Royal Academy of Engineering

THIS IS ENGINEERING

SUSTAINABLE FUTURES

Student Guide

Some of the biggest challenges we face stem from how we interact with our environment, and engineering is at the heart of finding sustainable solutions.

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

INTRODUCTION

SOME OF THE BIGGEST CHALLENGES WE FACE STEM FROM HOW WE INTERACT WITH OUR ENVIRONMENT, AND ENGINEERING IS AT THE HEART OF FINDING SUSTAINABLE SOLUTIONS.

From renewable power to recycling, to making our homes more energy efficient, engineering is a vital field.

In a changing environment, what makes a hero?

Whatever change you want to make, choose engineering and be the difference.

Check out *'Help the environment - This is Engineering'* at: https://www.thisisengineering.org.uk/what-interests-you/the-environment/

MUSEUM OF ENGINEERING INNOVATION

Engineering is everywhere – but often we don't notice it.

The planes flying overhead, the food on our tables, and the inside of your fridge are just some of the engineering innovations that make life easier every day.

Engineers are also problem-solvers, tackling the world's biggest challenges and shaping the future.

Energy experts and chemical engineers are developing solutions to the climate crisis. Mechanical engineers are working on wind turbines and solar panels. Civil engineers are making buildings greener world-wide.

This is Engineering celebrates the engineering that shapes the world and shows how engineers make a difference in our lives.

Visit the Museum of Engineering Innovation online to discover more about these inventions, and the engineers who are building a sustainable future.

CHOOSE YOUR CHALLENGE

Olivia

The problem with plastics

Investigate how much plastic there is in the products we use every day.

Explore the good and bad of plastics.

The seven types of plastics fact sheet.

Sorting plastics using electrostatic charge.

Page 10

Waste not, want not

What do we mean by circular and linear economy?

How long does it take to decompose?

Packaging for a circular economy.

Page 15

Enass

Battery power

Investigate how much charge is left in your batteries.

Make and test your own lemon battery.

Page 20

Energy efficiency

Discuss accessing electricity.

Make your home more energy efficient.

Page 23

Halvard

Optimum growing conditions

What are the acid and alkaline levels of your soil?

Do your plants need watering?

Where is the best place for your plants to get the sunlight they need.

Page 27

Just ripe

Create a test that will tell you how ripe your fruit is.

Page 33

Competition

Sustainable Futures Innovation Challenge

Find the 'Sustainable Futures Innovation Challenge' booklet at
http://stemresources.raeng.org.uk/this-is-engineering-sustainable-futures

THE *DATAHIVE* GREEN

The *DataHive* Green is a device which has multiple sensors to measure:

- Temperature (°C)
- Light (Lux)
- Voltage (V)
- Resistance (Ohm Ω)
- Electrostatic charge

The *DataHive* is used for many of the challenges in this booklet. Keep an eye out for images of the *DataHive*.

The *DataHive* can be powered by a coin cell battery* (included) or by connecting it to a computer or laptop using a Micro-USB (not included).

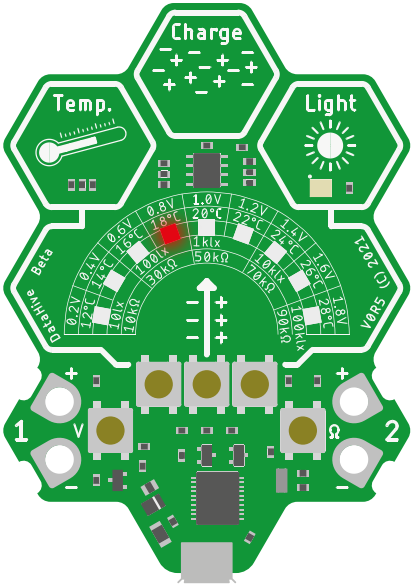
You can view data from the *DataHive* in a number of different ways.

The *DataHive* has a clock, which will automatically set to the correct date and time.

The *DataHive* has many more applications than the activities in this booklet. We want you to explore, experiment and come up with your own ideas for how it can be used.

Instant data

You can get an instant reading when you have the coin cell battery in the *DataHive* and press the corresponding button for the different sensors.



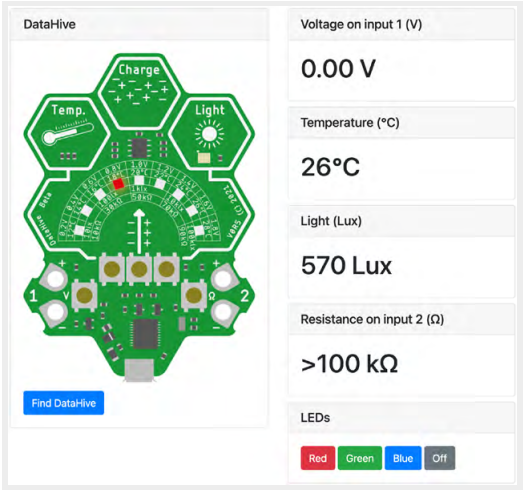
*Coin cell batteries are small and can be easily swallowed. Take care when using these, especially with smaller children.

Live data

Connect your *DataHive* to a computer or laptop using a Micro-USB and visit data.Redfern.uk. Use Chrome or Microsoft Edge.

Click 'Connect' to connect the *DataHive*. You will see live data for each of the five sensors.

You can also turn on all the LED lights red, green or blue using the LED light controller.

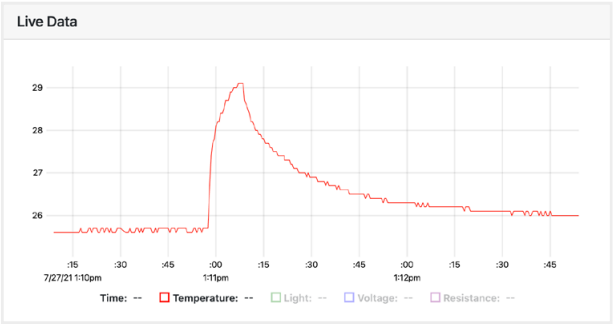


Graphing live data

You will see data displayed live for all the sensors except for the electrostatic charge sensor on a graph.

The x-axis represents time.

You can select which of the four sensors data you would like to view on the graph.



Logging data

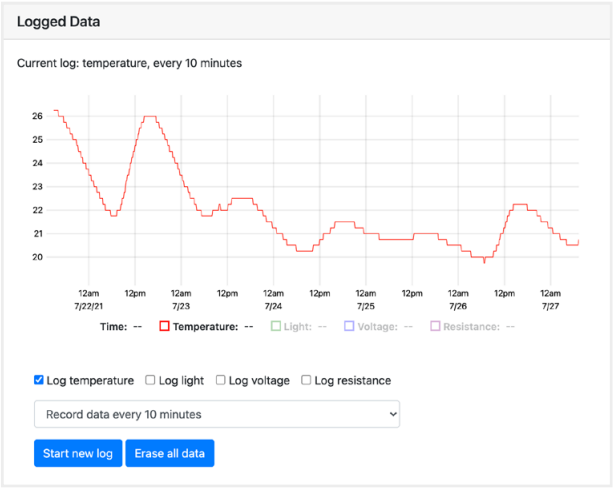
If your *DataHive* is connected to power (either the coin cell battery or connected to a computer or laptop), it can record temperature, light, voltage, and resistance*.

You can view your logged data by connecting to a computer or laptop and visiting data.Redfern.uk.

You can select how regularly you would like to record data. You can also select what data you would like to record.

Once the memory is full, it will start overriding historical data.

You can also delete historical data manually by visiting data.Redfern.uk.



STEM BADGES

STEM BADGES REWARD YOU FOR YOUR COMMITMENT TO STEM.

For each activity you complete from this booklet, think about which engineering habits you are using and mark this out on the STEM badge record sheet.

Once you have completed enough of the activities and challenges, cash them in for your STEM badges!

The badges are digital so you can link them to your online profiles and applications and you can't ever lose them.

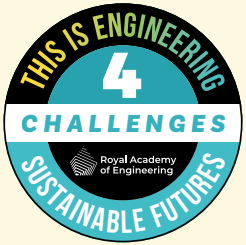
How to collect your badges
For each challenge, mark out up to three 'engineering habits' you have been using on the following page.

Show and tell your teacher what challenge you have been working on and answer these questions:

- What problem did you solve?
- Which engineer or area of engineering does this challenge relate to?
- What did you discover by working on this challenge?
- Which engineering habits did you use?
- Did you work in a team or independently?
- What worked well?
- How could you improve this?

HOW TO COLLECT

COMPLETE SIX
challenges



COMPLETE FOUR
challenges

COMPLETE TWO
challenges

Tell us what you think...

Take our short survey for a chance to win £500 of robotics/coding equipment for your school.

Scan the QR code on your phone, or go to stemresources.raeng.org.uk/student-survey

STEM BADGE TRACKER

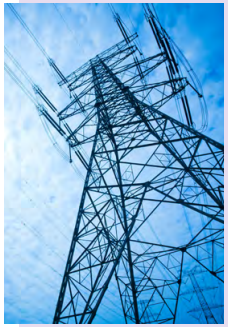
Name:

THE PROBLEM WITH PLASTICS

WASTE NOT, WANT NOT

BATTERY POWER

ENERGY EFFICIENCY



OPTIMUM GROWING CONDITIONS

JUST RIPE

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: Sustainable Futures 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: Sustainable Futures' page on our STEM resource hub.

OLIVIA

FRAGRANCE FINDER

ABOUT ME

Reduce, reuse, recycle – I grew up hearing these words since primary school and am passionate about creating a waste-free world.

"ENGINEERS ARE PART OF THE MODERN WORLD AND HELP MAKE DREAMS BECOME REALITY WITH THEIR PROBLEM-SOLVING SKILLS."

My house was a blend of science and art thanks to my parents. I did A-Levels in Music and English literature as well as maths and chemistry. Doing a degree in chemical engineering allowed me to follow my passion for sustainable choices in a tangible way.

After completing my degree, I started working for cosmetics company Lush. Working there and sourcing and creating chemicals in a sustainable way has given me the power to make a difference.

For me, chemical engineering means you can end up creating anything based on your own curiosity.

I now work for a sustainable waste consultancy – Resource Futures. My passion and interest for the circular economy led me to this role.

Find out more about Olivia by visiting the This is Engineering website

CHALLENGE

THE PROBLEM WITH PLASTICS...

OLIVIA'S ROLE, BOTH AT LUSH AND AT RESOURCE FUTURES INVOLVES INVESTIGATING THE MATERIALS WE USE, WHERE THEY COME FROM, HOW THEY ARE PRODUCED AND, MOST IMPORTANTLY, WHAT WE THROW AWAY.

And one of the biggest resources we consume globally is of course plastic!

Plastics everywhere
Plastics are everywhere. They are an integral part of our modern life. Their use has increased by twenty-fold in the last 50 years and is expected to double again in the next 20.

Today, nearly everyone, everywhere, every day comes into contact with plastics – especially plastic packaging.

One minute plastic challenge

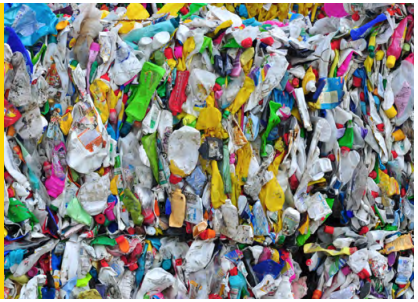
Individually, write down as many things as you can that are made from or use plastic.

After one minute, share answers with your group. Did you have something that no one else had? Did any of the answers surprise you?

Mini-glossary

Plastics are a group of materials, either synthetic or naturally occurring, that may be shaped when soft and then hardened to retain the given shape.

Plastics are **polymers**.
A **polymer** is a substance made up of many repeating units.



WE USE PLASTICS IN:

In your small groups, come up with more than one example where plastic is used for each category.

Time to reflect

The good and the bad
Individually, or in small groups discuss the following:

- What are some of the benefits and what are some of the drawbacks of using plastic?
- Is all plastic the same?
- Do you know of any innovative approaches to how plastic has been used?

There are of course many benefits to using plastic; however we need to make some big changes around how we make, use and dispose of plastic.

If we carry on as we are, research suggests that by 2050 there will be more plastic than fish in the sea.

Time to calculate

In 2014, for every 100 fish, how much plastic was there? Use the diagram shown below for the ratios.

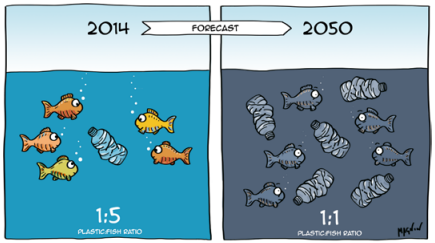


Illustration by Alexandre Magnin:
www.sustainabilityillustrated.com

Stretch and challenge

Take one small sample of the ocean. From 2014 to 2050, predictions show that there will be an additional 200 pieces of plastic. How much plastic was in that sample in 2014?

Time to research

It can feel like a bit of a minefield out there with so many types, uses and recycling properties of different plastics.

Time to get some questions answered and get 'clear on plastic'.

Visit https://clearonplastics.com and find out about one of the following:

- What happens to plastic in our tea bags?
- Why is plastic used in our health and beauty products? How can we stop this?
- Why can't we replace plastic with other materials such as glass or paper?
- Is recycling worth it?
- What about bio-plastics, biodegradable and compostable plastics?

Once you have carried out your research, share your findings with the rest of your group.

Check out this video which explains types of plastics and what they are used for:
https://clearonplastics.com/what-are-the-types-of-plastic-and-what-are-they-used-for/

Watch 'Solving Plastic Pollution' video, by the Ellen MacArthur Foundation and narrated by Sir David Attenborough. to find out more about plastic pollution.

THE SEVEN TYPES OF PLASTIC – FACT SHEET

Not all plastics are made the same.

The type used will depend on what they are being used for.

Some can be really flexible, others brittle, others withstand heat and some are extremely lightweight.

Some plastics can be recycled, whereas some are really difficult to recycle. And some plastics will contaminate other plastics if recycled in the same batch.

Polyethylene terephthalate (PETE)

What products is it used in?
Clear bottles, food trays.

What does it look like?
A tough plastic which discolours if you bend it.

Can it be recycled?
One of the most commonly recycled plastics.

High-density polyethylene (HPDE)

What products is it used in?
White milk bottles, cleaning products, shampoo bottles and some bottle caps.

What does it look like?
A thick tough plastic which will spring back if bent, caps can usually be flexed.

Can it be recycled?
Very commonly recycled.

Polyvinyl chloride (PVC - U)

What products is it used in?
Clear bottles (look for a line on the bottom of the bottle), food trays, toys, piping, wire insulation.

What does it look like?
More fragile and will crack and/or stay bent if stressed, bottles make a 'crinkle' cracking sound if squeezed.

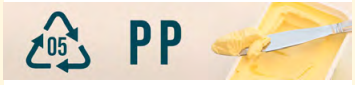
Can it be recycled?
Rarely recycled. It can also contaminate other recycling.

Low-density polyethylene (LPDE)

What products is it used in?
Carrier bags, bin liners, and packaging film.

What does it look like?
Can be thin to thick, but is known as flexi-plastic and is easily torn.

Can it be recycled?
Very difficult to recycle. You can reuse bags or some supermarkets might have specific collection points.



Polypropylene (PP)

What products is it used in?
Margarine tubs, clear fresh soup containers, some bottle caps, microwaveable meal trays, also produced as fibres and filaments for carpets and vehicle upholstery.

What does it look like?
Will shatter into stripes if compressed. Caps will usually be too hard to flex. Can usually in the microwave and freezer.

Can it be recycled?
Not generally recycled.

Polystyrene or styrofoam (PS)

What products is it used in?
Yoghurt pots, insulated disposable cups, some trays, parcel packaging. Also used for insulating material in construction industry.

What does it look like?
Will tear or pull apart depending on the form.

Can it be recycled?
Not generally recycled.

Other

What products is it used in?
Reading glasses, crisp packets. DVDs and their cases, electrical connections and wiring, general household plastics.

What does it look like?
The majority of these plastics are very tough and are likely to shatter if pressure is applied.

Can it be recycled?
Not generally recycled.

Images courtesy of: https://www.open.edu/openlearn/science-maths-technology/chemistry/the-seven-types-plastic

Sorting plastics

What's in your bins?
What about the plastic we throw away? What happens to that? Are we recycling correctly?

Check your bins and recycling for any plastic.

Do they have the labels that you could see on the fact sheet?

Visit www.recyclenow.com/what-to-do-with and find out what can be recycled and how.

Sorting plastics using electrostatic charge

Different plastics have different properties and so have different uses. In order for waste plastic to be recycled, it needs to be separated. There are many different technologies used for sorting plastics. These will often be carried out using programmed machines. One method used to sort plastics is by their **electrostatic properties**.

When two **non-conducting materials** are rubbed together, **electrons** migrate from one material to the other, leaving one material with a positive charge and the other with a negative charge. By rubbing different combinations of materials together and recording which one become positively charged and which one becomes negatively charged, you can start ordering the plastics based on their electrostatic charge.

This is called a **triboelectric series**.

Your *DataHive* has a **electrostatic charge** sensor which can measure positive and negative charge. Use this to find the electrostatic properties of different plastics.

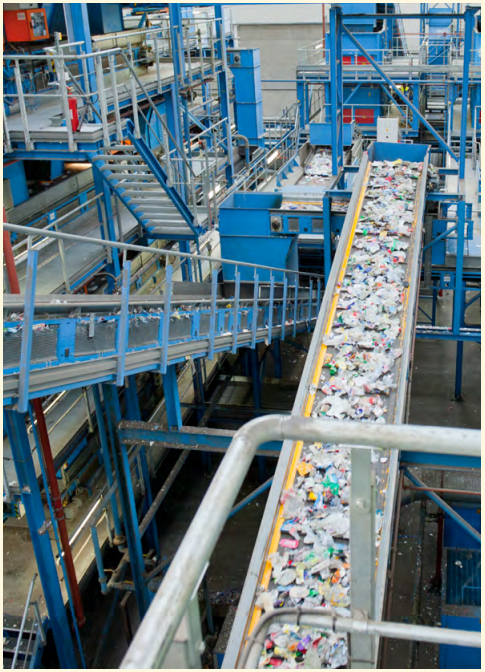
Find a piece of plastic and identify it using the fact sheet on **page 12**. Using your *DataHive*, press the button for the electrostatic charge function, move the *DataHive* towards the plastic and read the LED gauge to find out the electrostatic charge of your plastic.

Now rub the plastic with a cloth, or a t-shirt, jumper or another piece of plastic. Now hold down the button again and move towards the plastic.

- What do you notice?
- Does it work the same if you do this with different materials?
- What do the fabrics have in common that transfer an electrostatic charge?

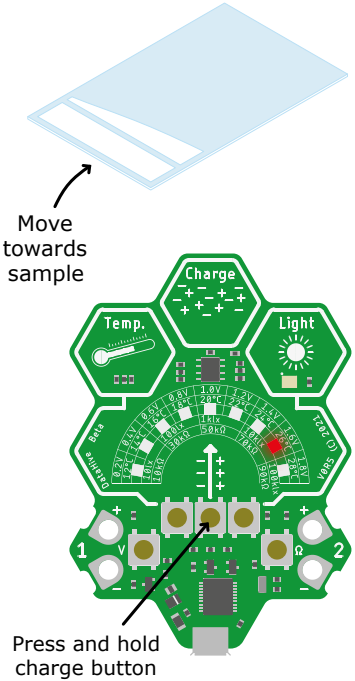
Try rubbing different materials together. Can you find any similarities between different plastics and different materials? Experiment with materials such as glass, hair and cardboard.

- Do all of them build up electrostatic charge?
- Do some build up more electrostatic charge than others?



Use the table below to help you sort the plastics and find out which are most likely to gain or lose positive or negative charge.

Material A	Material B	Positive	Negative



LED gauge will move to the left if negative charge is detected, or to the right if positive charge is detected.

CHALLENGE WASTE NOT, WANT NOT

OLIVIA SPENDS A LARGE PART OF HER JOB INVESTIGATING WHAT WE THROW AWAY, AND WHAT HAPPENS TO OUR RUBBISH AND RECYCLING AFTER IT HAS LEFT OUR HOMES.

Poor waste management has devastating effects on the environment. Waste that gets into our water systems and soil can contaminate them. Air pollution can also be a major problem, with landfills and waste burning facilities producing large amounts of harmful chemicals contributing to the serious issues of climate change.

Olivia works on how we can move from a **linear economy** to a **circular economy**.

Not on my doorstep
We put our rubbish in bins, recycling or into compost. In many countries around the world, rubbish and recycling collection does not exist in the same way. Sometimes our rubbish and recycling is taken to countries with poor waste management, which means we don't have to think about it, but it has a huge impact on other communities.

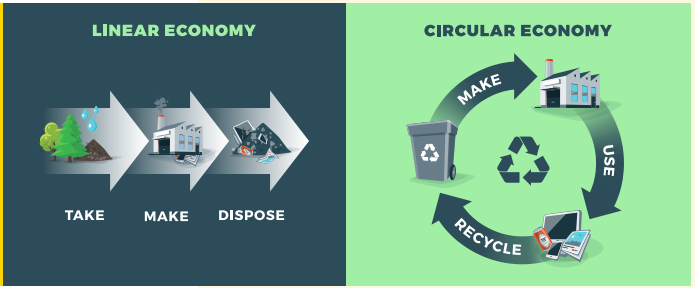
Linear economy
Although there are many plastics and other materials that we use that can be recycled, approximately one quarter of our waste goes straight to landfill. This is called a **'linear economy'**.

A linear economy follows the 'take-make-dispose' journey. This means that raw materials are collected, and then transformed into products that are used until they are finally discarded as waste.

Circular economy
What if we had a model that was 'circular', and kept products and materials circling within the system, removing waste from the equation completely?

A circular economy is based on designing out waste and pollution, keeping products and materials in use, and regenerating natural systems.

Watch the YouTube video, **'Explaining the circular economy'** made by the Ellen MacArthur Foundation.



Time to reflect

What do you think is happening here?

Time to reflect

Can you think of an example of somewhere you have seen circular economy in action?

WASTE TIMELINE

Put the items on the timeline* depending on how long you think they take to decompose.

LEATHER SHOE

BATTERY

T-SHIRT

PLASTIC BOTTLE

ORANGE PEEL

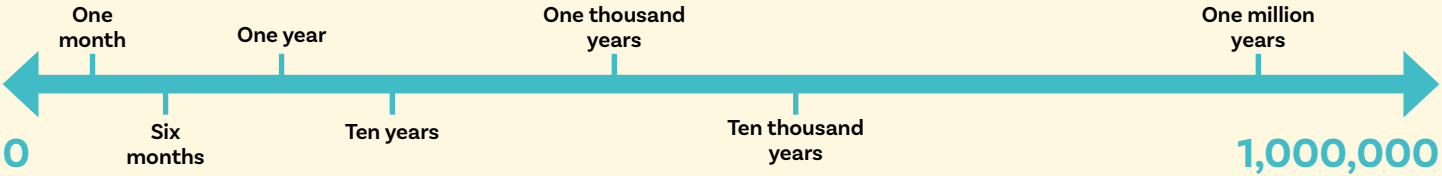
TEA BAG

GLASS

STYROFOAM

WET WIPES

PLASTIC BAG



*Timeline not to scale

Packaging for a circular economy

One example of a circular economy is an engineer who has been turning potato peel into sustainable bioplastics for the fashion and interior design industry.

Another example of circular economy in action is how Olivia, during her time at Lush, developed a new facial cleanser using waste banana skins.

Lush are also a good example of working within a circular economy not just in their products, but their packaging.

Over 50% of their products have been designed in such a way so that there is no packaging at all.

Read more about Lush's sustainability plan at: https://weare.lush.com/lush-life/our-impact-reports/go-circular/

The plastic problem
Some companies have made and are making big changes to how they deliver their products. But there is still along way to go.

Most plastic packaging has a life-span of mere minutes. Every year about 8 million tonnes of plastic escape into the oceans from coastal places. Plastics can take up to 500 years to breakdown.

A pair of glasses made from Parblex: bioplastic from potato waste

Time to reflect

Think about a food item that you have recently bought. Or an electrical item you have recently purchased. Maybe a game. Or clothes, make up or health and beauty products. Visit your local supermarket, what does the fruit and vegetable aisle look like?

- Is there any packaging?
- What is the purpose of the packaging material?
- Can the packaging be reused or recycled?

Use the fact sheet on **page 12** to help identify different types of plastic and whether they can be recycled.

WHAT DO YOU SEE HERE?

Sustainable Futures Innovation Challenge

You might want to think about the circular economy when working on your **'Sustainable Futures Innovation Challenge'**. You can also expand on an idea that you have started as part of this challenge for your competition entry.

At the heart of many of many engineering solutions working towards a more sustainable future is ensuring that we do not create more harmful waste and work towards a 'circular economy'. When designing a new product, it is important to think about not just what happens to the packaging, but what actually happens to that product once you no longer need it.

Watch the YouTube video, **'The Sachet Challenge'** made by the Ellen MacArthur Foundation to get you started.

Rethinking packaging

In groups choose a product that you know the packaging cannot be easily recycled or reused, and redesign the packaging. Ideally choose something that you can actually bring in and test. For example a food item, or a health and beauty product.

What are the pros and cons of the existing packaging?

Write a list of the things your packaging needs to do:

How can we design packaging for ..... that ..... and is still fit for a circular economy?

Brainstorm as many ideas as you can think of.

The idea we have chosen to explore further and prototype is...

Lets start prototyping!

Use any recycled material you can and get making.

It doesn't have to be perfect, make and test different options.

Share your ideas.

What was the initial problem you were tackling?

The product we have chosen is ..... **because** .....

MATERIALS

- ☐ The product you want to rethink the packaging for, ideally in its original package.
- ☐ Post-it notes and large paper
- ☐ Coloured pens
- ☐ Scissors and glue
- ☐ Recycled cardboard, newspaper and scrap paper
- ☐ And anything else you can come across!

This activity was inspired by **'Redesigning Plastics'** activity from the Ellen MacArthur Foundation.

ENASS
POWER PIONEER

ABOUT ME

I have always been an activist at heart. From a young age, I thought about air pollution, climate change, and the effects of burning oil and gas for energy on the environment.

After a trip abroad during my PhD, I realised how much of a luxury electricity was, with hospitals in some places only receiving electricity for half the day.

"FOR ME, ENGINEERING IS SIMPLY ABOUT WANTING TO SOLVE A PROBLEM AND HAVING THE PASSION AND THE IMAGINATION TO CREATE A SOLUTION."

I saw this as a problem that engineering could fix, and in the process, help save lives and the environment too.

I founded my company straight out of the University of Cambridge – focusing on developing a hydrogen battery that would be able to store clean and renewable energy in countries without an electrical grid.

Find out more about Enass by visiting the This is Engineering website

CHALLENGE BATTERY POWER

THERE ARE MANY DIFFERENT TYPES OF BATTERIES THAT HAVE DIFFERENT USES.

Although many of the electronic devices we use have rechargeable Lithium Ion (Li-ion) batteries, single-use Alkaline batteries are still used in many of the devices we come across.

Time to reflect

- What devices do you use that use single-use or 'disposable' batteries?
- What do you think the problem with using single-use batteries is?

Sometimes new and old batteries will become mixed and it is difficult to tell which ones still have power so we end up disposing of batteries that still have energy stored. Or once we think a single-use battery has run out of energy, we will dispose of it even if it still has energy stored.

The problem
Single-use batteries contain many hazardous metals and chemicals. If batteries end up in general waste, and onto landfill this has serious damaging effects to our environment, with the potential for this toxic waste to end up in our water supply.

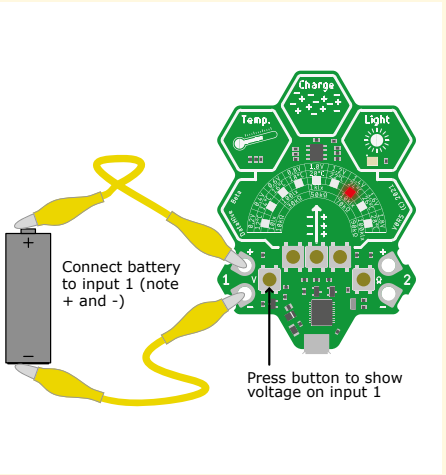
The solution
Batteries can be disposed of at a 'battery bank' where they should hopefully go on to be recycled. Valuable materials can be captured from the old batteries and any toxic waste can be captured. Unfortunately, it has been recorded that 97% of single-use batteries end up in landfill.

But if we could reduce the amount of batteries that we dispose of in the first place, then we could at least start to reduce the amount that end up in landfill.

Test your batteries
Your *DataHive* has a voltmeter at 'Input 1'. Attach the two croc leads to the positive and negative pads on the *DataHive*. Find a battery that you think is fully charged, and find another that you think is dead. Hold the croc leads at either end of the positive and negative end of the battery and push the voltmeter button.

Which way round do you think you need to connect the croc leads to get a reading on the voltmeter?

The LED gauge will show you the voltage of the battery. A standard AA battery is a 1.5 Volt cell. But different batteries have different voltages and different battery chemistry. As the battery is discharged (using energy),



the voltage decreases and so we can use this as an indicator of remaining energy.

Test the batteries in different electronic devices. Some products are more efficient than others, and will use more of the available energy because they can keep functioning at lower voltages.

Do you have a device that has stopped working because you think the battery has died?
Does the battery still have energy stored?
Can this battery be used in a different device?

Time to make

It can be tricky to attach croc leads to batteries and measure their voltage.

Make a device that will hold AA and AAA batteries to make it easier for people to test their batteries.

But what are batteries?
Batteries are containers that store chemical energy, which can be transferred electrically.

They depend on an **electrochemical reaction** to do this. The reaction typically occurs between two pieces of metal, called **electrodes**, and a liquid or paste, called an **electrolyte**. Once these are in place **ions** (atoms with too few or too many electrons) are formed from the materials in the electrodes.

At the same time, electrons move from one electrode to another. For a battery to work, the electrodes must be made from two different conducting materials. One of the materials 'likes' to give up electrons, the other likes to receive them. This difference is what produces electricity. Connect the two electrodes with a material that can conduct electricity well (called a **conductor**). This allows the chemical reactions and the battery to produce electricity!

MAKE AND EXPERIMENT WITH YOUR OWN BATTERY

Staying safe
In this experiment, you will be making a very low-voltage battery. The amount of electricity produced by this homemade battery is safe, and you will even be able to test it by touching your finger to it and feeling the weak current. Higher voltages of electricity, however, can be very dangerous and even deadly; you should not experiment with commercial batteries or wall outlets.

Making your battery

- We are using a screw and a copper coin as our two **electrodes**
- Insert a penny into a cut on one side of the lemon. Part of the penny should be in contact with the lemon juice. The lemon juice is what acts as the **electrolyte**.
- Push a screw into the other side of the lemon. The screw and penny must not touch.

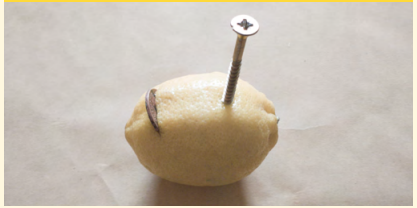
*You have just made a battery! Otherwise known as a **cell**.*

It has two electrodes of different metals and an electrolyte separating them.

What do you think is missing so that your battery generates electricity?

MATERIALS

- Two different metals to use as the **electrodes**. For example, a copper coin or a steel nail.
- Croc leads (a good **conductor**)
- A juicy lemon (lemon juice is an **electrolyte**)
- Knife (ask for adult help when using a knife)
- *DataHive* to measure the **voltage**



Your battery will generate electricity only once the electrodes are in contact with something that conducts electricity.

Connect a croc lead to the screw and another croc lead to the copper coin. Connect the croc leads to the pads at Input 1 on the *DataHive* and press the voltage button.

Hint: If it's not showing a reading, you might need to swap the croc leads round.

What is the voltage of your lemon battery? Which electrode is positive, and which is negative? How can you tell?

Taking it further
Try changing the **electrolyte** by using different fruit and vegetables.

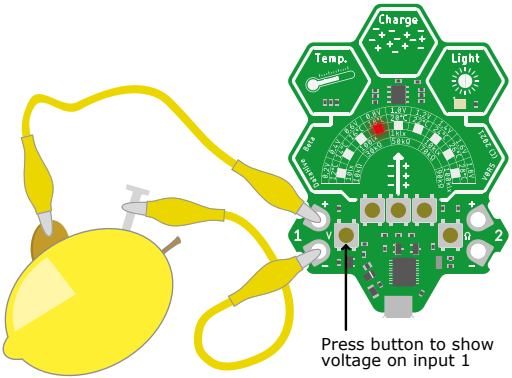
Do all of them work? What do you think is common about those that did work? Does the voltage change?

Try using different **electrodes** by changing the metal you use.
Do all of them work? Does the voltage change?

More juice, more power
Make several individual batteries (called **cells**) and wire them together.

Can you use the same piece of fruit to make several cells?
*What happens to the voltage or current if you wire them in **series**?*
*What happens if you wire them in **parallel**?*

Most red LEDs need 2v before they conduct electricity. How many lemons do you need to light an LED?



*Check out our resource **'Power Up'** for more on energy stores and transfers.

CHALLENGE ACCESSING ELECTRICITY

WE RELY HEAVILY ON APPLIANCES, DEVICES AND TECHNOLOGY THAT ARE POWERED BY ELECTRICITY.

- How do we use electricity? Think of as many ways as you can.

In 1879 Thomas Edison was able to produce a reliable, long-lasting electric light bulb which revolutionised industry across the world!

- How has the way we use electricity changed over the last 150 years?
- How do you think the we use electricity will change in the next 50 years?

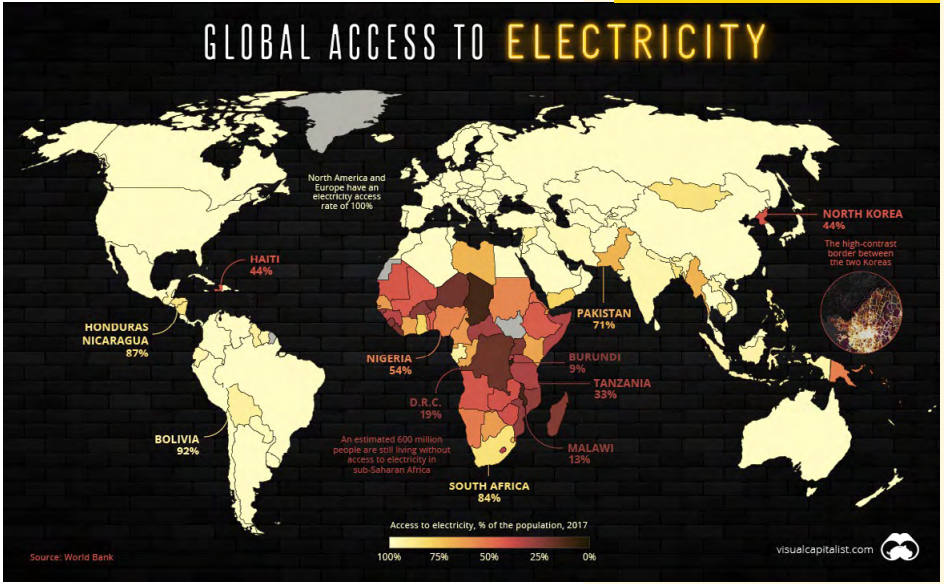
1.2 billion people around the world have no reliable access to electricity!

After travelling and visiting other countries, Enass realised that there are many people around the world who see electricity as a luxury. This inspired and motivated her to want to tackle this problem of ensuring that everyone around the world has regular access to reliable, clean and safe energy.

Time to reflect

- What impact do you think having limited access to electricity has on people's lives?
- What do you think affects access to reliable electricity?
- How do you think Enass's innovation of a hydrogen battery that stores energy tackles the problem of ensuring that people in remote places have access to clean, renewable and reliable energy?

Image and fact source: **https://www.visualcapitalist.com/mapped-billion-people-without-access-to-electricity/**



Energy efficiency at home

Even if our homes are lucky enough to have access to instant energy, it is important for us to be mindful of how we use both electricity and gas around our homes, schools and workplaces.

The environmental impact of being energy efficient at home is significant. In the UK, it is said that 40% of emissions come from households*.

The UK also has plans to phase out gas boilers, and banning them completely from new homes by 2025. This means will become more dependent on electrical energy sources.

What is the benefit of using electricity as an energy source?

How hot is your home?
The *DataHive* has a temperature sensor. Push the temperature sensor button and the LED gauge will give you a reading. The central LED shows 20°C.

What is the approximate temperature of the room you are in?

The higher the temperature we use to heat our homes, the more energy we are using.

Measure the temperature in different rooms around your home.

Are you heating some rooms too high? Are you heating some rooms you don't use? Is the heating on and the windows open in some rooms?

The *DataHive* can record temperature over a long period of time.

Visit data.Redfern.uk and connect the *DataHive* to the computer using a USB. Follow the instructions on the website so you can set the *DataHive* to log temperature.

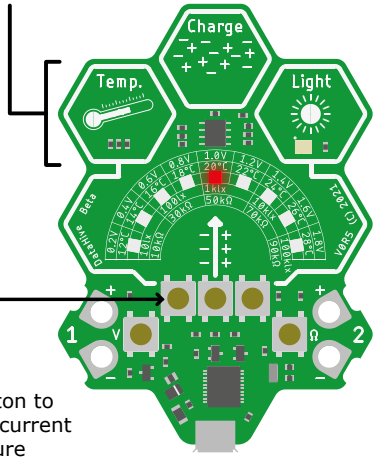
Put the *DataHive* in a room at home or at school for 24 hours. After this period, collect the *DataHive* and connect to the computer again.

Visit data.Redfern.uk where you will be able to view the recorded data as a graph for this period.

What do you notice? How energy efficient was this room? How can you tell? What changes might you make after seeing this data?

*According to the Committee on Climate Change in 2014.

When moving to a new location, wait a few minutes for the sensor to read accurately.



Match the house heating scenario to the graph

House heating scenarios

House A
Well insulated, thermostat between 19 and 20 degrees.

House B
Heating on all the time

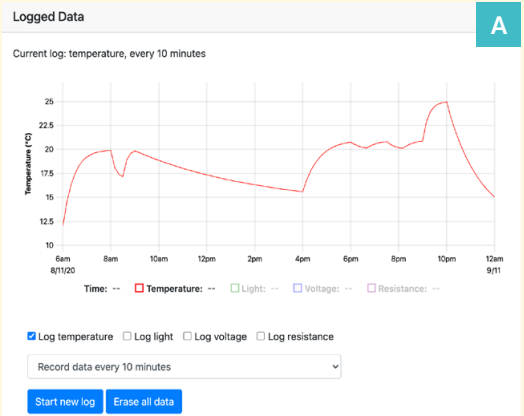
House C
Poorly insulated in the winter.

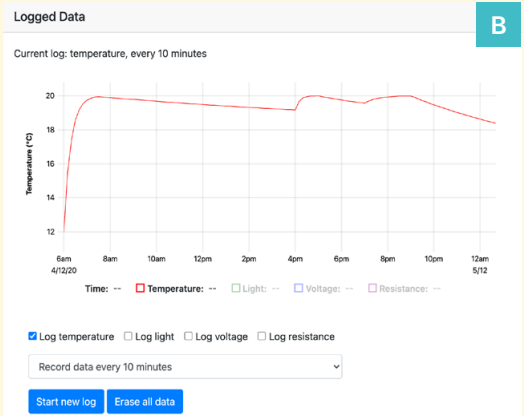
House D
Door left open in the morning, heating turned up to 25°C in the evening.

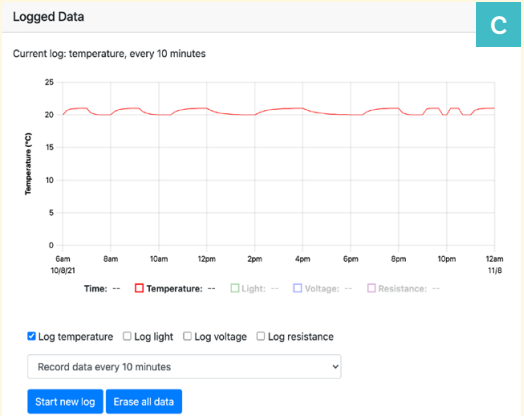
- Create your own scenario and matching graph.
- Show your classmates the graph. Can they work out what the scenario is?

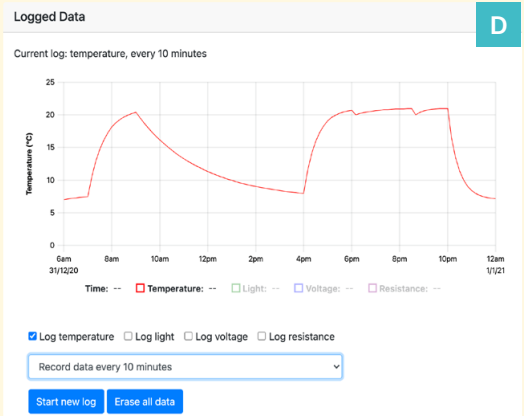
Time to analyse

- What do you notice about the scales on each graph?
- How does the impact what the temperature change looks like?
- How much does the temperature drop between 9am and 4pm on graph A?
- What about the same time on graph B, graph C, and graph D?









ABOUT ME

I grew up in Norway surrounded by farms and playing with Lego. As a Robotics Engineer, I combine my love for nature and putting things together to create robots that will revolutionise farming.

I decided to study mechanical engineering so I could invent and create my own robots. I now work for Saga Robotics creating agricultural robots, that do everything from ploughing and weeding to picking strawberries and testing the soil.

"I LIKE TO SOLVE PROBLEMS AND LOVE THAT MECHANICAL ENGINEERING CAN BE ANYTHING FROM MAKING TOYS TO AEROPLANES – TO ROBOTS THAT CAN HELP FEED THE WORLD."

For me, feeding the planet is important. With the world population growing, more food and crops will be needed.

The better we are at using the land, keeping plants and fields healthy and sustainable, the more people we can feed.

Find out more about Halvard by visiting the This is Engineering website

CHALLENGE OPTIMUM GROWING CONDITIONS

THE ROBOTS THAT HALVARD DESIGNS ARE EQUIPPED WITH SENSORS AND GADGETS TO MAKE SURE THAT THEY HAVE THE OPTIMUM CONDITIONS FOR GROWING DIFFERENT CROPS.

The robots test the soil, find the perfect space to grow different crops, they plough and weed and pick different fruit and vegetables.

By using the robots, crops can be farmed in the most effective and sustainable way. Efficient farming methods is one solution for **sustainable farming**.

The story beneath the soil

Soil is the loose upper layer of the Earth's surface where plants grow. Soil consists of a mix of organic material (decayed plants and animals) and broken bits of rocks and mineral. Soil contains nutrients that plants use to grow.

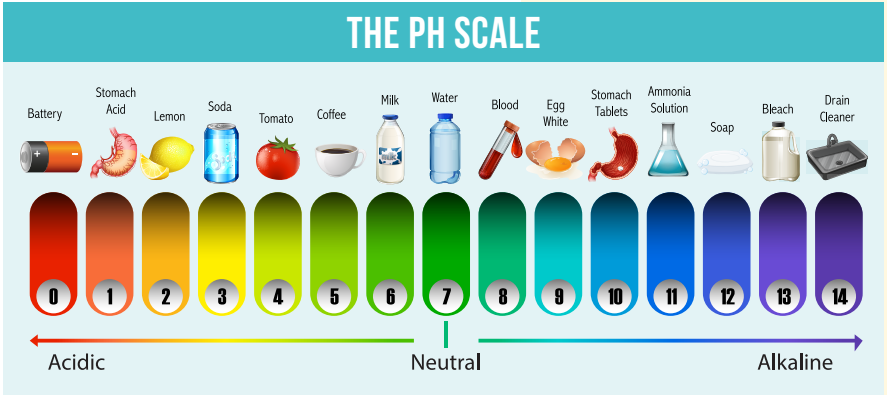
Farmers must know as much as possible about their land, especially the soil properties. Halvard's SAGA robots are able to test the properties of the soil, rather than having to send it off to labs. The robots can detect the **acidity** or **alkalinity** of the soil, and soil nutrients such as **nitrogen** (N), **phosphorus** (P), and **potassium** (K).

Testing the pH level of soil

Certain plants can only access the soil nutrients if the pH (**potential hydrogen**) levels are within a certain range. Soil pH tests how many hydrogen ions are in the soil. The pH scale ranges from 0 to 14, with a pH of seven representing a neutral level (**see image of the pH scale**).

A pH less than seven is acidic, seven is neutral, and anything higher than seven is alkaline.

Most plants prefer soil that is neutral, or slightly acidic with a pH level between 6 and 7. Some plants prefer more acidic soil, such as blueberries and strawberries, and others prefer soil that is alkaline such as asparagus.



TESTING FOR ALKALINE OR ACIDITY

MATERIALS

- Hand shovel/trough (something to collect your soil sample with)
- 500ml water
- 125ml wine vinegar
- 3 tablespoons of baking powder

Time to test

1. Collect a soil sample from your garden or somewhere around the outside of your school. Dig around 15cm deep. Put your sample in a glass bowl.
2. Remove stones, sticks and any other debris. Break up any large clumps.
3. Add around 150ml of tap water to your sample. Add enough water to turn the soil into a muddy texture.
4. Add 125ml of white vinegar *If it fizzes, you have alkaline soil. If it does not fizz, then repeat steps 1 and 2.*
5. Add the 150ml of **distilled water**.
6. Add 3 tablespoons of baking soda. *If it fizzes you have acidic soil. If nothing happens, your soil is neutral with a pH of 7.*

Soil sample with water and vinegar

This is our soil sample after adding baking powder. Do you think our soil sample is acidic or alkaline?

DISTILLING WATER

The water from our taps is rarely neutral. It will contain minerals such as calcium or magnesium making it alkaline, or metal ions such as copper, lead or zinc making it more acidic. Distillation will leave you with pure, clean water.

Distillation is the method we see every day in nature.

Distillation involves boiling the water to produce vapour, leaving behind any and all contaminants (which have a higher boiling point than H_20).

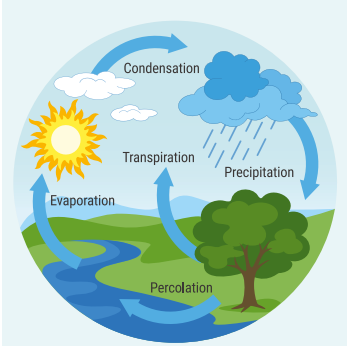
Once the water entirely vaporises, that vapour is put into a clean container where it condenses back into pure water.

How to distill water at home

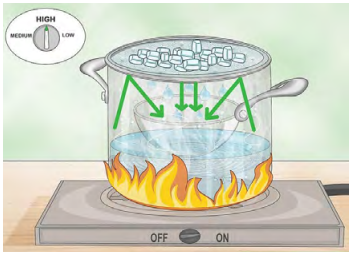
- Fill a large pan (ideally with a non-flat lid) approximately ½ full with water
- Place a smaller glass bowl (it should float) in the pan
- Place the lid on the pan upside down
- Place a handful of ice cubes on the lid (this is used to speed up the process).

Make sure you are working with a responsible adult when using the hob for this activity.

THE WATER CYCLE



- Turn up the heat and watch the magic happen!
- The water will start to vaporise. Once it reaches the cool lid, it will convert back to water to form water droplets which will start collecting in your glass bowl.



MAKE A RED CABBAGE PH INDICATOR

The test on page 28 tells us whether our soil is alkaline or acidic. But what if we want more detail than that?

If we have a better idea of what level pH our soil is this might help us to know how to make it more or less acidic/alkaline if we need to.

1. Take three or four leaves of your red cabbage and cut into pieces. Put the pieces in the blender.
2. Add approximately 500ml of water to the blender and blend the two together to create a cabbage juice.
3. Strain the juice into a large glass. This is your red cabbage indicator.
4. In a test tube, cup or other vessel, put a small amount of each of your solutions. Label each vessel so you know what is in it.
5. Add red cabbage juice in each vessel.
6. Arrange them in order of their pH using the pH scale on the next page. Number each solution with the correct pH number.

You can now use your scale as a reference point when testing your soil samples.

Time to test your soil

Put teaspoons of garden soil in a jar and cover with the red cabbage juice.

Wait 20/30 minutes and check the colour.

Match the colour with your pH indicators. What is the pH level of your soil?

Test the pH levels of other ingredients you have around the house. For example:

- Black tea
- Cows milk
- Lime
- Coffee grounds
- Tap water – what do you notice? Is it neutral? How might this have affected your soil testing?

Adjust your pH levels

Depending on what is growing, we might need to change the pH level of soil.

Try changing the pH level of your soil using the information you know about substances that are alkaline and acidic.

- What do you need to add to make your sample more acidic?
- What do you need to add to make your sample more alkaline?

Mini-glossary

Optimum condition in farming means the best condition for something to grow.

Nitrogen is needed for plant growth. It gives plants their green colour and is involved in creating food for the plant.

Phosphorous is vital to plant growth. It promotes root growth, flowering and setting seed.

Potassium is associated with the movement of water, nutrients and carbohydrates in plant tissue.

MATERIALS

- Red cabbage
- Water jug
- Vinegar
- Baking powder
- Lemonade
- Sugar solution
- Lemon
- Tomato
- Surface cleaner
- Test tubes or tall glasses
- Blender
- Strainer

These are just the items we have used. You can find your own items to make your own pH cabbage indicator.

1

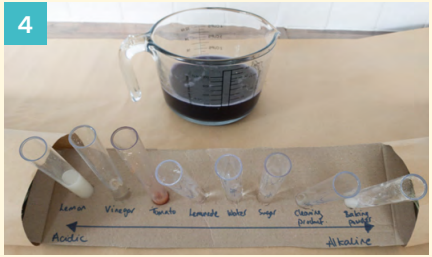
2

Blend cabbage leaves and water

3

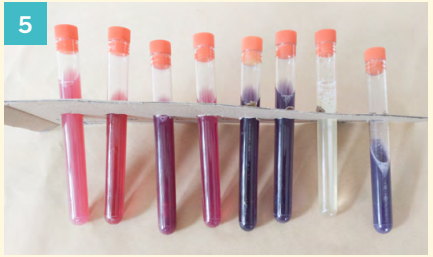
Strain the cabbage mix

4



Put solutions in different vessels and label

5



Solutions with cabbage juice poured in

6

A RED CABBAGE PH INDICATOR

GROW YOUR OWN

Taking care of crops and plants isn't just for large farms and agriculture. We can all get growing in our homes.

From herb gardens, to fruit and vegetables, to flowers and house plants. And to grow at home, we need to be able to look after our plants by watering, feeding and providing them with enough sunlight.

Aurelia, who works at Twitter, developed an app that measures moisture in plant soil. Can you make something similar?

Is it time to water?
Use the *DataHive* to set up a system which will notify you when your plant needs watering.

The *DataHive* has a ohm (Ω) metre which measures **resistance** at input 2. Resistance is a measure of how difficult it is for electrical current to flow through a material.

Time to reflect

What materials do you think have a high electrical resistance? What materials do you think have a low electrical resistance?

Using the *DataHive*, test different materials for their electrical resistance. Connect the crocodile clips to the pads at input 2.

Find materials and touch the material with the other end of the crocodile clips.

Why not try...

- Graphite pencil
- Metal spoon
- Cardboard
- Painted metal object
- Damp cardboard
- Tap water

Set-up the *DataHive* so that it measures the moisture of a plant at home or at school. This way you can find out when the soil is dry and your plant needs watering.

What would you expect the electrical resistance to be when the soil is dry?

- Find a plant at home or at school and use the *DataHive* to test the moisture levels.
- Using two metal paperclips, straighten these out and stick them into the soil making sure that they are not touching.
- Connect the crocodile clips which are already connected to the *DataHive* to the paperclips

What is the electrical resistance reading on the LED gauge?

How can you use this to monitor your plant and find out when you need to water it?

Keep it watered

Many farms will now have **irrigation** systems in place. Either to keep a steady flow of water reaching the soil or to control the moisture levels. Machines have been programmed to monitor the water levels in the soil.

Create a system that will either keep the soil moist or hold in the moisture for longer. Test this using the *DataHive*.

To test whether your system works, log the data over a longer period of time.

Visit data.Redfern.uk and connect the *DataHive* to the computer using a USB. Follow the instructions on the website so you can set the *DataHive* to log electrical resistance (Ohms).

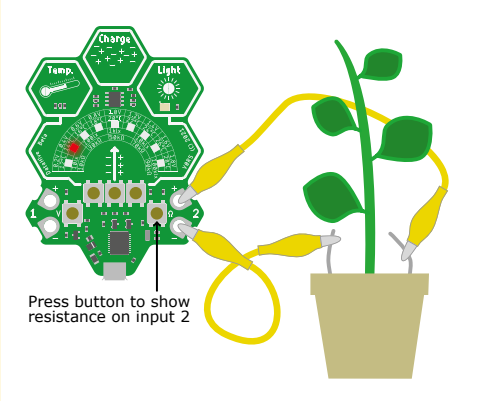
Place the *DataHive* in a plant that is using your moisture holder device for 24 hours. Compare this to another similar plant that does not have a moisture holding device.

After this period, collect the *DataHive* and connect to the computer again. Visit data.Redfern.uk where you will be able to view the recorded data as a graph for this period.

- What do you notice?
- Compare your results to your classmates?
- Who has the most effective device?
- How can you tell?

Time to reflect

What do you think the different readings tell you about the electrical resistance of the materials you have tested?



Visit **thisisengineering.org.uk** and find out more about Aurelia, Code Creator.

SUNLIGHT LEVELS

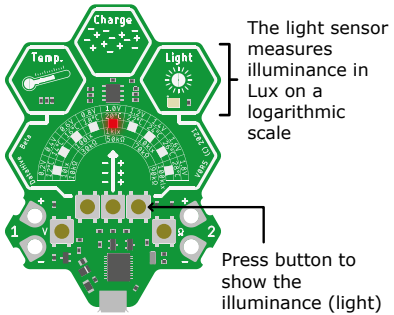
Plants rely on energy in sunlight to produce the nutrients they need.

Even around the house, at school or in outside spaces, we need to find the best place to place our plants where they will get the right levels of sunlight.

The *DataHive* has a light sensor. Find and press the light sensor button.

How much light is in the room or space you are in?

The LED gauge tells you how much light is falling on the *DataHive* as a measure in **Lux**. Lux is a measure of **illuminance**. It is equal to one lumen per square metre. The lux scale is **logarithmic**, which is a way of displaying numerical data over a very wide range of values in a compact way.



These are three different plants which have different sunlight needs (see images, right). Use the *DataHive* to find the best place for each one.

Decide on how much light we mean by direct, medium and small light.

Visit data.Redfern.uk and connect the *DataHive* to the computer using a USB. Follow the instructions on the website so you can set the *DataHive* to log light levels.

Find a spot to place the *DataHive*, and keep it there for 24hours. After this period, collect the *DataHive* and connect to the computer again. Visit data.Redfern.uk where you will be able to view the recorded data as a graph for this period.

What do you notice? How can you tell?

Repeat this for a different spot where you think one of the plants would be best suited.

What do you notice? How can you tell?

Compare results with your classmates. As a group, can you decide on the three best places for your three plants.

Direct sunlight
Sunflower

Medium sunlight
Moth orchid

Shade/minimal sunlight
Spider plant

	Lux	Description
	50,000	British summer sunshine
	5,000	Overcast sky
	500	Well-lit office
	300	Minimum for easy reading
	50	Passageway/ outside working area
	15	Good main road lighting
	10	Sunset
	5	Typical side road lighting
	2	Minimum security risk lighting
	1	Twilight

CHALLENGE JUST RIPE

HALVARD'S ROBOTS ARE DESIGNED TO PICK FRUIT AND VEGETABLES, ONLY ONCE THEY ARE READY. THEY ARE ABLE TO DETECT WHETHER THEY ARE READY TO BE HARVESTED OR EATEN.

Fruits naturally produce gas ethylene that causes fruit to ripen. **Climacteric fruits** continue to ripen after they are picked and non-climacteric fruits will slowly rot after they are separated from their host plant.

Grocery stores will buy climacteric fruit and store it in a temperature-controlled warehouse until they are ready to send the product to stores.

Then they'll release ethylene gas into the room and the fruit will start to ripen again. Delayed ripening is one approach to reducing food waste whilst providing consumers with ripe fruit.

Slow the ripen
Create a prototype that can delay and speed up the ripening process of fruit.

- Where have you seen fruit and vegetables ripen quickly?
- Where have you seen them last longer and ripen slowly?

Design and create a prototype for a device that will slow down the ripening and extend the life of fruit.

- Will the same design work for all fruit?

MATERIALS

- Bags
- Plastic wrap
- Fruit
- Boxes

IS IT RIPE?

Colour is just one way to tell if a fruit or vegetable is ready to be harvested or eaten.

Using your *DataHive*, build a circuit that uses light and colour to detect whether something is red or green.

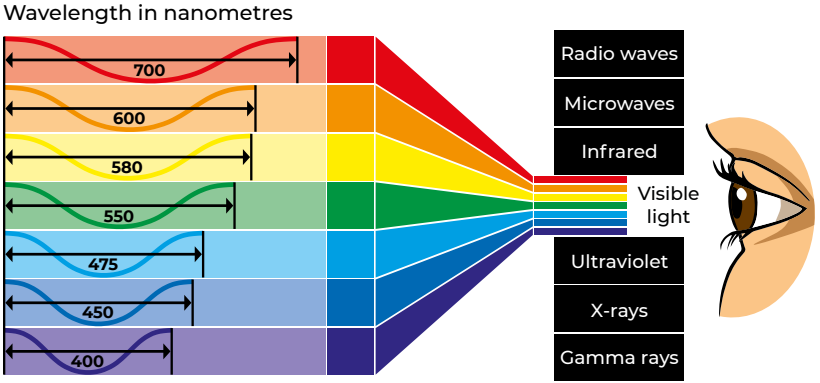
Visible light come in all the colours of the rainbow (which is measured by the wavelength of the light) and are part of the **electromagnetic spectrum**.

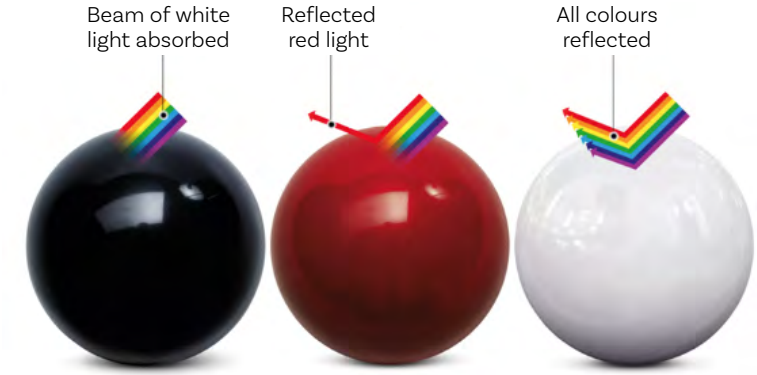
Light behaves in different ways depending on what objects it meets. Almost all objects absorb light to some extent.

If an object is white, all colours are reflected; if it is black, many of the colours are absorbed. An object that we see as red reflects mostly red light and absorbs the other colours.

Using this information use your DataHive to test whether a tomato is ripe and ready to eat.

Check out our resource **'Light saver'** for more activities on the electromagnetic spectrum and the properties of light.





MATERIALS

- Small box (you might need to build one)
- A tomato (or a red object)
- A green tomato (or a green object)
- *DataHive*
- USB cable
- Computer

What colour light would a red tomato absorb?

- Connect the *DataHive* to a computer. Visit data.Redfern.uk to view live data from the *DataHive*.
- Put a red tomato (or red object) and the *DataHive* in a box. This is so that you can do this experiment in a dark space and reduce the amount of interference from other light sources.
- Push the button that will turn on all the red LEDs.
- Check the reading on the graph at data.Redfern.uk

What do you notice? What does this tell you?

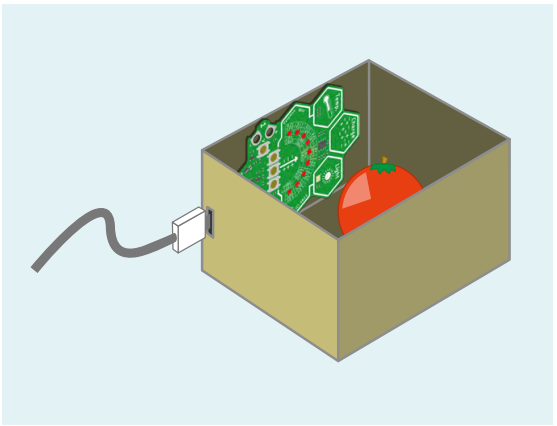
- Try this with a green unripe tomato (or a green object)

What do you notice? What does this tell you?

You can change the colour of the LED from data.Redfern.uk. Find ways to test different fruit.

What colour LEDs would you need to test whether a banana is ripe?

What colour LEDs would you need to test whether different colour peppers are ripe?



Royal Academy of Engineering

The Royal Academy of Engineering is harnessing the power of engineering to build a sustainable society and an inclusive economy that works for everyone.

In collaboration with our Fellows and partners, we're growing talent and developing skills for the future, driving innovation and building global partnerships, and influencing policy and engaging the public.

Together we're working to tackle the greatest challenges of our age.

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We're growing talent by training, supporting, mentoring and funding the most talented and creative researchers, innovators and leaders from across the engineering profession.

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We're driving innovation by investing in some of the country's most creative and exciting engineering ideas and businesses.

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