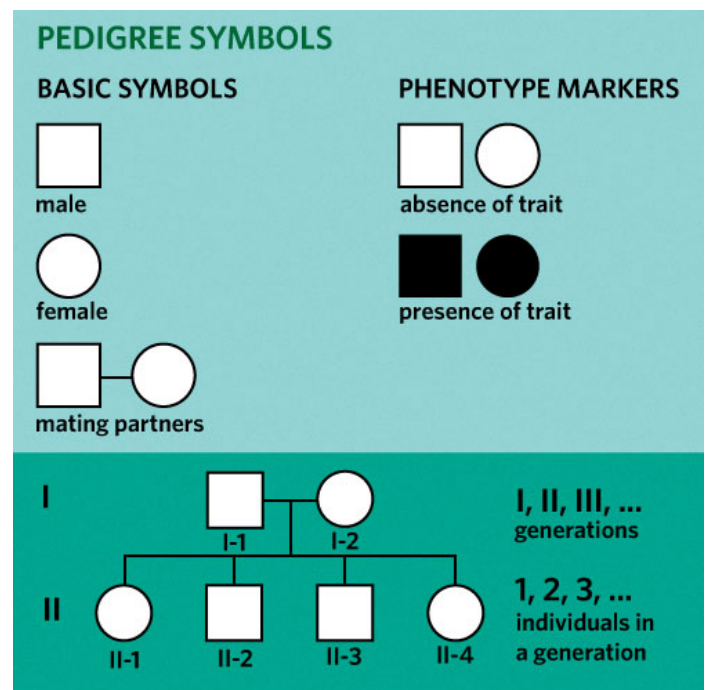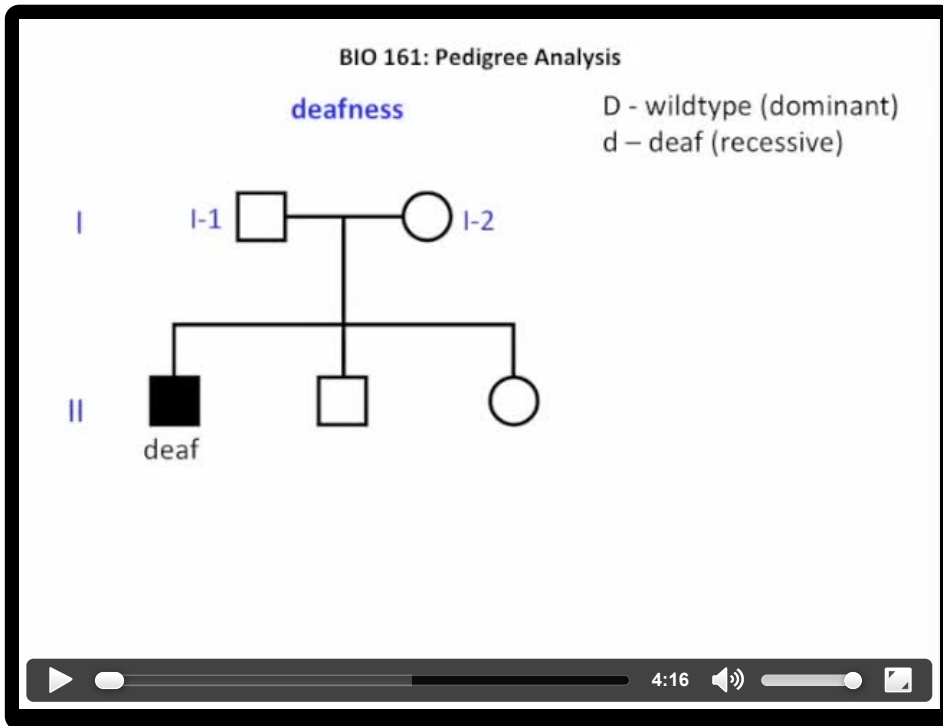
Question 1

Complete: Complete the table by:

- stating the phenotype (deaf or not deaf) for each of the possible genotypes, and
- classifying each allele in the genotype as either recessive or dominant.

The first row has been filled in for you.

Genotype	Phenotype	First allele	Second allele
DD	not deaf	dominant	dominant
Dd			
dd			

Question 2

Decide: Is it possible for a man with the genotype DD and a woman with the genotype Dd to have a child who has this type of genetic deafness?

- ☐ Yes
- ☐ No

Question 3

Explain: If the deaf individual II-1 has any children then they must also be deaf – true or false? Explain your answer.

_____
_____
_____
_____

Working with pedigrees

Albinos are people and animals who have little or no coloured pigment in their skin, eyes and hair – or feathers! Albinism is a recessive trait and is controlled by a single gene.

🖊️ Question 4

Infer: The pedigree in the sketchpad below traces the inheritance of albinism through three generations of a human family. The symbols for all of the individuals with albinism are shaded.

As shown in the video, we can often work out genotypes from phenotypes by gradually adding allele symbols to a pedigree. Use your knowledge of recessive inheritance patterns to work out the genotypes needed to fill the spaces – two genotypes are already provided.
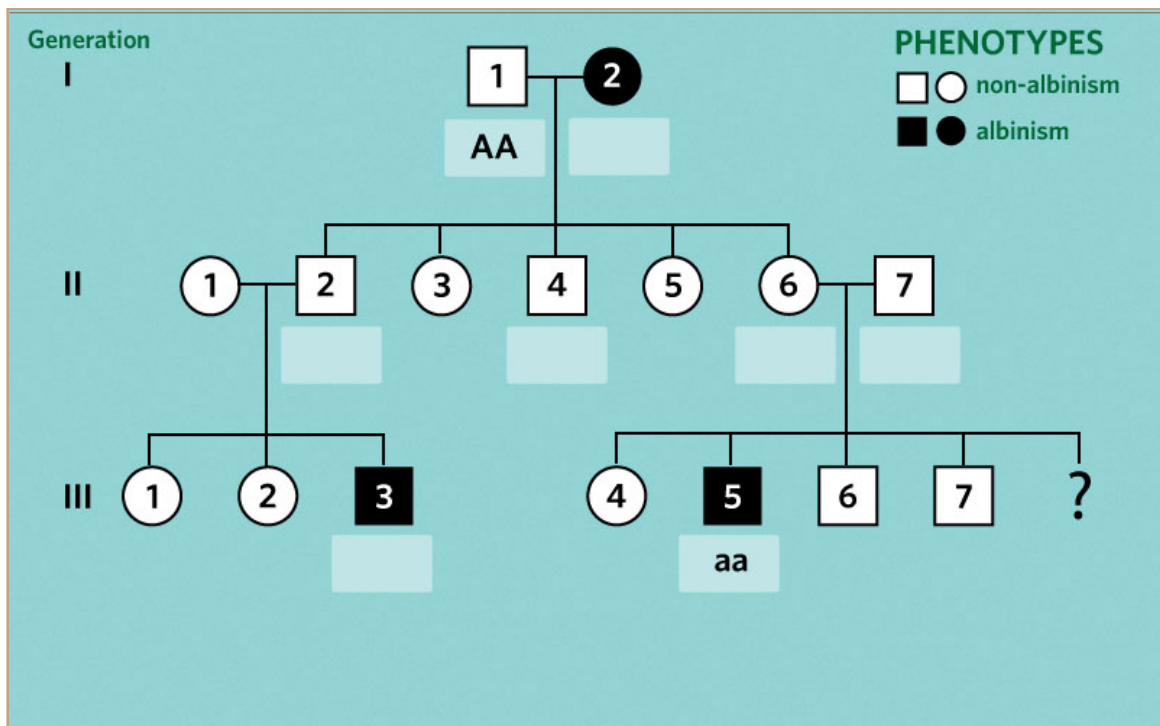
Question 5

Select: Which of the following statements are true?

- [ ] Individuals II-1 and II-2 have had one daughter and two sons.
- [ ] All of the children of I-1 and I-2 are heterozygotes.
- [ ] Individual III-1 has the genotype aa.
- [ ] If Individual II-4 has a child, it might have albinism.

Question 6

Calculate: Individuals II-6 and II-7 are expecting their fifth child, indicated by the question mark. What is the probability that this child will express the albinism trait?

- [ ] 0%
- [ ] 25%
- [ ] 50%
- [ ] 75%

Did you know?

Pedigree analysis of several human diseases has revealed simple inheritance patterns, indicating that they're caused by single genes.

For example, cystic fibrosis is a life-threatening genetic disorder that affects the lungs and other internal organs. It follows a recessive inheritance pattern meaning that people are often unaware that they have the faulty version of the gene until they have children with the condition.

Huntington's disease is a genetic condition that can lead to dementia and the loss of muscle coordination among other symptoms. It follows a dominant inheritance pattern but people with only one copy of the defective gene often show symptoms only later in life. So before they discover that they have the disease, they can pass it on to their children.

Both of these examples show the importance of developing new methods of genetic testing to allow early detection and prediction.

Dominant inheritance patterns

So far in this section you've seen two examples of recessive inheritance patterns – deafness and albinism. Now we'll have a look at a case in which the trait we're interested in is dominant.

People with fused digits have two or more of their fingers or toes joined together. This trait depends on a single gene and follows a dominant inheritance pattern.

Question 7

Complete: Fill in the gaps in the pedigree to show the genotypes for the seven individuals shown.

*Hint: Given that having fused digits is the dominant trait, you know that anyone with **unfused** digits must have the genotype ff. For each individual with fused digits, you need to infer whether their genotype is FF or Ff.*
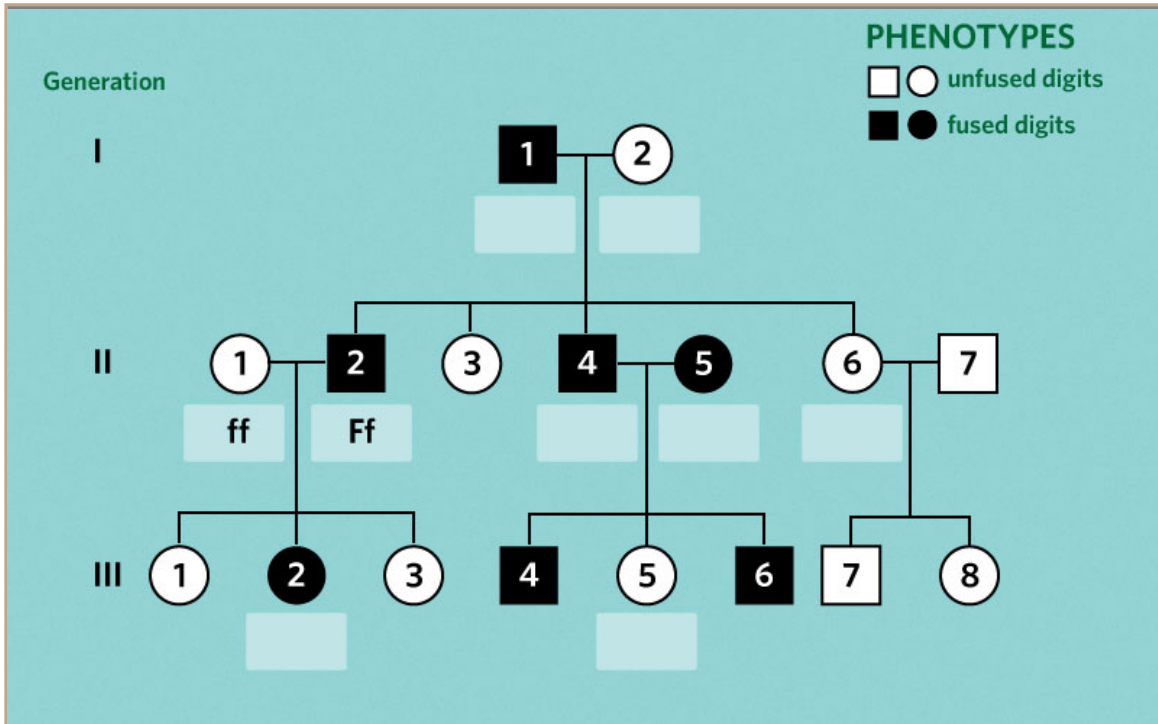
Question 8

Justify: Explain how it's possible for two parents with fused digits – for example, II-4 and II-5 – to have children who lack this trait.

Note: Use the terms *dominant*, *recessive* and *heterozygote*.

Apply: Simple inheritance

Construct a genetic family tree

In this section of the lesson you can choose to complete *either* Question 1 *or* Question 2:

1. Construct a pedigree for your family (or a family that you know very well).
2. Construct a pedigree for the fictional Novak family.

Dominant trait	Recessive trait	Allele symbols
widow's peak	straight hairline	W and w
straight thumb	hitchhiker's thumb (curved)	T and t
presence of freckles	absence of freckles	F and f
bent little fingers	straight little fingers	B and b
detached earlobes	attached earlobes	E and e
ability to roll tongue	inability to roll tongue	R and r
presence of mid-digit finger hair	absence of mid-digit finger hair	M and m
presence of dimples	absence of dimples	D and d
no cleft in chin	cleft in chin	C and c
separate eyebrows	joined eyebrows	S and s
long eyelashes	short eyelashes	L and l
almond-shaped eyes	round eyes	A and a
interlaced fingers: left thumb over right	right thumb over left	I and i
hair on back of hand	no hair on back of hand	H and h

Single gene traits in humans

Question 1

1. Construct a family tree that starts with you and goes back to at least your grandparents. Select a single gene trait from the table above that distinguishes some members of your family from others. Gathering together family photos might help to identify some traits, such as the presence of freckles or a cleft chin.

2. Using your family tree and the information you've collected, construct a pedigree to show how the trait has appeared in the phenotypes of your relatives. Remember to follow the standard rules for constructing pedigrees and include a phenotype key to clearly show the meaning of the shaded symbols. If you draw the pedigree by hand, use a ruler to draw neat lines and leave enough space under each symbol to write the individual's name and genotype.

3. Fill in as many genotypes as possible using appropriate allele symbols. If you know that someone has a dominant allele but you can't figure out whether the other allele is dominant or recessive then use an underscore for the unknown allele, e.g. "A_".

4. When you're finished, upload the pedigree into the project space below, either as a file or as a photo of a hand-drawn pedigree.

Did you know?

One of the most famous examples of a genetic disorder being passed down through a family is the case of haemophilia in the descendants of the British monarch, Queen Victoria. This rare disease follows a sex-linked inheritance pattern and shows up mainly in males, preventing their blood from clotting properly and sometimes leading to death.

Because of the tendency of Europe's royals to intermarry, the recessive trait was passed on to the royal families of Russia, Germany and Spain.

Queen Victoria with four of her eldest grandchildren in 1871.

Question 2

Here's a short history of the Novak family:

Tomas and **Helga** Novak settled in the small town of Barrow in 1946. Tomas was a respected dentist and Helga worked as a nature photographer until her frail health and growing blindness forced her to give it up. Before her health declined, Helga gave birth to three sons – **Jakob**, **Felix** and **Alexander** – followed by a daughter, **Natalie**.

Jakob married a school teacher named **Rosa** and together they had three children: **Hannah**, **David** and **Emily**. Although Hannah was healthy, her two siblings were very sickly and David developed cataracts in his eyes just like his grandmother, who had died many years before.

Felix took over his father's dental practice and eventually married his assistant, **Frances**. They had a daughter, **Janet**, a few years later but the child developed severe kidney problems and spent much of her childhood in hospital.

Alexander had a talent for music and became a well-known concert pianist but his hectic touring prevented him from ever settling down and starting a family.

Natalie moved to the nearby town of Hampton and married a wealthy banker, **Graham**. Their two boys – **Theo** and **Ben** – were both blessed with good health but were fiercely competitive with each other.

David, Emily and Janet were all eventually diagnosed with a rare form of galactosemia, a genetic disorder that can cause kidney failure, cataracts and various other health problems. The doctors concluded that their grandmother, Helga, had also suffered from galactosemia.

1. Use the information provided to construct a pedigree for the galactosemia trait in the Novak family – children are introduced above in birth order. Remember to follow the standard rules for constructing pedigrees and include a phenotype key to clearly show the meaning of the shaded symbols. If you draw the pedigree by hand, use a ruler to draw neat lines and leave enough space under each symbol to write the individual's name and genotype.

2. Given that galactosemia is determined by a single gene, use the inheritance pattern to decide whether it's a dominant or a recessive trait. *Hint: You can assume that if a trait is dominant then it can't be present in a child if it's absent in both parents.*

3. Fill in as many genotypes as possible using appropriate allele symbols. If you know that someone has a dominant allele but can't figure out whether the other allele is dominant or recessive then use an underscore for the unknown allele, e.g. "G_".

4. When you're finished, upload the pedigree into the project space below, either as a file or as a photo of a hand-drawn pedigree.

Career: Simple inheritance

Even in long overalls, gloves and a mesh hood to protect her from stings, Emily Remnant was still jittery when she opened the lid on the honey bee hive for the first time. It was a wooden box, slightly bigger than a microwave, with bees busily crawling about each frame of honeycomb. The hive had a distinctly sweet aroma of honey blended with wax, as well as a hint of the smoke – from burning pine needles – that is used to calm the bees.

That was three years ago, and now collecting samples from hives is a normal part of Emily's job as a molecular geneticist. Emily works in the Social Insects Laboratory at the University of Sydney, where she dissects tissues from honey bees, grinds up the samples and extracts DNA and RNA to analyse. Her research focuses on honey bee diseases and viruses, as well as how each honey bee parent contributes DNA differently to their offspring.

Growing up, Emily didn't really have a career goal in mind. She simply chose high school classes based on what she liked, signing up for biology and chemistry as well as music and theatre. She continued to do this at the University of Melbourne, where she earned an undergraduate degree in biomedical science and then a PhD in genetics, working first with flies and later with honey bees.

Emily actually had insectophobia before taking on her PhD. She had to learn how to overcome it, and now she can't imagine doing anything else – she even loves the gentle hum the bees make.

"Working in a honey bee lab means that there is the risk of getting an occasional sting," Emily admits. But, "we make up for this as there is an endless supply of honey!"

When she isn't buzzing about the lab, Emily enjoys live music, cooking, jogging and yoga.

📝 Question 1

Reflect: If you were a biologist, which type of animal would you most like to study, and why? Would you need to overcome any fears – of animals, water, heights, etc. – to follow this career path?