Royal Academy of Engineering

THIS IS ENGINEERING

ENTERTAINMENT

Student Guide

Engineering is at the cutting edge: from artificial intelligence and gaming, to advanced sports equipment and creating the future of film and music.

Find stories of inspiring engineers and bring the work that they do into your home or classroom.

INTRODUCTION

Engineering is at the cutting edge: from machine leaning, artificial intelligence and gaming, to advanced sports equipment, CGI, designing hi-tech sets and materials, and music production.

Engineers create incredible devices, software and systems that make the impossible possible.

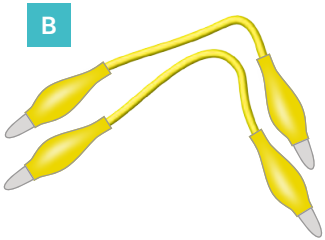
Whether you're into phones, apps, games or virtual reality, you can be part of how technology shapes the future.

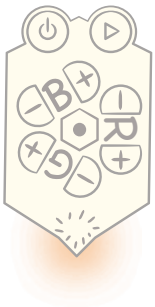
Find stories of inspiring engineers who followed what they love into engineering, each with different passions and different journeys.

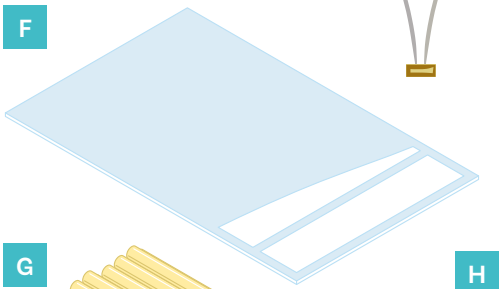
Whatever you're interested in, whatever your background, choose engineering and choose to be the difference in the world.

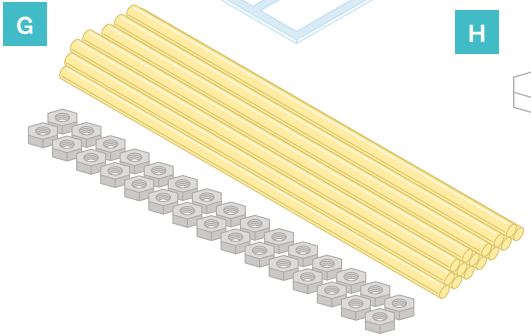
Visit thisisengineering.org.uk

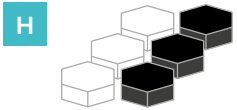
WHAT'S IN THE PACK?









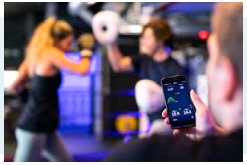


- A Bumble Beep
- B Croc leads x two
- C Coin cell battery
- D Light dependent resistor
- E R G Bug
- F Perspex sheet
- G Dowels x 15 and nuts x 30 (approx.)
- H Game tokens x six

CHOOSE YOUR CHALLENGE

Sports and engineering

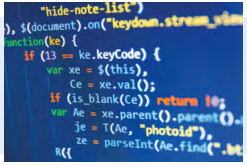
Track your skip
Page 6



Sporting data
Page 9

VR gaming and engineering

Enter the fourth dimension
Page 14



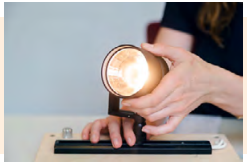
Computer always wins
Page 17

Broadcasting and engineering

All about the sound
Page 23

Synthetic beats
Page 25

Lighting and engineering



Setting the mood
Page 28

Visual effects and engineering

Creating a horror scene
Page 31

The full production
Page 34

ENGINEERING HABITS

ENGINEERS MAKE 'THINGS' THAT WORK OR MAKE 'THINGS' WORK BETTER. BUT THEY DO THIS IN PARTICULAR WAYS.

The 'engineering habits' describe the way engineers think and act.

How do you think and act like an engineer?

Take the quiz at This is Engineering: Entertainment to discover your 'engineering habits'.

But remember, results are not fixed! If you take the quiz several times, you might find that different engineering habits are stronger depending on the type of activity or challenge you are doing.

Engineering is all about having a diverse group of people and skills so having different engineers with different habits of mind in any team is always important!

I AM GOOD AT...

Creative problem-solving	Improving	Problem-finding	Adapting	Visualising	Systems thinking
Coming up with lots of new and good ideas	Making what I have done better	Thinking about the world around me and how it could be better	Deciding how something could be done differently	Thinking out loud when I am being imaginative	Using ideas from one subject in another
Working successfully in a group	Experimenting with things just to see what happens	Finding out why something does not work	Explaining how well I am doing to my teachers and friends	Making a plan before I start work	Putting things together to make something new

Find the full quiz on the 'This is Engineering: Entertainment' page on our STEM resource hub.

CHARLES
WORKOUT HACKER

ABOUT ME

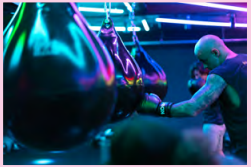
Charles is a mechanical engineer and an entrepreneur. He combined his passion for sport and engineering to invent a boxing app, helping top athletes improve their game.

"ENGINEERING MEANS YOU LEARN SKILLS THAT COULD BE USED TO SOLVE ANYTHING AND LETS YOU BUILD YOUR PASSIONS INTO A CAREER."

His invention of wearable technology provides performance feedback to athletes and coaches in combat sport training. The sensors measure speed, power, type of punch, and work rate, and let athletes track and improve their performance.

Charles's mission is to help people from all skills levels, to assist athletes from grassroots sport to high-performance elite competition.

Find out more about Charles by visiting the *This is Engineering* website



CHALLENGE TRACK YOUR SKIP

MONITORING AND TRACKING YOUR DATA HAS BECOME A HUGE PART OF THE SPORTING INDUSTRY.

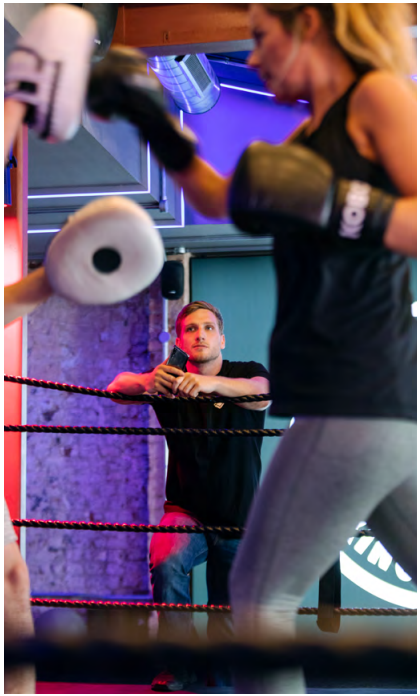
We can measure how many steps we take each day, how far we have run, cycled or swam, and we can view this data on our phones using different apps, making it easy for us to track our progress, set goals and share with friends.

Accelerometers are devices that measure **acceleration**. They are found in smartphones and game controllers to give them motion control.

Skipping is a great example of **acceleration** and it's great exercise! Professional boxers do it to improve their **coordination** and to improve their **endurance**.

Did you know? The most skips in one minute is 203 and was achieved by Zorawar Singh in Delhi, India, in November 2019.

Approximately how many skips is this per second?



MATERIALS

- Smartphone
- Different length skipping rope, or rope that can be used at different lengths

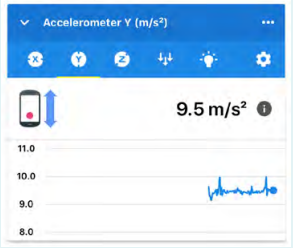
CHALLENGE

Do you think the length of the rope might change how many jumps you could make in one minute?

Getting started

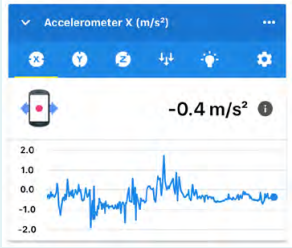
- Download the 'Science Journal App' on your smartphone. You can use the app without creating an account.
- Find a way to secure the phone to yourself – a hip bag would work well or a tight pocket. Make note of whether your phone will lie vertically (upright) or horizontally (on its side).
- Decide which direction **accelerometer** (either X or Y) you would like to use. Test out each one and try moving your phone in different directions to see what happens.

VERTICAL



Use this if your phone is sitting upright.

HORIZONTAL



Use this if your phone is on its side.

TIME TO TRACK

1. Start a new experiment on the Science Journal App.

2. Select either the X or Y accelerometer to take your measurement depending on the direction you will be able to secure your phone.

3. Press the record button and attach the phone to your body.

4. Start skipping. Try and skip for a full minute. Once you have finished, press the record button again to stop recording.

5. Use the 'crop' feature to shorten your data to a length of exactly one minute. Make sure you crop off the parts at the beginning and end of the data while you were handling the phone, which may look irregular or spiky on the graph.

6. Look at the graph of your acceleration. The graph should be periodic (the same pattern repeats over and over). Each repetition of the same pattern, or **period**, represents one complete jump.

7. Each peak on your graph is one jump. Count the number of peaks in one minute.

8. Repeat this process using three different length ropes.

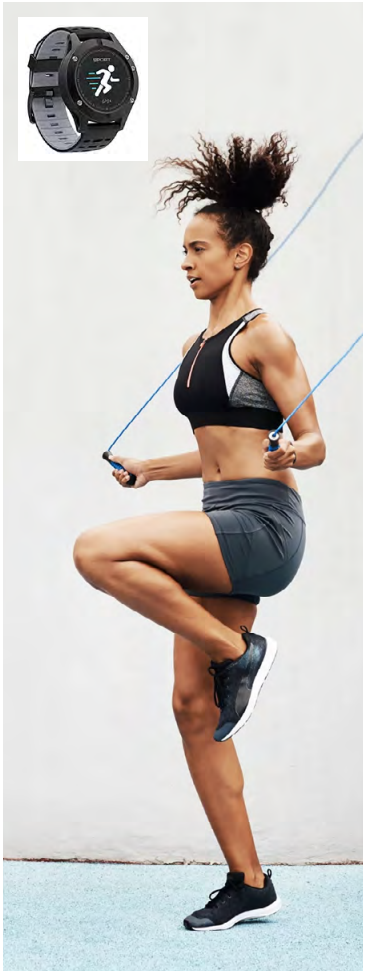
9. Repeat with different people.

With which length rope did jumpers find they could skip the fastest/slowest?

Did this change for different jumpers? Did their height have an impact?

Did the length of the rope impact endurance (how long jumpers could continue skipping)?

Height of person	Length of rope	Skipping time	Number of skips	Skips per second
	1m			
	1m			
	1.3m			
	1.3m			
	1.6m			
	1.6m			

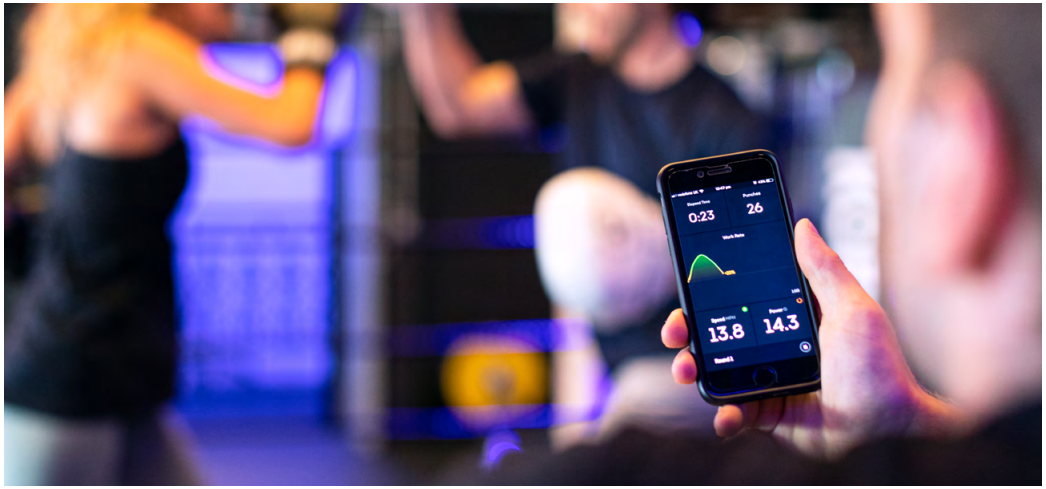


Design an app using this data that generates personalised skipping fitness plans.

- What will the personalised fitness plans look like to your users?
- Do you need to collect more data or carry out more research so you have the best information to create the fitness plans?
- How will your app work? What is the user journey?
- What information will you need to collect from users?

Find a template for your app design on the *This is Engineering:* Entertainment page on our resource hub.

Visit Science Buddies to experiment with the accelerometer in the Science Journal App.



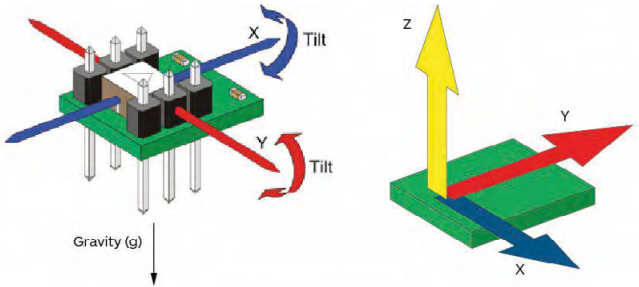
Mini-glossary

Acceleration is change of velocity.

Velocity is change of distance over time (m/s).

An **accelerometer** is an electromechanical device that will measure acceleration forces. These forces may be static, like the constant force of gravity pulling at your feet, or they could be dynamic, caused by moving or vibrating the accelerometer.

Most smartphones will have an accelerometer sensor.



Diagrams illustrating the axes of 2-axis (left) and 3-axis accelerometers. This particular 2-axis sensor is also capable of tilt measurement.
Image credit: Parallax | Kerry Wong

CHALLENGE SPORTING DATA

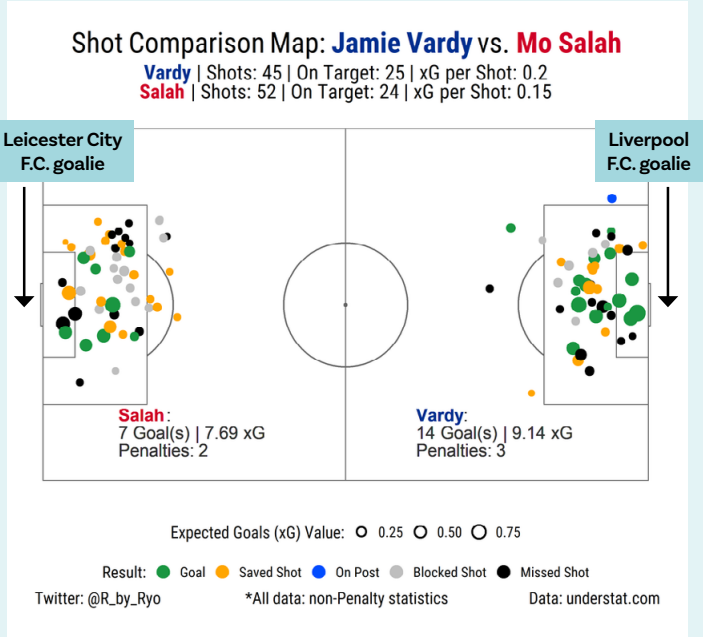
SPORTS STATISTICIANS, TRAINERS, COMPETITORS OR COMPETITION ORGANISERS USE DIFFERENT TOOLS TO VISUALISE AND REPRESENT DATA.

This can help them analyse performance, inform training programmes, improve motivation, and plan sporting events.

CHALLENGE

Have a go at using the graphics to answer the questions about the different sporting events.

Shot comparison map: Jamie Vardy vs. Mo Salah

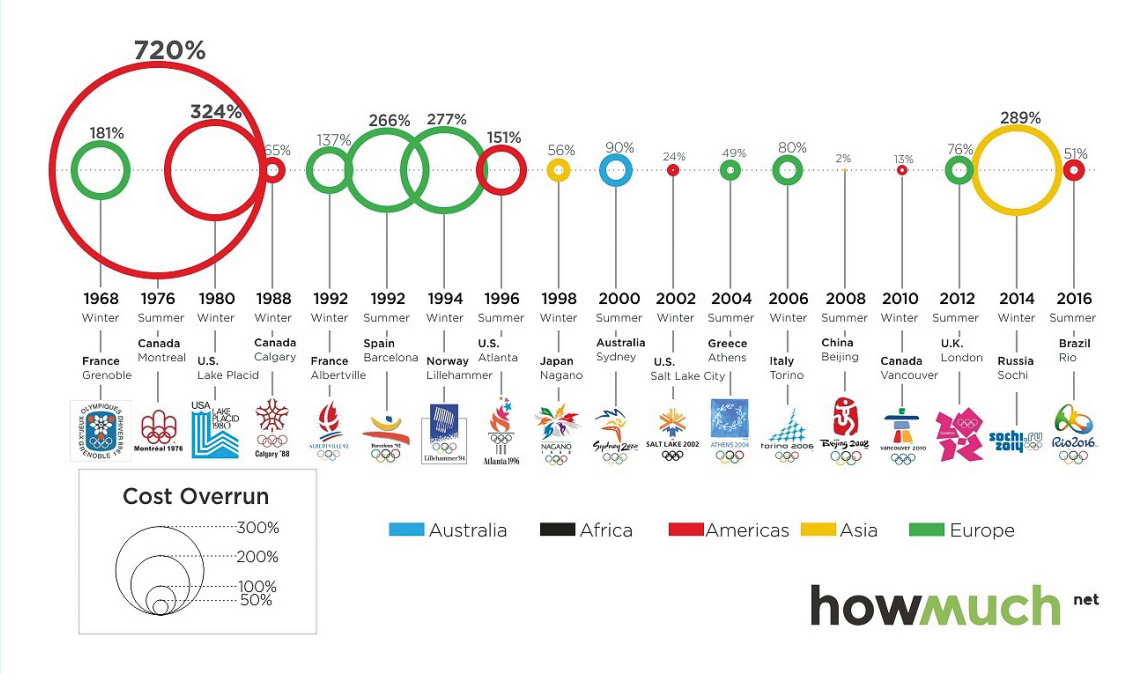


- How many goals did Salah score?
- How many did Vardy score?
- Who saved the most shots?
- Who has missed the most shots?
- How do they differ in positions from where they take shots?
- What do you think works well in this graphic?
- What could be improved?

Graphic taken from Ryo Nakagawara Reddit

CHALLENGE SPORTING DATA

Graphic showing how much over budget countries spent during their Olympic games.



- Which country had the highest cost overrun?
- Which country was almost on budget?
- In which continent have most of the Olympic games taken place?
- In which continent have the least Olympic games happened?
- What else might you be able to tell from this graphic?
- What can you not tell from this graphic?
- What do you think is good about this graphic?
- What do you think could be better?

Graphic taken from Visual Capitalist, Rio Games Success – 51 % overbudget

Graphic showing the number of Grand Slams

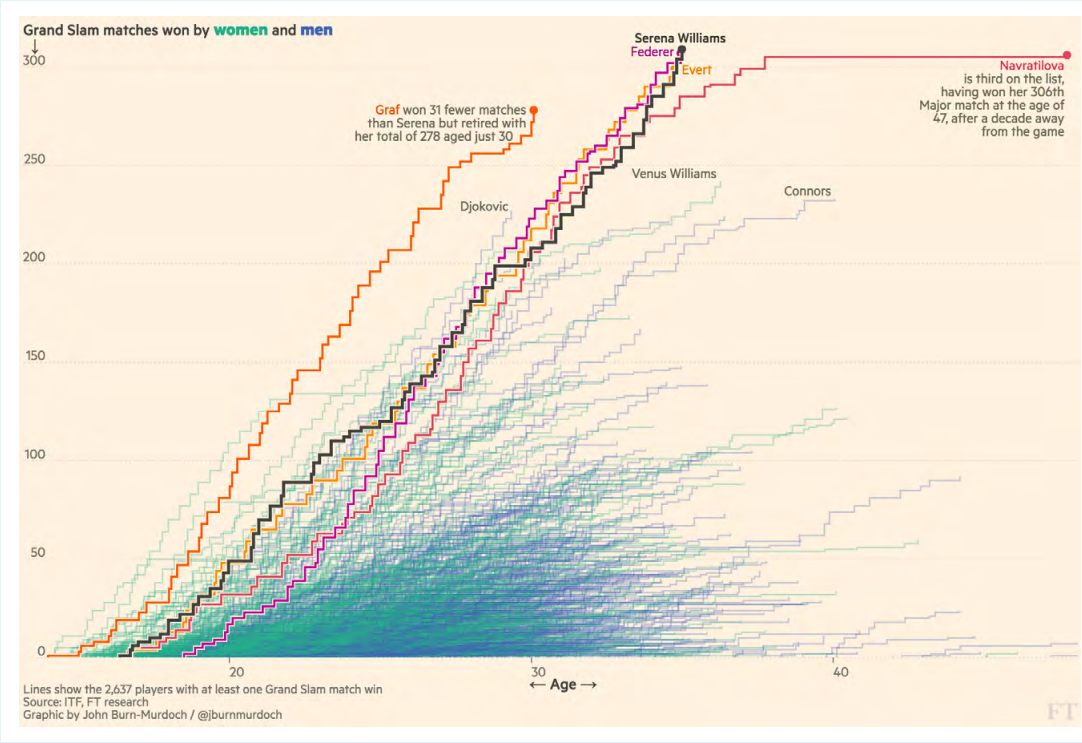
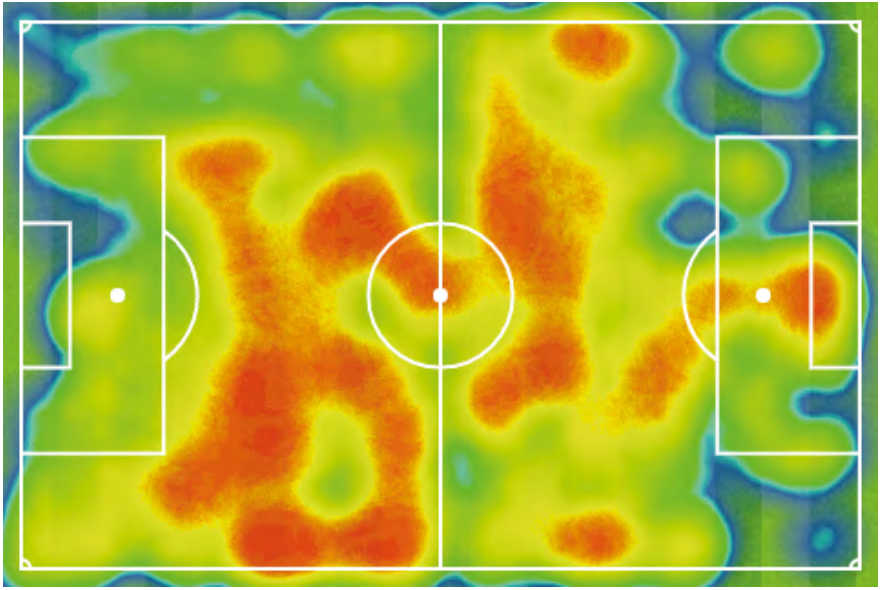


Image taken from
Financial Times Sport, A visual history of women's tennis

- Who is the oldest player to win more than 300 Grand Slam matches?
- Approximately how old was Serena Williams when she won her first Grand Slam?
- Who was the youngest player to reach 200 Grand Slams?
- How many players have won more than 250 Grand Slams?
- What other information can you tell from this graphic?
- What is difficult to decipher from this graph?
- What do you think is good about this diagram?
- What do you think could be better?

CHALLENGE SPORTING DATA

Heat map showing the position of players in one team in a football match



Direction of play

- Which direction was the team playing?
- Did this team spend more time attacking or defending?
- Where was much of the action of the game focused?
- What formation was this team using in this match?
- What strategy do you think the team was using in this game?
- What strategy do you think the opposing team might have been using?
- What do you think an ideal heat map would look like for the opposing team (what strategy might they use against this team)?

Image and questions taken from
Nrich Maths, Charting Success

What next?

Have **you** found any good (or bad) examples of representations of sports data? What makes them good (or bad)?

DANIELA
WONDER MAKER

ABOUT ME

Daniela is creative, an engineer, an innovator and a businesswoman. Problem-solving, art and design were her passions from a young age, and she realised she could bring her art and design ideas into reality through engineering.

"ENGINEERING MEANS MAGIC. YOU CAN CHANGE HOW PEOPLE DO THINGS IN THEIR EVERYDAY LIVES."

She now runs Gravity Sketch, her own company, which empowers designers to create in the most intuitive way by sketching in 3D using virtual reality (VR).

By understanding how things were built and how they worked, Daniela can make her ideas come to life and challenge how they were made. Engineering opened the door for her to come up with crazier and more innovative ideas for the world.

Find out more about Daniela by visiting the *This is Engineering* website

CHALLENGE

ENTERING THE FOURTH DIMENSION

DANIELA HAS DEVELOPED SOFTWARE THAT EMPOWERS GAME DESIGNERS TO CREATE IN THE MOST INTUITIVE WAY BY SKETCHING IN 3D USING VR.

Most 3D objects used in game design are made up of usually **regular polygons**.

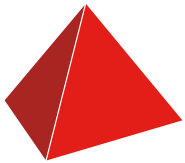
Regular polygons are 2D shapes where every edge is the same length and every angle is the same size (such as a square or equilateral triangle).

Exploring platonic solids

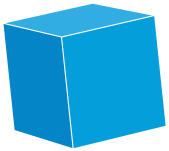
Platonic solids are a special type of **polyhedron** (3D shape) with special properties.

There are only five solids that have both these properties:

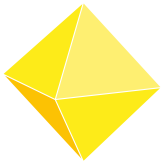
- Describe the platonic solids.
- What do you think the special properties are?



Tetrahedron

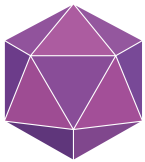


Hexahedron



Octahedron

Dodecahedron



Icosahedron

MATERIALS

- Straight biodegradable straws
- Pipe cleaners
- Bubble mixture (or soap)
- Water
- Bucket

TIME TO MAKE

Tetrahedron

1. Cut your straws so you have six equal pieces.

2. Thread your pipe cleaner through one end and bend one end to secure it in place.

3. Add two more pieces of straw and twist the pipe cleaner to secure it in place.

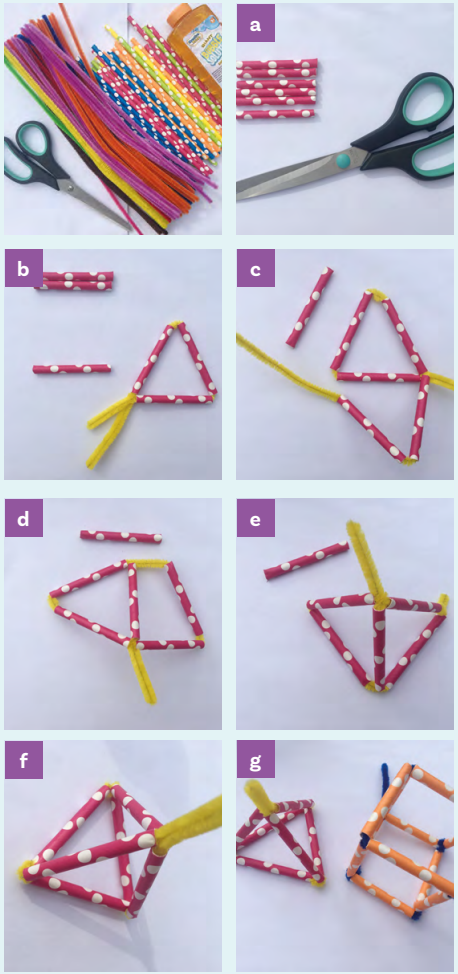
4. Add more pipe cleaner by twisting more on to one of the loose ends.

5. Add two more straw pieces and bend it back to one of the joints.

6. Secure the loose end of the pipe cleaner in place by threading it through the straw that will form the adjacent edge.

7. Attach the final straw piece so the two vertices (corners) meet it.

8. Extend the pipe cleaner to form a handle.



Making platonic solids
How many pieces of straw would you need for a hexahedron (cube)?

How many pieces of straw would you need for a dodecahedron (the table on the next page might help you)?

Have a go at making a hexahedron and octahedron using straws and pipe cleaner. Write a set of instructions for someone else to follow so they can make their own.

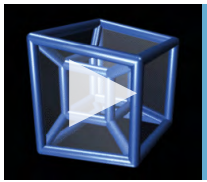
Stretch and challenge
Challenge yourself to make a **dodecahedron**. What about an **icosahedron**?

Into the fourth dimension
What is the fourth dimension and does it exist? The **fourth dimension** is related to the other three **dimensions** by imagining another direction through space; just as the dimension of depth can be added to a square to create a cube, the **fourth dimension** can be added to a cube to create a tesseract.

- Add water and bubble mixture to a bucket or large bowl.
- Dip your tetrahedron into the bubble mixture.
- Dip your hexahedron into the bubble mixture.

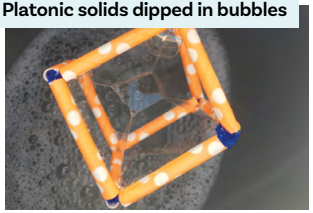
What do you notice?

Try this with the other straw and pipe cleaner platonic solids you have made.



Check out this moving animation of a tesseract projected in two dimensions: en.wikipedia.org/wiki/Four-dimensional_space#/media/File:8-cell-simple.gif

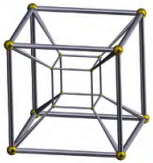
Platonic solids dipped in bubbles



Two-dimensional representations of four-dimensional shapes

A four-dimensional tetrahedron is known as a **5-cell**.

A four-dimensional cube is known as a **tesseract**.



CHALLENGE ENTERING THE FOURTH DIMENSION

Investigating platonic solids and other 3D shapes
Although the properties of polyhedra (3D shapes) are still used in game development, the relationship between the number of vertices (corners), edges and faces was discovered by Leonard Euler in 1758.

Name	Sketch of shape	Vertices	Edges	Faces
Tetrahedron				
Hexahedron (cube)				
Dodecahedron				
Square-based pyramid				
Choose your own solids to investigate				

Choose different 3D solids and complete a record to show your results.
Find a relationship between the numbers.

CHALLENGE THE COMPUTER ALWAYS WINS

IF YOU HAVE EVER PLAYED A VIDEO GAME, YOU HAVE INTERACTED WITH ARTIFICIAL INTELLIGENCE (AI).

The most common role for AI in video games is controlling non-player characters (NPCs). Designers often use tricks to make these NPCs look intelligent. One of the most widely used tricks, called the **Finite State Machine (FSM) algorithm**, was introduced to video game design in the 1990s.

In an FSM, a designer generalises all possible situations that AI could encounter, and then **programs a specific reaction for each situation**. Basically, an FSM AI would promptly react to the human player's action with its pre-programmed behaviour.

Computer vs human — noughts and crosses
You might have played noughts and crosses against friends or family members.

Do you have any strategies to win? Is it best to go first or second?

The aim of the game is to get either three noughts or three crosses in a line.

How to play?

1. Draw a three by three grid
2. First player draws a cross in an empty section of the grid.
3. The second player draws a nought in an empty section of the grid.
4. Repeat this process until either player has three crosses or three noughts in a row OR all the spaces are full and no-one has three in a row.
5. Play several games taking it in turns to play first and second.

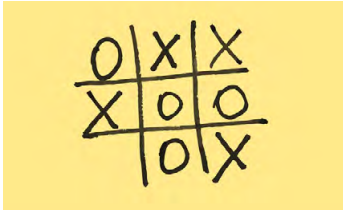
What do you notice?
Write a set of instructions to play noughts and crosses for a computer to follow.

Rules and instructions that we give to computers are called **algorithms** and a collection of instructions is a computer program.

- Write a computer program so the computer always wins if it plays first. Is this possible?
- Write a computer program so the computer does not lose if it plays second. Is this possible?

We have started some games for you below. What could happen next?

What might be some of the issues with developing video games where the computer always wins?

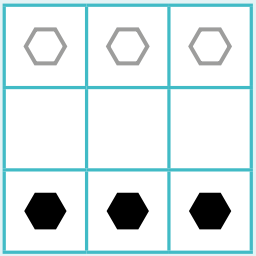


Route one
Computer: Draw a cross on one of the corners
Human: Draw a nought in the centre
Computer:

Route two
Computer: Draw a cross on one of the corners
Human: Draw a nought on the opposite corner
Computer:

Route three
Computer:
Human:
Computer:

Route four
Computer:
Human:
Computer:



Starting positions

Ideas for game set-up

The colour of the arrows needs to match the colour of the tokens under each compartment of your game.

Computer vs human — Hexapawn

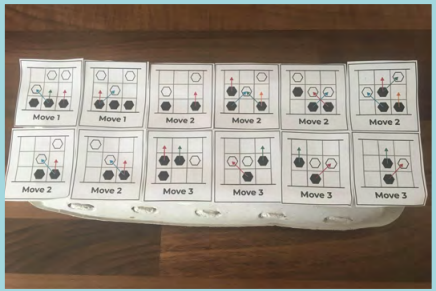
After playing several rounds of noughts and crosses and learning from your experience, you wrote a 'computer program' that responds to any move that the human plays. This idea of responding to players' moves is the basic principles of how game developers use AI.

Hexapawn is another game that you can build to respond to players' moves and eventually becomes unbeatable.

How to play

- Draw a three by three grid.
- Place three counters of the same colour on either side of the board.
- Each player plays with one colour.

Try playing hexapawn online



Moves

- Taking it in turns, each player can move one counter forward if there is nothing in that space **OR**
- Take the opponent's piece that is in a diagonal space.

Winning

- Getting a piece onto the last row.
- Blocking your opponent so they cannot play.
- Taking all your opponent's pieces.

Have a go at playing a few rounds with a friend or family member.

Are there any strategies that help you win? Does it help to go second or first?

Build an unbeatable hexapawn computer game

MATERIALS

- 24 small boxes or two 12 egg cartons.
- At least four different coloured tokens (you could use sweets, beads or counters). You'll need a large number of each.
- A blank three by three board.
- Two different playing pieces (these are included in your pack or make your own). Three of each.
- A copy of the 24 board positions that are on pages 20 to 21. There is also a copy in your box.
- Coloured pens and pencils the same colour as your tokens.

Building your hexapawn computer game

Copy and cut out the 24 images of the board.

Stick one on each box or on top of every egg holding space on your carton. These represent every move that the 'computer' will be able to make.

Colour all the arrows so that they match the colours of the tokens you have (we have used red, green, blue, and orange).

Fill each box or space in your egg carton with tokens with the colours that match the arrows.

Playing your hexapawn computer game

- Decide on the colour for the 'human' player. They will always play first.
- All the moves the machine can make are shown on the 24 image of the board.
- The 'human' player makes the first move.
- Look for the image that shows the same move the 'human' player has made (human is white and computer is black).
- Take out one of the tokens at random from under this image.
- The 'computer's' token moves according to the direction of the arrow that is the same colour as the token pulled out.
- The 'human' player makes their second move.
- Look for the image that shows the same move the 'human' player has made.
- Take out one of the tokens at random from under this image.
- The 'computer's' counter moves according to the direction of the arrow that is the same colour as the token pulled out.
- Repeat this sequence until the 'human' or the 'computer' have won.

Learning to become unbeatable

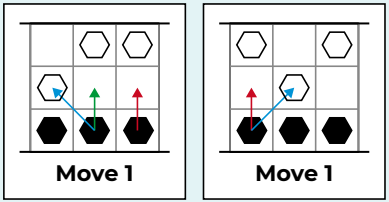
- Each time the 'computer' loses a game, remove the token that corresponds to the last move it played.
- If they win, make no changes.
- What happens? How does the 'computer' become unbeatable?
- Can you adapt the computer game to increase the chance that the computer will win?
- Can you adapt the computer game to decrease the chance that the computer will win?

Stretch and challenge

How many games does it take for the computer to learn how to play a perfect game?

Does this number change depending on how well the 'human' plays?

Develop a system to record and show your results.



Choose the image that shows the move the 'human' has made.

The coloured token should match one of the coloured arrows on the image.

This will tell you what move the 'computer' will make.

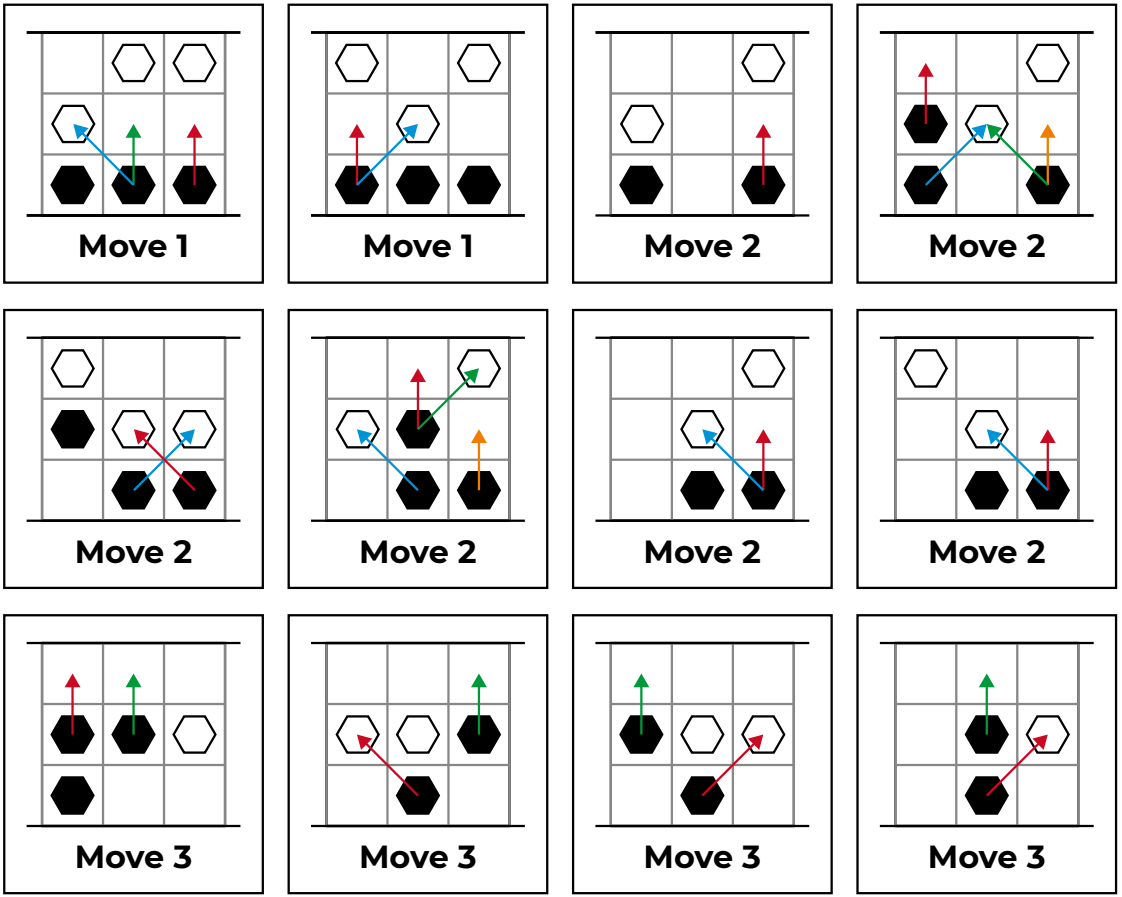
Copy and cut out the images of the hexapawn boards

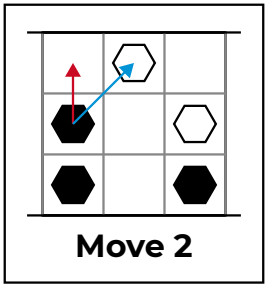
Each board represents the moves the computer could make.

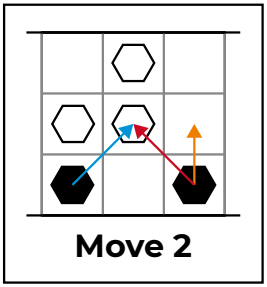
The colours of the arrow represent the coloured tokens in the box under the image.

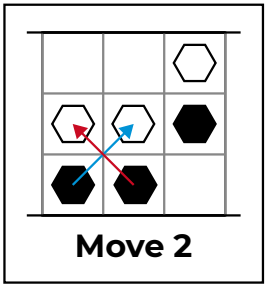
The arrows represent the different moves that the computer will make depending on which colour token is selected.

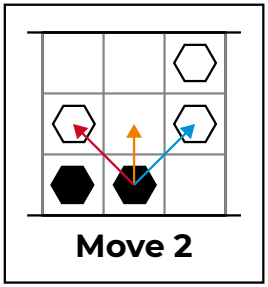
A PDF version of the game moves can be found on the *This is Engineering:* Entertainment page on our resource hub.

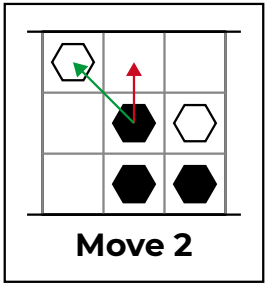


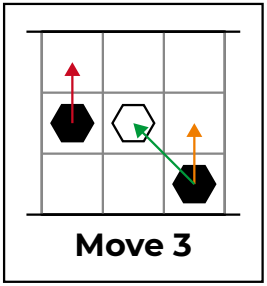

Move 2

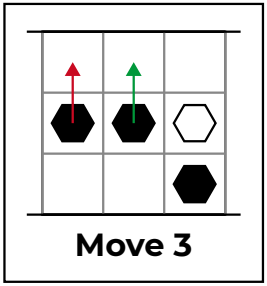

Move 2

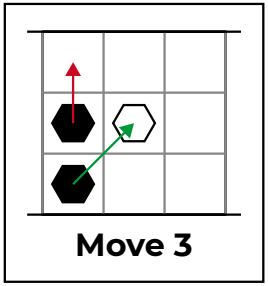

Move 2

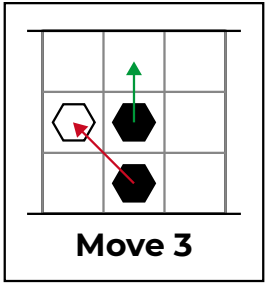

Move 2

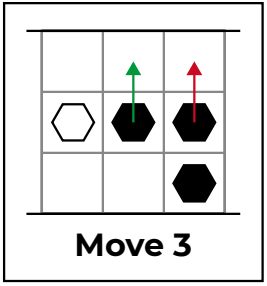

Move 2

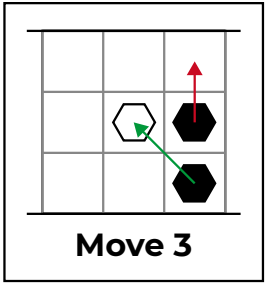

Move 3

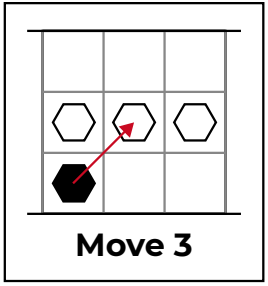

Move 3


Move 3


Move 3


Move 3


Move 3


Move 3

JAHANGIR
BROADCAST HERO

ABOUT ME

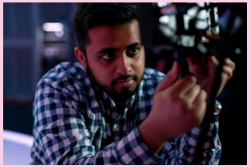
Jahangir grew up making cardboard cameras and pretending he was behind the scenes. This led to his work keeping programmes on air for the BBC and Sky.

"ENGINEERING IS CREATIVE. YOU HAVE TO THINK DIFFERENTLY AND APPROACH PROBLEMS IN A DIFFERENT WAY."

From music festivals to political debates, he is there with the action and makes sure everyone watching doesn't miss a moment.

A big part of the job is working as a team to bring the shows together successfully and every new show, whether it's Glastonbury or the BAFTAs, brings a whole new team of different people to learn from.

Find out more about Jahangir by visiting the *This is Engineering* website



CHALLENGE ALL ABOUT THE SOUND

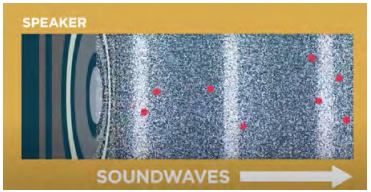
SOUND PLAYS A BIG PART IN BOTH TV AND RADIO BROADCASTING

What is sound?
Sound is a way that **energy** can be transferred when things **vibrate**.

If you bang a drum, you make the tight skin vibrate many times per second, this makes the air around it vibrate and as the air moves it transfers energy out from the drum in all directions.

How does sound travel?
Sound must travel through a **medium**. It travels approximately 343 m/s (metres per second) through the air and faster through liquids and solids. The waves transfer energy from the source of the sound to its surroundings. Your ear detects soundwaves when vibrating air particles cause your ear drum to vibrate. The bigger the vibrations, the louder the sound.

Sound waves travel as **longitudinal waves,** which means that the vibrations travel backwards and forwards in the same direction as the wave moves.



MATERIALS

- Sticks (included in pack)
- Nuts (included in pack)
- Masking tape
- Somewhere to attach the wave demonstrator

TIME TO MAKE

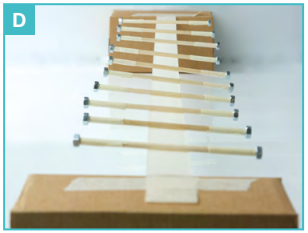
Time to make your own wave machine to show the properties of waves.

A Wrap each end of a stick with one or two loops of tape.

This will give the nut a surface to bite into.

B Thread a nut onto end of the stick.

C Repeat this for all the sticks.



D Stretch a piece of tape sticky side up between two supports (wall, chair or even two boxes) and tape down the ends. Place the sticks across the tape, evenly spaced.

Give one end of the skewer a 90° twist. What happens?

E If you are doing this activity and don't have the sticks and nuts then skewers and jelly babies/ marshmallows also work well!

CHALLENGE ALL ABOUT THE SOUND

Time to investigate
We can look at some of the behaviours of soundwaves using **transverse** waveforms. We can use this to show the pitch, volume of noise and how it behaves when it meets a solid object.

Amplitude shows us the height of each wave. The greater the amplitude of a wavelength, the louder the noise.

Wave frequency (number of waves that pass a point in a given time) shows us the **pitch**. The greater the frequency, the higher the pitch.

Your wave machine will show how a wave travels.

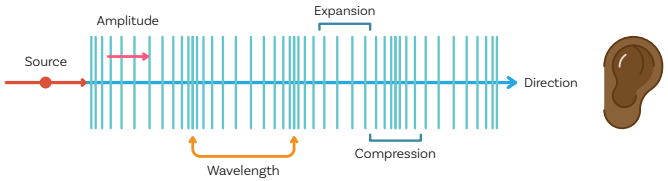
Use your wave machine to show:

- a change of **volume/amplitude**
- a change in **pitch/frequency** of sound.

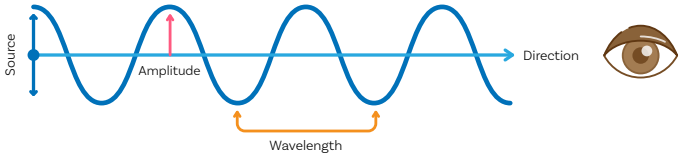
Soundwaves travel faster underwater. Use your wave machine to show a change in the speed in which the waves are travelling half way across your machine.

Handy hint: Try removing the nuts from half of your sticks. What happens? What do you think this shows?

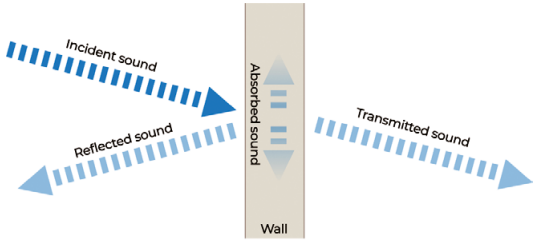
Longitudinal waves



Transverse waves



Soundwaves are reflected back when they meet certain objects (think about echoes you might hear) or are disturbed through other objects (such as a wall).



Use your wave machine to show how waves are not transmitted but reflected upon meeting a solid object.

Use your wave machine to show what happens when soundwaves are partially transmitted and partially reflected through an object.

CHALLENGE SYNTHETIC BEATS

SOME ELECTRONIC MUSIC YOU WILL HAVE LISTENED TO WILL USE SYNTHESIZERS.

Synthesizers are electronic keyboards that can generate or copy virtually any kind of sound, making it mimic the sound of a traditional instrument, or create brand new sounds.

What sounds can you invent?

Oscillators form the core of many synthesis systems. They make sound by vibrating at a steady rate, known as its frequency (or pitch).

As synthesizers mimic the sound of virtually any other instrument, they have a number of different voices or oscillators, which produce waves of different shapes. Different types of sound will produce different types of waveforms. It can combine waves to make complex sounds and release to make the sounds mimic existing instruments like pianos.

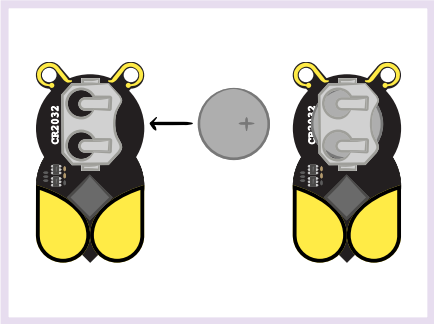
Bumble Beep

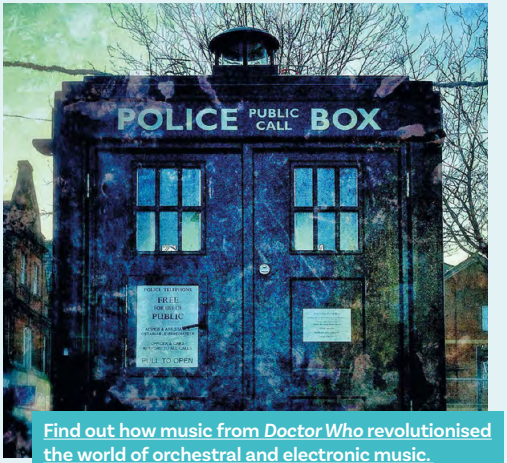
In your packs there is an oscillator to produce synthetic sounds called the Bumble Beep.

The Bumble Beep contains two oscillators that can be activated by connecting different materials between either the bee's antenna or the wings.

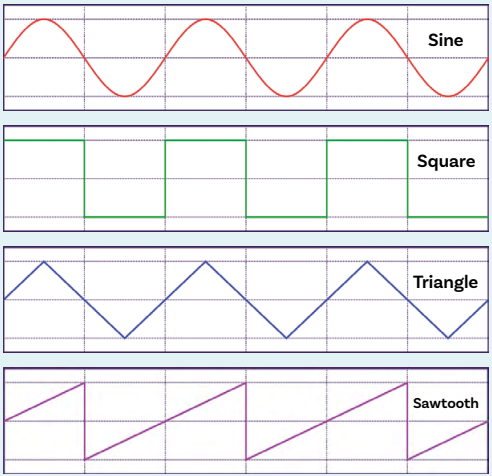
The frequency of the oscillator will depend on the electrical conductivity of the material connected. The oscillator powers a small piezo speaker so we can hear it.

Getting started
First insert the CR2032 coin cell to power the Bumble Beep.





Find out how music from *Doctor Who* revolutionised the world of orchestral and electronic music.



CHALLENGE SYNTHETIC BEATS

Sound conductor
Did you know that you conduct electricity?

Try holding the bee's antenna between your thumb and finger; one in each hand. The bee should start making a sound.

What do you notice about the pitch (or frequency) if you squeeze harder? Do you hear a change? If so, why do you think that is happening?

The more electricity that flows (between the antenna or between the wings) the higher the frequency the oscillator runs at and we hear a higher-pitched sound.

The oscillator connected to the wings has a lower sensitivity to allow a range of different materials to be investigated with Bumble Beep.

What sound effects can you make with just your fingers?

Light theremin
Let's try connecting a component called a **light dependent resistor (LDR)** to make a musical instrument you can control by simply moving your hand around in the air!

Because the LDR is a relatively good conductor in daylight, we will connect it to the wings with crocodile clips as shown in the image on the right.

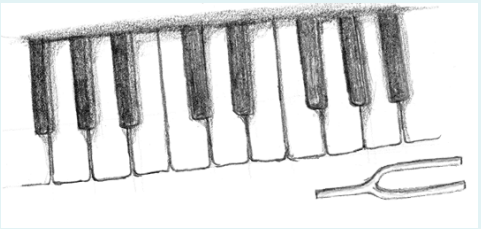
You should hear a tone play. Try moving your hand closer to the LDR. What happens to the pitch?

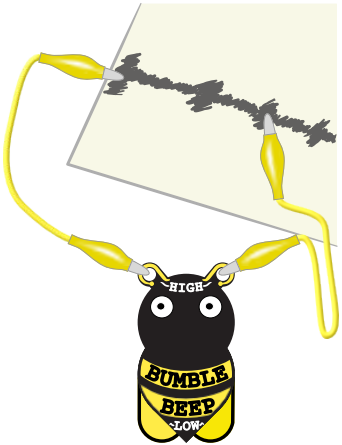
Can you play a tune by moving your hand carefully enough?

Pencil organ
Graphite, used in pencils, also conducts electricity, even when it's drawn onto paper! We can make our own variable resistor by simply drawing a continuous line onto paper. You may need to experiment with different pencils. Softer pencils work best, but coloured pencils might not work as well as they contain wax, which is an insulator.

Draw a long rectangle and fill it in with a few layers of pencil. Connect the crocodile clips to the bee's antenna and try touching them to various points. You can clip one lead to the edge of the paper to make this easier.

Can you tune your drawing by modifying the shape or amount of colouring to make a paper organ?





THIS IS ENGINEERING

PAVLINA

LIGHT PAINTER

ABOUT ME

Pavlina loves travelling and is passionate about fashion and expressing her own style.

As a lighting engineer, Pavlina has designed lighting for fashion shows, museums and art galleries.

"ENGINEERING GAVE ME THE CHANCE TO COMBINE MY TWO PASSIONS: SCIENCE AND ART."

She collaborates with fashion designers to create lighting effects for their shows at events, including Paris Fashion Week, as well as working with museums and art galleries to create the perfect environments for their exhibitions.

Find out more about Pavlina by visiting the *This is Engineering* website

CHALLENGE SETTING THE MOOD

What do you think?
Where have you seen lighting effects used?

How can different types of lighting make us feel? How is lighting used in, for example, gigs/horror films/stage productions?

Myth-buster:
Many people are taught that a rainbow is made of seven colours: red, orange, yellow, green, blue, indigo, and violet. Actually, there are an almost infinite range of colours in a rainbow as they all mix into each other (there is no hard edge between the colours). There is also a type of light that is invisible to humans, called ultraviolet light.

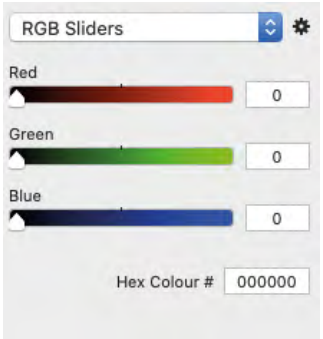
Colour mixing
There are only three colours of light needed to create any colour you can imagine! These are called 'primary colours of light' and are **red**, **green** and **blue**.

"But this is different to the primary colours I use for painting?"

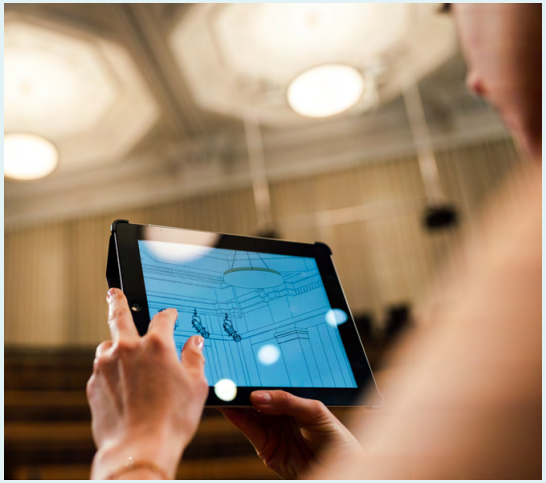
Correct. When we talk about 'material colours', like the ones used by painters, then red, blue and *yellow* are the primary colours. If we are talking about physics and light, then the primary colours are red, blue and *green!*

When selecting a different colour for your text or images on a computer you can make your own colours using 'red', 'green' and 'blue' sliders.

What is the maximum number of intensities available for each colour?



A hex colour code is a six digit number to represent a colour in RGB format.

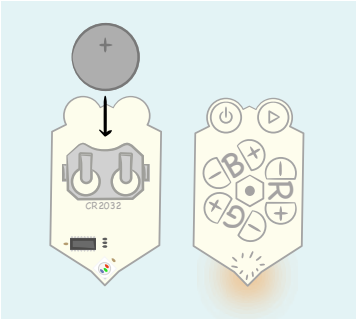


RGBug

The RGBug has an LED (light emitting diode) on its tail that can emit each of the three primary colours of light: **red**, **green** and **blue** (RGB). The RGB LED is actually three separate LEDs that have been packaged together.

By mixing different intensities of the three primary colours, we can cause the human eye to perceive many more colours.

Getting started
First insert the CR2032 coin cell to power the bug.



Turn the bug over and place on a white surface, like a piece of paper, so that we can see the glow from the tail.

Try increasing the intensity of one of the colours by tapping

Each colour can be set to five different intensities: 0%, 25%, 50%, 75% and 100%.

That's five levels for each colour.

What is the total number of different colours the bug can create?

Modern screens commonly use 256 different levels for red, green and blue, giving a huge **16,777,216** possible colours!

Finding colours
Let's explore the colour spectrum.

Look at the table (right) and use the RGB values in the first two rows. What colours do you get?

What happens to the colour output if you double the intensity of the RGB colours?

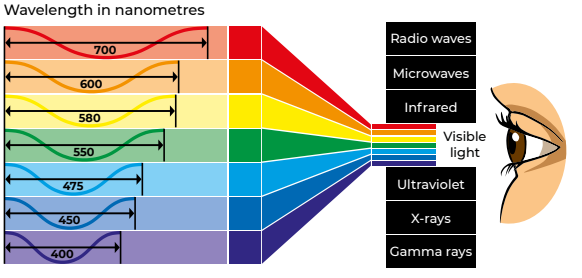
White light is the complete mixture of all of the wavelengths of the **visible spectrum**.

Can you predict what combination would make white light and test your prediction with the bug?

Light sequences
Press the play button on the bug and watch the LED cycle through the **spectrum**.

Red	Green	Blue	Colour
0%	0%	25%	
75%	0%	25%	
			Yellow
			Orange
			White
			What other colours can you find?

The visible spectrum is the portion of the electromagnetic spectrum that is visible to the human eye.



Check out our other resource – *Light saver* – to find out more about the visible light spectrum.

ABOUT ME

Sonya loved drawing and making up stories as a child, and also loved maths.

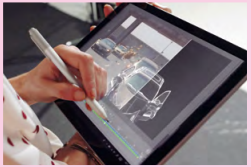
"ENGINEERING BRINGS MY IDEAS IN FILM TO LIFE."

Bringing together these two interests seemed impossible until she completed a degree in engineering and computer science, and landed her first job working for Disney Animation as a visual effects artist.

Engineers in special effects are presented with seemingly simple problems like how to create digital fires, or water that looks realistic but is actually animated.

Using creativity, technical skills and attention to detail, Sonya brought ideas like these to life on the screen.

Find out more about Sonya by visiting the *This is Engineering* website



CHALLENGE CREATING A HORROR SCENE

VISUAL EFFECTS IN THE FILM INDUSTRY HAVE COME A LONG WAY WITH COMPUTER-GENERATED IMAGERY (CGI) PLAYING A BIG PART IN FILM PRODUCTION.

However, before CGI, film-makers and engineers found all sorts of creative ways to enhance film-making through innovative approaches to visual effects.

Horror films in particular have always been at the forefront of visual effects since the early days of film – you can't show zombie corpses, ghosts, ghouls and gore without some visual trickery.

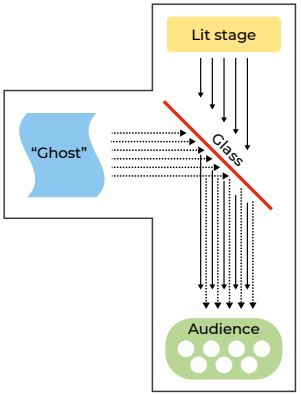
One of the oldest visual effects used is known as 'Pepper's Ghost'. It is an illusionary technique that creates transparent ghostly images that can appear to talk, move, hold objects, or even fight!

Modern versions of this are still used today including in Disney's Haunted Mansion ride and at Whitney Houston's hologram tour bringing her back to life even after she has passed away.

How does it work?
It is all about the properties of light.

The illusion involves placing a piece of glass at an angle between a brightly lit 'stage' room in which viewers look straight ahead, and a hidden room, kept dark, that holds a 'ghostly' scene.

Most of the **light rays** from the lit stage are **transmitted** through the glass toward the audience, while some of the **incident rays** from the hidden room are **reflected** by the glass. The images in the two rooms both reach the audience, creating the Pepper's Ghost illusion.



Mini-glossary

An **incident ray** is a ray of light that strikes a surface.

Reflection is when light bounces off an object. If the surface is smooth, like glass, it will reflect at the same angle as it hit the surface.

Stage setup for Pepper's Ghost during a theatre show. To the audience, it appears as if the ghost is on stage.

Image of the dancing ghosts in the ballroom in Disney's Haunted Mansion.

CHALLENGE CREATING A HORROR SCENE

Setting up your Pepper's Ghost illusion

Recording your video

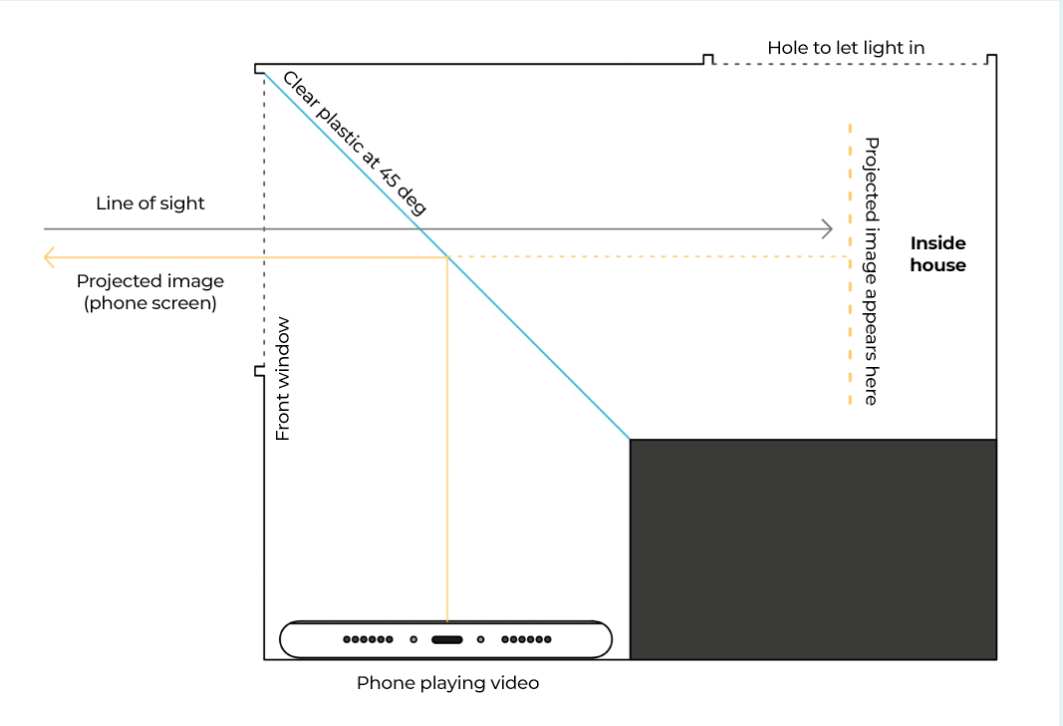
- Use a dark/black background.
- Make sure the subject (thing you're filming) is well lit and in focus.
- Film as steadily as possible – prop up your camera if you can.

If you can't record a video, an image with a black background and lit subject will work too or you can find pre-made versions on YouTube.

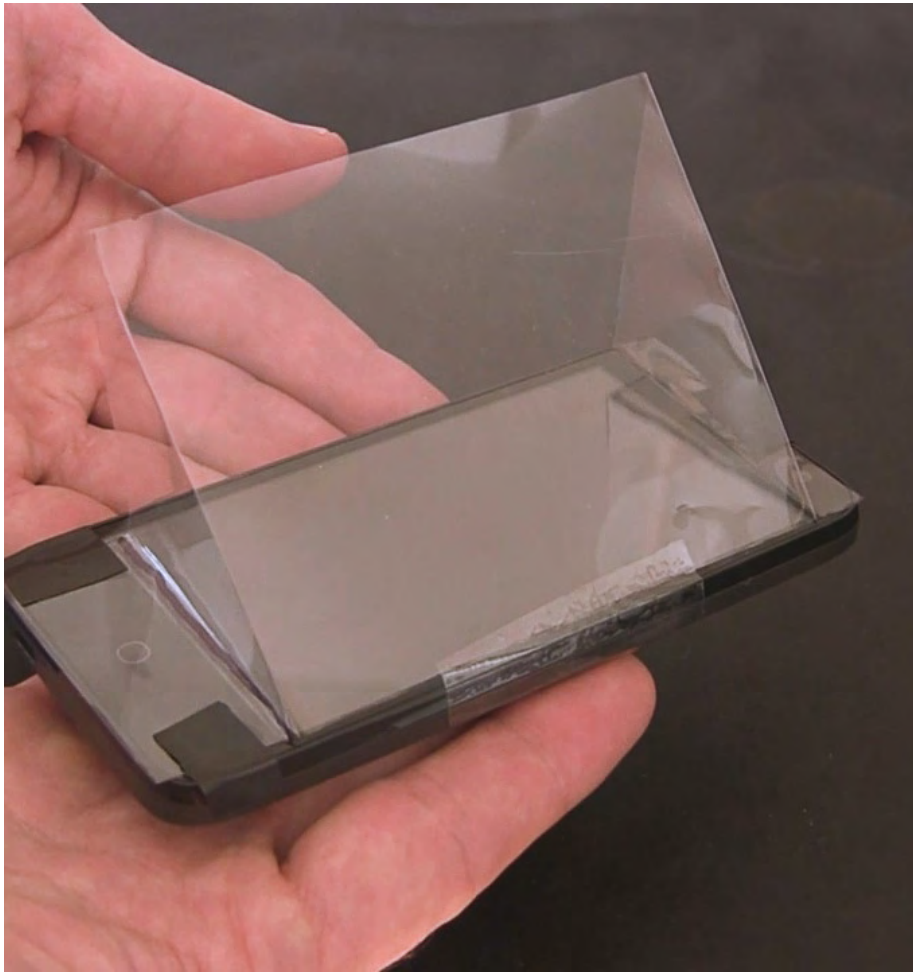
Making your stage

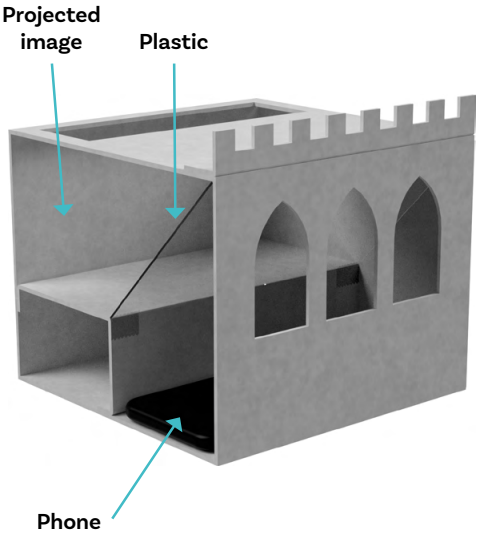
- Use card to make the basic shape.
- Fix clear plastic (you can find this in the pack) at 45° to the phone.
- The projected image will appear distance in the room as it is from your phone screen.

Keeping the area around your phone dark will help with the illusion.



Side view of illusion set-up




Projected image
Plastic
Phone

CHALLENGE THE FULL PRODUCTION

KNOWLEDGE OF LIGHT AND SOUND EFFECTS IS A CRUCIAL ELEMENT OF EVERY FILM PRODUCTION.

Especially now, when special effects are getting more popular and sophisticated by the day. And people behind these achievements are none other than engineers, among other members of the crew.

Bring together the skills and tools you have used in this challenge booklet from the mixing colours activity and the synthetic sounds activity to create your own short horror film.

Story

- Keep it simple – don't try and cram too much into 60 seconds!
- Give it a beginning, a middle and an end.
- Use what's around you – everything in your life can be part of the film.
- You don't have to tell a story. A sequence of images or montage can also make fascinating films.

Directing

- Create a storyboard and use this to add in when you will include special effects.
- Keep your camera steady.
- Make sure the light is good. What lighting effects could you create with the RGBug?
- Keep your subjects in the camera frame.
- Take care of what angle you are filming at.

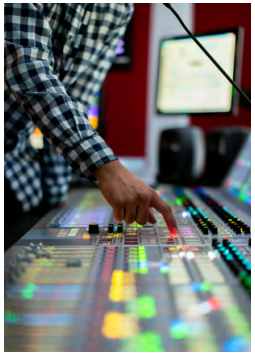
Editing

- Download OpenShot. It is a free video editing tool. Or you might be able to use inbuilt apps on your phone or tablet.
- Working from a storyboard might help to shoot the film in several parts.
- Remember continuity when you put them together.

Sound

- Sound is a crucial part of horror films and is often what makes them scary!
- Recording the sounds separately might make your film look more professional. This way you don't pick up any background noise when you are filming the visual shots.
- Use the Bumble Beep to create your own sounds.

Watch this one minute short horror film *The Familiar* for inspiration.



Royal Academy of Engineering

The Royal Academy of Engineering creates and leads a community of outstanding experts and innovators to engineer better lives. As a charity and a Fellowship, we deliver public benefit from excellence in engineering and technology and convene leading businesspeople, entrepreneurs, innovators and academics across engineering and technology. As a National Academy, we provide leadership for engineering and technology, and independent, expert advice to policymakers in the UK and beyond.

We have three goals:

Sustainable and Innovative Economy, where sustainability drivers, innovative industries and resilient infrastructures are aligned to drive growth and productivity that will support better lives for all.

Technology Improving Lives, where technology in all its forms is used to meet the most important human needs, avoid harm, support fairer societies and break down barriers to opportunity.

Engineering Community Fit for the Future, where our community reflects society in its diversity, commits to creating inclusive cultures to help drive engineering excellence, and has the skills to meet future needs safely, securely and ethically, and to keep pace with innovation.

Our work is enabled by funding from the Department for Science, Innovation and Technology, corporate and university partners, charitable trusts and foundations, and individual donors.

Royal Academy of Engineering
Prince Philip House
3 Carlton House Terrace
London SW1Y 5DG

Tel: +44 (0)20 7766 0600
www.raeng.org.uk

Registered charity number 293074