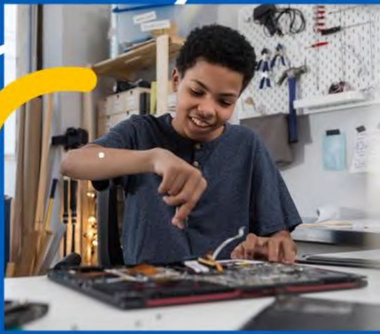
NEXT ENGINEERS



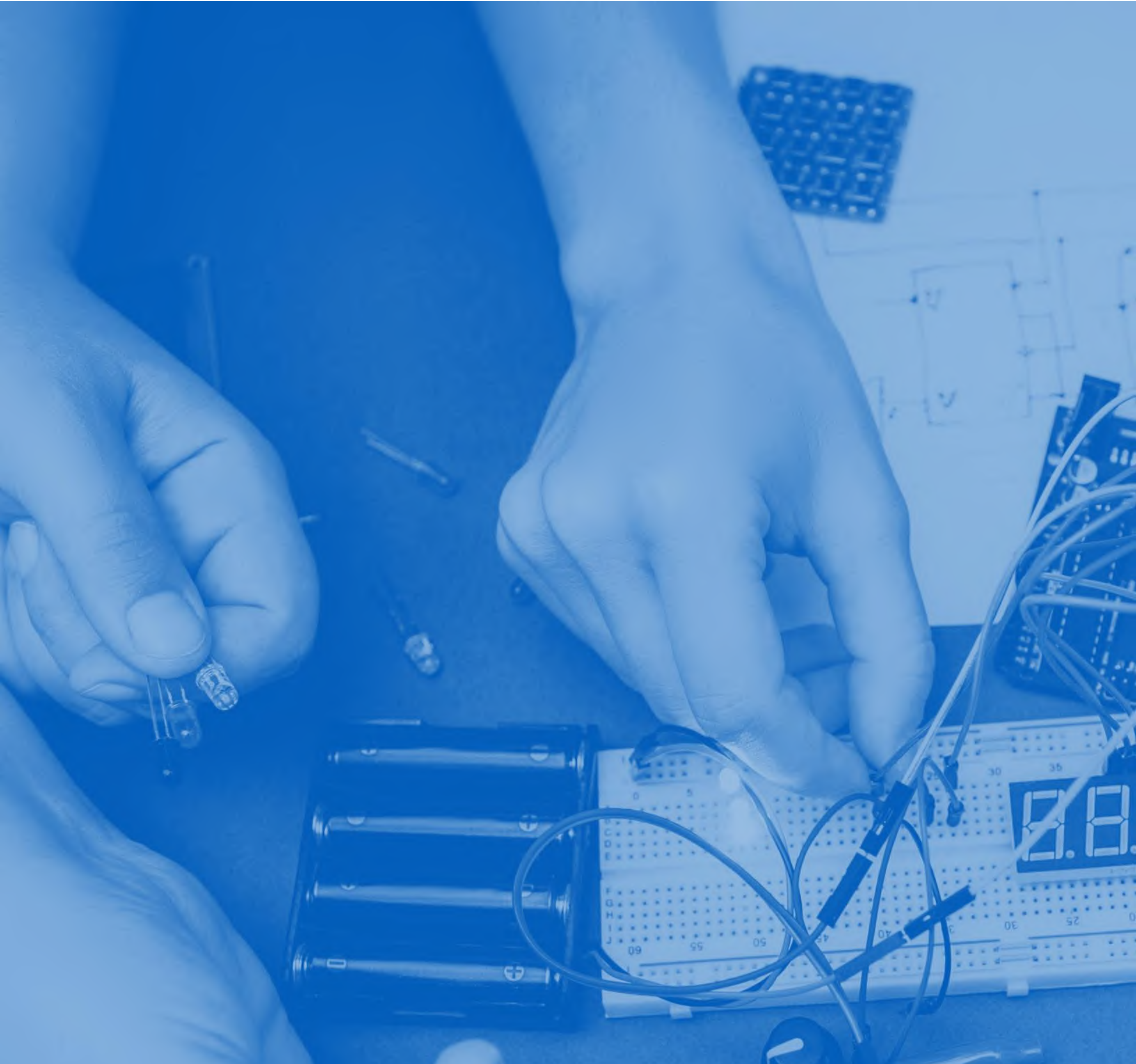
ENGINEERING CAMP

Move the Heat

Topics:

Energy Engineering
Chemical Engineering
Materials Engineering

GE Foundation



Move the Heat is part of the Engineering Camp series curated by FHI 360 for the GE Foundation's NEXT ENGINEERS and is based on an activity originally created by NASA's Jet Propulsion Laboratory (Feel the Heat, https://www.jpl.nasa.gov/edu/teach/activity/feel-the-heat/). NEXT ENGINEERS is a college and career readiness program that inspires and develops the next generation of engineers. Adapted content and graphic design courtesy of FHI 360.

Version 1 – 12 April 2022

Move the Heat

ICE-BREAKER CHALLENGE

Time	Cost	Group size (teams)	Activity Type
85 minutes	Medium	3 - 4 students	Ice-Breaker Challenge
Engineering Areas			
• Energy Engineering • Materials Engineering	• Chemical Engineering		

Activity Description

Heating water takes a great deal of energy. We say that water has a high specific heat. It can absorb lots of energy before its temperature rises. This is why water is such a good option to use in cooling systems – moving heat energy away from where it is not wanted.

But water is, therefore, also good at retaining heat. It needs to lose lots of energy before its temperature decreases. This makes water equally useful in heating systems - moving heat energy to where it is needed.

This challenge explores water as a heat transfer mechanism.

About the Engineering Design Challenge

In this challenge, students are divided into teams to design, build, and test a device that can capture the heat from sunlight or a lamp to raise the temperature of a given amount of water by at least one degree Celsius and move it 1 m (3.3 ft) from its source.

Success Criteria

- The device must raise the temperature of 200 ml (6.8 fl oz) of water by at least 1°C (1.8°F).
- The device must move the heated water 1 m (3.3 ft) from the source cup to the destination cup.

Constraints

- Students may only use the materials provided.
- Students must complete the challenge in the given time.
- Only water can flow through the device (i.e., no additive may be added).

STUDENT DISCOVERIES

Students will:

- Know more about engineering
- Learn about the Engineering Design Process
- Participate in a team-based learning experience
- Learn about the importance of testing and iterating
- Learn about how water can effectively absorb heat energy
- Have fun experiencing engineering

Materials

Students will need blank paper and pens/pencils to draw their designs.

The following materials will be required **per group** for this activity:

- 2 polystyrene cups (about 250 ml (8.5 fl oz)) – these are better insulated than paper cups – mark one of the cups at the 200 ml (6.8 fl oz) mark
- Four 0.5 m (1.5 ft) lengths of clear plastic tubing (about 6 mm (0.2 in) outside diameter)
- A large sheet of cardboard (about A3 size and about 160 gsm or 11 in x 17 in cardstock)
- Aluminum foil (about 30 cm x 90 cm (12 in x 36 in))
- Food plastic wrap (about 30 cm x 60 cm (12 in x 24 in))
- 3 – 4 sheets of black paper (A4 or letter size)
- A black marker (non-permanent)
- A jug of water or access to water for testing
- Scissors
- 8 drinking straws – try and make sure that the clear plastic tubing fits inside the straws
- A roll of packing tape
- Access to direct sunlight or a heat lamp with a 100 W bulb
- 1 copy of the Engineering Design Process Summary (below)
- 1 copy of the Student Worksheet (below)

The following materials are required for testing and evaluating the designs:

- A jug of water
- A measuring tape
- A thermometer able to read tenths of a degree (digital is preferable) – if possible, have a few that teams can share while they build.

Facilitation Principles

These documents contain helpful advice for anyone facilitating a Next Engineers engineering activity or challenge.

- **Working with Youth: Facilitation Tips** (https://www.nextengineers.org/resource/working-youth-facilitation-tips) is a handy summary of the key facilitation principles that facilitators need to keep in mind when facilitating any activity with students.
- **Ten Guidelines for Building New Engineers** (https://www.nextengineers.org/resource/ten-guidelines-building-new-engineers) gives ten practical guidelines on how to facilitate all Next Engineers engineering activities and challenges to build new engineers.

KEY WORDS

- Absorption
- Constraints
- Criteria
- Design
- Drag
- Engineering Design Process (EDP)
- Engineering Habits of Mind (EHM)
- Engineers
- Iteration
- Radiant Energy
- Reflection
- Solar radiation
- Specific Heat

TOP TIP

You can easily extend this challenge by increasing the minimum temperature gain that students need to achieve.

Facilitator Preparation

1. Read the step-by-step instructions.
2. Collect the materials.
3. Practice doing the activity yourself to identify where students may struggle. The important aspects to investigate are how quickly the water flows through the device and how to control this, how to increase the amount of energy the water in the tube can absorb through color and reflection, how to increase the amount of water exposed to the heat source (how long the tube is and how it is positioned), and how to prevent the water that has already been heated from cooling down too quickly.
4. Plan when and how you will share your engineering story in a relevant and personal way. Try to integrate your story into the challenge as much as possible. You can find the following resources for how to tell your story on the Next Engineers website:
    a. **I'm an Engineer! Storytelling Worksheet** (https://www.nextengineers.org/resource/im-engineer-storytelling-worksheet)
    b. **I Work with Great Engineers! Storytelling Worksheet** (https://www.nextengineers.org/resource/i-work-great-engineers-storytelling-worksheet)
5. Practice asking and answering questions students may ask. See **Frequently Asked Student Questions** (https://www.nextengineers.org/resource/frequently-asked-student-questions).
6. Print out copies of the Student Worksheet for each group.
7. Set up each group's materials before the start of the activity.

Step-by-Step Instructions

Time	Instructions	Materials
3 min	**Welcome & Introductions** • Welcome students to the activity and, if necessary, briefly introduce yourself, noting what kind of engineer or engineering student you are and why you think engineering is great. • If this is the first activity, ask students if any of them knows what engineering is about. What do engineers do? How do engineers work? What do engineers make? • Explain that engineers use science, mathematics, and the engineering design process to design solutions to problems that help people and make our lives better. The solutions that engineers design range from artificial heart values to mobile phones to bicycle helmets and everything in between. Feel free to use or include your own examples.	

TOP TIP

As there will be spilled water and teams will need access to direct sunlight, you should try and host this activity outside.

TIPS FOR WORKING WITH STUDENTS

- **Be prepared** by practicing the activity beforehand. Being prepared is the best start to leading confidently and having fun.
- **Facilitate like an engineer** by reflecting during and after each session. What worked? What could be improved? How could you do things differently next time?
- **Teamwork is critical** in engineering so encourage it among students. Make sure no one dominates and that everyone gets to play.
- **Give one instruction at a time** to keep a large group on task and doing what you need them to do.
- **Give regular time updates** to keep students on track.

	• Ask the group to name things in their own lives that engineers have helped design.	
5 min	**Pre-Challenge Exploration** • Ask the group if any of them have a central heating system at home or at school. What does it do? How does it work? Why is it filled with water? • For students unfamiliar with central heating systems, you can ask instead about radiator systems in cars. What do they do? How do they work? Why do they need to be filled with water? • Explain that it takes a lot of energy to heat water up. To raise the temperature of 1 L (0.26 gallons) of water by one degree Celsius takes 4 182 J of energy – that is enough energy to power a 12 W LED lightbulb for about 6 minutes. But this is also the amount of energy 1 L of water needs to lose before it drops in temperature by one degree. • Explain that this means that water is a great way to transport heat as is done in heating systems and radiators. • Ask the group what other applications of water's excellent ability to transport heat they can think of.	
2 min	**Challenge Overview** • Explain that students are going to work together in teams to build a device that can capture the heat of the sun or a lamp to raise the temperature of 200 ml (6.8 fl oz) of water by at least one degree Celsius (1.8 degrees Fahrenheit) and move this water 1 m (3.3 ft) from a source cup to a destination cup. • Explain that these are the success criteria – the things their device must be able to do to be considered successful. • Next explain that students may only use the materials provided (show the group the materials), must work within the given timeframe (60 min), and that only water may flow through the device. • Explain that these are the constraints, the rules that students need to work within. • Tell students that before the 60-minute build period ends, they need to demonstrate to you how well their device works so you can record their official temperature increase. To determine the temperature difference, you will	Building Materials

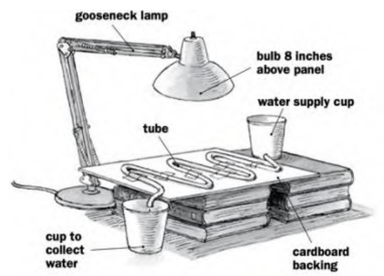
QUICK CALCULATION

Ask students to calculate how much energy it takes to heat 200 L (44 gal) of water by 40 ^{o}C (72 ^{o}F). How long could this power a 12 W LED lightbulb if the bulb consumes 12 J/s?

TIPS FOR MAKING CONNECTIONS

- **Give constructive feedback** to help students grow and improve.
- **Ask open-ended questions** to better understand what and how students are thinking.
- **Be respectful** by listening actively and responding openly and authentically. Give students your undivided attention and the respect you want them to give you.
- **Be honest** about what you know. Say if you don't know something. Encourage students to keep trying by sharing some of your own failures and the lessons you learned.

	first measure the temperature of the water in the source cup then, once all 200 ml (6.8 fl oz) has flowed into the destination cup, you will measure the temperature of the water in this cup.	
60 min	**Engineering Design Challenge** • Divide the group into teams of three or four and hand each team its building materials and a copy of the Student Worksheet. • Tell teams that they have 50 minutes in which to design, test, and re-design their devices before the official testing phase. • Have teams produce sketches of their designs before they start building anything. • As teams work, circulate around the room, encouraging them and answering any questions they might have. As you do so, ask students to think about how the rate of flow through their system might affect how much heat the water can absorb and how much the water that has already been heated may cool down. What effect will the length of tubing that they use have on the effectiveness of their design? What color tube and background should be used to absorb the most heat possible? Would focusing the light or preventing heat from escaping from near the tube help? • Encourage teams to test and refine their devices repeatedly. • Remind teams that before the 60-minute build period is up, they need to call you to come record an official temperature change.	Building Materials Student Worksheet
15 min	**Reflection and Closing** • Give teams about five minutes to discuss the reflection questions in the Student Worksheet. • After this time, bring the group back together to discuss their answers, paying particular attention to what students learnt about engineering and the engineering design process.	Student Worksheet



An example of a water heating and transfer device
Image by NASA is used under fair use
https://www.jpl.nasa.gov/edu/pdfs/solarwaterheater_worksheet.pdf

Extension

This activity can be extended in the following ways:

- Increase the temperate rise that teams need to achieve.
- Increase the amount of water that needs to be heated.
- Impose a time limit of the heat transfer process.

Key Words

- **Absorption**: The transfer of the energy of a wave to matter as the wave strikes it or passes through it.
- **Reflection**: The abrupt change in direction of the propagation of a wave when it strikes a boundary or passes from one medium to another.
- **Solar radiation/radiant energy**: Energy transferred by electromagnetic radiation, such as light from the sun.
- **Specific heat**: The amount of energy (in joules) required to raise the temperature of 1 kg of a substance by 1^{o}C.

- **Constraints**: Limitations of materials, time, budget, size of team, etc.
- **Criteria**: Conditions that the design must satisfy to be considered successful.
- **Design**: a plan or drawing made before something is built to show and explain what it will look like and how it will work.
- **Engineering Design Process (EDP)**: The process engineers use to solve problems and design solutions.
- **Engineering Habits of Mind (EHM)**: Six unique ways that engineers think.
- **Engineers**: Inventors and problem-solvers of the world. Twenty-five major specialties are recognized in engineering (have a look at the infographic at https://tryengineering.org/wp-content/uploads/18-EA-381-InfographicEngineering_R2-6.pdf).
- **Iteration**: The process of gradual improvement through repeated design, testing, and redesign.
- **Prototype**: A working model of the solution to be tested.

Activity Background

There are four important ideas explored in this challenge. The first is that water has a relatively high specific heat. A substance's specific heat is the amount of energy that 1 kg of the substance needs to absorb or lose for it to change temperature by 1^{o}C. In the case of water, this is about 4 184 J/kg ^{o}C.

Some other specific heats are as follows:

Substance	Specific Heat (J/kg ^{o}C)
Dry air	1 005
(Ethyl) Alcohol	2 440
Bone	440
Concrete	880
Copper	385
Gold	129
Iron	449
Wet soil	1 480

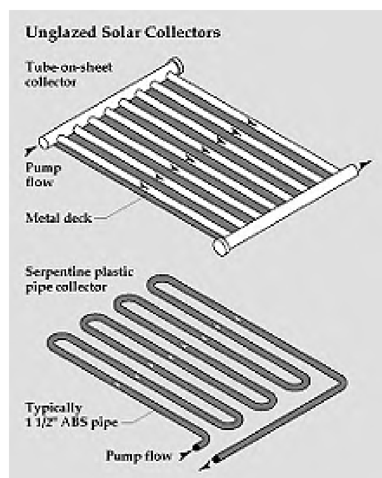


Diagram of two types of solar collector
Image by PASolar is used under fair use
https://pasolar.ncat.org/lesson02.php

While other substances, like ethyl alcohol, have high specific heats, water has one of the highest of any commonly available substance.

This makes water an excellent substance to use in systems where heat needs to be transferred from one place to another. In the case of central heating systems, heat is transferred from a boiler to the rooms of a building. In the case of a car's radiator, heat is transferred away from the engine to the grill.

The second key concept is that dark colors are much better at absorbing radiation or heat energy. This is why solar water heaters are almost always black or dark blue. The dark coloring helps them absorb more of the sun's radiant energy which is then transferred to the water (or other kind of liquid).

Related to this is that reflective materials like tin foil don't absorb but can reflect radiant energy to where it is required and materials like glass (and plastic wrap) are good at letting radiant energy into a space and keeping it there.

The third key concept is that, to absorb as much energy as possible, the water needs to be exposed to the sun's radiant energy for as long as possible. This means that designs where the tubing snakes or loops back and forth are very effective.

Finally, the fourth key concept is related to controlling the flow rate. The slower water flows, the more time it will be exposed to the sun's radiant energy, the more of energy the water can absorb. Water flows downhill. The steeper the gradient, the faster the water will flow. Therefore, the height difference between the start of the tubing in the source cup and the end of the tubing in the destination cup will be a key factor in determining the flow rate through the system. The greater this height difference, the greater the flow rate.

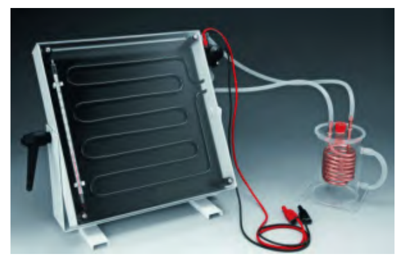
In this challenge, students will need to balance factors. For example, the lower the flow rate of water through their device, the more time the water in the tubing will have to heat up. However, the longer it takes 200 ml of water to flow through the system, the longer the water in the destination cup will have to cool down. This means that teams will have to try and find an optimal flow rate.

In addition, tin foil will be useful in directing more light (and heat) towards the tubing. However, the more foil used for this purpose, the less will be available to insulate the water that is not being heated or that is already in the destination cup.

Also, students need to make sure that the source cup and destination cup are 1 m apart, this means that they will not be able to use all of their tubing to heat the water so they are going to have to make optimal use of the tubing they can dedicate to the heating process.

Finally, students will need to ensure that their device does not leak too badly. However, the more tape they use to plug any holes, the less of the tubing that will be exposed to the sun.

A solar water heating system
Image by Enway Power Systems is used under fair use
https://www.enway.co.za/Low-pressure-110-litre-Kwikot-Solar-Geyser



A Solar thermal collector
Image by DJD Microtech is used under fair use
https://www.djb.co.uk/ppen_solar_thermal_collector.htmlx

DIY solar pool heater
Screenshot by Nicole Michael DIY is used under fair use
https://www.youtube.com/watch?v=HdBCWR3z2D4

Additional Resources

- *How Exactly Do Solar Water Geysers Work?* https://www.kwikot.com/latest-news/how-exactly-do-solar-water-geysers-work/
- *MyEnergy How Solar Water Heaters Work* (1:25) https://www.youtube.com/watch?v=NsCZD1MZPPo
- *DIY Solar Water Heater Full Build* (9:44) https://www.youtube.com/watch?v=EO8SyoGmWFw
- *Improved Solar Pool Heater - Full build* (17:46) https://www.youtube.com/watch?v=cCn_eriDbEo
- *DIY Solar Pool Heater - Simple & Easy Design - Did it work?* (7:01) https://www.youtube.com/watch?v=x9hb-ckXY1A

References

This activity is based on **Feel the Heat** originally created by **NASA's Jet Propulsion Laboratory** and available at: https://www.jpl.nasa.gov/edu/teach/activity/feel-the-heat/.

Visit the **NASA Jet Propulsion Laboratory's Education** (https://www.jpl.nasa.gov/edu/) website for a host of other great engineering activities and resources.

Jet Propulsion Laboratory
California Institute of Technology

Move the Heat

STUDENT WORKSHEET

Challenge Overview

You are part of a team of engineers who have been given the challenge of designing and building a device that can capture the heat from sunlight or a lamp to raise the temperature of a given amount of water by at least one degree Celsius and move it 1 m (3.3 ft) from its source.

Success Criteria

- The device must raise the temperature of 200 ml (6.8 fl oz) of water by at least 1^{o}C (1.8^{o}F).
- The device must move the heated water at least 1 m (3.3 ft) from the source cup to the destination cup.

Constraints

- Students may only use the materials provided.
- Students must complete the challenge in the given time.
- Only water can flow through the device (i.e., no additive(s) may be added).

Total Time: 60 minutes

Materials List

To build your device, you will have access to the following materials:

- 2 polystyrene cups – one will be marked at the 200 ml (6.8 fl oz) mark so use this as your destination cup
- Four 0.5 m (1.5 ft) lengths of clear plastic tubing
- A large sheet of cardboard
- Aluminum foil
- Food plastic wrap
- 3 – 4 sheets of black paper
- A black marker
- A jug of water
- Scissors
- 8 drinking straws
- A roll of packing tape
- Access to direct sunlight or a lamp with a 100 W bulb

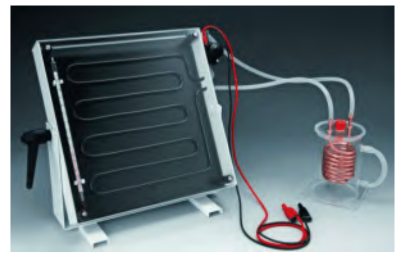
NOTES

Research & Planning (5 minutes)

Remember your challenge is to build a device that can capture the heat of the sun or a lamp to raise the temperature of 200 ml (6.8 fl oz) of water by at least one degree Celsius and move it 1 m (3.3 ft) from the source cup to the destination cup. To find the temperature difference, you will first measure the temperature of the water in the source cup. Then, once all 200 ml (6.8 fl oz) has flowed into the destination cup, you will measure the temperature of the water in this cup.

As engineers, you need to start the engineering design process by researching and planning. Think about the following questions:

- What colors absorb heat well? What colors reflect heat well?
- How might you get water to flow from one cup to the other?
- How might you expose the water to the heat source long enough to heat it up?
- How might the rate at which water flows through your device affect how well it works?
- How can you prevent the water you have already heated from cooling down too quickly?



A Solar thermal collector
Image by DJD Microtech is used under fair use
https://www.djb.co.uk/ppen_solar_thermal_collector.html

Design Phase (10 minutes)

Take some time to look at the materials you have and think about how you can use them to build your device.

- How are you going to move the water from the source cup to the destination cup?
- What color should you make the tube and background?
- How can you lay the tube to help the water absorb as much heat as possible?
- How can you direct more light and heat towards the tube?
- How can the amount of time the water in the tube is exposed to the heat source be extended?
- How can the heat around the device be captured so that more of it has time to heat up the water?
- How could you control the rate of flow of water through your device? Is a faster flow rate or a slower flow rate better?
- How can you prevent the water you have already heated from cooling down too quickly?
- How can you keep water from leaking out of your device?

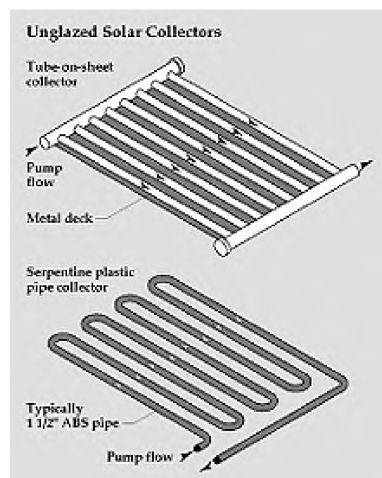


Diagram of two types of solar collector
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https://pasolar.ncat.org/lesson02.php

It is always best to make some sketches of your designs before you start. This is a good way to test your thinking. Failing on paper is far faster than failing with a real built object.

As a team you can each do your own designs and then compare and combine the best elements of each into a final team design, or you can design together from the start. Which way do you think would be better? Which way do you think will generate the best ideas?

After you have some sketches of your designs, it is time start building and testing.

Build it! Test it! (45 minutes)

Now it's time to build your device. It is useful to test as you go. Test early and test often. Test each piece of your device to make sure it works the way you want it to.

Remember that when a design doesn't work, it is just an opportunity to learn. Engineers learn by testing lots of different designs to see which ones work or work best. As you test different designs, think about what ideas are working well and which ones you want to reject. What could you try to improve your design? What are other teams trying and what can you learn from their experience?

You are free to change aspects of your design or your entire approach at any time.

When you are ready, call your instructor over for an official temperature check.

Reflection

As a team, discuss the following questions:

1. How does the final device you created compare with the design you based it on? What is the same? What is different?
2. Did your device use a faster or a slower flow rate? Why did you choose this flow rate?
3. In what shape did you lay your tubing? Why did you choose this shape?
4. Did you try to keep the heat absorbed by your device? How did you do this?
5. What challenges did you run into in while building your device? What other tools or materials might have helped you make your device work more effectively and be able to heat up more water by a greater amount?
6. What specific uses can you see for a heat capturing and transfer device like yours?
7. What feature(s) of other teams' devices do you like the best? Why?
8. What was it like working as a team? What were the pros and cons? Would you have preferred to work as an individual? Why?
9. What did you learn about engineering during this activity?

DIY solar pool heater
Screenshot by Nicole Michael DIY is used under fair use
https://www.youtube.com/watch?v=HdBCWR3z2D4

AT HOME

When you get home after camp, why not tell your family about the heat transfer device you built? Tell them about how you worked in a team to design, build, and test your device and what you learned about engineering.

After telling your family about today's activity, tell them what you liked/didn't like about it and what you would change or add to the activity.

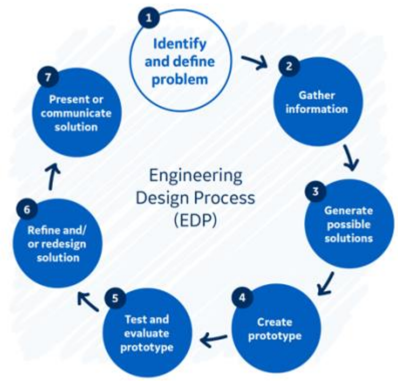
If you like, you can also discuss some of the reflection questions with them.

The Engineering Design Process

STUDENT HANDOUT

The engineering design process (EDP[1]) is the key process engineers follow when they solve problems and design solutions.

1. Identify and define the problem



Engineers start by asking lots of questions. What problem must be solved? Who has the problem? What do we want to accomplish? What are the project requirements? What are the limitations? What is the goal? Through this process, engineers start to identify the **criteria** (the conditions the solution must satisfy to be considered successful) and the **constraints** (the limitations they need to design within).

2. Gather information

Engineers dig deep into the problem by collecting **information and data** about the problem and any existing solutions that might be adaptable. They talk to people from many different backgrounds and specialties to assist with this research.

3. Generate possible solutions

Now the fun really starts! Engineers start to **brainstorm** ideas and develop as many solutions as possible, sometimes even crazy ones. This is the time for wild ideas and deferred judgment. It is important to build on the ideas of others while staying focused on the core problem and keeping the criteria and constraints in mind. For example, if there is a budget, can the potential solution be developed within that budget?

4. Create a prototype

Engineers choose one or more of the most promising solutions to **prototype**. A prototype is a working model to be tested.

5. Test and evaluate the prototype

Most prototypes **fail**, but that is good. It tells engineers which ideas they should focus on. Engineers also need to decide if the design really does solve the original problem.

6. Refine and/or redesign the solution

After learning through testing, engineers **redesign and retest** until they have the best solution possible – one that balances the criteria and constraints.

7. Present or communicate the solution

Finally, engineers reach a point where they are satisfied with their solution. It does not need to be perfect, but it should '**satisfice**' - meet the criteria within the constraints. Engineers now communicate their solution to others.

[1] Adapted from https://www.teachengineering.org/design/designprocess