ENGINEERING materials for a GREENER planet

Creating environmentally conscious engineers of the future

ROYAL ACADEMY OF ENGINEERING

THIS IS ENGINEERING

Introduction

Engineering materials for a greener planet lets pupils explore the creative and practical side of STEM (science, technology, engineering, and maths) subjects, as well as introducing the essential role engineers have in deciding what materials to use.

Each activity is straightforward, fun and designed so that students can work together to develop teamwork skills and reasoning, as well as career awareness through practical STEM application.

Materials used for each activity are included in the resource box based on a class set of 30 students. A shopping list is provided for each challenge when materials run out and for teachers downloading the resource.

A full curriculum map on page 5 gives a quick look at which activities best match certain teaching topics.

A recommended length of time to complete each activity is given, however teachers can introduce additional stretch and challenge to extend the learning based on ability and differentiation.

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How can materials engineers solve the biggest environmental challenges facing our generation?

Engineering materials for a greener planet features a series of real-world engineering activities that puts the environment at the heart of learning.

1. MATERIALS TO CIRCUMNAVIGATE THE GLOBE
2. CLEANING UP THE WORLD'S OCEANS
3. 3D PRINTING SUSTAINABLE BUILDINGS OF THE FUTURE

Each global challenge is linked to **Engineering Habits of Mind (EHoM)**, which explore ways to create better and more engaging learning opportunities for would-be engineers. Further information about EHoM is on page 6.

Each challenge contains a series of STEM activities for primary and secondary school students to undertake and is supported by real-life case studies of engineers and experts in their specialist fields.

Several of the challenges are open ended, designed to develop enquiring minds with no fixed solution. The teacher's guide at the end of this resource provides answers to certain sections of the resource where solutions are required to move learning forward. An electronic copy of this resource and 'editable' PowerPoint presentation have been designed to use in the classroom.

These are available to download at http://stemresources.raeng.org.uk/

Contents

Links to the National Curriculum

Each challenge bridges several topics within the STEM curriculum. For ease of reference these have been linked to one and two subject specialisms only.

Materials to circumnavigate the globe	**Subject**	**Key Stage**	**Curriculum link**
Challenge one **Rethink**	*Maths*	2 3 3	multiplication and division compare power ratings of appliances in watts (W, kW) apply formulae to calculate and solve problems
Challenge two **Redesigning energy supply**	*Design/ technology*	2 3	understand and use electrical systems in products critique, evaluate and test ideas and products
Challenge three **Reuse**	*Chemistry*	2 3	simple techniques for separating mixtures filtration, evaporation, distillation and chromatography
Extension task **Future-proof products**	*Design/ technology*	2 3	research and develop to inform the design of innovative, functional, appealing products that are fit for purpose reformulate and solve design problems
Cleaning up the world's oceans	**Subject**	**Key Stage**	**Curriculum link**
Challenge one **Deformation**	*Science*	3 3	ask questions and develop a line of enquiry based on observations of the real world motion and forces
Challenge two **Degradation in water**	*Science*	3	understand and use the properties of materials and the performance of structural elements to achieve functioning solutions
Challenge three **Choosing the right material to clean up the oceans**	*Maths* *Science*	2 3	measurement – apply mathematical concepts and calculate results make and record observations and measurements using a range of methods for different investigations
Extension design challenge **How to clean up an ocean?**	*Design/ technology*	2 3	identify and solve own design problems understand how to reformulate problems given to them
3D printing sustainable buildings of the future	**Subject**	**Key Stage**	**Curriculum link**
Challenge one **Handheld extrusion**	*Chemistry*	3	pure and impure substances – mixtures, including dissolving
Challenge two **Finding the best material to extrude**	*Engineering*	3	understand how more advanced mechanical systems used in their products enable changes in movement and force
Challenge three **Design your 3D-printed house**	*Design/ technology*	2 3	identify and solve own design problems understand how to reformulate problems given to them

Learning to be an engineer (EHoM)

Learning to be an engineer presents a different way of encouraging more young learners to continue studying STEM subjects and to consider engineering as a suitable career for them.

It suggests that in order to attract more young people into engineering, students and teachers need to develop a better understanding of the ways in which engineers think and act.

EHoM explores ways to create more engaging learning opportunities for would-be engineers. The methodology builds upon six EHoM and seven Learning Habits of Mind (LHoM).

Systems thinking	Seeing whole systems and parts and how they connect, pattern-shifting, recognising interdependencies.
Problem finding	Clarifying needs, checking existing solutions and investigating contexts.
Visualising	Move from abstract to concrete, manipulating materials, mental rehearsal of physical space and of practical design solutions.
Improving	Make things better by experimenting, designing, sketching, guessing, conjecturing, thought-experimenting and prototyping.
Creative problem solving	Applying techniques from other traditions, generating ideas and solutions with others, generous but rigorous critiquing, seeing engineering as a team sport.
Adapting	Adapting, testing, analysing, reflecting, re-thinking and changing (physically and mentally).

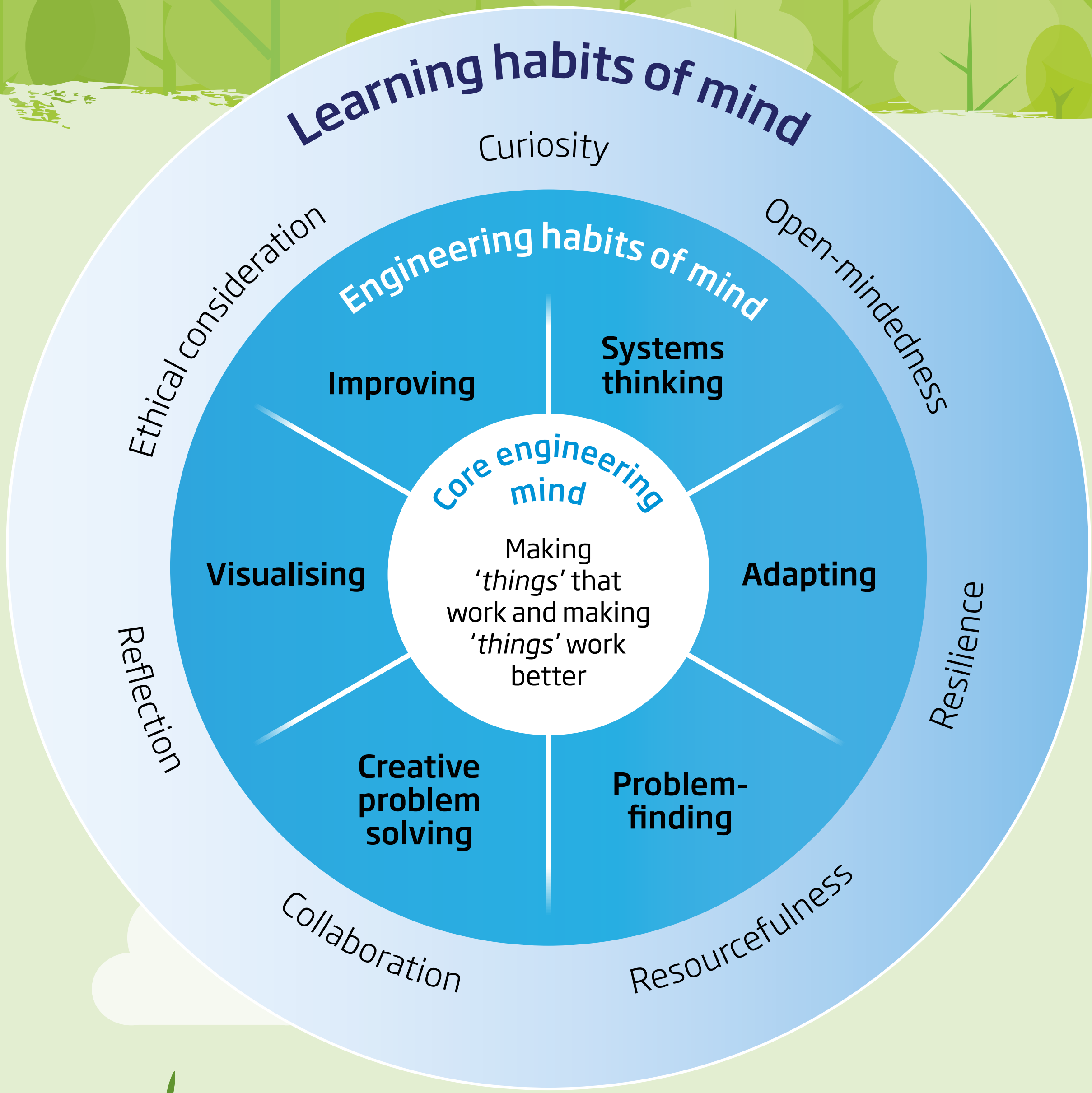
The **Engineering materials for a greener planet** resource has been designed to support teachers in helping students find more meaning and relevance in engineering and, as a result, engage more with the subject.

This resource actively explores the interaction between engineering, design and technology (D&T), computing and science, including the use of thematic curricula with real-world contexts.

It is designed to be incorporated into Key Stage 2 and 3 of the school curriculum as well as delivered in STEM clubs and after-school activities.

The framework supports teachers to embed an alternative teaching and learning method into everyday teaching.

To learn more about the Academy's **Learning to be an engineer** research project, or download case studies and resources created by the teachers, visit https://www.raeng.org.uk/ltbae

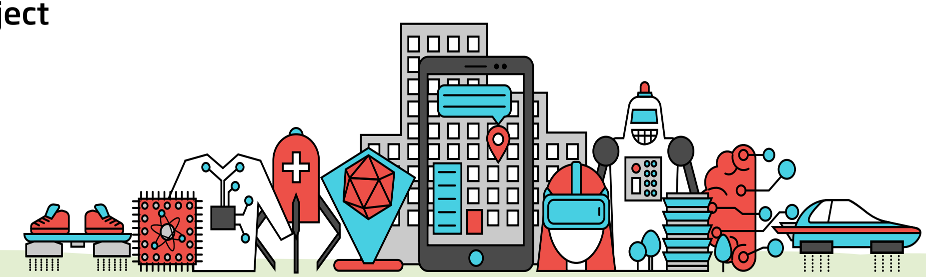


About CREST Awards

CREST is an easy-to-run STEM enrichment scheme. It enables 5 to 19 year olds to build skills and demonstrate personal achievement in creative STEM project work that supports their curriculum-based learning.

CREST, run by the British Science Association, accredits national schemes and offers tangible benefits to both students and teachers.

Around 30,000 students in the UK gain CREST Awards every year.



Discovery Awards

Engineering materials for a greener planet gives students the freedom to run their own investigations and project work. Working together in self-managed groups, students complete five challenges to receive their Discovery Award.

Complete five challenges to achieve a CREST Discovery Award.

Find out more at www.crestawards.org

How to get your CREST Discovery Award

1. Sign-up for a free account at **https://my.crestawards.org**
2. Download the teacher guide and Discovery Passport
3. Create a project. For example – **Engineering materials for a greener planet**
4. Students provide details of the project in their passports
5. Upload pupils' names and two or three passports and any accompanying work
6. Assess pupils. Have they:
    a. completed around five hours of work on the project?
    b. participated fully in the project?
    c. reflected on their learning?

    For more information on assessing a CREST Discovery awards visit: **http://bsa.sc/assess-discovery**
7. Submit online

Taking their work further

If pupils want to take activities further, they can work towards a CREST Bronze or Silver Award.

CREST Bronze Awards require around ten hours of enquiry, project-based work, and Silver Awards require 30 hours of work at GCSE or equivalent standard.

Using one of the activities for inspiration, pupils choose a question or topic to investigate. For example, this could be the questions asked in the **extension challenge: design a clean ocean** and extend that work by researching if there really is a plastic problem and if so investigate, what can we do to protect our oceans and prevent anymore plastic getting into our food chain?

Guidance on how to run CREST Bronze and Silver Award projects is available on the CREST Awards website and help centre.

Starter activity - class discussion

BY 2050, THERE WILL BE AN EXTRA TWO BILLION PEOPLE IN THE WORLD

What are the biggest challenges facing the human population and that engineers will need to find solutions to:

POLLUTION?

CLIMATE CHANGE?

WATER SCARCITY?

RAPIDLY RISING ENERGY DEMAND?

Discuss in groups of two or three and feedback to your teacher.

Materials to circumnavigate the globe

10 mins

Identifying the problem

How many students in the class have a mobile phone? Multiple this by the number of students in the school.

What do you do with your old phones? How can the waste from mobile phones be used as the source for new products?

How many students in the class replace their mobile phone every two years?

Did you know?

Every mobile phone contains precious metals including gold, silver and platinum. They also contain a range of rare earth elements.

Old phones often get left in a drawer and forgotten about, or thrown away. Less than 10% of mobile phones get recycled and their precious components recovered and reused.

Mobile phones contain 0.034 grams of gold. A gold ring contains 5-10 grams of gold and this would be worth about £150 to £300.

The precious metals recycled from 80,000 mobile phone are helping to create approximately 5,000 medals for the Olympic and Paralympic Games in Tokyo 2020.

Where does your phone come from? Watch this short video to find out:
www.youtube.com/watch?v=cKvGzS8LYbY

Engineers of the future

Traditionally, we have used materials without consideration of the planet and the effect it has on the environment. This means we source the raw materials to create the product, we use it, then we dispose of it.

Identifying ways to reuse or recycle the metal, plastic and glass components of mobile phones for example will not only reduce the accumulation of waste in landfills (some of which is toxic), it can also create new businesses and reduce our use of the limited resources in the Earth.

As engineers of the future, you will need to rethink how we use materials to make products and use them so that we design a process that eliminates waste and pollution, keeps the products and materials in use, and regenerates natural systems to promote healthy ecosystems.

An example is designing the processes and building the industry to collect used mobile phones and remanufacturing them. Or reusing the precious metals for new phones or other products such as medals.

? TIME TO LEARN

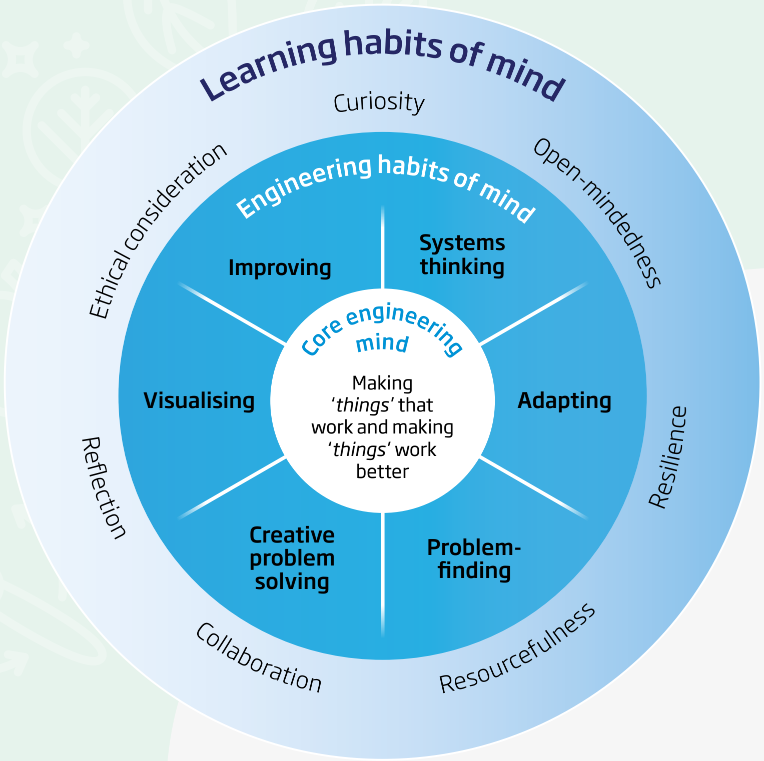
This challenge takes sailing a yacht around the globe as an activity to rethink, redesign and reuse the materials we use.

Crossing 26,000 miles of water to circumnavigate the globe requires careful planning to ensure there are sufficient resources, power and fresh water to complete the trip. How could you redesign your yacht, rethink what items to take with you and reuse valuable resources?

Could you beat the world record of 71 days?
Complete the three challenges to find out.

SHOPPING LIST

Description		Supplier
Solar cell	4.5 Volts	mindsetsonline.co.uk
Fabric	A4	amazon.co.uk
Acrylic paint	120 mL tube	amazon.co.uk
Yacht kit		mindsetsonline.co.uk
Filter paper	Pack of 350	shop.tchibo-coffee.co.uk



EHoM core skills

- Open mindedness
- Resilience
- Resourcefulness
- Adapting
- Creative problem solving

Challenge one: rethink

45 mins

TYPICAL DAILY POWER CONSUMPTION

Item	Quantity	Consumption (watts)	Total watts	Consumption (amps)	Ah/day ampere hours per day
Pilot	1	50	50	4	38.4
Multi functional display (MFD), instrument system	1	24	24	2	48
Nav lights	2	10	20	1.67	13
Radar (standby)	1	9	9	0.75	18
Radar (transmit)	1	28	28	2.33	14
Laptop	2	40	80	6.5	16
VHF (short range radio)	1	1	1	0.08	2
SSB (long range radio)	1	125	125	10.42	12.5
Satphone (standby)	1	12	12	1	24
Interior lights (LED)	6	1.5	10	1	1
Watermaker	1	120	120	10	12
TV/DVD (21 inch)	1	24	24	2	5
Fridge	1	60	60	5	36
Freezer	1	60	60	5	36
Water pumps	1	150	150	12	6

In addition to food, a range of equipment is needed to complete a safe voyage and sustain the pilot.

As a solo pilot, use the 'typical daily power consumption' table to think about the essential equipment required (including yourself) and the electrical power needed to complete your voyage.

TIME TO THINK

- How many WATTS and AMPS does that item consume?
- How many AMP hours will be used?

Work in teams to figure out the solutions to these questions. Record your calculations and share your answers with your teacher.

Reference panel

W — Electrical power is measured in **WATTS**. The more watts, the more power is consumed. Find out more about watts at **www.bbc.com/education/clips/z3hd2hv**

A — Current is measured in **AMPS**. Current is the rate of flow of electric charge. For example – along a wire of a plug to charge your phone. The more flow, the quicker the charge.

Ah — **Ah** stands for ampere hour. This indicates how much power can be stored.

Based on the items you have selected:

1. What is your total consumption of WATTS per day?
2. How many **WATTS** will be consumed over the duration of one month? (*based on 30 days*)
3. How many **WATTS** will be consumed over 71 days?
4. How many **AMPS** would you use each day?
5. How many **AMPS** would you use if you completed the challenge in 68 days?

Stretch and challenge

6. How many **AMPS** per hour (Ah) would you use over the course of 24 hours?
7. How could you reduce the total amount of power used and still break the world record for sailing around the world in the fastest time?

Challenge two: redesigning energy supply

180 mins

This huge sea craft is entirely powered by solar energy

Electricity generators using fossil fuels are typically used to meet power requirements. But this needs enough fuel to be carried onboard, which adds to the weight of the boat and makes the voyage take longer, not to mention polluting the local environment.

Carrying insufficient fuel will require making multiple refuelling stops and lost time.

This can be avoided using solar energy, which has the added important advantage of reducing the carbon footprint of the voyage. Solar panels convert sunlight into electricity. They use a material called silicon. The silicon is covered in glass to protect the panel.

The silicon absorbs sunlight to release electrons. Electrons carry electricity that are moved to an external circuit, such as a motor to power the yacht.

? TIME TO THINK

An off-the-shelf silicon solar cell converts 15% of the Sun's energy to electrical power. The sun's energy is 1000 Watts per square metre on a sunny day at midday. Therefore, the larger the solar cell, the more power is generated to power the boat.

Explorer one is a birds eye (often known as a plan or aerial) view of a yacht deck, see **support sheet 1**.

The boat is 20 metres wide and 40 metres long.

Draw and label your essential items on the yacht **(including the solar cell or cells)**.

Discuss as a team before you make your final decision. You can still remove non-essential items at this stage.

- **Calculate the total area available on the deck for your solar panels. Is there enough space on the deck to generate enough electricity to power your essential items?**
- **Can you explain why?**

Thin film solar cells are made from conducting plastics

The sails of the yacht provide for a significantly larger area; however, silicon solar panels cannot be used because the silicon will break when bent.

A new technology that has been developed is solar cells based on films that are 1,000 times thinner – thin films. These thin film solar cells are made from conducting plastics. These extremely flexible giant solar panels can be attached to sails.

Because the materials are so much thinner, they can be mounted onto a flexible material, such as a sail cloth, and not crack during operation.

Each square metre of the panel can generate 100 watts.

TIME TO INVESTIGATE

1) **How many square metres of sail would it take to generate 1000 watts?**
2) **If a solar-powered flexible sail generated 2,500 watts, how many square metres would the sail need to be?**

TIME TO EXPERIMENT

This experiment replicates the process of making thin film solar cells from conducting plastics.

- **Using dimensions given on the sail template on support sheet 2, cut a piece of fabric to the correct size and shape.**
- **Using the acrylic (plastic-based) paint provided in the box, apply a thick layer of paint to the fabric and let it dry. What happens if you bend the fabric with the paint on it?**
- **Try applying a layer of paint on a different material such as tracing paper.**
- **What happens when you peel the layer of paint off?**
- **What happens when you apply a thicker layer of paint?**

TIME TO BUILD

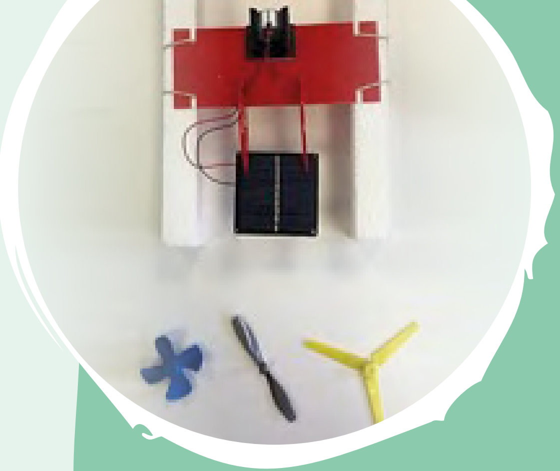
Your task is to build a solar powered yacht from the kit provided. All the required materials are in the box. Use **the instructions in the pack** to guide you through the process.

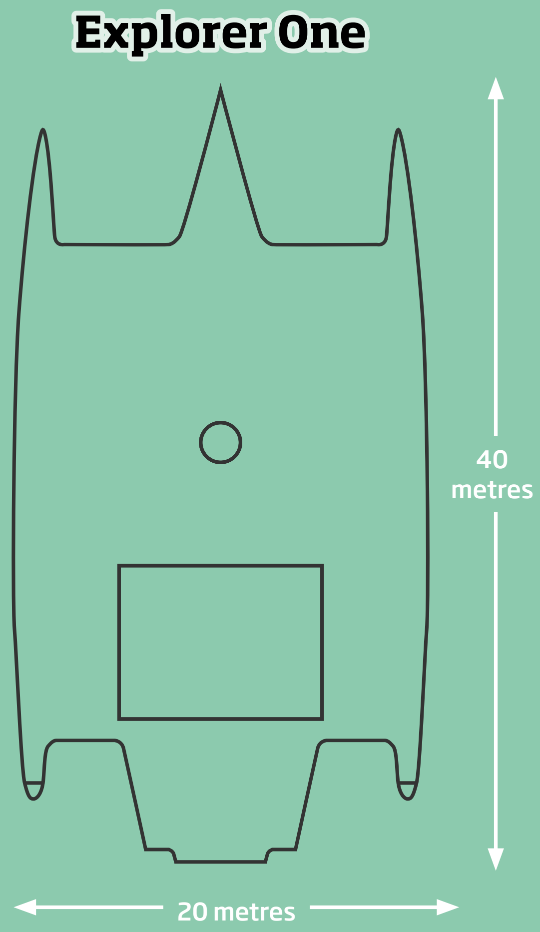
Working in teams of two or three, re-engineer the yacht to include the following:

- **Reposition the solar panel and motor to improve performance.**
- **A deck to store the essential items for your voyage.**
- **Experiment with the three different types of propellers.**
- **Show where additional solar panels could be built in – could these be positioned on the sail?**

Test your yacht. How well does it travel through water? Adapt it to see if you can improve its performance.

By doing this, you are using an **iterative process**, modifying something until you achieve the desired outcome – in this case, the fastest and most seaworthy yacht. You are also creatively solving problems, and developing the key traits and habits of mind of an engineer.





Challenge three: reuse

45 mins

Another important resource for a sailor is a supply of fresh water. Seawater contains high quantities of salt, aquatic species and other minerals that are not suitable for human consumption.

TIME TO EXPERIMENT

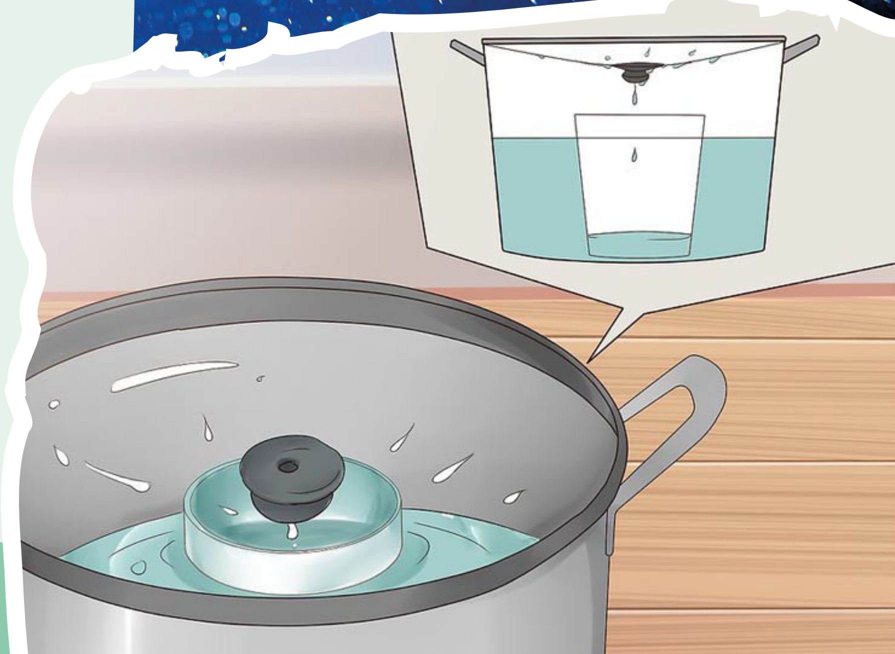
One of the processes onboard that uses the most energy is purifying water. Let's work out different ways to do this so that we minimise how much energy we use and therefore how much energy we have to supply.

Method one – boiling sea water

- Pour 250 millilitres of water into a saucepan and add 1 tablespoon of table salt. Place the saucepan on a stove.
- Place a ceramic cup in the centre of the saucepan. The cup should be empty of all contents and clean. If the cup floats, you can weigh it down with a heavy object.
- Place the lid upside down on the saucepan so that the centre handle is in the centre of the cup.
- Turn on the stove and heat the salt water to boiling point (100+ degrees Celsius). Salt water has a slightly higher boiling point
- As the salt water boils, steam condenses and drips back into the cup.

Wear insulating mittens for this next step

- Turn off the stove, remove the cup and let it cool.
- Pour the contents of the cup into a glass and you will have fresh drinking water.
  1) Where did the salt go?
  2) Can you explain how the salt was extracted?



Method two - salt water filtration

The second method is filtration. Fold a piece of filter paper into a cone and put this into the cup. Add the salt water gradually into the filter paper cone and wait for the water to filter through. The semi-permeable membrane has small pores that may trap the salt and only let the fresh water through.

- Which method purifies the water most effectivity?
- Which method do you think requires more energy and why?

TIME TO REFLECT

Let's recap what we have learnt on our journey. We thought about what processes we have onboard and how we can provide the energy needed using renewable methods, and how we can substitute processes that take lots of energy and redesign them to reduce our energy demand.

We then thought about the energy required onboard. We thought about how we can engineer the energy supply and energy demand. For energy supply, we thought about how we could replace fossil fuel power sources with solar energy.

For energy demand, we chose one of the most energy-intensive processes and thought about how we can redesign this to take up less energy.

Extension task: future proof products

Creating products, especially consumable products that don't require recycling or that can be re-used over and over again is a challenge that scientists, engineers and product designers are trying to address through innovation and their collective creativity.

What products or systems that we use every day do you feel could be better designed or engineered so that they don't need to be thrown away or recycled? Could we create products that help us to better use the planets resources?

Using the skills you have learnt, research what is known behind these questions and design your own solutions, with particular consideration to the resources we will need to manufacture or consume alongside your product idea.

Be curious, reflective and resourceful!

CREST AWARDS

Investigate these ideas and questions further and work towards a Bronze CREST Award.

Find out more at www.crestawards.org

Cleaning up the world's oceans

10 mins

Identifying the problem

This sea bin collects rubbish in the water

HEADLINES...

"FLOATING TRASH COLLECTOR SET TO TACKLE PACIFIC GARBAGE PATCH"

"GIANT PLASTIC CATCHER HEADS FOR PACIFIC OCEAN CLEAN-UP"

"WORLD'S FIRST OCEAN CLEAN-UP SYSTEM HEADS FOR LARGEST OCEAN GARBAGE PATCH"

Plastics are widely used, from shopping bags and furniture, to wearable electronics and plastic cutlery. This is because it is a cheap material, strong but lightweight and can be produced in large quantities. However, these popular materials have been a victim of their own success.

If we take the example of plastic bottles.

- How many plastic bottles does each student in the class use each week?
- Now multiply that number by the number of pupils in the school. What number do you have?
- Using your answer to the previous question, calculate how many plastic bottles are used by pupils in your school over the course of a whole year. What number do you have?
- Multiply this number by the number of school pupils in the UK. What number do you have?
- Now estimate how many plastic bottles are used in the world each year?

This rotating water wheel drags waste out of the water and into a rubbish bin.

Consider the impact discarded bottles have on the environment. Now add carrier bags and other household plastic waste into the system and you can see the scale of the problem.

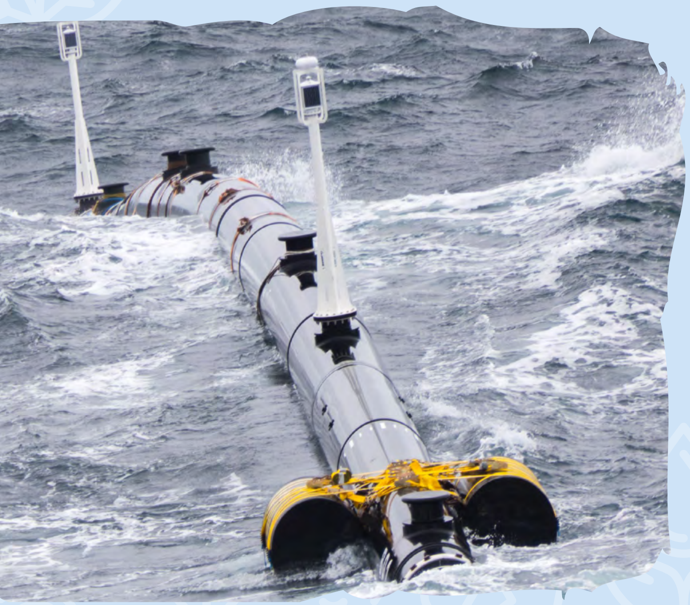
Carelessly disposed plastics are filling up the world's oceans. Because they are durable and water resistant, they are slow to degrade and can affect marine life, from microscopic zooplankton to whales. It is estimated that plastic debris kills 100,000 marine mammals each year, as well as millions of birds and fish.

The campaign to rid the world's oceans of plastic trash has begun and engineers are on a mission to clean up. But the problem is vast. The Great Pacific Garbage Patch, located between California and Hawaii, contains between 45,000 to 129,000 tonnes of plastic over an area of 1.6 million square kilometres. This is seven times the land area of the UK.

Several solutions have been proposed that target different scales of clean-up. Some target the clean-up of inner harbours. These include floating bins connected to a pump to collect floating plastic waste.

Another larger solution has a rotating water wheel to drag waste out of the water and into a rubbish bin.

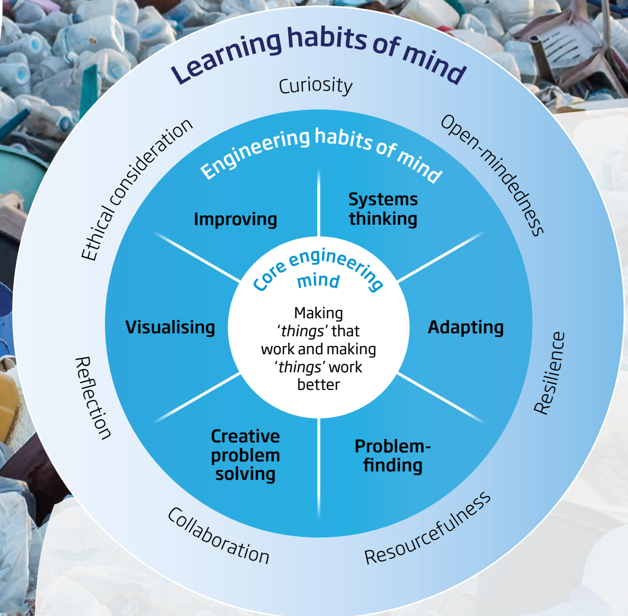
This giant boom will collect rubbish from the ocean



Other solutions target clean-ups on a larger scale in the oceans themselves. These include deploying floating 600 metre booms. These have a tapered skirt beneath them that is longer in the middle, resulting in more drag in the middle and the booms forming an arc that directs trash to be collected in the middle.

Described as a giant 'Pac-Man', the system will rest on the ocean surface in the shape of a U and move slowly through the water, driven by currents and winds, and can capture plastics on the surface, as well as debris almost three metres below the surface. As plastic is collected in a dense mass, it will be picked up by a ship and transported back to dry land to be recycled. The Ocean Clean-up's goal is to clean up 50% of the garbage patch within five years.

This resource will consider what materials are needed for these ideas to work.



EHoM core skills

- Systems thinking
- Curiosity
- Creative problem solving
- Collaboration
- Reflection

SHOPPING LIST

Description		Supplier
UHMWPE plastic - green	5mm thickness	directplastics.co.uk
Stainless steel	1mm thickness	lakelandsteel.uk
LDPE plastic - white	0.187 inch thickness	amazon.com
Steel	1mm thickness	themetalstore.co.uk
Eco film	900mm wide	mindsetsonline.co.uk

Density and buoyancy

The materials need to be resilient (tough and durable) to the forces acting on the structure when deployed in the water. These include surface waves, wind and undercurrents. The materials also need to be strong enough to weather storms and turbulence.

This would point to materials that are strong, such as steel. However, steel has a higher density than water. Density is the mass per unit volume. This means that steel will sink.

Water booms Imagine our plastic-collection device is comprised of a cylinder of steel that is 100 centimetres in diameter and 1,000 centimetres long. This cylinder (a water boom) needs to float on the surface of water.

? TIME TO THINK

- How can we change the structure of the water boom so that the density is lower than that of water while keeping the same material and allowing it to float?

Reference panel

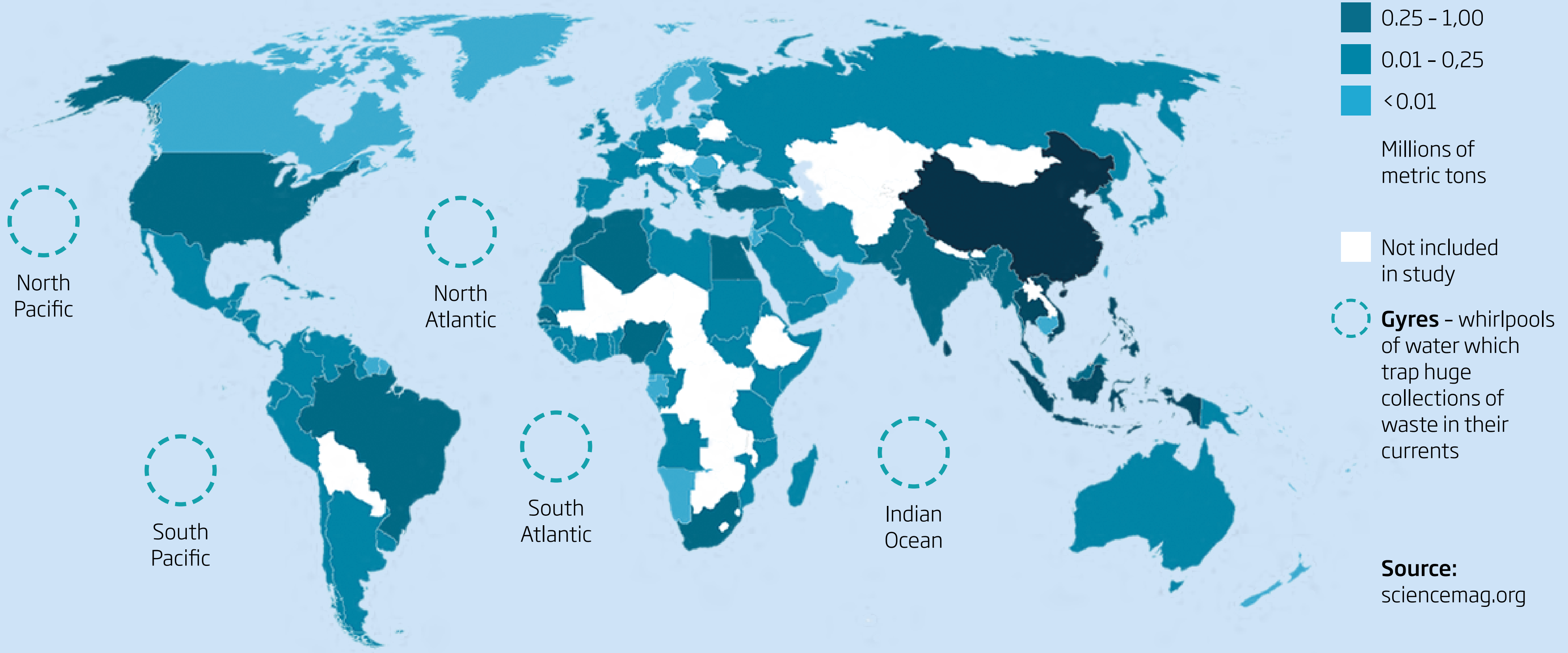
Water boom:
This is a floatation device that is buoyant on water. It sometimes has a skirt attached to the underneath to collect objects and divert oil spills.

Young's modulus: A modulus measures the true value of something. Young's modulus measures the stiffness of a solid material and how much it stretches or bends under external forces.

An example of a water boom in action

Reference panel: Global mismanaged plastic waste

Global map with each country shaded according to the estimated mass of mismanaged plastic waste generated living within 50 km of the coast.



Source: sciencemag.org

Challenge one: resistance to deformation - Young’s modulus

10 mins

An important property of a water boom is how easy it is to bend the material when deployed in the water. The structure of the boom needs to form an arc and move flexibly with strong waves to weather storms more easily.

Young’s modulus relates to the deformation of a rod when you bend it. In engineering, deformation is the amount of change in shape when a force is applied. The easier a rod is to bend, the lower the Young’s modulus.

The resource box provides five materials:

1. **UHMWPE plastic (green) -** used in high-performance yachting sails
2. **Stainless steel -** used in taps
3. **LDPE plastic (white) -** used to make shopping bags
4. **Steel -** used in buildings
5. **Eco film -** used to shrink wrap objects

- Order and rank these materials from the lowest Young’s modulus (5) bendy to highest Young’s modulus (1) stiff.
- Describe the appearance of each material.

Material	Young’s modulus ranking	Appearance
UHMWPE plastic - green		
Stainless steel		
LDPE plastic - white		
Steel		
Eco film		

Challenge two: resistance to degradation in water

30 mins

Investigate these ideas and questions further and work towards a Bronze CREST Award.
Find out more at www.crestawards.org

CREST AWARDS

The structures deployed in the ocean to clean up the plastic will need to be used for extended periods of time. For small floating bins, this could be over the course of weeks, but floating booms would ideally be deployed for five years or longer.

An important challenge is that sea water contains salt and dissolved oxygen. This makes it easy for materials to degrade through a chemical process called corrosion. Alternatively, the materials can be degraded through a physical process called dissolution.

This challenge compares the resistance of different materials to degradation in salt water.

TIME TO INVESTIGATE

- In a suitable container, dissolve 50 grams of table salt in 500 mL of water. Immerse the five materials given in this container of water and observe the appearance after 1 week compared to the original appearance.
- Write down whether the materials have low (5) or high (1) resistance to degradation in water.
- Record the changes of appearance in the table.

STRETCH AND CHALLENGE

Discuss whether the degradation you observe is caused by physical or chemical processes.

Material	Degradation value	Change of appearance
UHMWPE plastic - green		
Stainless steel		
LDPE plastic - white		
Steel		
Eco film		

Reference panel

Physical degradation: Physical degradation involves changes to materials resulting from exposure to sunlight, heat, humidity and general wear and tear.

Chemical degradation: Chemical degradation involves a reaction between chemicals. For example, iron (in steel) reacts with water and oxygen to an oxide and rusts

Challenge three: choosing the right material to clean up the oceans

45 mins

Choosing the right material depends on what properties are required for the application. Very often, this is not based on one property, but a collective range of properties based on how important they are.

The strength and cost of the materials are given in the table (right).

When deploying booms in the oceans, fill out the following three tables to work out the right material to use.

Material	Strength (MPa- Megapascal)	Cost per unit volume (£ per cubic metre)
UHMWPE	2400	£2,910
Stainless steel	800	£16,380
LDPE	10	£1,710
Steel	220	£3,120
Eco film	5	£1,547

TABLE ONE: IMPORTANCE

Score how important each property is for the application (1 = not important, 5 = very important).

Property	Importance
Strength	
Young's modulus	
Corrosion resistance	
Cost per unit volume	

TABLE TWO: MATERIALS SELECTION

Score how good each material is for each property (1 = very poor, 5 = very good). For example, the material with the lowest Young's modulus (very bendy) would have a score of 5 for that property, but the material with the highest cost would have a score of 1 for that property.

Material/Property	Strength	Young's modulus	Degradation resistance	Cost for 1 cubic metre
UHMWPE				
Stainless steel				
LDPE				
Steel				
Eco film				

TABLE THREE: DECIDING ON THE RIGHT MATERIAL

Multiply the scores in the materials selection **table two** with the importance factors in **table one**. Then add up the values of each material to give the total sum for each material.

Material/ property	Strength	Young's modulus	Degradation resistance	Cost/volume	Sum
UHMWPE					
Stainless steel					
LDPE					
Steel					
Eco film					

The material with the highest score has the best combination of properties for the ocean boom.

Which materials would you pick?

Extension design challenge: how to clean up an ocean?

The problem of cleaning up the world's oceans is far from solved and a lot of creativity and collaborative problem solving is needed. Can you invent the first feasible method for extracting large amounts of plastic debris from the ocean?

Some of the questions under debate are: where is the plastic concentrated? Should we collect the plastic from the oceans themselves, or from the rivers and harbours that feed into them? How much will it cost to scale a solution and how durable is it? How can we clean up plastic without affecting marine life?

Using the skills you have learnt, research what is known about these questions and design your own solutions, with particular consideration to the materials needed.

Be creative, innovative and revolutionary!

3D printing sustainable buildings of the future

45 mins

A 3D printed house of the future

Identifying the problem

Concrete is one of the most common materials used in the building industry. However, concrete contributes to 5% of the world's CO_2 emissions.

CO_2 is a greenhouse gas that contributes to climate change and this could lead to changeable weather patterns and rising sea levels. Rising sea levels could have an impact on coastal communities and housing in the future.

One way to reduce CO_2 emissions from the concrete industry is to reduce waste, such that less concrete is used to make the same structure. This can be achieved with 3D printing. 3D printing automatically extrudes (forces out) construction materials based on a computer-drawn design and can give rise to more complex structures with less wastage and fewer differences between each structure.

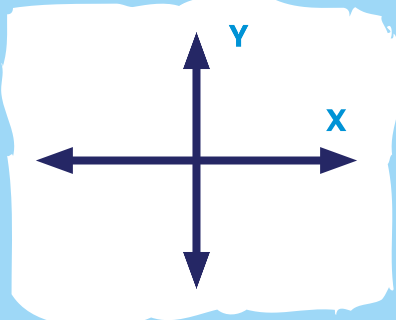
This resource asks you to build a 3D printer and use this to design and 3D print your own structure. You will use chocolate as your model building material because it has a workable form and sets into a solid shape, much like concrete does.

Watch how to 3D print chocolate at:
www.youtube.com/watch?v=-TNf_1LhGCU

Reference panel

Extrusion:
A 3D-printing process pushes a material through an opening, building layer upon layer.

X and Y axis:
A coordinate grid has two perpendicular lines. The x-axis is horizontal (across), while the y-axis is vertical (up-down).



SHOPPING LIST

Description		Supplier
Syringe (20mL)	20mL	amazon.co.uk
3D Printer construction kit		mindsetsonline.co.uk

TIME TO INVESTIGATE

Identifying the right materials for construction depends on their availability, cost, the process and suitability for the environment they are used in, as well as the size of the building. Below is a list of five building materials. Discuss the advantages and disadvantages of each for construction and think about which communities and locations they would be used in.

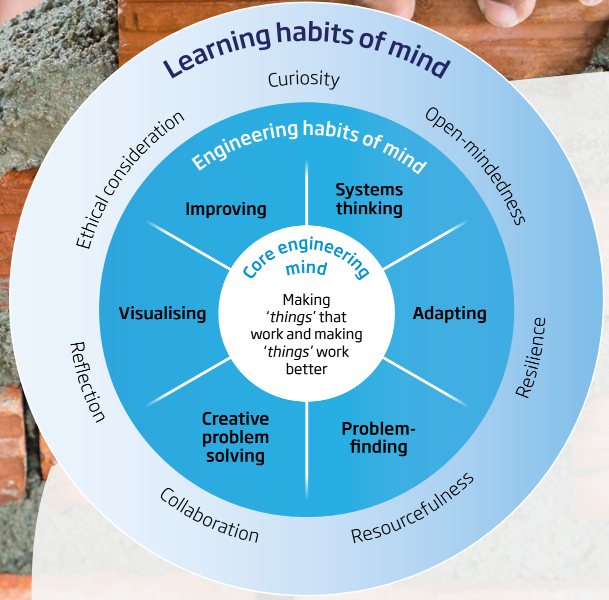
Record your observations.

MATERIAL: STEEL

Properties	Advantages	Disadvantages
Community		

MATERIAL: THATCH (STRAW)

Properties	Advantages	Disadvantages
Community		



EHoM core skills

- Problem finding
- Visualising
- Improving
- Adapting

MATERIAL: ICE

Properties	Advantages	Disadvantages
Community		

MATERIAL: WOOD

Properties	Advantages	Disadvantages
Community		

MATERIAL: CLAY

Properties	Advantages	Disadvantages
Community		

Challenge one: handheld extrusion

30 mins

In this challenge, you will use a syringe to extrude (push out) plain dark chocolate to create a hollow block shape by hand.

Materials

- Chocolate bar – plain dark chocolate
- Saucepan, ceramic bowl and spoon to stir
- Baking paper
- Syringe (20mL)

Process

- Put the bowl in the saucepan and pour tap water into the saucepan, so that the water comes halfway up the bowl.
- Break the chocolate into small chunks and place into the bowl in the saucepan.
- Heat the chocolate on a low heat stirring occasionally.
- Fold a piece of baking paper to form a cone.
- Pour the chocolate into the cone and cut off the end.
- Squeeze the chocolate through the small hole at the end and into the syringe. This is like decorating a cake.

  Caution: The chocolate will be very hot so take extra care when pouring into the syringe.
- Press the plunger of the syringe slowly to create a rectangular shape that is 5 centimetres long, 2 centimetres wide and 0.5 centimetres high.

TIME TO INVESTIGATE

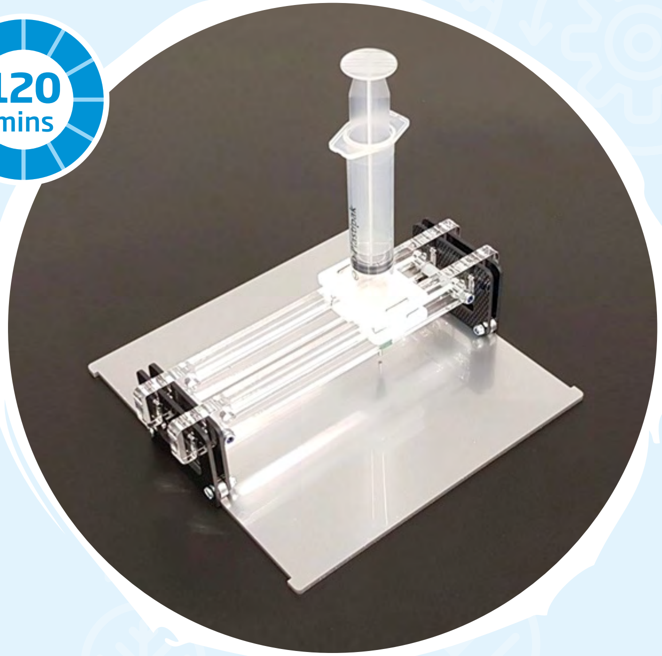
- **What difficulties did you encounter?**
- **Could you redesign your structure to make the process easier?**

TIME TO BUILD

Your task is to build a 3D printer from the kit provided. All the materials and equipment required are in the box. Use **the instructions in the pack** to guide you through the process.

Challenge two: finding the best material to extrude

120 mins



In this challenge, you will use the 3D printer you have built to create your hollow rectangular blocks from chocolate. Each chocolate should be tested individually.

You will conduct an experiment to identify the best chocolate material to use. Three chocolates will be available: white chocolate, milk chocolate and dark chocolate.

Materials

- Plain chocolate bars - white, milk and dark
- Saucepan and spoon to stir
- Syringe (20mL)

Process

- Repeat the chocolate melting process undertaken in **Challenge one**
- Draw the liquid chocolate up into the syringe or spoon in at an angle, avoiding air bubbles
- Place the syringe in the holder of the 3D printer
- Move the syringe along the X (left and right) and Y (up and down) axis of the 3D printer whilst slowly extruding the chocolate to create your shape

TIME TO INVESTIGATE

- **Is the level of control easier or harder than extruding by hand?**
- **Which type of chocolate extrudes the best?**

Fill out the table (right) and discuss which type of chocolate is best for printing.

Chocolate	Consistency after melting	Diameter of material extruded	Consistency five minutes after printing
White			
Milk			
Dark			

Challenge three: design your 3D-printed house

90 mins

Many towns and cities across the globe are overpopulated with limited space to build housing from traditional methods. Homelessness is a problem around the world.

Design the world's first habitable 3D-printed houses fit for people to live in comfortably. Your design should be energy efficient, cost efficient and consider the manufacturing process.

Select the country where the house will be built and design it to blend in with its surroundings, making use of the environment's natural materials.

Remember – we need creative, innovative and revolutionary engineers to save the planet!

Investigate these ideas, research what solutions may already be out there. Test, evaluate and record your ideas and you can work towards a Bronze CREST Award.

Find out more at www.crestawards.org

CREST AWARDS

Teachers guide

Materials to circumnavigate the globe

How do we move away from taking, making and disposing?

Challenge three: reuse

METHOD ONE – BOILING SEA WATER

- Explain that water boils at 100 °C. Maybe get the students to measure with a thermometer. Caution: beware of scald.
- Explain what the mass of water is per unit volume (for example, explain what density is). 1 millilitre of water = 1 cubic centimetre of water and weighs 1 gram.
- The energy required to boil the water depends on how much water there is. As a point of reference, if we have 100 millilitres of water, and we boil from room temperature (25 °C) to 100 °C, the energy would be 257 kilojoule.
- Put the energy into context. One joule is the energy required to drop 100 gram (for example, 1 newton weight) by 1 metre. 257 kilojoules would be like dropping 26,000 kilograms by 1 metre. That's about 10 cars.

METHOD TWO – SALT WATER FILTRATION

The filter is a membrane that has tiny holes, however the membrane must have pores that have 0.1 microns in size to filter the salt ions and only allow the water molecules to pass through. It is likely that not all salt ions will be collected in this experiment and the filtered water will still contain elements of salt, making it less purified than method one, but more energy efficient.

Filtration using normal school filter paper is a standard method used in schools to show that salt water can not be separated by filtration as the dissolved salt particles are too small to be filtered out. To remove more salt, we need to have smaller pores, on the order of nanometers.

Cleaning up the world's oceans

A mission to remove 16 million pounds of plastics

In 2010, 4.8 to 12.7 million tonnes of plastic entered the oceans in the world. Predicted to double by 2025.

If all 45,000 to 129,000 tonnes of plastic were from plastic bottles, that would be two to four billion bottles. Can compare this to the exercise earlier. Main message: we have lots of plastic in a large area of ocean.

Density and buoyancy

The solution is to make a hollow structure. This reduces the mass of steel in the same volume, such that the density of the total structure is lower than that of water.

Challenge one: resistance to deformation – Young's modulus

Order is LDPE, UHMWPE , Eco film and then the steels.

Challenge two: resistance to degradation in water

Material	Degradation value	Change of appearance
UHMWPE	4	No change
Stainless steel	3	No change
LDPE	5	No change
Steel	2	Rusted
Eco film	1	Dissolved

Stainless steel is more resistant to corrosion because of additives (e.g. Cr), which lead to the formation of a protective oxide layer (e.g. Cr_2O_3)

Challenge three: choosing the right material to clean up the oceans

Strength is the stress (force per unit cross-sectional area) at which material starts to stretch without springing back to original shape. We call this plastic deformation. Higher strength means that the material can withstand larger forces in the ocean.

Eco film scores highly but we should eliminate this material because it dissolves in water.

UHMWPE and LDPE are the highest scoring materials. However, the low strength of LDPE is probably concerning and we should not use this in a high stress environment.

Probably use UHMWPE.

Should discuss the advantages and disadvantages of this method.

Advantage: can evaluate multiple materials and multiple properties simultaneous.

Disadvantage: relies on human judgement. It would be preferable if we could compare materials based on the measured values of their properties directly.

3D printing sustainable buildings of the future

Addressing housing needs in developing nations

Identifying the problem – time to investigate

MATERIAL: STEEL

Properties	Advantages	Disadvantages
Hard and tough Resistant to wear Magnetic Conductive of heat	Strong, can be made at scale, long-lasting	Heavy, can corrode, requires heavy industry to process
Community – large urban areas, towns and cities		

MATERIAL: ICE

Properties	Advantages	Disadvantages
Brittle Easy to shape Cheap	Easy to chisel and shape. Readily available in cold climates, good insulator (high latent heat of fusion), lower density than water	Melts in warmer climates
Community – northern hemisphere, Greenland, Iceland and Scandinavian countries		

MATERIAL: CLAY

Properties	Advantages	Disadvantages
Malleable Brittle Durable Stable	Easily workable, abundant source materials, good thermal insulator, low cost	Poor sound insulation, time consuming construction, not resistant to earthquakes
Community - global		

MATERIAL: THATCH (STRAW)

Properties	Advantages	Disadvantages
Lightweight Easy to shape and form Ecological	Cheap, simple to process, biodegradable	Low strength, not durable
Community – rural and developing communities		

MATERIAL: WOOD

Properties	Advantages	Disadvantages
Durable Readily available Malleable Cheap Variety of type	Low cost, strong, durable	Can form mould, cutting down trees removes CO_2 sinks – be wary of depletion
Community – global		

Clay is the oldest known building material.

Bricks are made by mixing clay with water, moulding, drying then firing.

Thank you

This STEM teaching and learning resource has been developed by the Royal Academy of Engineering as part of its national **Connecting STEM Teachers** (CST) programme.

CST is a support network for teachers across all STEM subjects ensuring they have the knowledge and confidence to engage a greater number and wider spectrum of school students with STEM. The programme operates across all regions of England, and in Scotland, Wales and Northern Ireland.

The programme, founded by the Royal Academy of Engineering, would not be possible without the generous support of its funders:

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