Royal Academy of Engineering

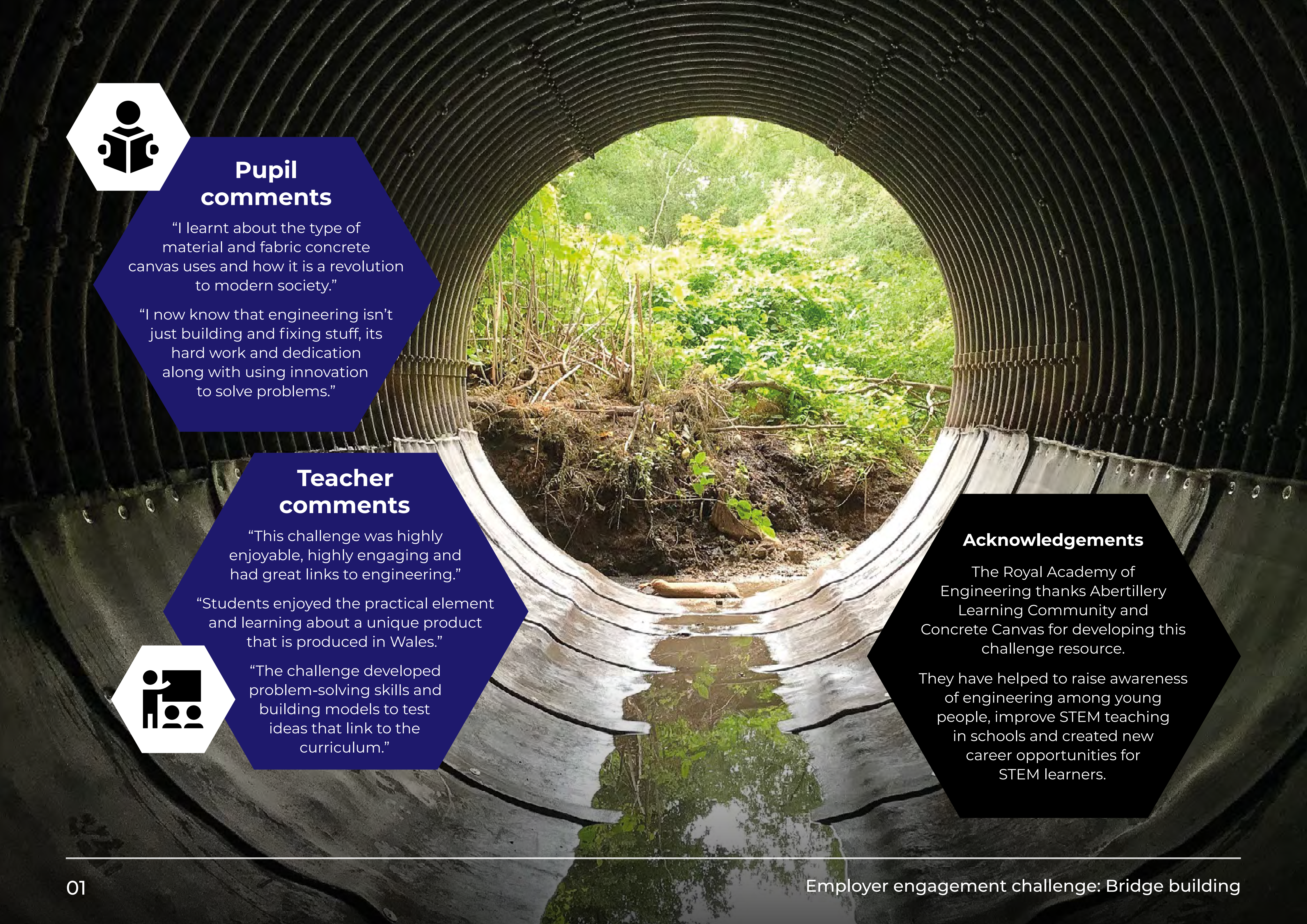
Employer Engagement Challenge

Bridge building

Can you build a stable bridge from flexible material?

Ariennir gan Lywodraeth Cymru
Funded by Welsh Government

THIS IS ENGINEERING



Pupil comments

"I learnt about the type of material and fabric concrete canvas uses and how it is a revolution to modern society."

"I now know that engineering isn't just building and fixing stuff, its hard work and dedication along with using innovation to solve problems."

Teacher comments

"This challenge was highly enjoyable, highly engaging and had great links to engineering."

"Students enjoyed the practical element and learning about a unique product that is produced in Wales."

"The challenge developed problem-solving skills and building models to test ideas that link to the curriculum."

Acknowledgements

The Royal Academy of Engineering thanks Abertillery Learning Community and Concrete Canvas for developing this challenge resource.

They have helped to raise awareness of engineering among young people, improve STEM teaching in schools and created new career opportunities for STEM learners.

Concrete Canvas

Concrete Canvas specialises in a new kind of concrete manufacturing. The concrete solutions as it is on a roll and is typically 10 times faster to install.

This means that it can be used in places where normal concrete cannot be used, such as regions heavily damaged by natural disasters.

The challenge

In disaster-hit regions, where lives are at risk and escape routes are cut off, innovative solutions are vital for quick and effective response. Concrete Canvas, with its inflatable and roll-out concrete technologies, has introduced new possibilities for shelter and infrastructure construction.

This challenge invites teachers to inspire their students to design and construct a bridge using flexible and mouldable materials. They should employ innovative manufacturing processes to address the critical need for safe passage and transportation during disaster response emergencies.

The challenge is to design and build a bridge that spans a one-meter gap while maximising its weight-bearing capacity. The bridge should be constructed using materials that has properties similar to Concrete Canvas.

This challenge encourages students to think creatively, understand principles of engineering and learn about emerging manufacturing techniques to create a bridge that not only demonstrates structural strength, but also provides a solution to a real-world problem.

This challenge is designed to support practitioners to follow Curriculum for Wales' careers and work-related experience guidance. It is supported by a set of videos that give an inside look at how engineers at Concrete Canvas work, and introduces first-hand how the challenge is delivered in school.

The challenge is recommended for secondary school pupils and can be adjusted to match different age groups and abilities.

Here are some of the learning opportunities that the challenge provides:

- **Real-world relevance**
- **Collaboration and teamwork**
- **Innovation design and making**
- **Material exploration**
- **Testing and analysis**

Challenge overview

Setting the class challenge

Welcome, young engineers! Disasters strike unexpectedly, cutting off escape routes and endangering lives.

In such critical situations, quick and effective solutions are needed to ensure people's safety. This is where your creativity and engineering skills come into play.

Your challenge is to design and build an innovative emergency bridge that can provide a safe passage and transportation route during emergencies. You'll be working with flexible and mouldable materials, similar to Concrete Canvas, to create a bridge that is both stable and reinforced. Your bridge should not only showcase structural integrity but also offer a practical solution for real-world problems.

By participating in this challenge, young learners will be developing the skills and practices that engineers use every day in their professional lives.

Asking questions, imagining and planning ideas, creating and refining outcomes, while continuously reflecting on how things could be improved, are all 'Engineering Habits of Mind' as demonstrated in 'the Progressing to be an Engineer' cycle.

The Progressing to be an Engineer cycle

Learning opportunities	Core skills
■ Real-world relevance ■ Collaboration and teamwork ■ Innovation design and making ■ Material exploration ■ Testing and Analysis	**Literacy:** Reading and technical vocabulary. Selective research. Writing and reporting. Presenting and communication. **Numeracy:** Data collection and analysis. Pattern spotting. Measurements and calculation. **Scientific:** Problem-solving and experimenting. Visual and spacial awareness. **Technical:** Systems thinking and problem-solving. Communication and teamwork.

Engineering design process		Activity	Success will look like
0–1 hour	Research the challenge	**Watch the challenge videos** – engineers films **Time to start** – exploring forces **Time to investigate** – triangulation **Time to research and present** – bridge design and construction	Understand the aims and requirements of the challenge, as well as how engineering concepts relate to it. Gather relevant information and have a clear and comprehensive understanding of the challenge.
1–2 hours	Ask	**Time to problem solve** – shaping mouldable materials **Time to question** – systems thinking	Identify problems and ask questions to understand how to resolve them. Explain how systems work while identifying ways they can be improved.
2–4 hours	Imagine Plan	**Time to imagine** – design and develop an emergency bridge **Time to plan** – identify and plan each stage of manufacture	Draw and label multiple design ideas, effectively communicating fitness for purpose and why certain ideas are better than others. Use simple annotated sketches to turn ideas into words and drawings. Plan a design that aims to solve a problem or task for a specific user, by transforming one idea into a better one.
4–6 hours	Create	**Time to create** – bridge construction and testing	Use knowledge of how systems and components work and interact to create a product that achieves a specific purpose. Evaluate the product's fitness for purpose and look to find ways to improve this based on observation and improvement.
6–7 hours	Improve	**Time to reflect** – on experiences in relation to each stage of the challenge.	Test the outcome for quality using a logical approach gathering evidence to make an informed decision Evaluate how the product is working, identifying areas for improvement and describe possible changes that can enhance the design.
7–8 hours	Present the challenge	**Time to present** – highlight the success of the challenge	Communicate ideas effectively and with confidence, making complex concepts understandable to the audience. Engaging interactions and making a lasting impression.

Research the challenge

Ask

Imagine

Plan

Create

Improve

Present the challenge

Time to start

Begin by showing the class the set of three engineer videos that showcase the diverse range of engineering roles within the company. Each video is approximately three minutes long.

Go to **raeng.org.uk/wvep** or scan the QR code to watch the videos.

Laurie: Technical sales representative

Alice: Design engineer

Mark: Research and development engineer

The aim of this first activity is to explore the forces of tension and compression and how triangulation creates stability in structures.

Begin by discussing with the class the concepts of tension and compression and how these relatable factors play a crucial role in bridge design and construction, where stability is an essential consideration for ensuring safety.

Explain that tension is a pulling force that stretches objects, while compression is an opposing force that squashes objects. When a force become excessive, objects can experience snapping or breaking.

Demonstrate real-life examples of tension, compression and snapping.

1. Stretch an elastic band and note how it becomes longer and thinner under tension.
2. Apply pressure to a ball of plasticine, noting how the plasticine becomes shorter and wider under compression.
3. Hold a piece of spaghetti at both ends and gently apply force to the centre until it snaps. Note how the spaghetti breaks due to excessive force.

Understanding these concepts is vital in structural engineering.

Tension and compression forces are at work in the various components of a bridge, such as cables, beams and supports.

Just like the elastic band, materials like steel and concrete can experience these forces, impacting their structural integrity.

Engineers must ensure that bridges are designed to handle both tension and compression forces effectively, preventing potential failures and maintaining stability.

Time to investigate triangulation

Briefly explain how triangular shapes are often used to provide stability in structures due to the angles and sides contributing to their strength.

For example the Eiffel Tower, geodesic domes, bridge construction and various natural forms all apply **triangulation** to maintain a rigid structure.

Starter activity: In pairs, ask students to construct a triangular prism by connecting toothpicks using plasticine at each vertex.

Encourage students to experiment with different sizes of triangles (equilateral, isosceles and scalene) to observe how the shape affects the stability of the prism.

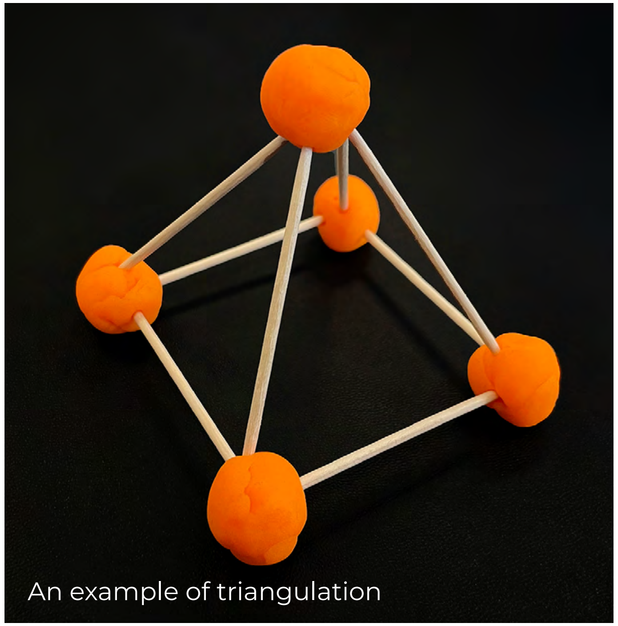
As students build, have them discuss which types of triangles create the most stable and rigid prisms. Emphasise how the triangular shape distributes forces evenly, preventing deformation.

Discuss the real-world implications and encourages critical thinking about structural design, especially in bridge construction where stability is essential.

The aim of this activity is to research examples of different types of bridges and investigate how they are constructed and the forces acting upon them.

Students work in pairs to research two of the six types of bridges listed below before presenting their findings to the class.

Arch	**Beam**	**Cable-stayed**
Cantilever	**Suspension**	**Truss**


An example of triangulation


A geodesic dome

Time to research

Ask pairs to work together to conduct in-depth research on the strength, construction, appearance and examples of their chosen bridges.

They should also focus on understanding how tension and compression forces act on these bridges, making notes and sketches of key concepts and examples.

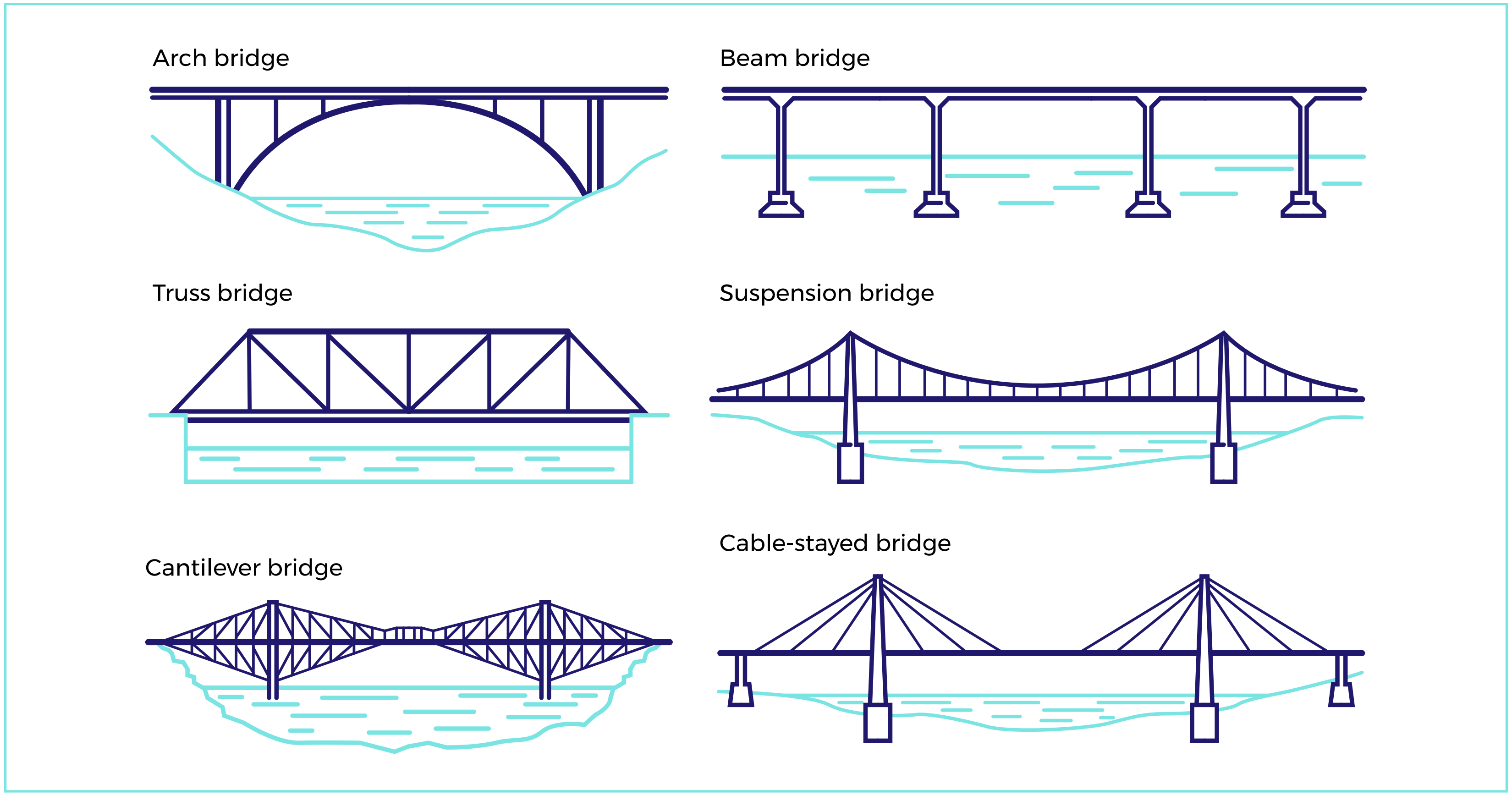
Provide a list of pre-approved websites to save time and ensure they access reliable and relevant information.

Time to present

Give each group an opportunity to present their findings to the class and emphasis the importance of each team member's involvement in some aspect of the presentation.

Ask students to share what they have learnt and any insights they gained about bridge engineering, including the roles of tension and compression forces. They can use presentations, drawings or verbal explanations to share the information they have found.

Encourage the other students in the class to ask questions and engage in discussions after each presentation.



Time to problem solve

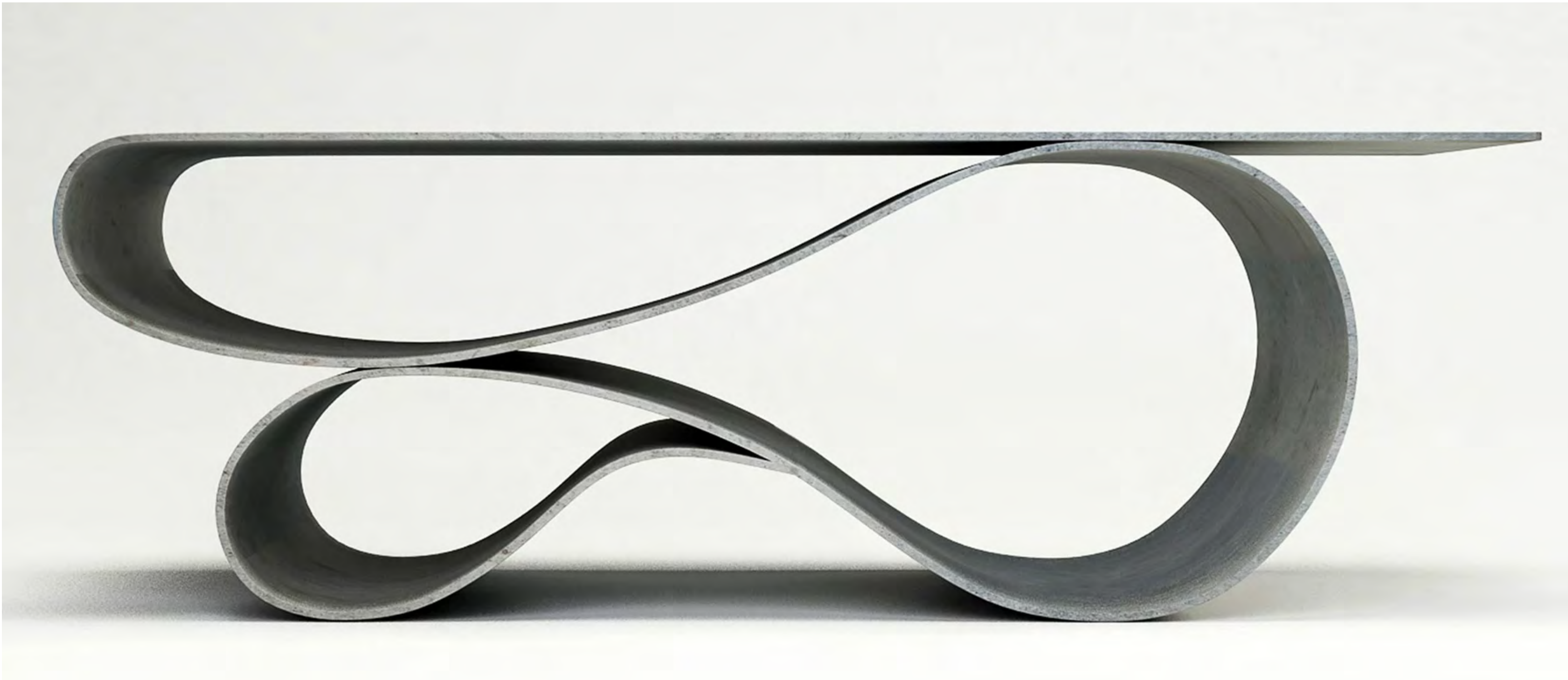
The aim of this activity is to understand how mouldable materials can be shaped effectively using modern manufacturing techniques.

Concrete Canvas is a flexible fabric that can be inflated or comes in a roll. Once unrolled, it can be moulded into the desired shape and then sprayed with water. Within 24 hours, it sets into this shape, forming a durable, reinforced concrete layer.

In this activity, students create their version of Concrete Canvas material using a Plaster of Paris solution. This solution is used to shape a mouldable form that replicates the properties of Concrete Canvas and the manufacturing technique employed.

The technique, known as rotational moulding, will be used by students to create a self-supporting, hard shell structure.

Materials
■ Plaster of Paris mix and containers filled with water ■ Balloons and funnels ■ Air pump and timer ■ Containers filled with water and mixing stirrers ■ Newspapers or plastic sheets (to protect the work area) ■ Personal protective clothing – aprons and gloves



A stylish table made from flexible Concrete Canvas

Problem-solving activity

Simulating rotational moulding with Plaster of Paris.

1. Divide the class into pairs and give them the necessary materials and personal protective equipment (PPE) to ensure safety during this activity.
2. In a mixing container, combine the Plaster of Paris mix with water according to the instructions. Stir well until a smooth consistency is achieved.
3. Attach the funnel to the neck of the deflated balloon and carefully pour the plaster mix into the balloon.
4. Once filled with the plaster mix, carefully detach the funnel from the balloon neck. Inflate the balloon using the air pump and tie the balloon's neck securely to prevent air from escaping.
5. Start the timer and rotate the balloon continuously in different directions for 20 minutes. This process allows the plaster to evenly coat the interior of the balloon.
6. Allow the plaster to set and harden for a few hours. Once the plaster is fully set, carefully pop the balloon with a pin. The hardened plaster shell will remain intact.

Test the load-bearing capacity of the plaster shell by adding weight.

This could lead to discussions about weight distribution, forces and the structurally engineered properties of the plaster shell.

Emphasise how the shape of the shell resists both inward and outward pressure. Discuss real-world applications where this structural design might be useful.

Time to question

Systems thinking is "explaining how things work together and why each part is there".

The questions below encourage critical thinking about the complexities involved in designing and constructing bridges, while also considering the balance between innovation, safety and sustainability.

Discuss these questions as a group and facilitate the conversations in class.

Systems thinking questions	
1	What should engineers consider to ensure the structural integrity of a bridge, enabling it to withstand various loads and weather conditions?
2	Why is reinforcement important in bridge construction? What does it help prevent, and how might different types of reinforcement such as steel cables, rods or trusses contribute to the bridge's strength?
3	How might mouldable materials allow engineers to create more complex and innovative bridge designs? Can you see scenarios where using mouldable materials would result in a more stable and cost-effective bridge?
4	How might the manufacturing technique of mouldable materials lead to faster bridge construction or reduced maintenance needs?
5	What potential challenges could arise when designing and constructing a bridge using mouldable materials, and how might engineers ensure that mouldable materials provide the required strength and stability for a safe crossing?
6	Why is it important for engineers to find a balance between designing an aesthetically pleasing bridge and ensuring its safety?
7	How might the choice between mouldable materials and traditional concrete processes impact the environmental footprint of bridge construction?

Research the challenge
Ask
Imagine
Plan
Create
Improve
Present the challenge

Time to imagine

The aim of this activity is to design an innovative emergency bridge that ensures structural integrity and stability.

Initial ideas

In teams, students sketch ideas for their bridge design, drawing upon their experiences from previous activities.

Encourage them to be as creative as possible and find innovative solutions for constructing a bridge in an emergency situation.

Prioritise structural integrity and the safety of passengers crossing the bridge. Ask teams to consider the mouldable materials they've used in problem-solving tasks and incorporate these techniques into their drawings.

Guide them to consider the manufacturing processes they will be using when modeling and prototyping their designs later on.

Development of ideas

In teams, review all of the initial design ideas and establish a ranking system. Use scores to determine the preferred designs and those that need improvement.

Students should take into account safety, stability, use of mouldable materials and the overall aesthetics of each bridge design.

The cumulative scores for each design should play a role in shaping the decision regarding which ideas to develop further.

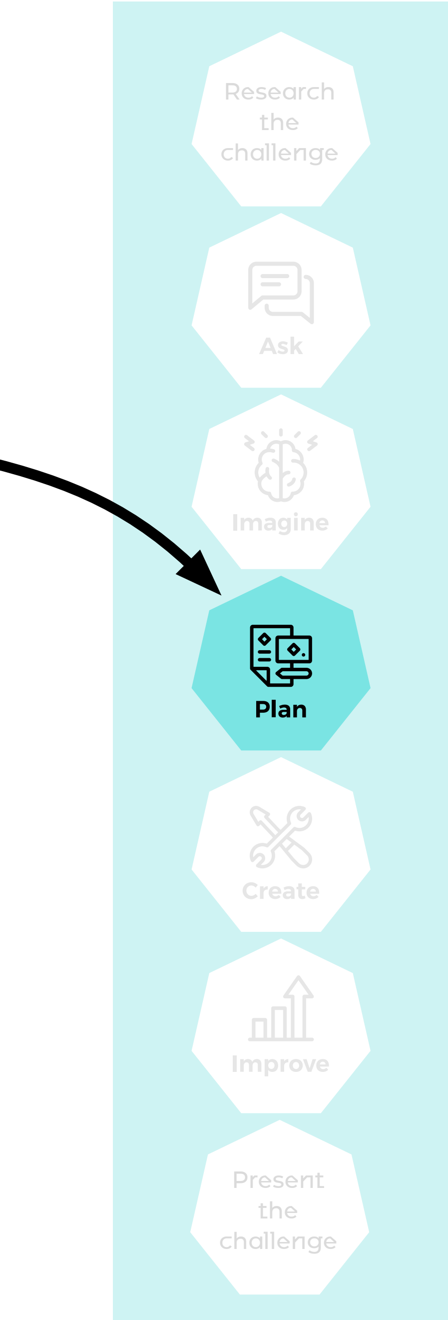
Final design

Create final designs using computer-aided design software or constructing models using building kits like Lego or K'Nex.

These designs should be three-dimensional or depicted from various angles to illustrate the bridge.

Share the final designs within the team and engage in a discussion about which features should and should not be integrated when constructing the emergency bridge.


The Ruyi bridge, China



Time to plan

The aim of this activity is to outline each stage of manufacturing the emergency bridge, considering choice or materials and construction techniques.

Before building begins, ask teams to plan each step involved in building the bridge. This should include moulding, cutting, shaping and assembling the materials according to the selected final design.

Guide teams to establish quality control measures to ensure the design meets the required standards. Identify any potential weak points or defects within the manufacturing process that might lead to instability.

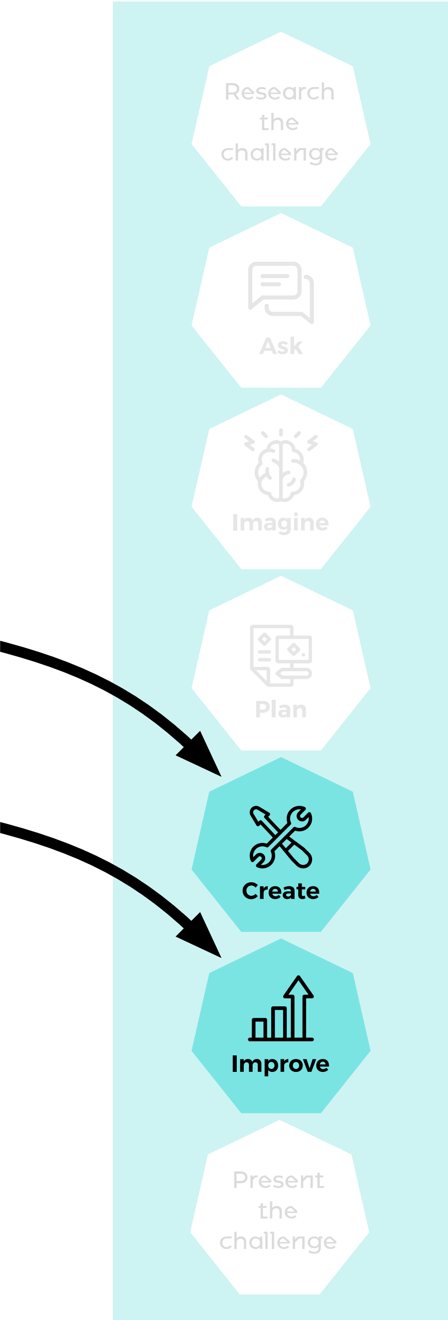
Encourage them to consider properties such as strength, weight, flexibility and stability before selecting which materials to use based on the designs they have drawn for the bridge's construction.

Teams should take into account lightweight yet robust materials capable of absorbing forces. Provide teams with materials such as Plaster of Paris and Modroc plaster strips, as well as recycled materials to choose from.

Materials

- Plaster of Paris or Modroc plaster strips
- Recycled materials, glue and tape
- Reinforcement materials such as lolly sticks and straws


Clyde Arc Bridge in Glasgow, Scotland



Time to create

The aim of this activity is to construct and test the emergency bridge spanning one metre that can provide a safe passage for people and vehicles.

In teams, provide the students with the building materials and let them start constructing their bridges based on their chosen design. Encourage them to collaborate, share ideas and help each other during the construction phase.

Once the bridges are constructed, explain the importance of load-bearing capacity.

Introduce the idea of testing by placing weights on the bridge to simulate the load it needs to support during an emergency. Students should carefully record the maximum weight their bridge can withstand before collapsing.

Huaihai South Road Bridge, Huai'an City, China

Time to reflect

Success can be based on the skills students develop and the practices they acquire throughout each stage of the challenge.

These include the ability to ask questions, imagine and plan ideas, create and refine outcomes, while continuously reflecting on how things could be improved.

Engineers also demonstrate the following practices as part of their day-to-day activities.

- Problem finding and creative problem-solving
- Systems thinking and visualising
- Adapting and improving
- Teamwork and collaboration
- Project and time management

At the end of the challenge, gather teams for a post-challenge debrief. Encourage them to reflect on their experiences and assess their personal growth in relation to the skills they have developed and practised throughout the challenge.

Present the challenge

Time to present

The aim of this final activity is to present outcomes, explain choices throughout the challenge and highlight what went well and what could be improved.

This should be a group task where every member of the team contributes to the presentation in some way.

The presentation can be divided into the following sections.

1. A summary of the final outcome and its features
2. What went well during the design and construction process?
3. What challenges did they face, and how did they overcome these?
4. How could the outcome be improved or enhanced?


Concrete Canvas fabric


Concrete Canvas emergency shelter

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.

What we do

Talent & diversity

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

We're developing skills for the future by identifying the challenges of an ever-changing world and developing the skills and approaches we need to build a resilient and diverse engineering profession.

Innovation

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

We're building global partnerships that bring the world's best engineers from industry, entrepreneurship and academia together to collaborate on creative innovations that address the greatest global challenges of our age.

Policy & engagement

We're influencing policy through the National Engineering Policy Centre – providing independent expert support to policymakers on issues of importance.

We're engaging the public by opening their eyes to the wonders of engineering and inspiring young people to become the next generation of engineers.

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

Tel: +44 (0)20 7766 0600
www.raeng.org.uk
Registered charity number 293074