Cool It Down (Museum Activity)

Program Type: Museum-based Demonstration	**_Audience Type:_** Grades 3–8

Description: Students design pathways to cool down a stream of water so that it can be safely returned to a river without harming the ecosystem.

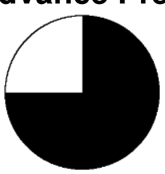
LEARNING OBJECTIVES

For Next Generation Science Standards alignment, see end of outline.

- Students will discover ways to decrease water temperature by changing variables and experimenting with different cooling mechanisms.
- Students will demonstrate how engineering can make a positive impact on the environment.

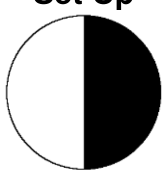
TIME REQUIRED

Advance Prep



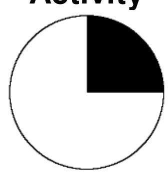
45 minutes

Set Up



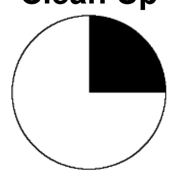
30 minutes

Activity



15-40 minutes

Clean Up



15 minutes

SITE REQUIREMENTS

- Access to a water source
- Access to at least one power outlet
- Stable desk or table (no wheels, or ability to lock and secure wheels)
- Large open area surrounding the power outlet
- Easy clean-up area in case of water spills (i.e., non-carpeted flooring)
- Best if done at a water table

PROGRAM FORMAT

Segment	Format	Time
Introduction	Large group discussion	5 min
Design, Test, Improve	Group Activity	5-30 min
Wrap-Up	Large group discussion	5 min

SUPPLIES

Permanent Supplies	Amount	Notes
Large water tub	1	Represents the river, could be a water table
Small rectangular plastic water tub	1	Represents a building; should be approximately 12”x16”x4” deep and wide enough to fit the immersion coil water heater
Metallic ramp with 1” rim along two of its parallel sides	1	Approx. 2.5’x3.5’ Could also be a wooden board with metal plates attached
Water pump	1	80 gallons per hour or fewer
Immersion coil water heater	1	Also called a beverage or bucket heater
Vernier temperature sensor or instant-read digital thermometer	1	Accurately and quickly reads 0.1-degree increments
Magnetic blocks or tiles	20–30	Such as Picasso Tiles®
Small magnetic spring clips	5–10	Also known as refrigerator clips
Small ice packs	2–4	
Plastic tubing for water pump	8–12 ft.	Plastic piping from a hardware store that fits the water pump connectors
Extension cord	1	
Sponge	1	Serves as a rest for the water heater so it doesn’t burn the small tub
Bubble wrap	4 sq. ft.	
Drill with ¼ inch drill bit	1	Needed for Advance Preparation
Small whiteboard	1	*(Optional)*
Whiteboard marker	1	*(Optional)*

ADVANCE PREPARATION

- Drill one or two 0.25" holes near the base of the long side of the small water tub. See Figure 1 for a visual guide.
- Make sure the small tub fits on the desk, and that the metallic ramp can rest between the base of the small tub (below the two holes) and the rim of the large tub without slipping off
- Make adjustments to the metallic ramp as needed to secure it (e.g., by adding rubber or hooks to the back of it to prevent slippage)
- Test the power outlets and ensure the extension cord reaches to where the activity will be set up
- Test the water pump and make sure it reaches from the larger bin (on the ground) to the smaller bin (on the desk) and that the pump is strong enough to pull the water up and maintain the water level in the small tank
- If the pump is not strong enough and the top tank is losing water too quickly, partially block the drainage holes to restrict the outflow of water

SET UP

SAFETY WARNINGS

- Water pump intake must be kept fully submerged while running.

- Water heater can burn the skin, melt through plastic, and short out if turned on out of water. Secure it firmly in the tank and prevent it from touching anything that could melt. ONLY plug in after it is fully submerged!

- Students should only touch the ramp–the water tanks are off limits. Caution signs/tape are recommended.

- Secure extension cord and power cords where they will not be tripping hazards.

Gather all of the supplies. Set up the small tub on top of a table or desk, resting the metallic ramp between the base of the small tub and the rim of the larger tank. The large tank should be on the ground or on a shorter table and filled with water. Water should be able to flow from the small tank, down the ramp, and into the larger tub without assistance.

Connect the hose to the water pump. Place the pump so it is fully submerged in the larger lower tank. Place the hose into the small bin at the top so that water is pumped through it from the large bin to the smaller one and plug in the pump. Water should flow out of the small bin and down the ramp at a slightly slower speed than it is being pumped in.

Once the small water tank is filled up with enough water to cover the water heater, place the device inside. **Do not run the pump if it is not fully submerged.** Rest it on the sponge to avoid burning the tank. **Make sure the metal part of the water heater is fully submerged in the water before plugging it in.**

Measure the temperature of the water in the tank with the Vernier sensors or thermometers**.** The small tub should be warmer than the large tub.

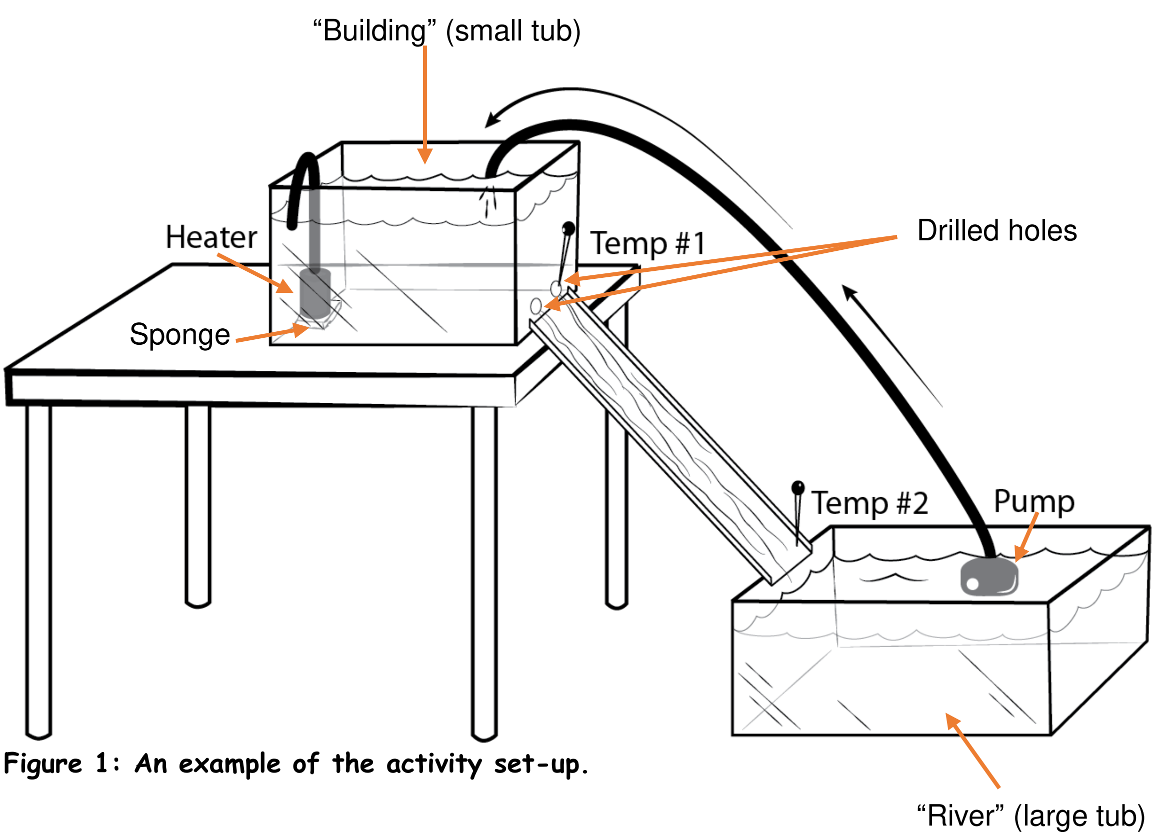


Figure 1: An example of the activity set-up.

INTRODUCTION

5 minutes

Let students speculate before offering answers to any questions. The answers given are provided primarily for the instructor's benefit.

Suggested script is shaded. Important points or questions are in **bold**. Possible answers are shown in *italics*.

Many places use water from nearby rivers to cool down their building. However, this heats the water so that when it goes back into the river it is warmer than when it was taken out.

Water bugs, plants, and fish are very sensitive to differences in temperature. A few tenths of a degree can be harmful: even though we wouldn't notice the difference if we put our hand in the water, it can make animals sick or force them to live somewhere else. The increase in river temperature can damage the ecosystems in the water, and animals and plants in the river may leave or die. We need to come up with a way to cool down the water before putting it back in the river.

Engineering a good water-cooling system will help our building protect the environment.

GROUP ACTIVITY

Design, Test, Improve

5-30 minutes

Here we have a model of a building using river water. There is water being pumped up from below ("the river") into this small bin ("the building"), where it is heating up and then coming back down to the river.

Demonstrate the path of the water. Your goal is to cool down the water before it flows back into the river.

You can use all the supplies laid out and the entire area of the metallic ramp over which the water flows.

Show students the supplies available.

SAFETY WARNINGS

- **There a number of power cords and delicate instruments. Watch where you step and don't crowd around the testing bed.**
- **The water heater and pump are delicate instruments, and only instructors can touch them.**
- **The ramp is the student zone. The tanks are for instructors only to touch.**
- **Be careful with water and don't splash anyone.**

have two temperature sensors that will measure the temperature of the water when it leaves this top tank and down here when it's about to return to the river.

Place one sensor by the hole on the side of the small bin. This sensor reads the temperature of the heated water. Place the other sensor at the bottom end of the ramp and measure the temperature of the water right before it falls into the main water source.

Encourage students to work together and engineer designs to increase the surface area of the water and slow it down before it reaches the bottom. Examples of designs include waterfalls, mazes, pools, and zigzag paths. When the water is brought into contact with the ice packs for as long as possible, the cooling can be significant.

Test as you go. Keep students informed about how the cooling system they are engineering is lowering the water temperature displayed on the sensor. Read and communicate the temperature often. You may choose to record the temperature data on a small whiteboard.

WRAP-UP

5 minutes

Ask for student observations. There is no correct answer. Let students guide the discussion and present their hypotheses before discussing explanations.

How many degrees colder did the water get?

What did you do that worked? What did you do that didn't work?

What seems to be the best way to cool the water?

What would you do differently if you were to have more time, or if you could do this activity again?

What would have to be different about your design if it was for a full-sized building (not a miniature version of one)?

CLEAN UP

15 minutes

- Unplug all appliances before cleaning up
- **Wait until water heater has cooled down before removing it from the water**
- Remove wet supplies and lay them out to dry
- Re-freeze the ice packs if needed
- Dispose of the water appropriately

BACKGROUND INFORMATION

Thermal Pollution in Aquatic Ecosystems:

When most people think of "water pollution," they think of chemical contamination. However, thermal pollution—or excessively warm water—is another serious issue. Water temperature has a major influence on biological activity and growth. Temperature determines the kinds of organisms that can live in rivers and lakes. Fish, insects, zooplankton, phytoplankton, and other aquatic species all have a preferred temperature—if temperatures range too far above or below, the number of organisms decreases until finally there are none.

Water temperature is also important because of its influence on water chemistry. The rate of chemical reactions generally increases at higher temperatures, and some compounds are also more toxic to aquatic life at higher temperatures. What's more, warm water holds less dissolved oxygen than cool water and may not contain enough dissolved oxygen for the survival of different species of aquatic life. Think about how much bubblier a cold soda is compared to a warm one. The cold soda can keep more of the carbon dioxide bubbles dissolved in the liquid than the warm one can, which makes it seem fizzier. (Source: www.usgs.gov.)

Sources of Thermal Pollution:

Power plants and factories often draw water from nearby rivers or aquifers and for use in industrial processes. Often, the water is used to cool down materials or machinery. In the process, the water absorbs excess heat. The question then becomes: What should we do with this warm water once we're done with it? Discharging warm wastewater directly back into rivers or aquifers harms aquatic ecosystems. The EPA has developed regulations that require industries to cool off wastewater before returning it to the river. Industrial engineers have developed three basic strategies, which may be combined to reduce thermal pollution:

- **Cooling Ponds** – Water is pumped into a wide, shallow pond, where it slowly cools off.
- **Cooling Towers** – Water is pumped into a tall tower, where excess heat is transferred to the atmosphere. (See Figure 2).
- **Cogeneration** – Hot water is put to use in heating buildings or generating steam to turn a turbine.

Figure 2 – Cooling Towers of Three Mile Island. The iconic, vase-shaped structures associated with nuclear reactors are actually not for generating power, but for cooling wastewater. (Photo: Wikimedia Commons).

NEXT GENERATION SCIENCE STANDARDS

	Practices
✓	Asking questions and defining problems
	Developing and using models
✓	Planning and carrying out investigations
✓	Analyzing and interpreting data
	Using mathematics and computational thinking
✓	Constructing explanations and designing solutions
	Engaging in argument from evidence
	Obtaining, evaluating, and communicating information

	Crosscutting Concepts
	Patterns
✓	Cause and effect
	Scale, proportion, and quantity
✓	Systems and system models
	Energy and matter
✓	Structure and function
	Stability and change

	Disciplinary Core Idea	3	4	5	MS
	Physical Science				
PS1	Matter and Its Interaction	n/a	n/a		
PS2	Motion and Stability: Forces and Interactions		n/a		
PS3	Energy	n/a			
PS4	Waves and Their Applications in Technologies for Information Transfer	n/a		n/a	
	Life Science				
LS1	From molecules to organisms: Structures and processes				
LS2	Ecosystems: Interactions, Energy, and Dynamics		n/a		
LS3	Heredity: Inheritance and Variation of Traits		n/a	n/a	
LS4	Biological Evolution: Unity and Diversity		n/a	n/a	
	Earth & Space Science				
ESS1	Earth's Place in the Universe	n/a			
ESS2	Earth's Systems				
ESS3	Earth and Human Activity			✓	✓
	Engineering, Technology, and Applications of Science				
ETS1	Engineering Design	✓	✓	✓	✓

DCI Grade Band Endpoints

3-5 ETS1.A: Defining and Delimiting Engineering Problems

- Possible solutions to a problem are limited by available materials and resources (constraints). The success of a designed solution is determined by considering the desired features of a solution (criteria). Different proposals for solutions can be compared on the basis of how well each one meets the specified criteria for success or how well each takes the constraints into account. (By the end of Grade 5)

3-5 ETS1.B: Developing Possible Solutions

- Research on a problem should be carried out before beginning to design a solution. Testing a solution involves investigating how well it performs under a range of likely conditions. (By the end of Grade 5)
- At whatever stage, communicating with peers about proposed solutions is an important part of the design process, and shared ideas can lead to improved designs. (By the end of Grade 5)
- Tests are often designed to identify failure points or difficulties, which suggest the elements of the design that need to be improved. (By the end of Grade 5)

3-5 ETS1.C: Optimizing the Design Solution

- Different solutions need to be tested in order to determine which of them best solves the problem, given the criteria and the constraints. (By the end of Grade 5)

MS ETS1.A: Defining and Delimiting Engineering Problems

- The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that are likely to limit possible solutions. (By the end of Grade 8)

MS ETS1.B: Developing Possible Solutions

- A solution needs to be tested, and then modified on the basis of the test results, in order to improve it. (By the end of Grade 8)
- There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. (By the end of Grade 8)
- Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors. (By the end of Grade 8)
- Models of all kinds are important for testing solutions. (By the end of Grade 8)

MS ETS1.C: Optimizing the Design Solution

- Although one design may not perform the best across all tests, identifying the characteristics of the design that performed the best in each test can provide useful information for the redesign process—that is, some of those characteristics may be incorporated into the new design. (By the end of Grade 8)
- The iterative process of testing the most promising solutions and modifying what is proposed on the basis of the test results leads to greater refinement and ultimately to an optimal solution. (By the end of Grade 8)

3-5 ESS3.C: Human Impacts of Earth Systems

- Human activities in agriculture, industry, and everyday life have had major effects on the land, vegetation, streams, ocean, air, and even outer space. But individuals and communities are doing things to help protect Earth's resources and environments. For example, they are treating sewage, reducing the amounts of materials they use, and regulating sources of pollution such as emissions from factories and power plants or the runoff from agricultural activities. (By the end of Grade 5)

MS ESS3.C: Human Impacts of Earth Systems

- Human activities have significantly altered the biosphere, sometimes damaging or destroying natural habitats and causing the extinction of many other species. But changes to Earth's environments can have different impacts (negative and positive) for different living things. Typically, as human populations and per-capita consumption of natural resources increase, so do the negative impacts on Earth unless the activities and technologies involved are engineered otherwise. (By the end of Grade 8)

Performance Expectations

3-5-ETS1-1	Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.
3-5-ETS1-2	Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.
3-5-ETS1-3	Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.
MS-ETS1-1	Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.
MS-ETS1-2	Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.
5-ESS3-1	Obtain and combine information about ways individual communities use science ideas to protect the Earth's resources and environment.
MS-ESS3-3	Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment.

FACILITATION GUIDE

Cool It Down

Description: Students design pathways to cool down a stream of water so that it can be safely returned to a river without harming the ecosystem.

Promoting collaboration and organization

- If space is limited, suggest that students take turns watching others test to improve their designs and get new ideas.
- Have students take turns designing the ramp and reading the water temperature.

Encouraging iteration

- Remind students about the purpose of this activity and what the different water tanks represent. Challenge them with the following questions:
  - Can you cool the water that flows into the river down even more?
  - Try out materials you haven't tested yet. Do any of them work better than others?
  - How can you slow the water down?
  - How can you get the water in closer contact with the ice packs?

Helping those who are stuck

- Ask them what they'd do to cool a hot beverage or food and then ask "Why does that work?"
- Draw a link between surface area and cooling. "How could you get more air to contact the water?" "How could you spread out the water here?"
- Convey changes in temperature clearly: "When you moved those tiles and that ice pack, the temperature dropped from 71.5 to 70.8°F—it fell by 0.7°F!"

Real-world applications

- How big a difference does a few degrees make? People are adaptable and can put on or take off clothes to stay the same temperature. Fish and bugs that live in the water aren't able to do that.
- A company called Makai Ocean Engineering makes large building cooling systems that take in deep, cold ocean water and release the "waste" warm water in a shallower area. This company claims its technology reduces AC electricity consumption by 80–90%.

Meet an Engineer Video - Caity Clark

Watch here: https://vimeo.com/254363516/9c385a2ef8

Energetic Ocean

Program Type: Classroom Program	**Audience Type:** Grades 3–8

Description: Students will design a model offshore wind and wave energy farm to maximize the amount of energy the farm can produce.

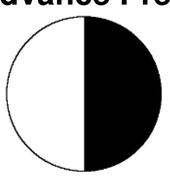
LEARNING OBJECTIVES

For Next Generation Science Standards alignment, see end of outline.

- Students will create a model of an offshore wind and wave energy farm using the benefits of wind turbines and wave energy converters to maximize energy output.
- Students will redesign their wind and wave energy farm based on various challenges such as migrating whales or shifting winds.

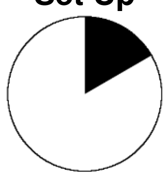
TIME REQUIRED

Advance Prep



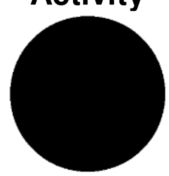
30 minutes

Set Up



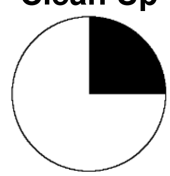
10 minutes

Activity



60-80 minutes*

Clean Up



15 minutes

* This activity can be adapted for a variety of student group abilities. See *Extension* for advanced variations.

SITE REQUIREMENTS

- Table space for each group of 3–5 students
- Power outlet near each table

PROGRAM FORMAT

Segment	Format	Time
Introduction	Large group discussion	10 min
Design, Test, Improve	Group activity	40-60 min
Wrap-Up	Large group discussion	10 min

SUPPLIES

Permanent Supplies	Amount	Notes
Cups	4/group	To elevate pegboard from the surface; sturdy paper or plastic cups work well
Pegboard	1/group	Approximately 24"x18" (with 1/8" holes 1" apart). *(*See Supply Note)*
Fan	1/group	Any electric fan. Will work best if it is at least 10 inches in diameter
Pinwheels	8–10/group	6" or larger Mylar pinwheels work best. **See note*
K'Nex®	16–20 rods and 8–10 round connectors/group	If possible, rods should be different lengths
Wave energy converter cutouts	6–8/group	See the *Appendix*
"How Much Does Energy Cost?" Worksheet	1/group	See the *Appendix*
"What We Know About…" Table	1/group	See the *Appendix*
Challenge Cards	3-5 sets	See the *Appendix*
Challenge Obstacles	1/group	See the *Appendix*
Sticky tack	1 pack	Or any firm but easily removable adhesive (even rolled pieces of tape)
Ruler at least 12" long	1/group	*(Optional)*
Scissors	1	For advance prep only
Painters tape or blue permanent marker	1	*(Optional)* for advance prep
Vis-à-vis (overhead projector) pens	1/group	*(Optional)* See advance prep
Meet an Engineer Video – Caity Clark	1	*(Optional)* Found on USB flash drive provided with manual and website listed in *Advanced Prep*
Computer, projector screen	1	*(Optional)* to show video
Laminator	1	*(Optional)*

**Note on Supplies:*

- Mylar pinwheels can be bought online from a variety of retailers. We found the ones from Century Novelty worked well. https://centurynovelty.com/products/jumbo-mylar-pinwheel
- Pegboard can be found at most hardware stores, usually sold in 4'x8' sheets. Often, store employees are able to cut it on-site. Cut the sheet once the long way, to make two long strips, each 24" wide. Then cut each strip into five pieces approximately 19" wide, for a total of 10 pieces. **You can reuse the same pieces of pegboard for Smooth Travels, another engineering activity in the Designing Our World curriculum.**

ADVANCE PREPARATION

- Read the *Background Information* section at the end of this outline to familiarize yourself with the research that inspired this activity.
- Mark a "wave zone" on the pegboard by coloring with permanent marker or marking it with tape (make sure the tape doesn't cover the holes). The wave zone can be any shape, but is best if it is wider in the front (near the fan). Larger wave zones are generally more difficult. To broaden options, each side of the pegboard can have a different wave zone demarcation for varied challenge levels. You may choose to make all wave zones identical, or give each group a different design.

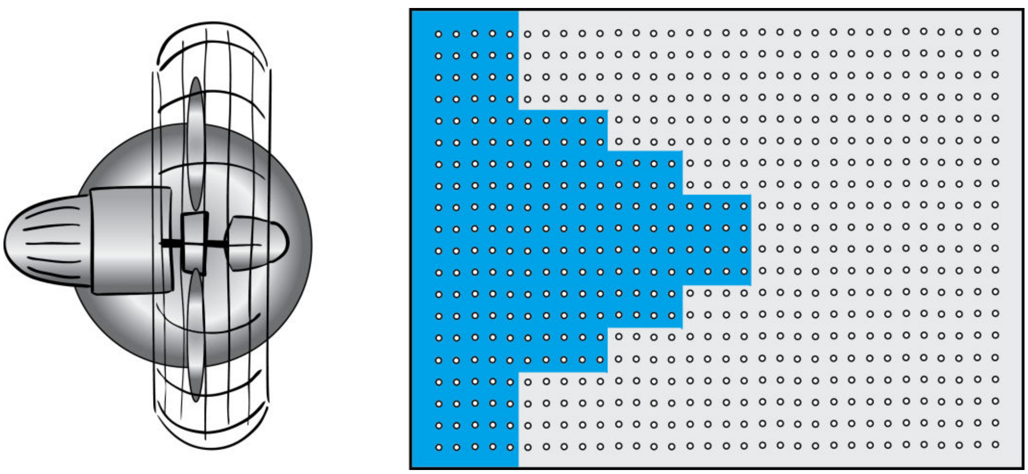


Figure 1: Possible wave zone shown in blue.

- Print and cut out materials (see Appendix). Laminate if desired:
  - Challenge Cards (3-5 sets total)
  - Challenge Obstacles (1 set per group)
  - Wave energy converter cutouts (6-8 per group)
  - Data sheets (1 per group) – If laminated, students can write and erase using Vis-à-vis overhead pens.
  - "What We Know About…" table (1 per group)
- Prepare the projector and computer to show the *Meet an Engineer Video – Caity Clark* found on the USB flash drive provided with this manual (if applicable), or at https://vimeo.com/254363516/9c385a2ef8
- If you can't show video to students, watch on your own for reference.

SET UP

- Prop up one pegboard per group using the cups. See the diagram below for a visual guide.
- Face pegboard so the wave zone is closest to fan.

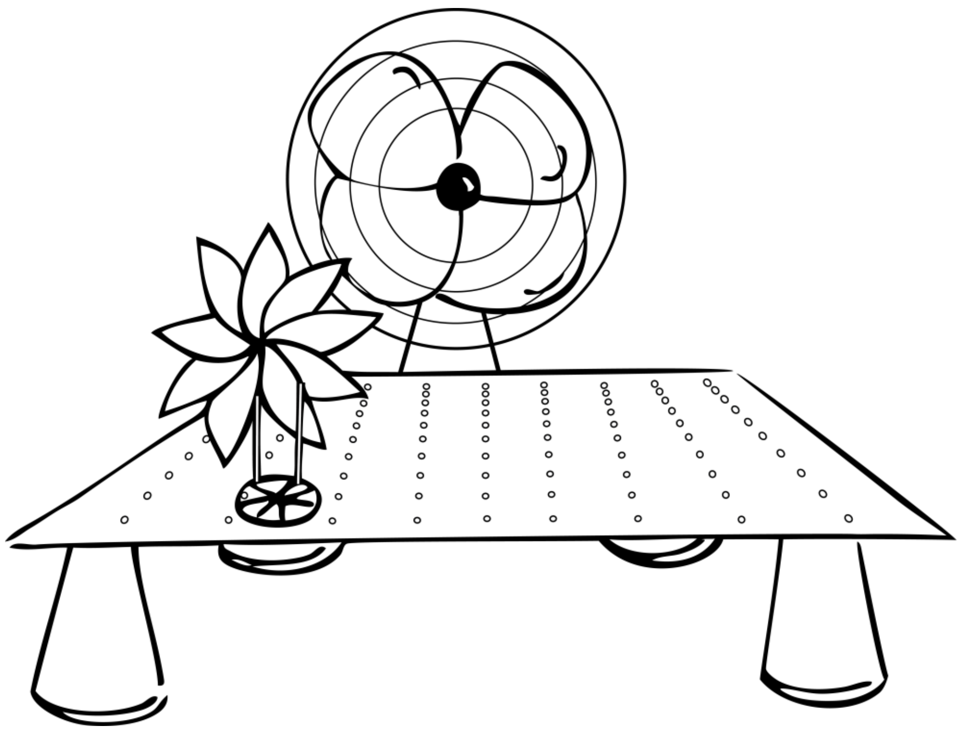


Figure 2: Example setup of the pegboard raised using cups.

- Arrange each table so there is an outlet nearby where the fan can be plugged in safely. Set a fan on each table and plug them in. Alternatively, have a testing station with one or more fans where students can bring their pegboards when they are ready to test their design. Create a raised surface at the testing station with cups.
- Distribute building materials to each table. Each group should get:
  - 20 K'Nex® rods of various sizes
  - 8–10 K'Nex® connectors
  - 8–10 pinwheels
  - 6–8 wave energy converter cutouts

INTRODUCTION

10 minutes

Let students speculate before offering answers to any questions. The answers given are provided primarily for the instructor's benefit.

Suggested script is shaded. Important points or questions are in **bold**. Possible answers are shown in *italics*.

We use energy like electricity all the time without thinking about it. Phones, lights, cars, and refrigerators are just some of the things that we use on a daily basis. Where does all this electricity come from? There are three main categories for the energy that makes electricity: fossil fuels, nuclear energy, and renewable energy. Today we are going to focus on renewable energy.

What do you think sets this kind of energy apart from fossil fuels and nuclear energy? *It's environmentally friendly, sustainable*

What are some renewable energy sources? *Wind, solar, water, geothermal*

We are going to watch a short video of an engineer, Caity, explaining the work she does to help create more opportunities for renewable energy resources.

Show video if computer and screen are available. Otherwise, explain the main points from the video to students.

What two energy sources does Caity discuss?
Wind and wave energy

Where are these wind and wave energy farms located? *In the ocean (offshore)*

Why do wind turbines and wave energy converters work so well together? *Wave energy converters protect turbines from wave forces if placed in front of them, and wind turbines can still collect wind energy behind the wave energy converter to maximize space.*

Today you are going to engineer a model offshore energy farm where wind turbines above the water can be combined with wave energy converters in the water to gather even more energy from our energetic ocean.

GROUP ACTIVITY

Design, Test, Improve

40-60 minutes

Divide students into groups of 3–5. Introduce the materials and activity goals.

Here is your model ocean.

Show pegboard.

The blue area is what we call the wave zone, where waves are the strongest. These pinwheels represent the wind turbines, and these paper cutouts represent the wave energy converters.

Show each material.

You must decide where to place your turbines and wave energy converters to generate the most energy for the least cost.

Depending on the group, you may choose to demonstrate how to secure the pinwheels to the board with the K'Nex® for more stability and adjustability, or to let students figure this out on their own. See the diagram below for one way to assemble K'Nex® without spinning.

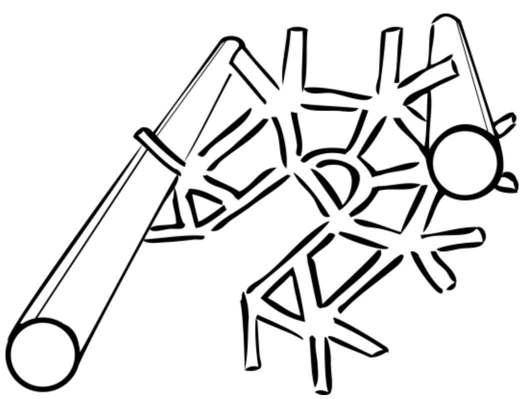


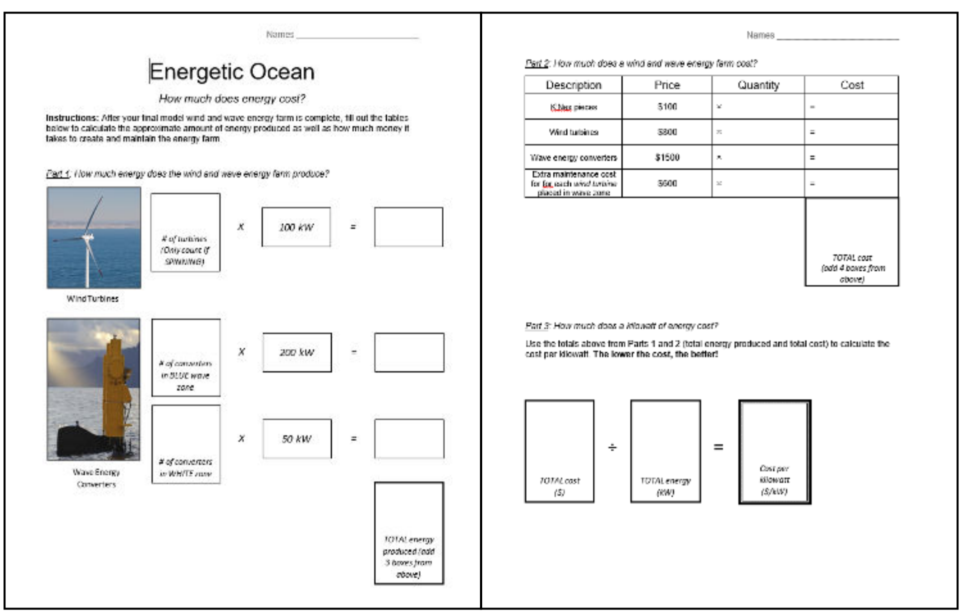
Figure 3: How to set up the K'Nex® so the pinwheels stay secure in the pegboard.

Your goal is to create as much energy as possible using these model wind and wave energy converters. Lets go over some important facts about wind turbines and wave energy converters before we begin our activity.

Hand out one copy of the *"What We Know About…"* table below to each group (See the *Appendix for full printable in English and Spanish)* and lead a discussion about what is the most important information to consider when designing an offshore energy farm. Complement the bullet points in the table with what you read in the *Background Information*. For students at a higher level of learning, you can read them the *Background Information* directly.

What we know about…	
Wind Turbines	***Wave Energy Converters***
• convert wind energy into electricity • don't affect the ocean waves • can block one another and not produce as much energy • allow for more effective maintenance when placed behind a wave energy converter, which leads to lower costs • can collect wind energy inside or outside the wave zone • produce more energy and fail less when they have a straight stream of fast air • will produce the same amount of energy with a wave energy converter placed in front • need to be anchored to the ocean floor	• convert energy from the "motion of the ocean" into electricity • don't affect the wind • protect wind turbines from waves, allowing maintenance crews easier access to wind turbines for repairs, even in high wave weather • work best when placed inside the wave zone, where the wave energy is greatest • absorb wave energy and consequently make smaller waves behind them

As you are testing out your ocean power plans, you will record your results on this data sheet.


Names ____________

Energetic Ocean

How much does energy cost?

Instructions: After your final model wind and wave energy farm is complete, fill out the tables below to calculate the approximate amount of energy produced as well as how much money it takes to create and maintain the energy farm.

Part 1: *How much energy does the wind and wave energy farm produce?*

Wind Turbines: *# of turbines (Only count if SPINNING)* x *100 kW* =

Wave Energy Converters: *# of converters in BLUE wave zone* x *200 kW* =

# of converters in WHITE zone x *50 kW* =

TOTAL energy produced (add 3 boxes from above)

Names ____________

Part 2: *How much does a wind and wave energy farm cost?*

Description	Price	Quantity	Cost
K'Nex pieces	$100	x	=
Wind turbines	$800	x	=
Wave energy converters	$1500	x	=
Extra maintenance cost for for each wind turbine placed in wave zone	$600	x	=
			TOTAL cost (add 4 boxes from above)

Part 3: *How much does a kilowatt of energy cost?*

Use the totals above from Parts 1 and 2 (total energy produced and total cost) to calculate the cost per kilowatt. **The lower the cost, the better!**

TOTAL cost ($) ÷ *TOTAL energy (kW)* = *Cost per kilowatt ($/kW)*

Pass out the Energetic Ocean worksheet: "How Much Does Energy Cost?" (See the *Appendix for full printable in English and Spanish).* In this worksheet, students will keep a record of the placement and success of their wind turbines and wave energy converters in order to determine the efficiency of their power plant. Remind students that the goal is produce the most energy for the lowest cost.

OPTIONAL VARIATIONS: For younger students—or if time is limited—eliminate the worksheet. Or, wait until the end and complete a single worksheet as a class, using one group's design as an example.

Optional discussion points before getting started:

- **Where is the best place for the wave energy converters?**
  In wave zone. In front of the wind turbine.

- **What about the wind turbines?**
  Outside of wave zone. Behind the wave energy converters.

- **How close can you place two turbines and have them both spin?**

- **How can you keep the wind turbines and wave energy converters from blocking one another?**

Allow students to build for 10-15 minutes. Set the speed of the fan to low or medium.

Design Challenges

After students have had some time to tinker with their designs, use the Challenge Cards found in the *Appendix*, to assign different challenges to each group depending on their current designs and/or the success of the group (e.g., if the design has very high windmills, give them the Bird Challenge card). The challenges don't have to be the same for every group. You may choose to give multiple challenges to groups working faster, or allow student groups to work through all the challenges at their own pace.

Explain the assigned challenge(s) to each group as you pass them their challenge card.

1) **Whale Migration:**

Whales migrate and travel great distances. Whales like to migrate through the area in which you are designing your wind farm. Redesign your farm to allow these whales to pass through safely without running into the turbines or wave energy converters.

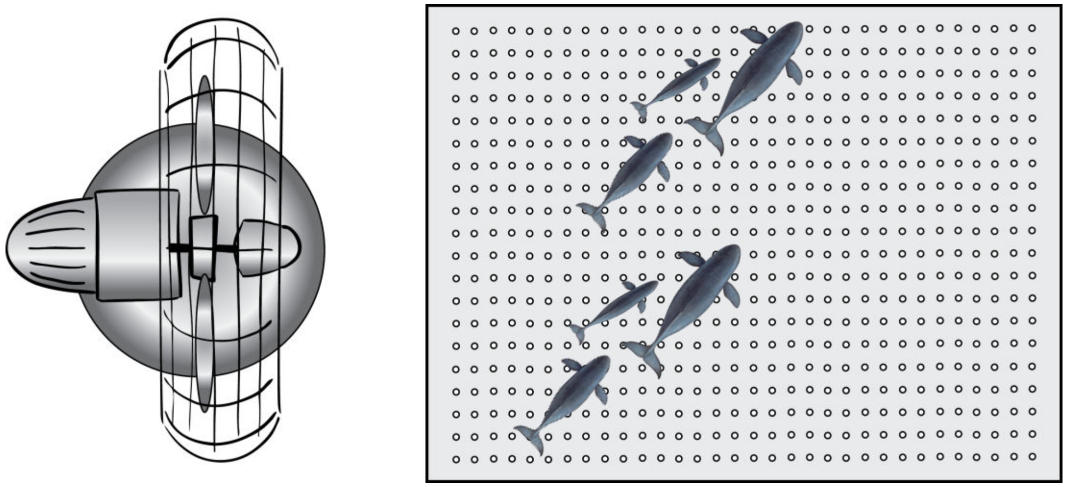


Figure 4: Example of whale migration challenge.

Using sticky tack, place laminated whale cutouts on the pegboard as shown in Figure 4. You may need to remove windmills and/or wave energy converters in the way of their migration paths and let students redesign that part of the model.

2) **Boulders:**
Some parts of the ocean floor are unsuitable for installing a wind turbine. The floor may be too unstable or not flat enough, and there may be big boulders in a part of your area that will prevent you from building there.

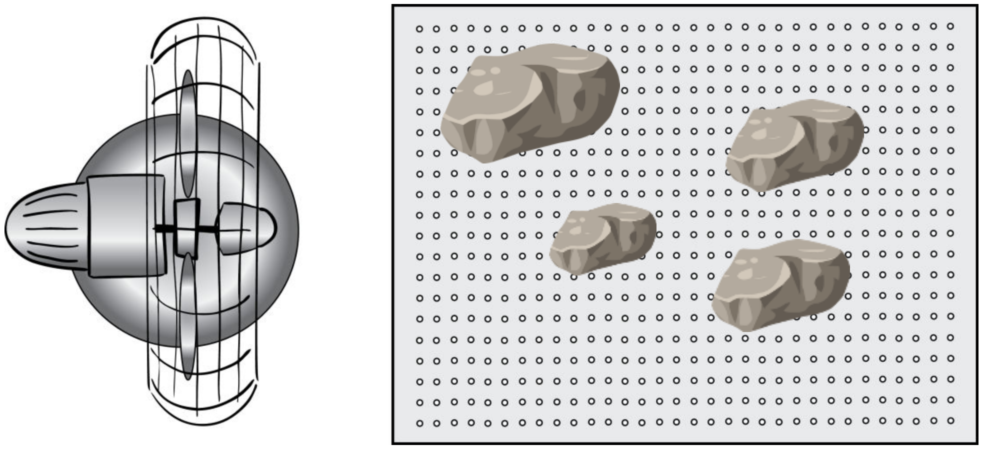


Figure 5: Example of boulder challenge.

Using sticky tack, place the laminated boulder cutouts on the pegboard similarly to the diagram shown in Figure 5. You may need to remove windmills and/or wave energy converters in the way.

3) **Birds**:
The area you have decided to build on has a lot of wind but it also is a favorite place for birds to ride the air current. In order to keep the birds from getting hurt and allow them to continue easily flying through the area, the top of all of your wind turbines must be shorter than 12".

If rulers are not available, hold a piece of copy paper vertically to estimate the height (the long side of paper measures 11").

4) **Shifting Wind**:
The direction of the wind can be affected by storms and temperature. As a result, wind direction can change with the seasons. Try redesigning your wind farm to maximize its efficiency in the face of seasons changing and wind shifting.

You can model the shifting wind by turning your fan to an angle. See Figure 6.

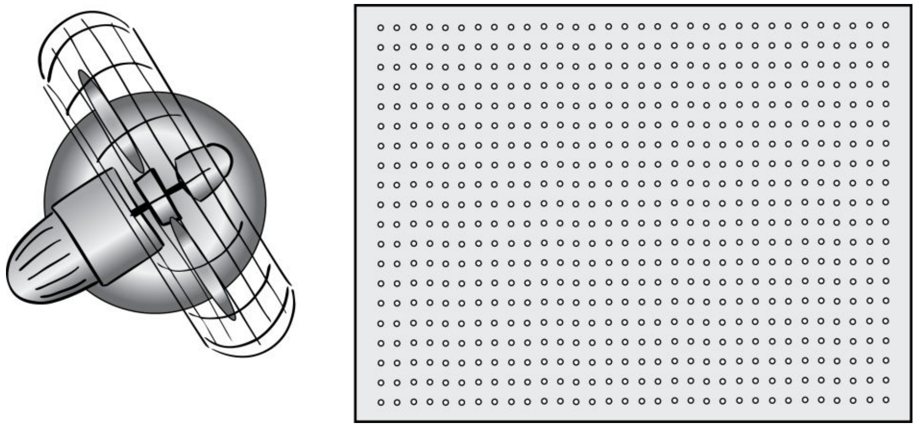


Figure 6: Example of fan placement for Shifting Winds challenge.

Move the fan so it is angled relative to the wave zone. If the fan has a rotating mode, you can use that instead.

WRAP-UP

10 minutes

When the groups are finished, host a final showcase to test all of the designs. **Before testing, let each group point out the notable aspects of their designs to the rest of the class.**

Test each power plan, looking at how many windmills and wave energy converters each group has set up and reviewing their efficiency on the "How Much Does Energy Cost?" worksheet.

Where are your wave energy converters and why did you arrange them that way?

Are all the wind turbines spinning at the same speed? Did the wind have to be stronger for some of them to turn?

How are your wave energy converters and wind turbines working together?

Why is it important to get our energy from sources like the wind and waves? Today, most things run on energy that comes from fossil fuels like coal and natural gas. Why should we change that and rely more on renewable energy?

Is it better to spend a lot of money making a wave energy converter able to withstand huge waves, or is it better to spend less money and put the wave energy converter in a place with smaller waves?

For an engineer, this kind of work involving competing objectives is fascinating. It's like a giant puzzle!

EXTENSION

Have students do their own research and determine the cost of different sources of energy. What are the "hidden costs" of non-renewable versus renewable energy sources?

CLEAN UP

5 minutes

Have students take apart their designs and return all materials where they found them

BACKGROUND INFORMATION

Wind and wave energy falls into a category of energy called **sustainable**, or **renewable**, energy. This category means that the source will not run out. Sustainable energy also releases significantly less pollutants than traditional energy sources.

Wind turbines convert wind into energy. Wind turbines produce more energy and fail less when they have a straight stream of fast air. However, when the turbines spin they decrease the speed of the wind as it passes, increasing turbulence so that any turbine in its **wake** produces less energy. A **wake** is the name for the area behind a turbine where there is decreased wind speed and increased turbulence.

Wave energy converters don't change the wind, and wind turbines don't change the waves (at least not enough to affect energy production). Therefore, a wind turbine will produce the same amount of energy when wave energy converters are put in front of it, but it will cost less to service each year. Plus, you get the additional energy from the wave energy converters!

Wave energy converters absorb wave energy and convert it to electricity. They can also protect turbines behind them from wave forces and wave-induced fatigue damage (or repetitive forces that cause failure over long periods of time). You would experience something similar to a turbine foundation and tower (the parts of the turbine in the water) if you were standing in the ocean or a river. You are feeling the repetitive force on your legs, and if someone were to stand in front of you, the person in front of you would feel the force instead, and protect you, so that you felt less force on your legs.

Absorbing wave energy also has ramifications for what we call "weather windows." When a turbine fails or needs maintenance, boats are only allowed to go service the turbine if the wave height is below 1.5 meters. As you can imagine, companies lose a lot of money watching a turbine not produce energy and waiting for a sunny day when the sea is calm to fix it. Placing wave energy converters to absorb wave energy reduces the wave height in these wind farms so that boats can go service the turbines more often (so instead of one day of fair weather, wave heights are reduced enough the day before and after the fair weather day that crews have three days to fix the turbine). This way, the wind turbine can produce energy and profit again more quickly and for a longer period of time. This latter point is particularly important for major repairs that take a lot of time to fix.

Background Information Courtesy of Caitlyn Clark, Doctoral Student of Mechanical Engineering at Oregon State University

Figure 7: Offshore wind farm. (Photo: viladetora.net).

Figure 8: Wave power technology in Scotland. (Image: waveenergyconsortium.com).

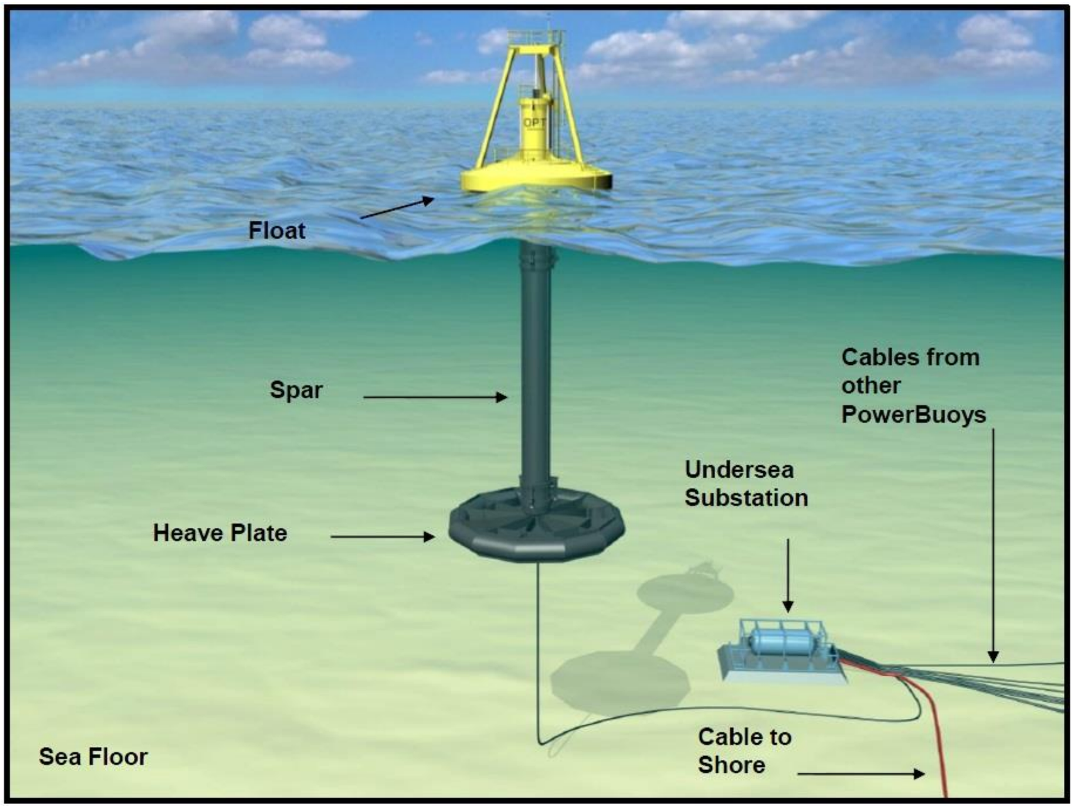


Figure 9: An example of a wave energy converter. (Image: oceanenergy.wikidot.com).

GLOSSARY

Offshore wind energy	The use of wind farms constructed offshore to harvest wind energy to generate electricity.
Renewable/sustainable energy	Energy that is essentially unlimited, without being reduced by the process of harvesting it (e.g., wave power, sunlight).
Wind turbine	A device that converts the wind's kinetic energy into electrical energy.
Wave energy converter	Technology that uses the motion of ocean surface waves to create electricity.
Weather windows	Periods of time when the weather is cooperative and wave swells are at a safe height for maintenance workers to get to a device that needs repair.

NEXT GENERATION SCIENCE STANDARDS

	Practices
✓	Asking questions and defining problems
✓	Developing and using models
✓	Planning and carrying out investigations
	Analyzing and interpreting data
	Using mathematics and computational thinking
✓	Constructing explanations and designing solutions
	Engaging in argument from evidence
✓	Obtaining, evaluating, and communicating information

	Crosscutting Concepts
	Patterns
✓	Cause and effect
	Scale, proportion, and quantity
✓	Systems and system models
	Energy and matter
	Structure and function
	Stability and change

	Disciplinary Core Idea	3	4	5	MS
	Physical Science				
PS1	Matter and Its Interaction	n/a	n/a		
PS2	Motion and Stability: Forces and Interactions		n/a		
PS3	Energy	n/a			
PS4	Waves and Their Applications in Technologies for Information Transfer	n/a		n/a	
	Life Science				
LS1	From molecules to organisms: Structures and processes				
LS2	Ecosystems: Interactions, Energy, and Dynamics		n/a		
LS3	Heredity: Inheritance and Variation of Traits		n/a	n/a	
LS4	Biological Evolution: Unity and Diversity		n/a	n/a	
	Earth & Space Science				
ESS1	Earth's Place in the Universe	n/a			
ESS2	Earth's Systems				
ESS3	Earth and Human Activity		✓	✓	
	Engineering, Technology, and Applications of Science				
ETS1	Engineering Design	✓	✓	✓	✓

DCI Grade Band Endpoints

3-5 ETS1.A: Defining and Delimiting Engineering Problems

- Possible solutions to a problem are limited by available materials and resources (constraints). The success of a designed solution is determined by considering the desired features of a solution (criteria). Different proposals for solutions can be compared on the basis of how well each one meets the specified criteria for success or how well each takes the constraints into account. (By the end of Grade 5)

3-5 ETS1.B: Developing Possible Solutions

- Research on a problem should be carried out before beginning to design a solution. Testing a solution involves investigating how well it performs under a range of likely conditions. (By the end of Grade 5)
- At whatever stage, communicating with peers about proposed solutions is an important part of the design process, and shared ideas can lead to improved designs. (By the end of Grade 5)
- Tests are often designed to identify failure points or difficulties, which suggest the elements of the design that need to be improved. (By the end of Grade 5)

3-5 ETS1.C: Optimizing the Design Solution

- Different solutions need to be tested in order to determine which of them best solves the problem, given the criteria and the constraints. (By the end of Grade 5)

MS ETS1.A: Defining and Delimiting Engineering Problems

- The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that are likely to limit possible solutions. (By the end of Grade 8)

MS ETS1.B: Developing Possible Solutions

- A solution needs to be tested, and then modified on the basis of the test results, in order to improve it. (By the end of Grade 8)
- There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. (By the end of Grade 8)
- Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors. (By the end of Grade 8)
- Models of all kinds are important for testing solutions. (By the end of Grade 8)

MS ETS1.C: Optimizing the Design Solution

- Although one design may not perform the best across all tests, identifying the characteristics of the design that performed the best in each test can provide useful information for the redesign process—that is, some of those characteristics may be incorporated into the new design. (By the end of Grade 8)
- The iterative process of testing the most promising solutions and modifying what is proposed on the basis of the test results leads to greater refinement and ultimately to an optimal solution. (By the end of Grade 8)

3-5 ESS3.C: Human Impacts on Earth Systems

- Human activities in agriculture, industry, and everyday life have had major effects on the land, vegetation, streams, ocean, air, and even outer space. But individuals and communities are doing things to help protect Earth's resources and environments. For example, they are treating sewage, reducing the amounts of materials they use, and regulating sources of pollution such as emissions from factories and power plants or the runoff from agricultural activities. (By the end of Grade 5)

Performance Expectations

3-5-ETS1-1	Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.
3-5-ETS1-2	Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.
3-5-ETS1-3	Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.
MS-ETS1-1	Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.
MS-ETS1-2	Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.
5-ESS3-1	Obtain and combine information about ways individual communities use science ideas to protect the Earth's resources and environment.

<u>Energetic Ocean</u>
Appendix

What we know about…

Wind Turbines	*Wave Energy Converters*
• convert wind energy into electricity • don’t affect the ocean waves • can block one another and not produce as much energy • allow for more effective maintenance when placed behind a wave energy converter, which leads to lower costs • can collect wind energy inside or outside the wave zone • produce more energy and fail less when they have a straight stream of fast air • will produce the same amount of energy with a wave energy converter placed in front • need to be anchored to the ocean floor	• convert energy from the “motion of the ocean” into electricity • don’t affect the wind • protect wind turbines from waves, allowing maintenance crews easier access to wind turbines for repairs, even in high wave weather • work best when placed inside the wave zone, where the wave energy is greatest • absorb wave energy and consequently make smaller waves behind them

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Qué sabemos sobre…

Turbinas eólicas	***Convertidores de energía de olas***
• transforman la energía del viento en electricidad • no afectan el oleaje • se pueden bloquear entre ellas y no producir tanta energía • su mantención es más fácil cuando se colocan detrás de un convertidor de energía de olas, lo que significa un gasto menor • pueden funcionar tanto dentro como fuera de la zona de oleaje • producen más energía y fallan menos cuando tienen una corriente directa de viento rápido • los convertidores de energía de olas no afectan su eficacia • deben estar ancladas al suelo marino	• transforman la energía del movimiento del mar en electricidad • no afectan el viento • protegen a las turbinas eólicas del oleaje, lo que les permite a los equipos de mantención reparar las turbinas más fácilmente, aun cuando hay alto oleaje • funcionan mejor cuando se colocan dentro de la zona de oleaje, donde la energía de olas es mayor • absorben la energía de las olas y por consecuente crean olas más pequeñas detrás

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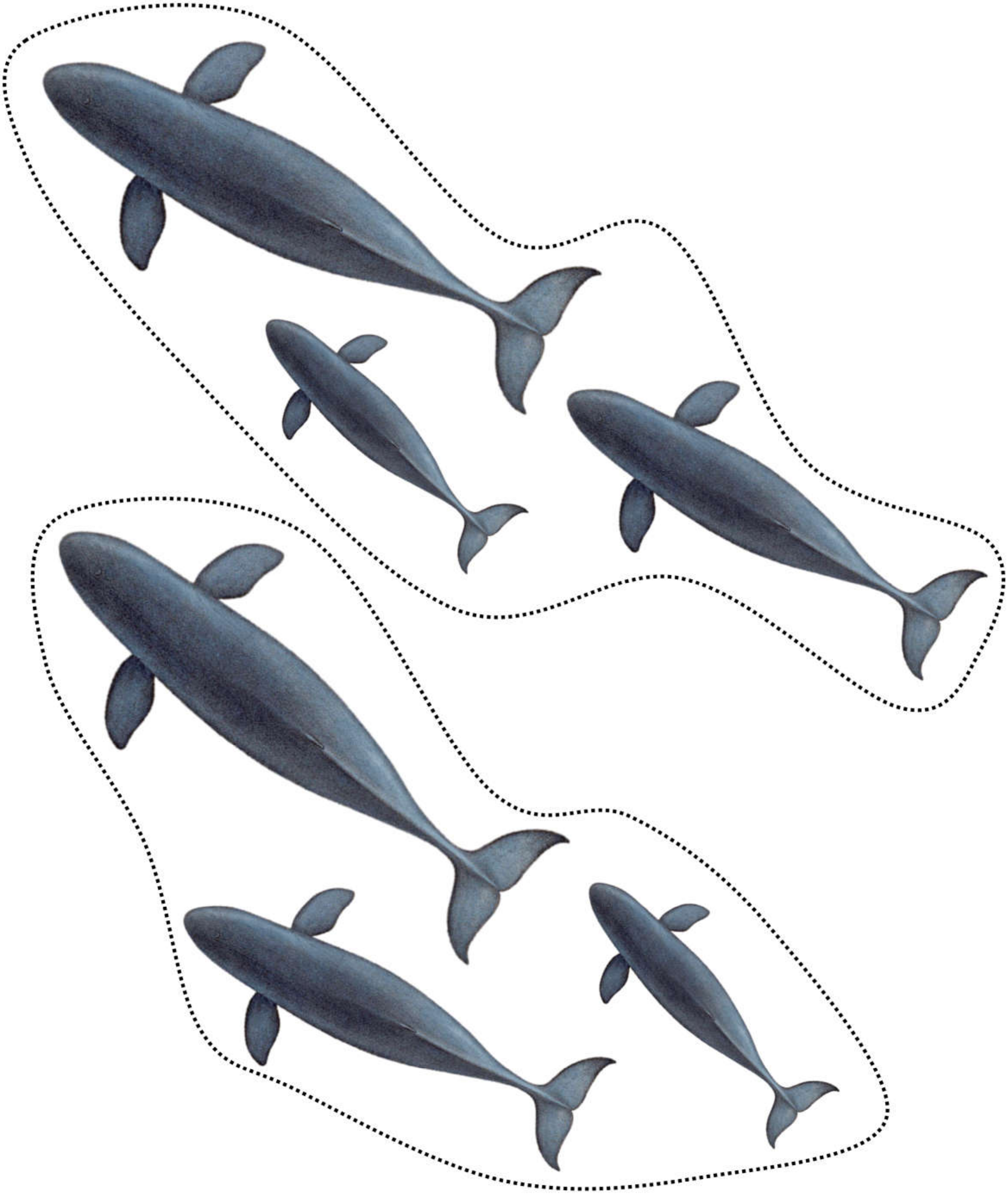
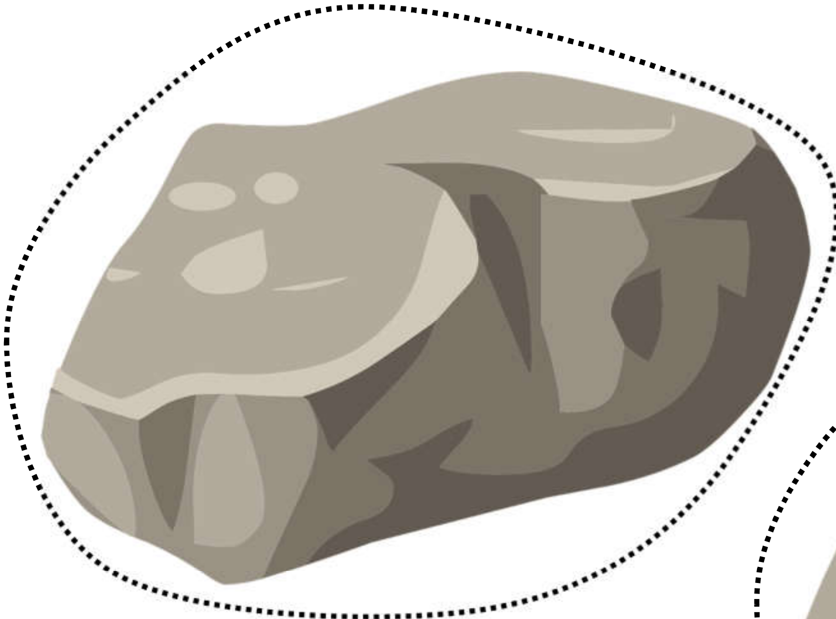
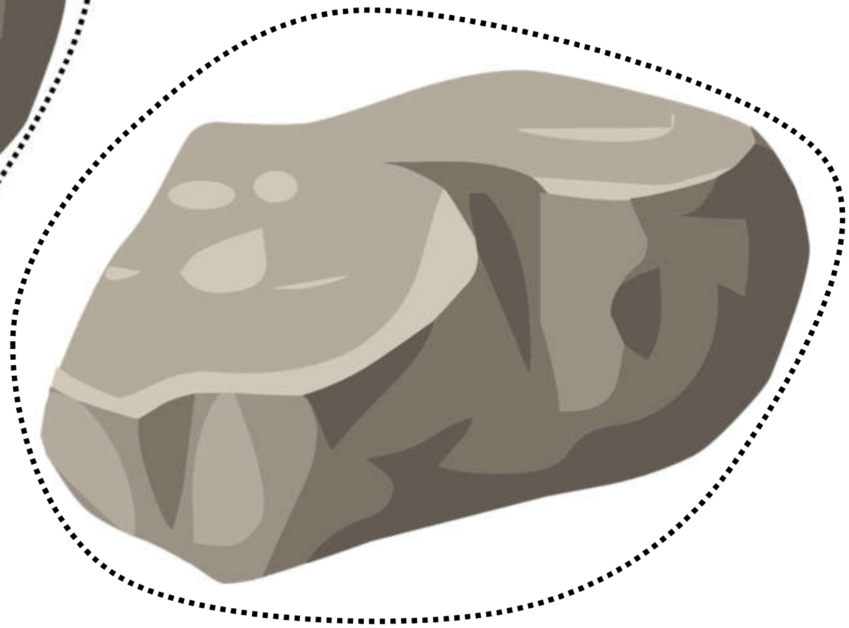
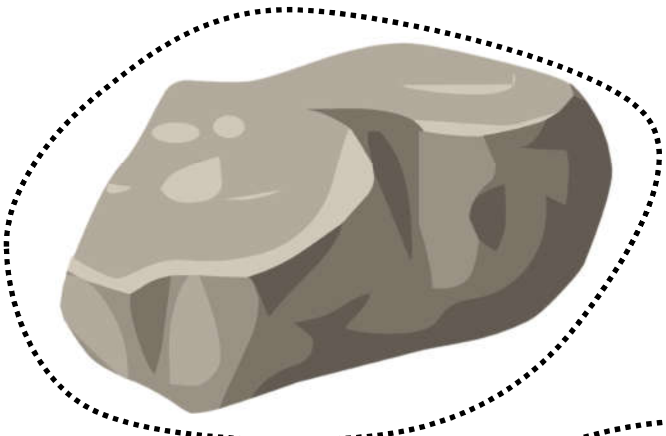
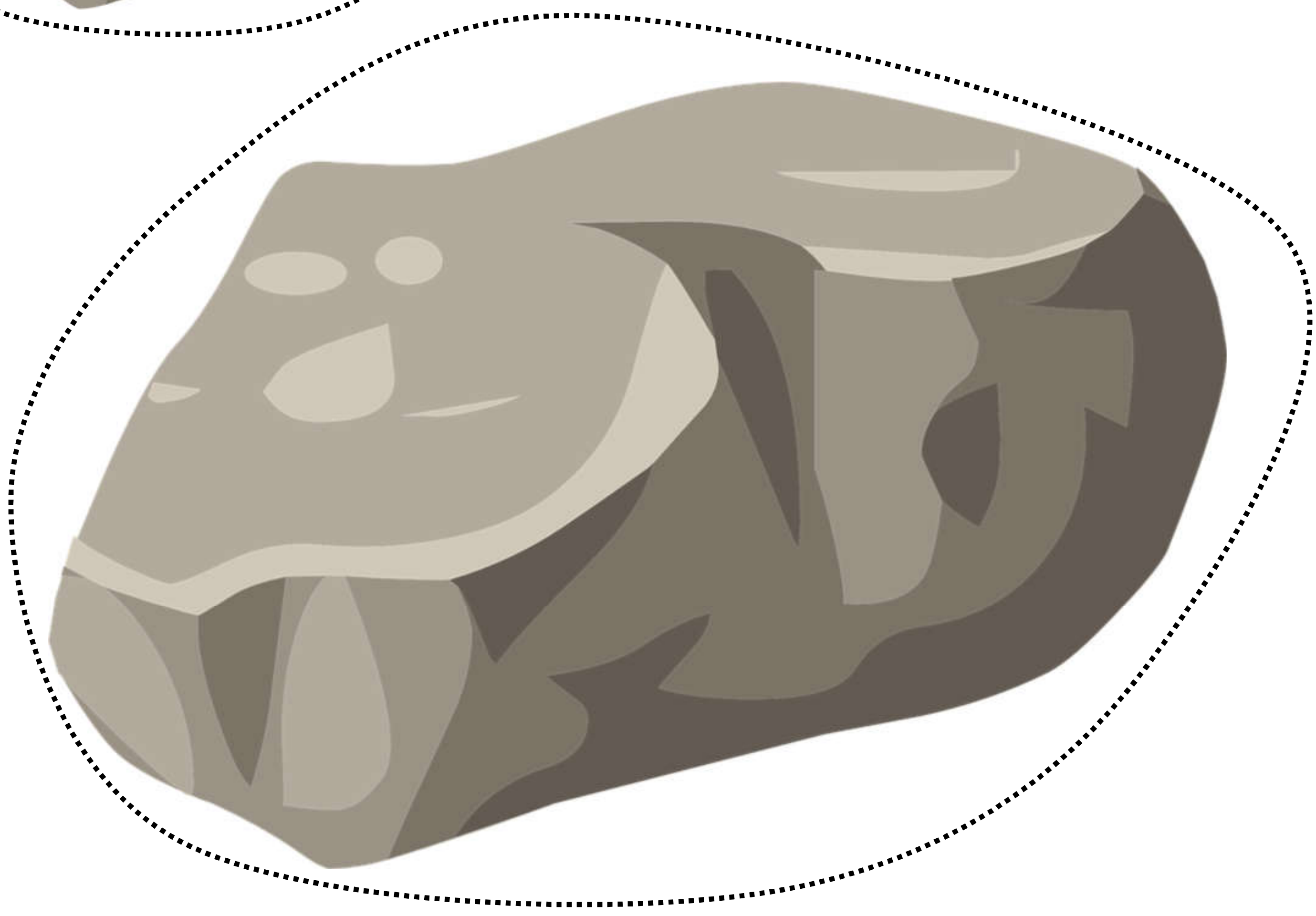
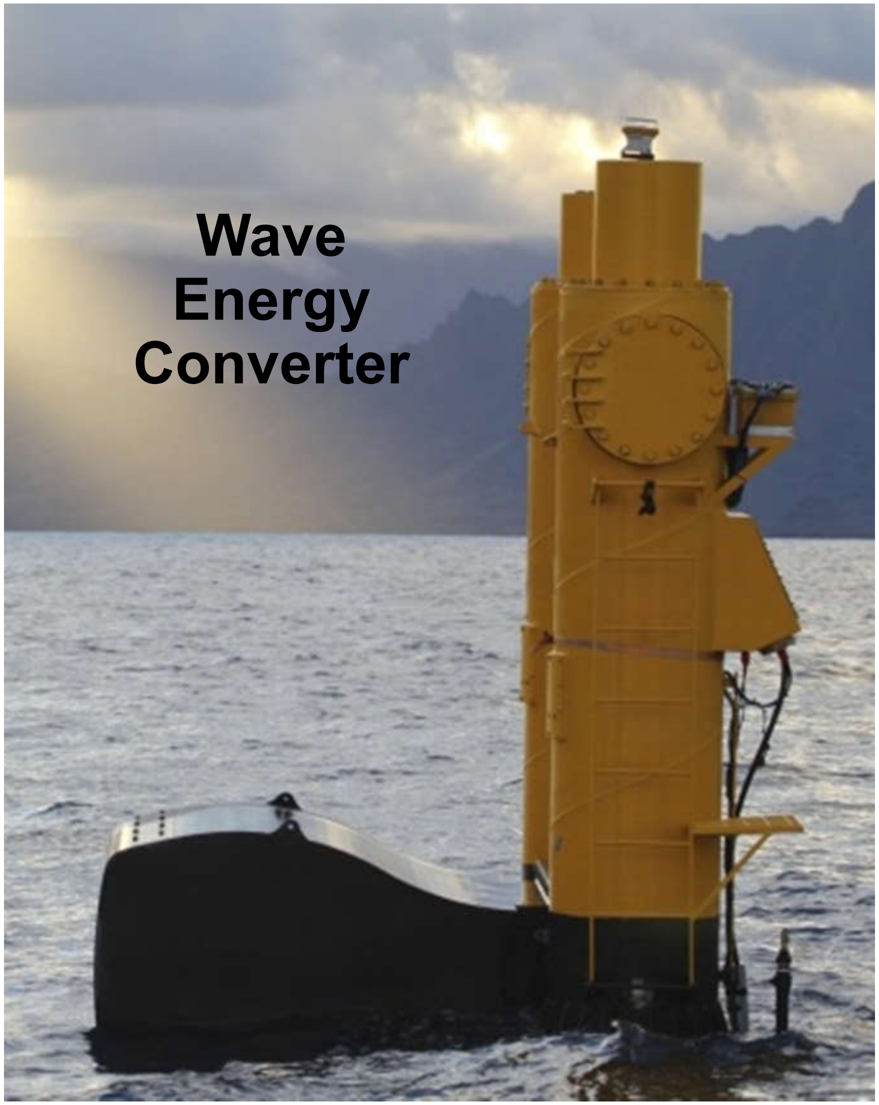
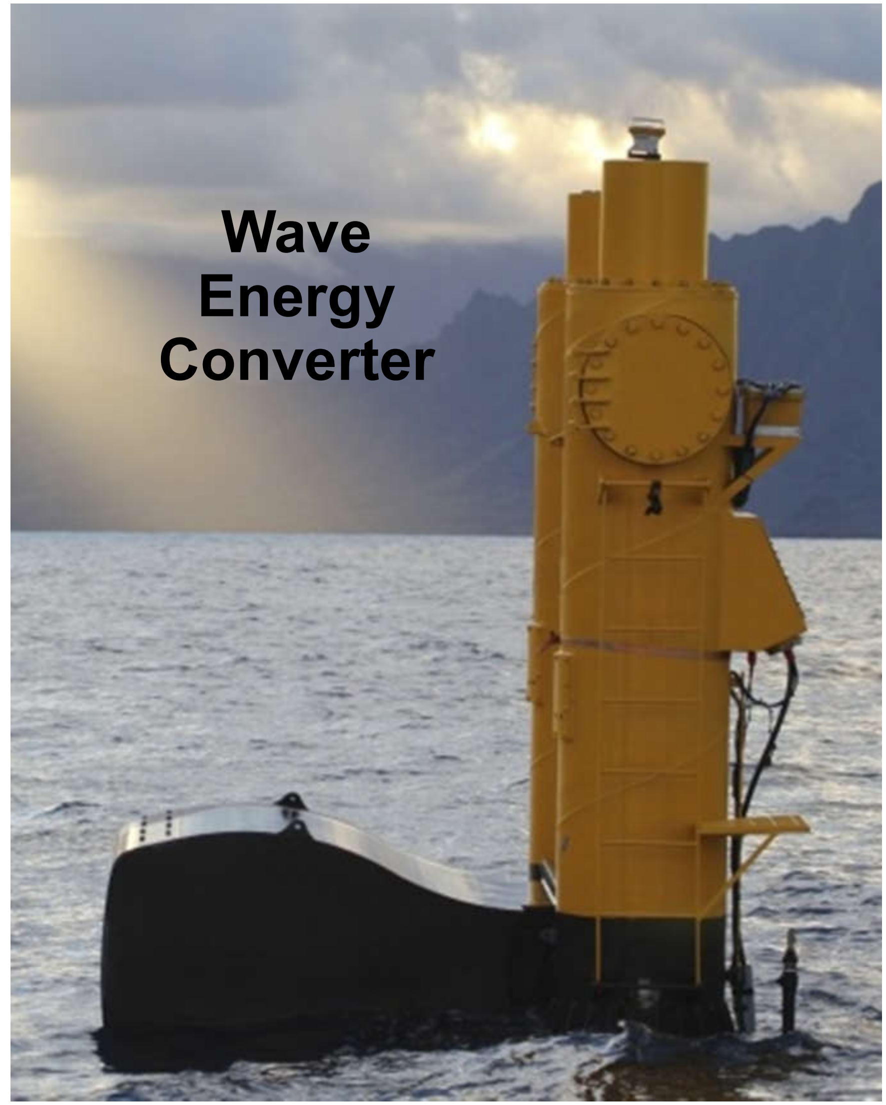



Wave
Energy
Converter


Wave
Energy
Converter


Convertidor de energía de olas


Convertidor de energía de olas

CHALLENGE

CHALLENGE

WHALE MIGRATION

Redesign your farm so the whales can pass through on their migration unharmed.

BOULDERS

There are giant boulders on the ocean floor that prevent you from building in certain areas.

CHALLENGE

CHALLENGE

BIRDS

Birds love to hang out in this area. In order to keep the sky safe for them, the top of your turbine cannot be more than 12 inches above the board.

SHIFTING WIND

The seasons and the temperature have changed, causing the wind to change directions slightly. Adjust your wind farm so it can still create just as much energy as before.

DESAFÍO

DESAFÍO

MIGRACIÓN DE BALLENAS

Vuelve a diseñar tu planta para que las ballenas puedan migrar de una forma segura.

ROCAS

Hay grandes rocas en el suelo marino que no te permiten construir ahí.

DESAFÍO

DESAFÍO

PÁJAROS

A los pájaros les encanta pasar por aquí. Para protegerlos, tus turbinas eólicas no pueden sobrepasar las 12 pulgadas sobre la tabla.

CAMBIO DE VIENTO

Las estaciones y la temperatura han cambiado, ocasionando un cambio en la dirección del viento. Rediseña tu planta para que siga generando la misma cantidad de energía de antes.

Names ___________________________

Energetic Ocean

How much does energy cost?

Instructions: After your final model wind and wave energy farm is complete, fill out the tables below to calculate the approximate amount of energy produced as well as how much money it takes to create and maintain the energy farm.

***Part 1**: How much energy does the wind and wave energy farm produce?*

Wind Turbines

# of turbines (Only count if SPINNING)	X	*100 kW*	=		

Wave Energy Converters

# of converters in BLUE wave zone	X	*200 kW*	=	
# of converters in WHITE zone	X	*50 kW*	=	
				TOTAL energy produced (add the 3 boxes from above)

Names ___________________________

***Part 2**: How much does a wind and wave energy farm cost?*

Description	Price	Quantity	Cost
K'Nex pieces	$100	×	=
Wind turbines	$800	×	=
Wave energy converters	$1500	×	=
Extra maintenance cost for for each *wind turbine* placed in wave zone	$600	×	=
			TOTAL cost (add the 4 boxes from above)

***Part 3**: How much does a kilowatt of energy cost?*

Use the totals above from ***Part 1*** and ***Part 2*** (total energy produced and total cost) to calculate the cost per kilowatt. **The lower the cost, the better!**

TOTAL cost ($) ÷ *TOTAL energy (kW)* = *Cost per kilowatt ($/kW)*

Nombres: ___________________________

Energetic Ocean
(Océano energético)

¿Cuánto cuesta la energía?

Instrucciones: Una vez que termines de diseñar tu planta de energía de viento (eólica) y de oleaje, completa las siguientes tablas para calcular aproximadamente cuánta energía es producida, y cuánto dinero cuesta la creación y el mantenimiento de tu planta de energía.

Parte 1: ¿Cuánta energía produce tu planta de energía de viento y olas?

Turbinas eólicas

Nº de turbinas (cuenta solamente las turbinas GIRANDO)	X	*100 kW*	=	

Convertidores de energía de olas

Nº de convertidores en zona AZUL	X	*200 kW*	=	
Nº de convertidores en zona BLANCA	X	*50 kW*	=	

Energía TOTAL producida (suma las 3 cajas de arriba)

Nombres: ___________________________

<u>Parte 2</u>: ¿Cuánto cuesta tu planta de energía de viento y olas?

Descripción	Precio	Cantidad	Costo
Piezas de K'Nex	$100	×	=
Turbinas eólicas	$800	×	=
Convertidores de energía de olas	$1500	×	=
Costo de mantención de *turbinas* en zona de olas	$600	×	=
			Costo TOTAL (suma las 4 cajas de arriba)

<u>Parte 3</u>: ¿Cuánto cuesta un kilowatt de energía?

Utiliza los totales de las partes 1 y 2 (energía total producida y costo total) para calcular cuánto cuesta cada kilowatt de energía. **¡Un costo bajo es mejor que un costo alto!**

Costo TOTAL ($) ÷ *Energía TOTAL (kW)* = *Costo por kilowatt ($/kW)*

FACILITATION GUIDE

Energetic Ocean

Description: Students will design a model offshore wind and wave energy farm to maximize the amount of energy the farm can produce.

Promoting collaboration and organization

- Circulate the room as teams are discussing their initial plan for their offshore energy farm. Encourage all students to provide input regarding the design plan.
- Encourage each member to pick where to put one of the pinwheels or wave energy converter cutouts. Then, facilitate a discussion about where to put remaining ones.
- Before students move anything, encourage discussion first. Why should we move this object? Will doing so yield a greater energy output?

Encouraging iteration

- There are many variations of this activity, and it can be adapted based on the needs and abilities of your group of students. Here are some questions that may facilitate further discoveries:
    - Can you try changing the heights of the wind turbines?
    - Should the tall/short ones go in front or in back?
    - Can you hear turbines knocking against one another? Remember that real wind turbines are hard and would probably break if they hit each other.
    - How can you make the turbines all spin at the same speed?
    - What happens with different speeds of wind? Does the wind still reach all of the turbines?

Helping those who are stuck

- Suggest that students try blowing on a pinwheel or holding it up to a fan. The students can then try holding up two pinwheels at a time and see how close together they can be and both spin.
- Have students stand where the fan is and lean down so their eyes are level with one of the middle-height pinwheels. Ask them if they can see all of their pinwheels. If not, maybe they should adjust their design.
- If pinwheels are rotating away from the fan, ask how they could alter the base to keep the pinwheel pointing towards the fan.

Real-world applications

- To minimize the need for everyday servicing, offshore turbines may have automatic greasing systems and heating and cooling systems to maintain the best conditions.
- Researchers at Oregon State University are working on a way to combine wind turbines and wave energy converters to maximize the amount of energy they can produce from one offshore farm. They use computers to solve the same problem we worked on today!

OMSI
Everyday Encounters with Science

Get It Together

Program Type: Classroom Program | ***Audience Type:*** Grades 3–8

Description: Students will plan an efficient assembly line process to put together emergency supply kits.

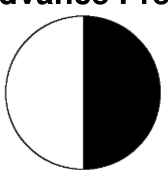
LEARNING OBJECTIVES

For Next Generation Science Standards alignment, see end of outline.

- Students will test the efficacy of an assembly line process versus an individual one in making emergency supply kits
- Students will make an assembly process quicker and more efficient by testing different production arrangements

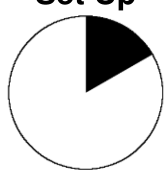
TIME REQUIRED

Advance Prep



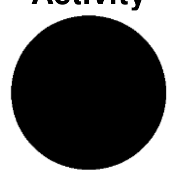
30 minutes

Set Up



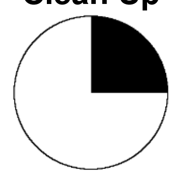
10 minutes

Activity



60 minutes

Clean Up



15 minutes

SITE REQUIREMENTS

- Five tables or large desks spaced around the room
- Space for students to gather and discuss (floor space is fine)

PROGRAM FORMAT

Segment	Format	Time
Introduction	Large group discussion	10 min
Assembly Trials	Large group activity	40 min
Wrap-Up	Large group discussion	10 min

SUPPLIES

Permanent Supplies	Amount	Notes
Large dry beans	¼ cup/person	Lima, kidney or similar
¼ cup measuring cups	3–4	Or small plastic cups
Reusable snack-size bags	1/person	
Plastic lunch trays	3–4	Any tray, plate, or shallow box to contain the beans
LED flashlights	1/person	Inexpensive LED flashlights with an on/off switch or a small bright item to represent a light
Wax paper sheets	1/person	Each sheet should be twice the size of the sandwich bag
Reusable sandwich bags	1/person	
Straws	1–2/person	
Connectors for straws	5/person	Ex: Strawbees.® See Note 1 below
String	1.5 ft/person	String, twine, or yarn
Cardboard pieces approx. 2”x3”	1/person	
Snap-together building tools	A few/person	See Note 2 below
Paper bags	1/person	Lunch bag size
Bin to store kits in	1	Medium–large storage bin
“Get it Together” Worksheet(s)	1 or 1/pair	*(Optional)* See Extension
Calculator(s)	1 or 1/pair	*(Optional)* See Extension
Pencils	1/pair	*(Optional)* See Extension
Whiteboard	1	*(Optional)* See Extension
Dry-erase marker	1	*(Optional)* See Extension
Document Camera and projector	1	*(Optional)* See Extension
Photos (in the *Background Information* section)	1 each	*(Optional)* Print or display digitally

Note 1: The straws and connectors are assembled to represent a multitool like a Swiss Army knife. An example is shown in the “Set-up” section. We used Strawbees® (www.strawbees.com), but you can also use binder clips, paper clips and/or pipe cleaners.

Note 2: The snap-together building tools represent a crank-operated radio. An example is shown in the “Set-up” section. We used K’NEX® building rods and connectors, but this item could be made with any easy-to-assemble tools that connect in specific ways. LEGO® blocks would work, for example.

ADVANCE PREPARATION

- Cut wax paper into sheets that, folded in half, would fit snugly inside a sandwich bag
- Cut straws into pieces about 3”–4” long
- Cut string into 1.5-ft pieces
- Cut cardboard into approximately 2”x3” rectangles and then cut notches as shown in Figure 1 below:

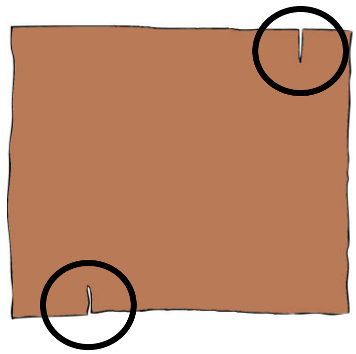
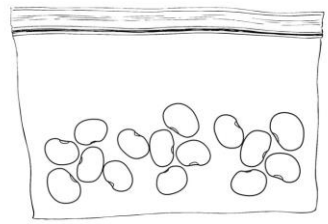
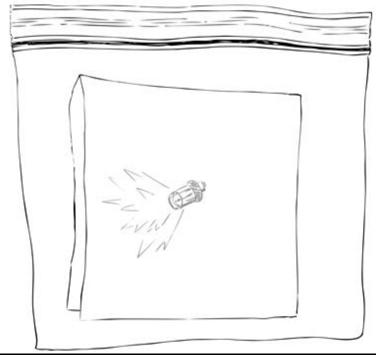
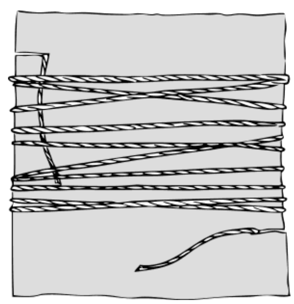
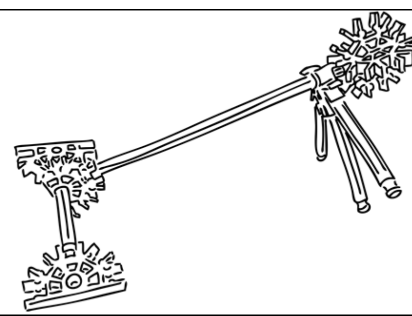
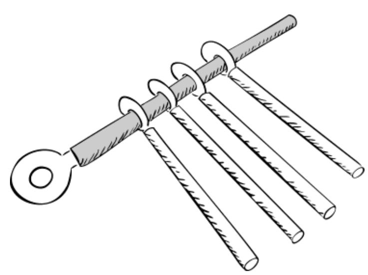


Figure 1: Cardboard notch placement.

SET UP

- In one paper bag, assemble an example kit with each of the materials in the table that follows.
- In a central, easy-to-access spot in the room, place a large storage bin to hold the completed emergency kits and the stack of empty paper bags.
- Set up five table stations—one for each type of item. Provide one pre-assembled item per table, to serve as a model. Tether it to the table with string, to ensure that nobody accidentally takes the example item to use in a new kit. Each station should have enough materials for each student to make 1 item.
- The stations listed in the following table are suggestions of types of materials you could use. However, you could create similar stations from any materials- the important part is that the item being made at each station requires multiple steps to build.
- *(Optional)* Set up the projector or document camera to show the images in the *Background Information* section or print photos to pass around.

Suggested Kit Supplies	Example Item
• <u>Station 1: Food</u> ❑ Container of beans ❑ Measuring cups ❑ Snack-sized bags ❑ Trays to contain the beans	
• <u>Station 2: Light</u> ❑ LED lights ❑ Sandwich bags ❑ Wax paper	
• <u>Station 3: Rope</u> ❑ String pieces ❑ Cardboard pieces with notches	
• <u>Station 4: Radio</u> ❑ Snap-together building tools	
• <u>Station 5: Multi-tool</u> ❑ Straws ❑ Connectors	

INTRODUCTION

10 minutes

Let students speculate before offering answers to any questions. The answers given are provided primarily for the instructor's benefit.

Suggested script is shaded. Important points or questions are in **bold**. Possible answers are shown in *italics*.

Look at one of your shoes. How many parts and different materials is it made of? How do you think those parts got made and put together, or assembled? The rubber sole had to be made and cut, the upper part had to be cut and sewn, and the laces or buckles had to be manufactured and put on. Think of all those steps.

Do you think a shoe is assembled by just one person?

What if someone needs to produce one thousand shoes? Would each worker make one whole shoe at a time? What about something even more complicated—like a bike, cell phone, or car?
It would be too complicated; you would have to know how to do everything.

When we need to make many of the same products, **industrial engineers** help design systems to make the process faster and more efficient. These systems are called assembly lines. Some parts may be automated (operated by machines) and some parts may be operated by people.

Today you will be industrial engineers, and you will have to create the best and most efficient way to produce a large number of something, making sure that each thing you create is exactly the same.

Introduce the activity using any large-scale recent natural disaster that students may be familiar with—or leave the introduction generic.

You can probably all remember a recent natural disaster that destroyed people's homes and made it hard for them to get food and supplies. In the past few years, there have been earthquakes, hurricanes, tsunamis, and floods in the United States and in other countries around the world. Today, we will be working as industrial engineers helping aid organizations get emergency supplies to people who have lost their homes and belongings in a disaster. In our scenario, one million people had to leave their homes and need your help! Our aid organization needs to make one million survival kits, and we engineers need to figure out the fastest, best way to do it. These are the survival kits that we will be making today.

Show the example bag and have student volunteers pull items out of the bag one at a time. Show each item to the group and explain what it is (or what it represents).

Each survival kit should have a bag of beans for food, a lantern, rope, a multi-tool, and a crank-powered radio.

There are __ students in here, so we will time ourselves to see how long it takes to make __ kits. First, each one of us will make one kit, and then we will come together and see if we can engineer a better process for making the kits.

In order to get this activity to work, we will need to listen to each other's ideas and communicate our own ideas very clearly!

Once a kit is ready and has been checked, it should be deposited in the large bin in the middle of the classroom.

GROUP ACTIVITY

Assembly Trials

5-30 minutes

Take a moment to go over each of the stations and demonstrate how to assemble each item.

To assemble a kit, you will need to visit each station to assemble each item, put all your items in a brown paper bag, and drop it off in the bin. We will start the timer when I say GO and stop the timer as soon as the last kit is in the bin.

Gather students into a line by the place where the brown paper bags are. Before starting the timer, instruct them that they will need to take one paper bag and encourage them to divide themselves evenly among each of the different stations. If possible, keep at least one facilitator by the turn-in bin to inspect kits as they are dropped off, or assign this task to the student who finishes assembling his or her kit first.

Round 1 – Test, Debrief, and Reset

Start the timer and instruct students to begin assembling their kits. Stop the timer when the last kit is turned in. Report to students the number of seconds it took.

If using the “Get it Together” worksheet (see *Extension*) calculate how many days it would take to assemble 1 million kits.

Gather the students to discuss how to improve the process to speed up the kit assembly.

- **What was the fastest item to assemble? What was the slowest?**
- **How could we speed up the process?**
- **What process could we engineer to make everyone’s time more efficient?** *Distribute people at each table; have someone open bags, have someone fill bags, have someone collect the items from each table and put one in each bag, etc.*
- **Is there a better way to organize the room?**

When students start talking about an assembly line or describing the assembly line process, and as they begin to develop a plan, begin asking questions to clarify their planning process.

- **What are the “jobs” each person will have?**
- **How many people will be at each station?**
    - **Which stations should have more people?**
    - **Which ones could get by with fewer?**
- **How will we know when we have made enough kits?**
- **How will we make sure that each kit is complete?**

Help students agree on a process for assembling the kits. Remind them they will be making the same number of kits as before. Suggest they move around the room and mime steps to clearly communicate their ideas.

<u>Note on clean up:</u>
Disassembling the kits after the first iteration can be a time-consuming process. Here are some options for facilitating this transition:

- If materials allow, consider providing enough supplies for each student to make two kits.
- Alternatively, if there is a second adult in the room, have them disassemble the kits during the calculations and planning discussion with the students.
- You can also streamline the process by assigning 2–3 students to each station. Those students can take the supplies for their station from the pile of assembled kits and be in charge of taking apart the materials and returning the station to its original state.

Round 2 – Test and Debrief

Do a second timed trial with students using an assembly line process. Share the new time and compare to the old; did you improve? If using the work sheet, calculate once again the time it would take to make one million kits.

Discuss if there are ways to speed up the process even more without compromising quality.

- **What steps go into making each item?**
- **Will dividing steps between multiple people make the assembly go faster?**
- **What other ways could we work together to assemble each item?**

If time allows, do a third timed trial and compare how long each trial took.

Repeat this process as many times as desired (or as many times as the schedule permits), trying different sizes of groups, different order of tasks, and rearranging stations.

WRAP-UP

10 minutes

Ask for student observations. There is no correct answer. Let students guide the discussion and present their hypotheses before discussing explanations.

Calculate how much time was saved by implementing the new assembly process.

[time from Trial 2] - [time from Trial 1] = time saved

Why do we care about saving time when making emergency kits?
Because the faster you can make and distribute the kits, the sooner they can help people in need. If students completed calculations, emphasize that their engineering skills got supplies to the disaster zone 10, or 20, or however many days sooner; that's a big deal for people experiencing an emergency!

How could we use other engineering processes to make it even faster?

Can you think of any other situations where an assembly line process would be a good idea?

OPTIONAL EXTENSION

For a math extension, use the “Get it Together” worksheet” after each trial to calculate how long it would take to assemble 1,000,000 kits. Students can work in pairs, or you can work as a class using a document camera. (If no document camera is available, write and solve the equation on a white board or poster).

[time in seconds] ÷ [number of kits completed] x 1,000,000 kits
= time in seconds to assemble 1,000,000 kits

Convert final time to hours/days/weeks/years.

[Time in seconds] ÷ 3,600 = [Time in hours]
[Time in hours] ÷ 24 = [Time in days]

Example: For a class of 35 students that took 5 minutes to make 35 kits:

5 minutes = 300 seconds

300 ÷ 35 students x 1,000,000 = 8,571,428 seconds

8,571,428 seconds ÷ 3600 = 2,381 hours
2,381 hours ÷ 24 = 99 days to make 1 million kits

CLEAN UP

- Disassemble the kits and put away the materials

BACKGROUND INFORMATION

Prior to the industrial revolution, almost all manufactured goods were made one at a time by a single person, or a small group of people. Beginning around the turn of the 20th century, various industries started to experiment with the assembly line process, where each worker would complete one step of the manufacturing process before passing the product on to the next worker, who would complete the next step, and so on. One of the first industries to apply the assembly line process was the meatpacking industry. Later, Henry Ford famously set up an assembly line process at his motor vehicle plant, allowing Ford Motor Company to produce Model Ts at a remarkable rate (see Figure 2).

Modern factories continue to rely on assembly lines and industrial engineers to create things that consumers enjoy, like clothing, food, and even pharmaceuticals. Assembly line techniques have also been adopted by disaster relief organizations, who rely on speed and quantity to effectively reach all of the people who are affected by natural disasters.

Industrial engineers are the people who design these systems. They also imagine and implement other innovations that help industries produce goods more quickly, safely, and cost-effectively.

Figure 2: Workers at a Ford assembly line, 1913. Each worker completes just one step before the unfinished product moves on. (Image: Wikimedia Commons).

Figure 3: The US Marines help Red Cross volunteers load completed kits for Hurricane Harvey relief in Texas. (Image: US Marines website: www.marines.mil).

Figure 4: A Red Cross volunteer distributes cleaning supply buckets to a Texas community after a storm in 2008. (Image: www.fema.gov).

NEXT GENERATION SCIENCE STANDARDS

	Practices
✓	Asking questions and defining problems
✓	Developing and using models
	Planning and carrying out investigations
	Analyzing and interpreting data
✓	Using mathematics and computational thinking
✓	Constructing explanations and designing solutions
	Engaging in argument from evidence
	Obtaining, evaluating, and communicating information

	Crosscutting Concepts
	Patterns
✓	Cause and effect
✓	Scale, proportion, and quantity
✓	Systems and system models
	Energy and matter
	Structure and function
	Stability and change

	Disciplinary Core Idea	3	4	5	MS
	Physical Science				
PS1	Matter and Its Interaction	n/a	n/a		
PS2	Motion and Stability: Forces and Interactions		n/a		
PS3	Energy	n/a			
PS4	Waves and Their Applications in Technologies for Information Transfer	n/a		n/a	
	Life Science				
LS1	From molecules to organisms: Structures and processes				
LS2	Ecosystems: Interactions, Energy, and Dynamics		n/a		
LS3	Heredity: Inheritance and Variation of Traits		n/a	n/a	
LS4	Biological Evolution: Unity and Diversity		n/a	n/a	
	Earth & Space Science				
ESS1	Earth's Place in the Universe	n/a			
ESS2	Earth's Systems				
ESS3	Earth and Human Activity				
	Engineering, Technology, and Applications of Science				
ETS1	Engineering Design	✓	✓	✓	✓

DCI Grade Band Endpoints

3-5 ETS1.A: Defining and Delimiting Engineering Problems

- Possible solutions to a problem are limited by available materials and resources (constraints). The success of a designed solution is determined by considering the desired features of a solution (criteria). Different proposals for solutions can be compared on the basis of how well each one meets the specified criteria for success or how well each takes the constraints into account. (By the end of Grade 5)

3-5 ETS1.B: Developing Possible Solutions

- Research on a problem should be carried out before beginning to design a solution. Testing a solution involves investigating how well it performs under a range of likely conditions. (By the end of Grade 5)
- At whatever stage, communicating with peers about proposed solutions is an important part of the design process, and shared ideas can lead to improved designs. (By the end of Grade 5)
- Tests are often designed to identify failure points or difficulties, which suggest the elements of the design that need to be improved. (By the end of Grade 5)

3-5 ETS1.C: Optimizing the Design Solution

- Different solutions need to be tested in order to determine which of them best solves the problem, given the criteria and the constraints. (By the end of Grade 5)

MS ETS1.A: Defining and Delimiting Engineering Problems

- The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that are likely to limit possible solutions. (By the end of Grade 8)

MS ETS1.B: Developing Possible Solutions

- A solution needs to be tested, and then modified on the basis of the test results, in order to improve it. (By the end of Grade 8)
- There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. (By the end of Grade 8)
- Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors. (By the end of Grade 8)
- Models of all kinds are important for testing solutions. (By the end of Grade 8)

MS ETS1.C: Optimizing the Design Solution

- Although one design may not perform the best across all tests, identifying the characteristics of the design that performed the best in each test can provide useful information for the redesign process—that is, some of those characteristics may be incorporated into the new design. (By the end of Grade 8)
- The iterative process of testing the most promising solutions and modifying what is proposed on the basis of the test results leads to greater refinement and ultimately to an optimal solution. (By the end of Grade 8)

Performance Expectations

3-5-ETS1-1.	Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.
3-5-ETS1-2.	Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.
3-5-ETS1-3	Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.
MS-ETS1-1.	Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.
MS-ETS1-2.	Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.

Get It Together

Appendix

Names ___________________________

Get it Together

How quickly can we make one million emergency kits?

	Time (seconds)		# of kits		Time in ***seconds*** to assemble 1 million kits		Time in ***hours*** to assemble 1 million kits		Time in ***days*** to assemble 1 million kits
Trial 1		÷		x 1,000,000		÷ 3600		÷ 24	
Trial 2		÷		x 1,000,000		÷ 3600		÷ 24	
Trial 3		÷		x 1,000,000		÷ 3600		÷ 24	

Conclusion

The faster you can make one million kits, the sooner the kits can be shipped to people in need. Using a new and improved assembly system, how much time did you save?

Nombres ____________________________

Get It Together
(Juntos ensamblamos)

¿Qué tan rápido podemos armar un millón de kits de emergencia?

	Tiempo (segundos)		Nº de kits		Tiempo en ***segundos*** para armar 1 millón de kits		Tiempo en ***horas*** para armar 1 millón de kits		Tiempo en ***días*** para armar 1 millón de kits
Prueba 1		÷		x 1,000,000		÷ 3600		÷ 24	
Prueba 2		÷		x 1,000,000		÷ 3600		÷ 24	
Prueba 3		÷		x 1,000,000		÷ 3600		÷ 24	

<u>Conclusión</u>

Contra más rápido armamos un millón de kits, más rápido podemos enviar estos kits a la gente que los necesita. ¿Cuánto tiempo ahorramos al mejorar el sistema de la línea de producción?

FACILITATION GUIDE

Get It Together!

Description: Students will plan an efficient assembly line process to put together emergency supply kits.

Promoting collaboration and organization

- Encourage the group to have planning conversations about the assembly line and express their ideas clearly and respectfully.
- During the large group discussion, encourage students to share with a partner before asking individual students to share out.
- Remind students that everyone needs to work together in order to minimize work time. It is important that everyone plays a role.
- Keep careless behavior in check by emphasizing that each kit needs to be exactly the same; if someone causes an accident by rushing too much it will slow everything down. Emphasize that round 1 (students assembling a kit individually) is not a competition.
- Use positive reinforcement: "I appreciate how careful you're being, putting things together the exact same way each time. You're making sure it will be fair for the people who will get these emergency kits."
- Before the timer starts, have each group member say out loud what he or she is going to do in the assembly line.

Encouraging iteration

- "How could you make that process more efficient?"
- "If two (or three) people worked together on this particular item, what could they each do to make the work go faster?"
- "Can you make sure that each item is exactly the same?"
- "After the first trial, what can we do differently to produce these kits in a shorter amount of time?"

Helping those who are stuck

- "Would it help to break this task up into smaller pieces?"
- "Is there a way to make the transitions between stations easier?"

Real-world applications

- A school cafeteria puts food on trays in an assembly line. Can you think of any other places where people use assembly lines to make a process go faster?
- Examine an everyday item. For example, a shoe has many different components: the sole, the insole, the laces, etc. How do you think a shoe is assembled?

Everyday Encounters with Science

Pollution Solution

Meet an Engineer Video – Emily Harris

Watch here: https://vimeo.com/254363553/555e253ccd

Pollution Solution

Program Type: Classroom Program	***Audience Type:*** Grades 3–8

Description: Students will create model neighborhoods that incorporate green spaces, such as bioswales and parks, to prevent pollution from flowing into a river.

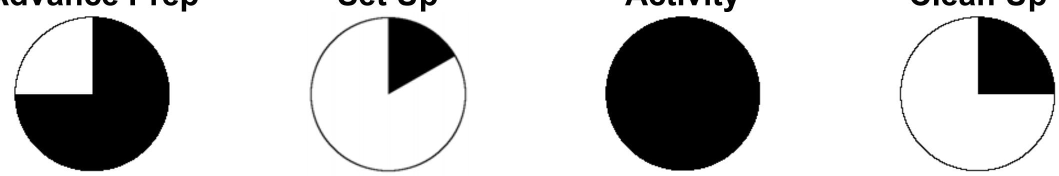
LEARNING OBJECTIVES

For Next Generation Science Standards alignment, see end of outline.

- Students will use the engineering design process to design a neighborhood with green spaces.
- Students will weigh various factors in planning their neighborhood, including population density, and amount and types of green space.

TIME REQUIRED

Advance Prep	Set Up	Activity	Clean Up
45 minutes	**10 minutes**	**60 minutes**	**15 minutes**



SITE REQUIREMENTS

- Tables or floor space for each group
- A central testing table, preferably on a surface that can get wet. If a waterproof surface isn't available, consider placing plastic sheeting around the testing table
- Access to water

PROGRAM FORMAT

Segment	Format	Time
Introduction	Large group discussion	10 min
Design, Test, Improve	Group activity	40 min
Wrap-Up	Large group discussion	10 min

SUPPLIES

Permanent Supplies	Amount	Notes
Disposable aluminum cookie sheet	1/group	
Small watering can or similar	1	1qt. size, with sprinkle head
Catchment container	1	Casserole-sized, watertight, rectangular container, wider than the width of the cookie sheet
Reusable metal cookie sheet	1	
Items to prop up testing bed (books, blocks, or boxes)		Must be taller than height of catchment container
Strainer	1	With small holes (sized to strain sequins from water)
Magnets	2	
Large sponges	2/group	Without scrub surface
Plastic mesh pot scourers	3/group	
Craft foam	2-4 sheets/group	Enough to make ~10 houses per group
Masking tape	1 roll/class	
Sticky tack	1 package	*(Optional)*
Brads	5-6 per group	
Sequins	1 small handful/group	A pack with small pouches of different colors is suggested
Graph paper	1–2 sheets/group	With large grid squares
Colored markers	5/group	
Razor knife	1	For use in advance prep
Hot glue gun	1	For use in advance prep
Permanent marker	1	For use in advance prep
Meet an Engineer Video – Emily Harris	1	*(Optional)* Found on USB flash drive provided with manual and website listed in *Advanced Prep*
Computer with Screen	1	*(Optional)* to show *Meet an Engineer* Video
Large measuring cup or pitcher	1	*(Optional)* See Extension
"Pollution Solution Extension" worksheet	1/group	*(Optional)* See Extension
Pencils	1/group	*(Optional)* See Extension

ADVANCE PREPARATION

NOTE: Refer to images in SETUP for context

- Use a razor knife to cut a thin rectangular strip large enough for sequins out of one end of the disposable aluminum cookie sheets leaving the rim intact. This will be the drainage hole.
- Cut the craft foam into rectangles of various sizes to represent houses and apartment buildings. Label with the number of occupants they can hold. Make the area of the rectangle equal to the number of people that can live in that space (e.g., 2 occupants = 1"x2", 9 occupants = 3"x3", 24 occupants = 6"x4"). Cut enough rectangles that each group has approximately 10 "buildings" to work with. (As a math extension, you could have students do this).
- Apply a rim of sticky tack or hot glue around the unmarked side of the "buildings" to help them stay put on the cookie sheet.
- Cut the large sponges into rectangles of different sizes: approximately 1.5"x1.5", 2.5"x2.5" 0.5"x2.5", and 1"x3". Cut enough that each group has approximately 5-10 sponge pieces to work with.
- Cut the tie holding the mesh pot scourers together so that they can be unrolled.

SET UP

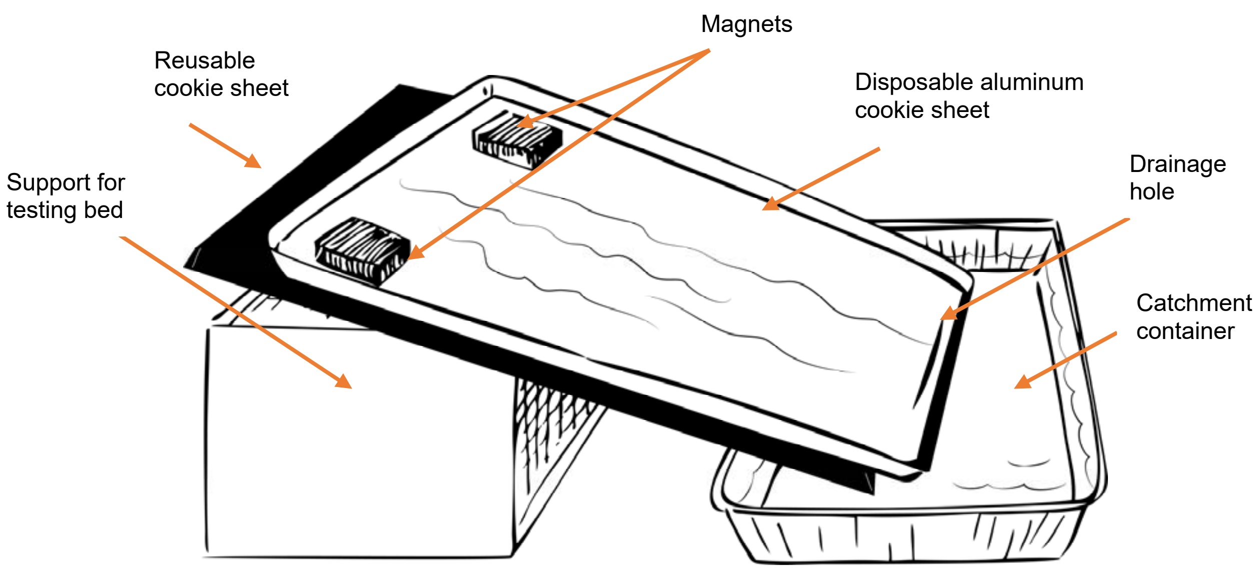


Figure 1: Testing bed apparatus. The upside-down reusable cookie sheet serves as a base for the student models. It is elevated above the catchment container and propped up at an angle using blocks. Two magnets hold the disposable cookie sheet in place on top of it.

- *Prepare the testing bed apparatus.* Turn the reusable cookie sheet upside down. Prop one end up to elevate it above the catchment container. Use tape, if necessary, to secure all the elements. Place the catchment container beneath the edge of the cookie sheet. Place the magnets nearby to hold the student models in place.
- Fill the watering can and have additional water on hand if there is no sink nearby.
- Place the testing bed apparatus in a place where all students will be able to see and use the magnets to secure an empty aluminum cookie sheet, as shown in Figure 1.

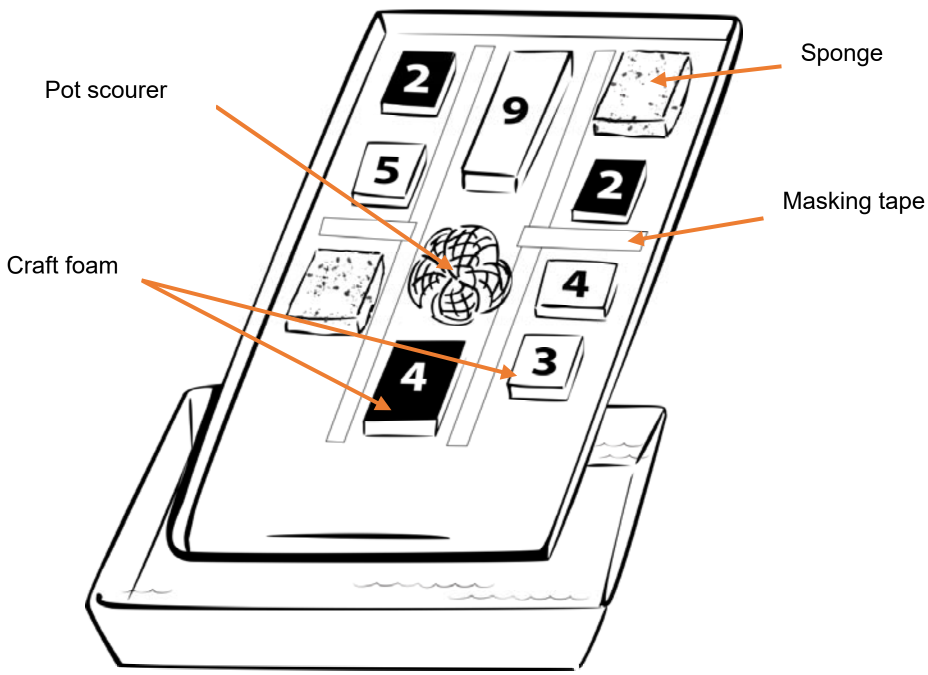


Figure 2: An example of a finished model. The masking tape represents the streets. The building capacity is shown by the numbers on the craft foam pieces. The sponges represent green spaces. The pot scourers, which can be used rolled or unrolled, represent bioswales.

- Prepare the projector and computer to show the *Meet an Engineer Video – Emily Harris* found on the USB flash drive provided with this manual (if applicable), or at https://vimeo.com/254363553/555e253ccd
- If you can't show video to students, watch on your own for reference.

INTRODUCTION

10 minutes

Let students speculate before offering answers to any questions. The answers given are provided primarily for the instructor's benefit.

Suggested script is shaded. Important points or questions are in **bold**. Possible answers are shown in *italics*.

Do you remember a time when it rained and rained and rained in your neighborhood? Where do you think all that water went?
Into the river, ground, sewer…

When it rains in a forest, or other places with lots of plants, the ground acts like a sponge and most of the water gets absorbed into the soil. Some of that water gets used by plants, and the rest of it flows slowly down through dirt and rock until it reaches a stream. Water that travels this way becomes clean and healthy for the animals, plants, and bugs that live in streams and rivers. You might not think of dirt and plants as things that can make water cleaner, but that's what they do!

What about rain that falls in the city? What happens to the water when it falls on the road or on a roof or in a parking lot?
It flows on top of the street, it doesn't get absorbed, it picks up pollution, then it goes into the sewer.

Water that doesn't get filtered through the ground is called runoff. Cities can have a lot of runoff because pavement and buildings are impervious, which means they don't let water go through. In some cities, too much runoff can cause sewers to overflow into nearby rivers! Cities can also have a lot of pollution in the form of gasoline, motor oil, trash, and pesticides from people's lawns and gardens that can get washed into the river with all the runoff.

What do you think happens to all that pollution?
It gets carried to streams and rivers, it hurts the fish…

If using the optional *Meet an Engineer* video, show it here. Emily Harris is an engineer who works on bioswales and rain gardens. In this 2-minute video, Emily explains her work in Water Resource Engineering.

Draw the students' attention to the testing bed apparatus with an empty cookie sheet.

This cookie sheet is a big impervious surface, like a parking lot. The catchment container below is the stream.

Sprinkle sequins across the sheet.

These sequins represent pollution.

Pour the water evenly across the entire sheet.

What do you observe when we add rain to this area?
It all runs into the stream…

Engineers realized that we could take something that works really well in nature and use the idea to make spaces in cities where plants and soil can filter out pollution naturally. Parks help soak up water, but there are other planted areas that are just for catching and cleaning up runoff. These areas are called bioswales or rain gardens. Water resource engineers design bioswales by choosing the right plants and the right mix of soil and gravel and by placing these components where they can capture the most runoff. Today we are going to be designing a city neighborhood that can filter pollution out before it reaches a stream.

Your city needs to have all the things that people need to live, like houses *(hold up craft foam houses)* and roads *(hold up masking tape)*, but you will also have parks *(hold up sponges)* and bioswales *(hold up mesh pot scourers)* to work with. Your goal is to stop the pollution from entering the river, and to slow the water down so that more of it soaks into the ground instead of running into the river.

Right now, unfortunately, you are engineers for a city that doesn't know that preventing runoff is important! They want your team of engineers to design a neighborhood for at least 15 people, with roads connecting everything, but they only made room for two parks in the budget! Let's see how environmentally friendly you can make your neighborhood with these limitations!

GROUP ACTIVITY

Design, Test, Improve

40 minutes

Round 1:
Divide students into groups of 3–5 and pass out graph paper and markers. Give the students roughly 5 minutes to plan their neighborhood. Encourage students to draw and label their diagram. Ask questions about how they are choosing to place their two parks.

Pass out an aluminum tray, two feet of masking tape, and two larger pieces of sponge to each group. If you decide to allow the students to use sticky tack to help secure items to the tray, pass out a small piece to each group. Give each group five or six craft foam houses to start with but leave extras in a central location and let students know they are free to get more houses and return ones they don't need.

As students finish, invite them to use the testing bed apparatus:

- **Set up –** Have students place their completed "neighborhood" (on disposable aluminum cookie sheet) on top of testing apparatus. Use magnets to hold in place. (See Figure 1).
- **Add pollution –** Have one student sprinkle sequins along the top of the neighborhood to represent pollution.
- **Add water –** Have another student use the watering can to "rain" down on the neighborhood, aiming most of the water near the top so that runoff flows down the sheet.
- **Observe**
    - Did your bioswales (sponges) trap most of the pollution (sequins)? Or did most of the pollution flow into the river (bottom basin)?
    - Did your bioswales absorb most of the rain, or did most of it run into the river?
    - How could you improve your neighborhood so that less water and pollution make it into the river?
    - **Note: if you wish to answer these questions in a more quantitative way, see Extension.*
- **Reset –** Have students remove remaining sequins off their sheets and squish their sponges so that any absorbed water flows into bottom basin. If bottom basin is starting to get very full (after a few groups), pour the water from the bottom basin back into the watering can, using the strainer to catch the sequins for re-use. (If the mouth of the watering can is small, you may need an intermediate, wide-mouthed container to strain water into before carefully pouring into the watering can).

While students are testing their models, encourage observation of the successful parts as well as brainstorming how they could make their models more effective at trapping the pollution before it runs into the river.

- **Where does the pollution get caught?**
- **Where does pollution get through?**
- **Where does water run off the fastest? How could you absorb some of it?**
- **What would change if you placed your parks somewhere else?**

Round 2:

The city government has seen how much run off there is and how much pollution gets washed into the river when there are only a couple parks in the neighborhood. They've decided to listen to their water resource engineers and let you have as much money for parks and bioswales as you need!

You still need to create roads and housing for at least 15 people, but now you can decide how many parks and bioswales to install and where to place them. Remember, more housing for people is better.

Give students another planning period to draw and label their neighborhood on graph paper. When they are ready, pass out additional sponges and two mesh pot scourers. Include a few brads and explain that they might be useful for holding the bioswales in place.

Circulate among the groups as the students design and build. Many groups will organically come up with the idea to stack housing units to increase population density. They may also layer gardens, housing, and bioswales to create green roofs and other building innovations.

WRAP-UP

10 minutes

When all of the groups are finished designing, have a final showcase to test all of the designs, using the same method as before. Before testing, let each group point out the notable aspects of their designs to the rest of the class. Compare the designs after they all have been tested, emphasizing the unique features and what worked well.

Which features of the models were most effective at catching pollution? Did it matter where you placed them?

Which features of the models were most effective at preventing runoff? Did it matter where you placed them?

Why do you think it would be important to include more bioswales and green spaces in our cities?

CLEAN UP

10 minutes

- Students squeeze out their sponges and pot scourers and place them somewhere to dry.
- Students throw away the masking tape from their trays and return craft foam houses and brads to the box.

- Rinse off the trays over the sifter to capture any stray sequins. Stack trays to dry.
- Pour the catchment container through the sifter and disassemble the testing bed.

EXTENSION

As an optional extension, have students quantify the amount of runoff and pollution that flows into the river, using the "Pollution Solution" Worksheet.

Use the procedure outlined above for testing student's models, with the following changes:

- Start with the bottom basin (the "river") empty of sequins. (This means emptying and straining the basin after each group).
- Have students measure a designated number of sequins to sprinkle on the sheet; either count them out, or use a relatively precise measuring tool, like a tablespoon.
- Have students measure a designated amount of water to rain down on the sheet; use a large measuring cup or a pitcher with gradation marks.
- After testing, have students measure the pollution in the river by counting the number of sequins in the bottom basin. Record results on the "Pollution Solution" worksheet.
- Lastly, have students determine how much runoff was absorbed by the sponges. To do this, first empty the basin. Then, have students wring out their sponges over the empty basin. Then, carefully pour that water back into the measuring cup. Record results on the "Pollution Solution" worksheet, using whatever units (mL, oz, cups, etc.) are on your measuring device. Remember, the more water that is absorbed by the sponges, the better!
- Clean trays and reset as usual.

BACKGROUND INFORMATION

Urban runoff is water that puddles and flows on streets, parking lots, and other impermeable, urban surfaces. It is a major source of flooding and water pollution. When rain falls on impermeable surfaces, it pools and flows, rather than absorbing into the ground. The result is flooding. What's more, as the water flows downhill, it picks up trash, oil, and other contaminants. This pollution eventually makes it into streams, rivers, and groundwater.

City planners and landscape engineers design ways to reduce flooding and water pollution associated with urban runoff.

Bioswales, or rain gardens, are permeable basins that collect water, allowing it to slowly soak into the ground. Layers of vegetation, soil, and sand filter out trash and contaminants. Bioswales are better for the environment and more cost-effective than traditional storm drains, which transport runoff to a central sewer system.

Bioswales are easy to find if you know what to look for. They can be found as road medians, ditches, and green islands in parking lots. Increasingly more of them are being installed around new urban constructions, schools, and municipal buildings.

The plants in bioswales are typically native plants chosen for their strong root systems and ability to do well in wet and dry conditions. They might not be the prettiest plants, but they have a job to do! There also might be a drainage grate for overflow control visible or a gravely area at the lowest point of the bioswale. Larger rain gardens can include shrubs and trees and can serve as little parks!

Other innovations to manage runoff include green roofs, permeable pavement, and rain barrels.

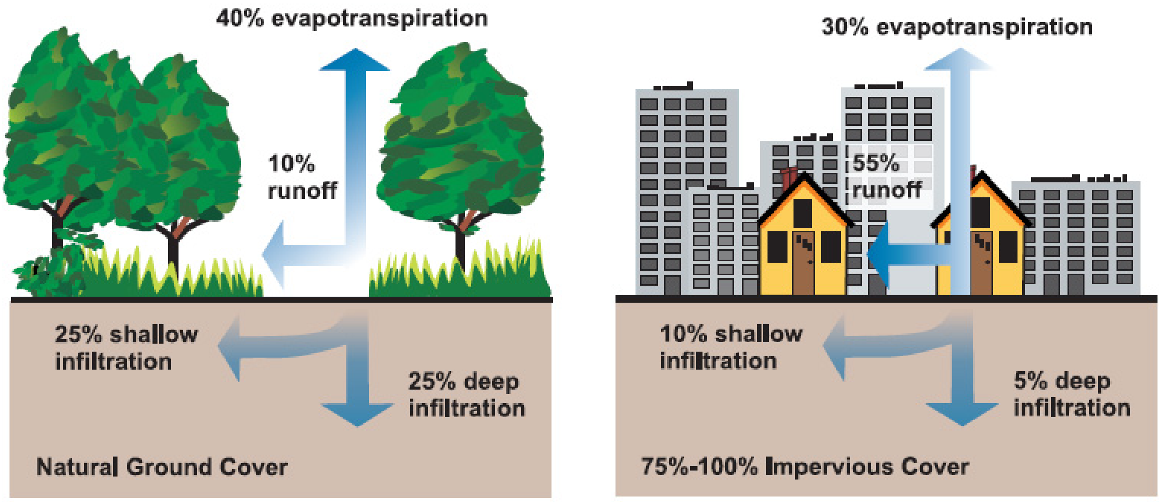


Figure 3: Spaces with permeable surfaces—like parks, rain gardens, and bioswales—generate less runoff than urban areas with primarily impermeable surfaces. (Image from EPA, courtesy of Wikimedia Commons).

Figure 4: A small bioswale in an urban area. The pavement dips slightly down towards the curb, causing water to flow into the planted area, where it slowly filters back into the ground. (Image from Greg Raisman, Flickr).

GLOSSARY

Bioswale	A rain garden that uses plants and soil to clean runoff from a road, construction site, or other urban or agricultural land that might contain pollutants.
Runoff	Precipitation that flows across the surface of the land that ultimately reaches streams. Since it doesn't flow through the ground, it can carry pollution or other types of particles into the water.
Non-point-source pollution	Non-point-source pollution comes from many sources, not just one place like a factory. It can happen when runoff from rain or snow carries pollution into streams. In agricultural land, pesticides and fertilizers get washed away; in cities, the pollutants are often gasoline, motor oil, and trash.
Impervious	An impervious surface is one that cannot effectively absorb or infiltrate rainfall. These surfaces include driveways, roads, parking lots, rooftops, and sidewalks. When natural landscapes are intact, rainfall is absorbed into the soil and vegetation.

NEXT GENERATION SCIENCE STANDARDS

	Practices
✓	Asking questions and defining problems
✓	Developing and using models
	Planning and carrying out investigations
	Analyzing and interpreting data
	Using mathematics and computational thinking
✓	Constructing explanations and designing solutions
	Engaging in argument from evidence
✓	Obtaining, evaluating, and communicating information

	Crosscutting Concepts
	Patterns
✓	Cause and effect
	Scale, proportion, and quantity
✓	Systems and system models
	Energy and matter
✓	Structure and function
	Stability and change

	Disciplinary Core Idea	3	4	5	MS
	Physical Science				
PS1	Matter and Its Interaction	n/a	n/a		
PS2	Motion and Stability: Forces and Interactions		n/a		
PS3	Energy	n/a			
PS4	Waves and Their Applications in Technologies for Information Transfer	n/a		n/a	
	Life Science				
LS1	From molecules to organisms: Structures and processes				
LS2	Ecosystems: Interactions, Energy, and Dynamics		n/a		
LS3	Heredity: Inheritance and Variation of Traits		n/a	n/a	
LS4	Biological Evolution: Unity and Diversity		n/a	n/a	
	Earth & Space Science				
ESS1	Earth's Place in the Universe	n/a			
ESS2	Earth's Systems				
ESS3	Earth and Human Activity			✓	
	Engineering, Technology, and Applications of Science				
ETS1	Engineering Design	✓	✓	✓	✓

<u>DCI Grade Band Endpoints</u>

3-5 ETS1.A: Defining and Delimiting Engineering Problems

- Possible solutions to a problem are limited by available materials and resources (constraints). The success of a designed solution is determined by considering the desired features of a solution (criteria). Different proposals for solutions can be compared on the basis of how well each one meets the specified criteria for success or how well each takes the constraints into account. (By the end of Grade 5)

3-5 ETS1.B: Developing Possible Solutions

- Research on a problem should be carried out before beginning to design a solution. Testing a solution involves investigating how well it performs under a range of likely conditions. (By the end of Grade 5)
- At whatever stage, communicating with peers about proposed solutions is an important part of the design process, and shared ideas can lead to improved designs. (By the end of Grade 5)
- Tests are often designed to identify failure points or difficulties, which suggest the elements of the design that need to be improved. (By the end of Grade 5)

3-5 ETS1.C: Optimizing the Design Solution

- Different solutions need to be tested in order to determine which of them best solves the problem, given the criteria and the constraints. (By the end of Grade 5)

MS ETS1.A: Defining and Delimiting Engineering Problems

- The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that are likely to limit possible solutions. (By the end of Grade 8)

MS ETS1.B: Developing Possible Solutions

- A solution needs to be tested, and then modified on the basis of the test results, in order to improve it. (By the end of Grade 8)
- There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. (By the end of Grade 8)
- Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors. (By the end of Grade 8)
- Models of all kinds are important for testing solutions. (By the end of Grade 8)

MS ETS1.C: Optimizing the Design Solution

- Although one design may not perform the best across all tests, identifying the characteristics of the design that performed the best in each test can provide useful information for the redesign process—that is, some of those characteristics may be incorporated into the new design. (By the end of Grade 8)
- The iterative process of testing the most promising solutions and modifying what is proposed on the basis of the test results leads to greater refinement and ultimately to an optimal solution. (By the end of Grade 8)

3-5 ESS3.C: Human Impacts on Earth Systems

- Human activities in agriculture, industry, and everyday life have had major effects on the land, vegetation, streams, ocean, air, and even outer space. But individuals and communities are doing things to help protect Earth's resources and environments. For example, they are treating sewage, reducing the amounts of materials they use, and regulating sources of pollution such as emissions from factories and power plants or the runoff from agricultural activities. (By the end of Grade 5)

Performance Expectations

3-5-ETS1-1	Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.
3-5-ETS1-2	Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.
3-5-ETS1-3	Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.
MS-ETS1-1	Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.
MS-ETS1-2	Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.
5-ESS3-1	Obtain and combine information about ways individual communities use science ideas to protect the Earth's resources and environment.

Pollution Solution
Appendix

Name ___________________________

Pollution Solution

Keep pollution and runoff out of the river!

Instructions: Each time you test your model neighborhood, measure how much pollution and runoff flows into the river. Can you use bioswales and greenspaces to absorb more runoff and trap pollution? Don't forget to include housing for at least 15 people.

	How many people can live in your neighborhood?	How much pollution flowed into the river? *Count number of sequins*	How much water did your sponges absorb? *Measure amount of water*
Trial #1			
Trial #2			
Trial #3			
Trial #4			

Were you able to improve your design?

What techniques worked best for keeping pollution and runoff out of the river?

Nombre ___________________________

Pollution Solution
(Solución a la contaminación)

¡Ayuda a que la contaminación y los vertidos no lleguen al río!

Instrucciones: Cada vez que pruebes tu prototipo de barrio, mide cuánta contaminación y exceso de lluvia llega al río. ¿Puedes utilizar bio-filtración y espacios verdes para absorber más exceso de lluvia y atrapar la contaminación? No olvides incluir viviendas para por lo menos 15 personas.

	¿Cuántas personas pueden vivir en este vecindario?	¿Cuánta contaminación llegó al río? *Cuenta el número de lentejuelas*	¿Cuánto exceso de agua está en las esponjas? *Mide la cantidad de agua*
Prueba #1			
Prueba #2			
Prueba #3			
Prueba #4			

¿Pudiste mejorar tu diseño?

¿Qué métodos funcionaron mejor para mantener la contaminación y los vertidos de agua lluvia fuera del río?

FACILITATION GUIDE

Pollution Solution

Description: Students will create model neighborhoods that incorporate green spaces, such as bioswales and parks, to prevent pollution from flowing into a river.

Promoting collaboration and organization

- Optional: Assign individual roles for students in collaborative groups. Possible roles can include group leader, recorder, materials manager, timekeeper, and ambassador (shares ideas with other groups). Index cards with the role descriptions can be given to each group prior to the activity, and students can switch roles with each iteration.
- Encourage groups to draw and label their design on paper before starting to build. However, their design on paper will naturally change during construction of the model.
- Have students take charge of clean up between test runs as much as possible to speed up the testing process.

Encouraging iteration

- *Round 1 (limited supplies):* "Does it matter where you put your two parks?"
- "Is there housing for 35 or more people?" "Are there roads connecting all the buildings?"
- *Round 2 (unlimited supplies)*: "How are you going to make room for both people and parks or bioswales?"
- "Do you think there will be any difference between the effectiveness of the parks and the bioswales? Would you put them in different places?"
- How could you fit more housing?

Helping those who are stuck

- Encourage students to go look at what their classmates are doing.
- If a group is having a hard time drawing, let them go look at the materials for a little while to get ideas.
- If a group is building too hastily or not working toward the same goal during construction, encourage them to go back to their drawing to solidify a plan.
- To encourage students towards green roofs and other innovative structures, show images of green roofs, green walls, etc.

Real-world applications

- Bioswales are increasingly common, especially in places that get a lot of precipitation. They are better for the environment and more cost effective than traditional storm sewer systems.
- Bioswales, or rain gardens, are easy to find if you know what to look for. They can be found as road medians, ditches, and green islands in parking lots. Look for them around schools and other public buildings, too.

Save the Day

Program Type: Classroom Program	**Audience Type:** Grades 3–8

Description: Students play a card game to generate ideas for creative designs that will help different people and animals in various disaster scenarios.

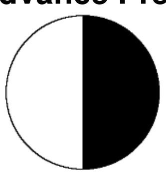
LEARNING OBJECTIVES

For Next Generation Science Standards alignment, see end of outline.

- Students will design an object for a specific person or animal in a disaster scenario.
- Students will work together to solve a problem using the engineering design process.

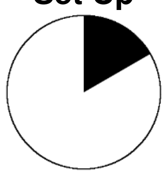
TIME REQUIRED

Advance Prep



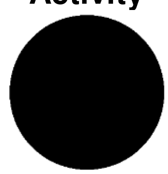
30 minutes

Set Up



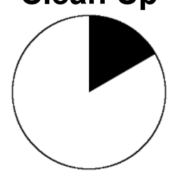
10 minutes

Activity



60 minutes

Clean Up



10 minutes

SITE REQUIREMENTS

- Tables or floor space able to accommodate groups of 3–5 students

PROGRAM FORMAT

Segment	Format	Time
Introduction	Large group discussion	10 min
Save the Day	Group activity	40 min
Wrap-Up	Large group discussion	10 min

SUPPLIES

Permanent Supplies	Amount	Notes
Design Challenge cards	1 set	Included in the appendix; see Note 1
Design Challenge sheet	1/group	Included in the appendix
Scrap paper	2–3/person	
Pencils/markers	1/person	
Building supplies	1 set/group	See "Suggested Supplies" below

Suggested Supplies
For simplicity, students can use just paper and markers for this activity. However, there is a greater opportunity for creativity and engineering when building supplies are provided. If you choose the hands-on building option, have a selection of supplies with 4–8 of each building material assembled in a container for each group. The items below are suggested building materials, but you may use any similar items.

- Rubber bands
- Wooden craft sticks
- Tongue depressors
- Straws
- Cardboard
- Cardstock or cereal boxes
- Craft foam sheets
- Paper clips
- Binder clips
- Brads
- Pipe cleaners
- String
- Sticky tack
- Bamboo skewers

ADVANCE PREPARATION

- Print and cut out the Design Challenge cards. (color and double sided)
- Print the Design Challenge sheet for each group (laminate if desired)
- Assemble the building supply kits for each group *(Optional)*
- Print or display the engineering design process diagram (see *background information*)

SET UP

- Set up space for partners or groups of 3–5 students to sit together
- Separate the Design Challenge cards into categories
- Place one Design Challenge sheet at each table
- Distribute supplies to each group (either just markers and paper, or the building kits along with markers and paper)

INTRODUCTION

10 minutes

Let students speculate before offering answers to any questions. The answers given are provided primarily for the instructor's benefit.

Suggested script is shaded. Important points or questions are in **bold**. Possible answers are shown in *italics*.

Today we're going to use our imaginations and creativity to design inventions for people in need.

How do people come up with inventions?
They need a new object to help them in some way. (Many examples may be given here.)

Inventions almost always begin with a problem. Engineers often design inventions to solve problems. Margaret Knight was an inventor in the early 1900s. After many friends at her workplace got hurt, she designed and built safety systems for factory machines. It took her many trials to come up with the equipment that worked just right!

The engineering design process is a cycle. Engineers make a plan of how to solve a problem. They make and test models of their inventions. Then they reflect on what they should change to make their invention better.

Show diagram in *background information*, or draw it on the board.

Starting now, you are all engineers! Soon we will be creating inventions of our own. These inventions will be used in some extraordinary situations to keep people and animals safe, comfortable, and happy.

To get our engineering creativity rolling, we'll play a card game that will give us ideas about the situations and people that our designs will help. But first, let's go through each step of the engineering design process and imagine what we will be doing as engineers.

Defining the problem: The card game will give us the problem to solve.
Plan solutions: You will work as a team to brainstorm ideas for a design that will solve this problem. We may draw pictures to show our ideas.
Make a model: We will build/draw our invention based on our plan. We may change it as we build.
Test the model: We will try our model and see if it works, keeping in mind who will use the invention.

Reflect and redesign: We will do some research, talk as a team, and make a new plan about how to make our original design better. You may be given a constraint—a restriction on your design.

Now we will use the card game to help define the problem that each group will face. When you receive your engineering challenge, be sure to follow the engineering design process and work together to create an invention. These are our "situation" cards—the extraordinary events for which we will design. Some are serious and some are silly.

Show the cards and read a few. Highlight one you think students will be interested in and will spark ideas.

What are some problems we might encounter in this situation?
(*Safety risks, technology not working, systems collapse, people being scared, etc.)*

Here are our "object" cards. These are the things we will be designing. The categories are vague, so they can include many things.

Show cards and read a few. Highlight one you think students will be interested in and will spark ideas.

What are some things that fit in this category?
Encourage and ask leading questions until you get a broad range of answers. Example: "Something to clean yourself with" might yield responses of "soap," "shower," "car wash," "scrub brush," "shampoo," "toothbrush," and "hand sanitizer."

Finally, these are our "user" cards. Engineers know that not everyone can use an object in exactly the same way because different people and animals have different needs.

Show cards and read a few. Highlight one you think students will be interested in and that fits well with the previous two cards.

Now we are going to combine all three cards! What sort of [object] could you invent for a [user] to use in a [situation]? Turn and talk with the person next to you to come up with a few ideas.

Remember to use your imagination and maybe even your sense of humor!

Let students talk for 1–2 minutes and then ask them to share some ideas. When the class appears to understand the activity, divide them into partners or teams of 3–5, introduce them to the materials, and then begin the activity.

GROUP ACTIVITY

Save the Day

40 minutes

The goal of the activity is for teams of students to design an object to suit a specific user in a disaster and then revise that design when a constraint is introduced.

Basic Gameplay
Ask each group to pull two cards from each of the “Object,” “User,” and “Disaster” categories. The group then discusses amongst themselves and chooses one of each card that they think will be a good combination. Once they have come to an agreement, they will place their chosen combination on the color-coded Design Challenge sheet and leave it where all other group members can see it. Students then return their three unused cards.

Planning (5–7 minutes)
Each group begins with several minutes of discussion and sketching. Here are some questions to pose:

- **What objects fit in this category?** (Example: “Something to wear” might yield responses of “*shirt,” “pants,” “coat,” “swimsuit,” “costume,” “armor,” and “uniform.”)*
- **What problems will come up in this disaster?** (Example: “Drought” might yield responses of “*limited water,” “heat,” “dust,” “food can’t grow,” and “habitat loss.”)*
- **What do we know about this user?** (Example: “Elephant” might yield responses of “*large,” “heavy,” and “they use their trunk for grabbing items.”)*
- **How will this disaster affect this user?** *(Example: “limited water for the elephant to drink” and “change in habitat may lead to disorientation.”)*
- **Will this user need any special adaptations to use this object?** (Example: “*babies can’t read,” “wheelchair users can’t use stairs,” and “pets don’t have thumbs.”)*

Creating/Testing (10–15 minutes)
Let groups begin to design a model by either drawing it or building it with the building supplies. Using building materials is recommended; the concrete task promotes creativity and detailed thinking, and it is easier for the entire group to participate. If the group members are not building, ask them to create a detailed drawing with labels that may include the materials used and the function of these materials.
Questions to pose:

- **What does this part do?**
- **How does this [object] help the [user] in the [disaster]?**
- **How does the [user] hold/wear/use your invention?**

Improvement (5–10 minutes)
As each group reaches the “mostly done” stage, choose a constraint card that would be an appropriate challenge for each group and place it on their Design Challenge sheet. Look for constraint cards that would prompt new ideas for each group based on their current design. For example, giving the “portable” constraint to a group with a design too large to move. Then give students an additional 5–10 minutes to improve their design to suit the constraint.

Sharing and Discussion (10 minutes)
Gather all groups with their finished projects and have them share in a circle and explain their designs. If there is limited time, or if the group is large, pair up groups and have them present to one another.

What is your invention and what problem did you solve?

Is this model close to your original plan for the design? What did you change?

Which part of the engineering design process was the most challenging? Why?

If you went through the Engineering Design Process cycle again, how would you improve your design?

Variations on Basic Gameplay

1. All students create designs for the same object, user, and disaster.
2. All students create different objects for the same user and disaster.
3. Speed up the pace: Impose short time limits for each stage of play, draw instead of build, and do several rounds of designs.
4. Groups choose challenge cards for one another.
5. Use the blank card templates to create cards that are personalized and specific to the interests of your class.
6. Have groups evaluate their own designs or the design of another group. (Example categories: *Safety, Ease of Use, Reliability, Comfort, Effectiveness, Uniqueness, etc.).*

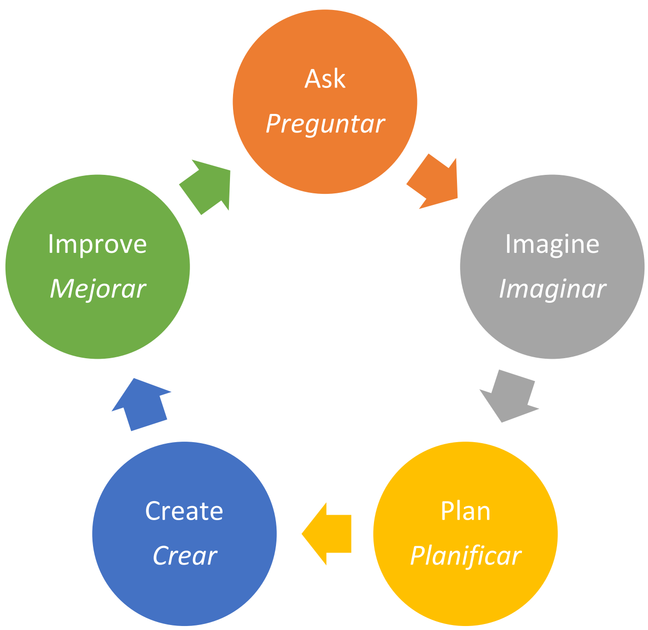
10 minutes

CLEAN UP

- Have student disassemble their creations or choose who brings it home.

BACKGROUND INFORMATION

Engineering Design Process
Proceso de diseño de ingeniería



Engineering design cycle adapted by the *Head Start in Engineering* team, with permission from the *Engineering is Elementary* project, Museum of Science, Boston.

Ask—Ask questions to understand the problem and what you need to solve it.
Pregunta*—Haz preguntas para entender el problema y qué necesitas para resolverlo.*

Imagine—Brainstorm as many possible solutions and designs as you can.
Imagina*—Piensa en la mayor cantidad de soluciones y diseños que puedas.*

Plan—Pick a design and decide how you will use your materials.
Planifica*—Escoge un diseño y decide cómo usarás los materiales*

Create—Build and test your design to see how well it solves the problem.
Crea*—Construye y pon a prueba tu diseño para ver qué tan bien soluciona el problema.*

Improve—Make changes to your design based on what you learned.
Mejora*—Cambia tu diseño en base a lo que aprendiste.*

The **engineering design process** is a cycle that engineers follow to create and test solutions to a problem. We also use this process to solve problems every day, like figuring out a food recipe or building a bookshelf. Talking about the engineering design process with students and using the steps when you work on problems is a great way to get learners interested in engineering and help them develop problem-solving skills.

NEXT GENERATION SCIENCE STANDARDS

	Practices
✓	Asking questions and defining problems
	Developing and using models
	Planning and carrying out investigations
	Analyzing and interpreting data
	Using mathematics and computational thinking
✓	Constructing explanations and designing solutions
	Engaging in argument from evidence
✓	Obtaining, evaluating, and communicating information

	Crosscutting Concepts
	Patterns
✓	Cause and effect
	Scale, proportion, and quantity
	Systems and system models
	Energy and matter
✓	Structure and function
	Stability and change

	Disciplinary Core Idea	3	4	5	MS
	Physical Science				
PS1	Matter and Its Interaction	n/a	n/a		
PS2	Motion and Stability: Forces and Interactions		n/a		
PS3	Energy	n/a			
PS4	Waves and Their Applications in Technologies for Information Transfer	n/a		n/a	
	Life Science				
LS1	From molecules to organisms: Structures and processes				
LS2	Ecosystems: Interactions, Energy, and Dynamics		n/a		
LS3	Heredity: Inheritance and Variation of Traits		n/a	n/a	
LS4	Biological Evolution: Unity and Diversity		n/a	n/a	
	Earth & Space Science				
ESS1	Earth's Place in the Universe	n/a			
ESS2	Earth's Systems				
ESS3	Earth and Human Activity	✓	✓		
	Engineering, Technology, and Applications of Science				
ETS1	Engineering Design	✓	✓	✓	✓

DCI Grade Band Endpoints

3-5 ETS1.A: Defining and Delimiting Engineering Problems

- Possible solutions to a problem are limited by available materials and resources (constraints). The success of a designed solution is determined by considering the desired features of a solution (criteria). Different proposals for solutions can be compared on the basis of how well each one meets the specified criteria for success or how well each takes the constraints into account. (By the end of Grade 5)

3-5 ETS1.B: Developing Possible Solutions

- Research on a problem should be carried out before beginning to design a solution. Testing a solution involves investigating how well it performs under a range of likely conditions. (By the end of Grade 5)
- At whatever stage, communicating with peers about proposed solutions is an important part of the design process, and shared ideas can lead to improved designs. (By the end of Grade 5)
- Tests are often designed to identify failure points or difficulties, which suggest the elements of the design that need to be improved. (By the end of Grade 5)

3-5 ETS1.C: Optimizing the Design Solution

- Different solutions need to be tested in order to determine which of them best solves the problem, given the criteria and the constraints. (By the end of Grade 5)

MS ETS1.A: Defining and Delimiting Engineering Problems

- The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that are likely to limit possible solutions. (By the end of Grade 8)

MS ETS1.B: Developing Possible Solutions

- A solution needs to be tested, and then modified on the basis of the test results, in order to improve it. (By the end of Grade 8)
- There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. (By the end of Grade 8)
- Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors. (By the end of Grade 8)
- Models of all kinds are important for testing solutions. (By the end of Grade 8)

MS ETS1.C: Optimizing the Design Solution

- Although one design may not perform the best across all tests, identifying the characteristics of the design that performed the best in each test can provide useful information for the redesign process—that is, some of those characteristics may be incorporated into the new design. (By the end of Grade 8)
- The iterative process of testing the most promising solutions and modifying what is proposed on the basis of the test results leads to greater refinement and ultimately to an optimal solution. (By the end of Grade 8)

3-5 ESS3.B: Natural Hazards

- A variety of hazards result from natural processes (e.g., earthquakes, tsunamis, volcanic eruptions, severe weather, floods, coastal erosion). Humans cannot eliminate natural hazards but can take steps to reduce their impacts. (By the end of grade 5)

Performance Expectations

3-5-ETS1-1	Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.
3-5-ETS1-2	Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.
3-5-ETS1-3	Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.
MS-ETS1-1	Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.
MS-ETS1-2	Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.
3-ESS3-1	Make a claim about the merit of a design solution that reduces the impacts of a weather-related hazard.
4-ESS3-2	Generate and compare multiple solutions to reduce the impacts of natural Earth processes on humans.

Save The Day
Appendix

Design

For

Design Challenge

To use in

One More thing...

Intentionally Left Blank

A Gift

A Drink Carrier

A Form of Protection

Something to Clean

Something to Carry Things In

A Communi-cation Device

Shoes

Something to Wear

A Source of Light

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Object

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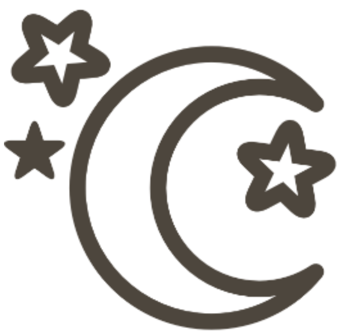
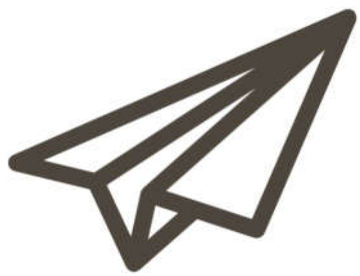
A Disguise

A Music Player

A Heat Source



A Place to Sleep



A Form of Transport

First Aid

A Time Keeper

A Cooking Utensil

Something to Sit On

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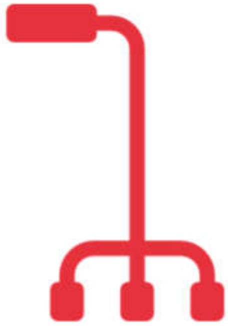


Elderly

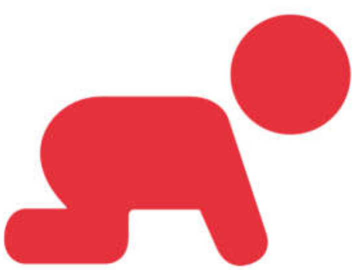
Family

Child

Doctor

Police

Pets



Baby

You

Adult

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User

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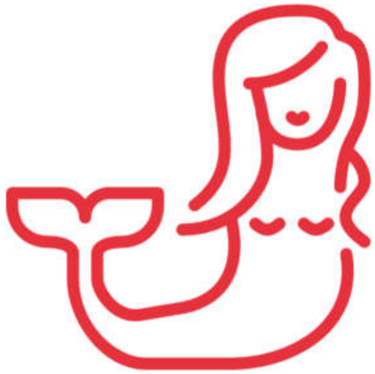
User

Teacher

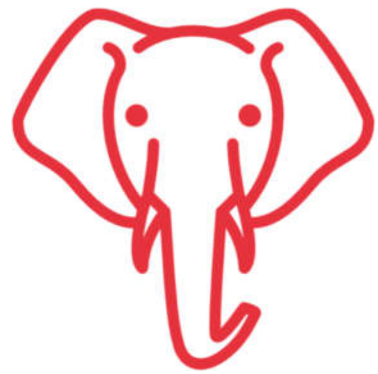


Mermaid

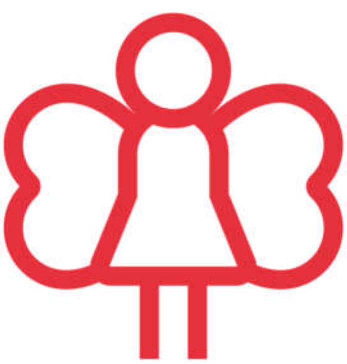
You and A Friend

President

Wheelchair User



Elephant



Fairy

Your Class

Scientist

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Earthquake

Flood

Asteroid

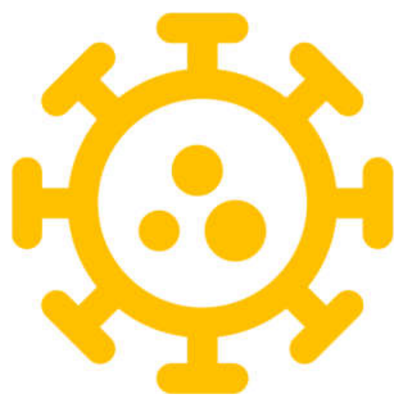
Drought

Blackout

Tornado

Fire

Tsunami



Epidemic

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Disaster

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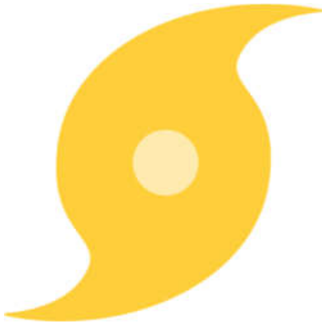
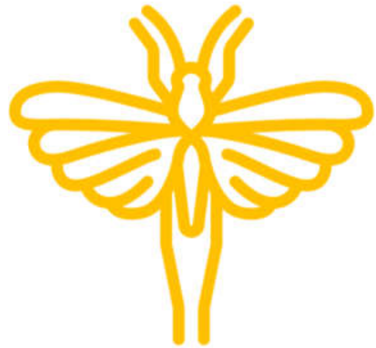
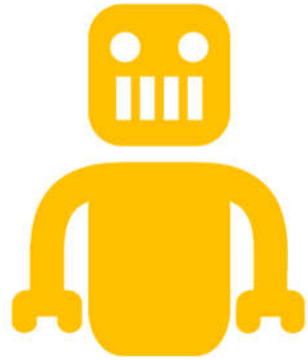


Hurricane

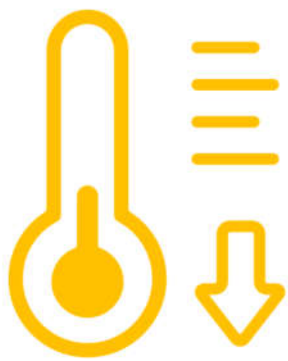


Plague



Robots

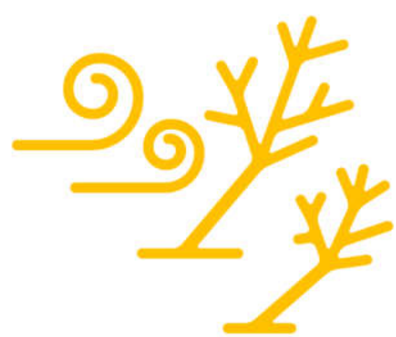
Zombies



Frozen

Aliens

Volcano



Windstorm

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Disaster

Second User

Second Location

Tiny Budget

Earth-Friendly

Portable

______

Automatic

Reusable

Does Two Things

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Constraint

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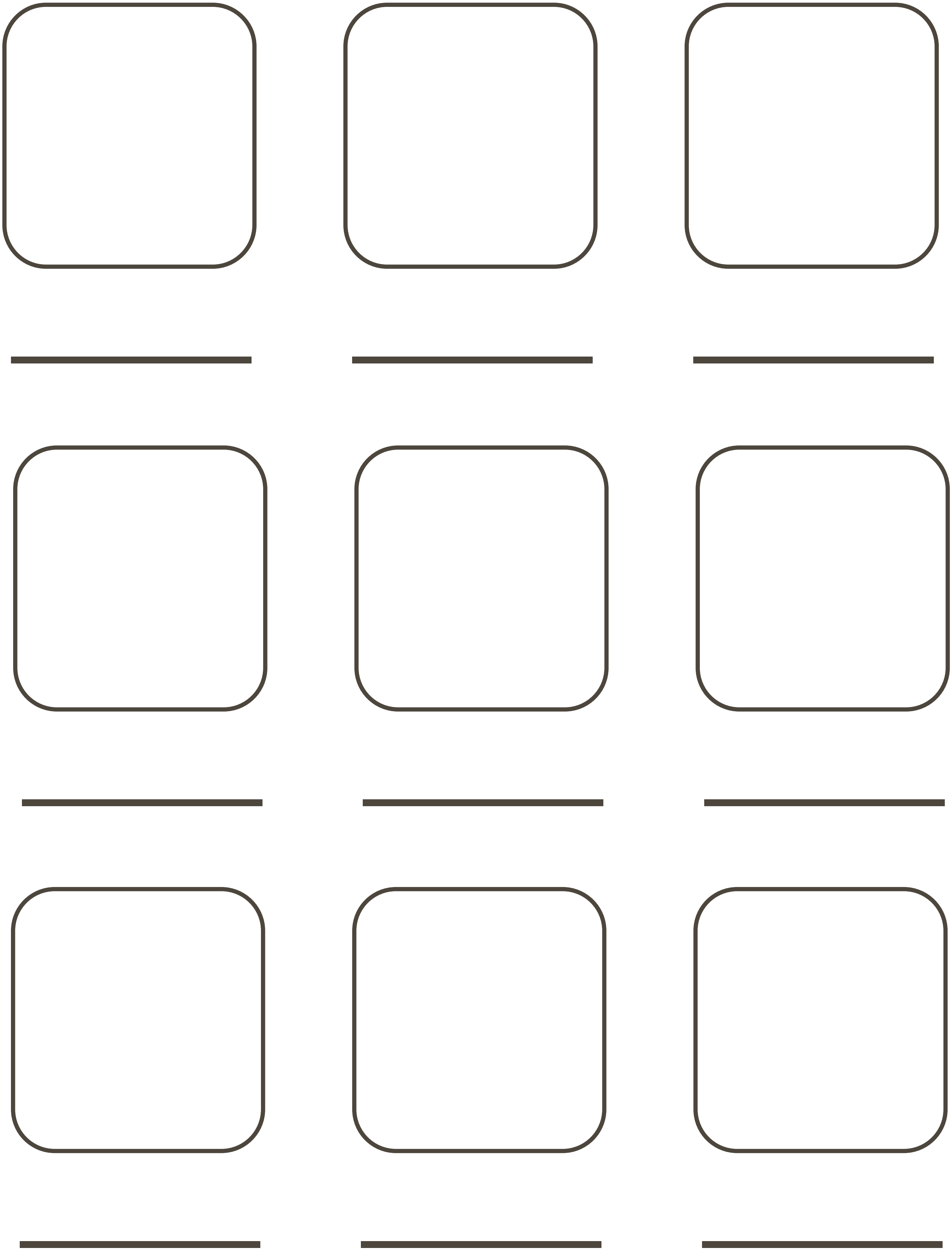
Constraint



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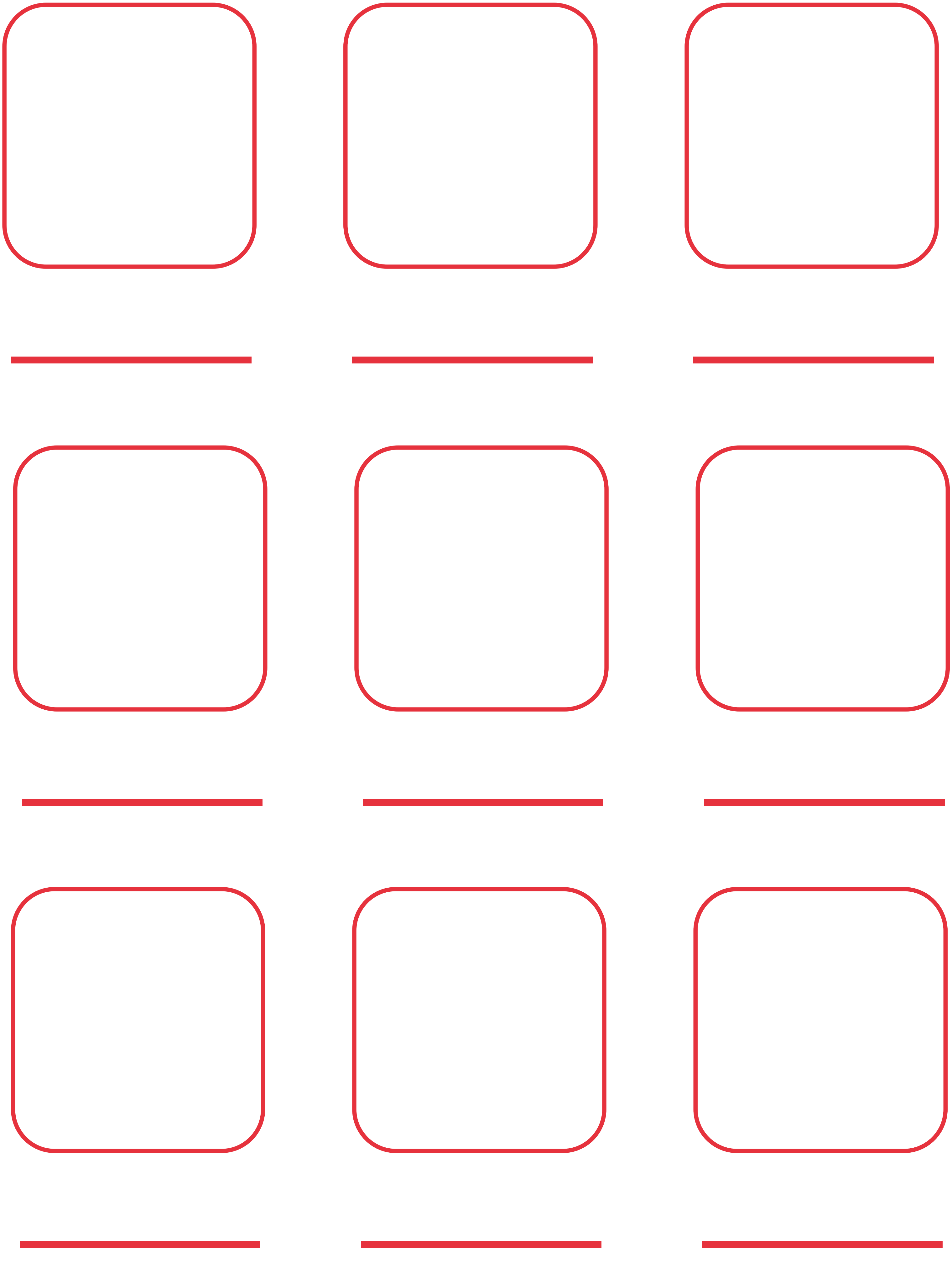

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User

FACILITATION GUIDE

Save the Day

Description: Students play a card game to generate ideas for creative designs that will help different people and animals in various disaster scenarios.

Promoting collaboration and organization

- Encourage collaboration through communication with teammates and other groups.
- Suggest that students use drawings with labels or physical demonstrations using building materials to communicate their ideas clearly.
- Encourage students to think big and use their imaginations. These are extraordinary situations they are designing for!
- Point out how students are following the engineering design process.
- Have each student build a different part of the design

Encouraging iteration

- Challenge students to dream up the ultimate invention to solving their problem, as presented by their set of cards:
  - "What does this part do?"
  - "How does this [object] help the [user] in the [disaster]?"
  - "How does the [user] hold/wear/use your invention?"
  - "What can you do to adapt your invention to meet the new constraint?"

Helping those who are stuck

- Give each student on the team an opportunity to share his or her thoughts and ideas regarding the design. Leading questions may include:
  - What objects fit in this category?
  - What problems will come up in this disaster?
  - What do we know about this user?
  - How will this disaster affect this user?
  - Will this user need any special adaptations to use this object?

Real-world applications

- "Can you think of any specialized tools you would like to have around to stay safe in a natural disaster and protect your house?"
- People can get really creative when designing objects to protect people in natural disasters.
  - An inventor in China named Wang Wenxi has designed a bed that drops you and your mattress into a re-enforced box full of supplies if it senses an earthquake.
  - A company named MPowered designed the Luci Light to help people affected by disasters and people living in places without electricity. It is solar-powered and inflatable.

Shake, Don't Break

Program Type: Classroom Program	**Audience Type:** Grades 3–8

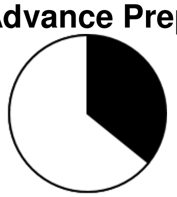
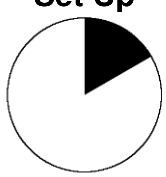
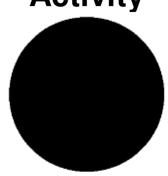
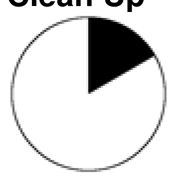
Description: Students will determine the effectiveness of various materials at isolating the base of a structure during a simulated earthquake.

LEARNING OBJECTIVES

For Next Generation Science Standards alignment, see end of outline.

- Students will apply what they learn about real-life base isolation systems as they construct two different building models
- Students will use the design process to improve their model by experimenting with various materials
- Students will quantify, record, and find patterns in the data generated by the testing of their models

TIME REQUIRED

Advance Prep	Set Up	Activity	Clean Up
			
5-20 minutes	10 minutes	60 minutes	10 minutes

SITE REQUIREMENTS

- Table space for each group of 3–5 students
- A shake table 2-3 feet wide (see the Advanced Preparation section for an alternative to a museum shake table)

PROGRAM FORMAT

Segment	Format	Time
Introduction	Large group discussion	10 min
Paper Tower Testing	Group activity	30 min
Dollhouse Testing	Group activity	15 min
Wrap-Up	Large group discussion	5 min

SUPPLIES

Permanent Supplies	Amount	Notes
Shake table	1	If you do not have access to a shake table exhibit, you can create one using the instructions in the advanced preparation section.
Projector, screen, and computer	1	*(Optional)*
Cookie sheets or cafeteria trays	1/group	
Paper reams	3/group	
Dollhouse w/ furniture and people figurines	1	*(Optional)* To use with shake table exhibit or DIY shake table. Can be store-bought or made out of cardboard (if cardboard, add weight to the bottom using paper reams or similar).
Shallow, rectangular bin	1	*(Optional)* Must fit the base of the dollhouse with at least 2” extra on each side.
Magnets	5–10 /group	*(Optional)* Use if using metal tray
Craft wax sticks	20–30 /group	Such as Wikki Stix
Paper cups	4/group	To contain Testing Materials
Cardboard tubes	4/group	To contain Testing Materials
Sticky Tack	1 pack /group	
Wine corks	15–30 /group	**Testing Materials** These supplies can be replaced by similar ones. You will need at least two testing materials for every group. Make sure your chosen materials vary in shape and size (i.e., provide large round objects, small round objects, non-round objects, soft objects, and hard objects).
Small round objects (Ex: bouncy balls)	15–30 /group	
Medium round objects (Ex: Golf balls)	15–30 /group	
Large round objects (Ex: Tennis balls)	15–30 /group	
Cotton balls	30+/group	
Marbles	50+/group	
Beads	300+/group	
Scissors	1/group	

ADVANCE PREPARATION

To set up the final activity, place the furniture and people in the dollhouse. If possible, hang something from the ceiling of the dollhouse to watch during the earthquake.

Shake Table – If you will be using a doll house and do not have access to a shake table exhibit, create your own with these instructions:

DIY Shake Table	Amount	Notes
PVC pipes (at least 2'' in diameter)	2	Any cylindrical objects work as long as they are roughly the same diameter. You can use rolls of butcher paper or full paper towel rolls, taped to keep them from unraveling
Pegboard or plywood	2	Approximately 1.5' x 1.5'. Both pieces must be of equal size and strong enough to hold 3 reams of paper without bending.
Thick rubber bands	4	When flat, rubber bands must be approximately the diameter of the PVC pipe tube. All four rubber bands must be the same size.
Zip ties	8	
Scissors	1	

Procedure:

1. If using plywood, stack the two pieces on top of each other and drill a hole in the corner of each board. The sturdier the material of the boards, the more use you will get out of your shake table. For pegboards, just stack the two pieces and line them up so the corner holes match up.
2. Take the two cylindrical objects and place them between the boards. Line them up so they are parallel to one another (see Figure 2).
3. Use a zip tie to attach a rubber band to the corner of the top board, and another tie to attach the other end of the rubber band to the bottom board. The rubber bands should be taut, but not stretched, when in a resting position. If they are too long, consider folding the rubber bands in half or finding larger cylindrical objects. Clip the ends of the zip ties to avoid injuries. Repeat on all four corners (see Figure 1).

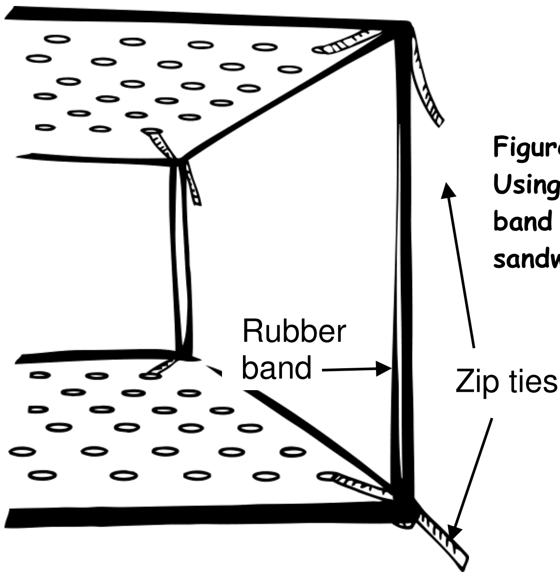


Figure 1: Zip ties and rubber bands. Using zip ties, attach each rubber band to the corners of the sandwiched pegboards,

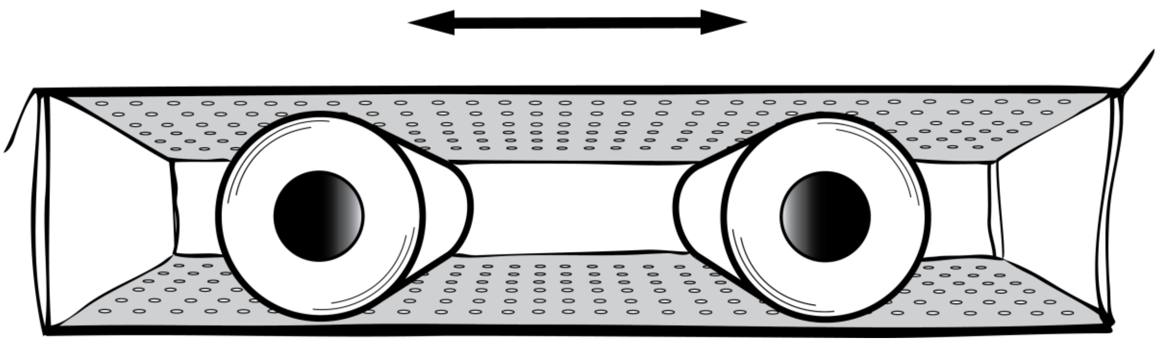


Figure 2: DIY Shake Platform. To shake, simply pull back on the top board like a slingshot. We recommend pulling about 5 inches, but make sure you don't pull too hard and snap the bands.

For an idea on how to build a high-tech shake table, check out:
Kiwiko - "Make an Earthquake Shake Table" https://youtu.be/6HgxiYBkh3U
(Duration 3:29)

SET UP

- Separate each type of testing material into its own container
- Place materials in a central area for easy access
- Set up one cookie sheet or tray at each table with three reams of paper stacked on top (see Figure 3)

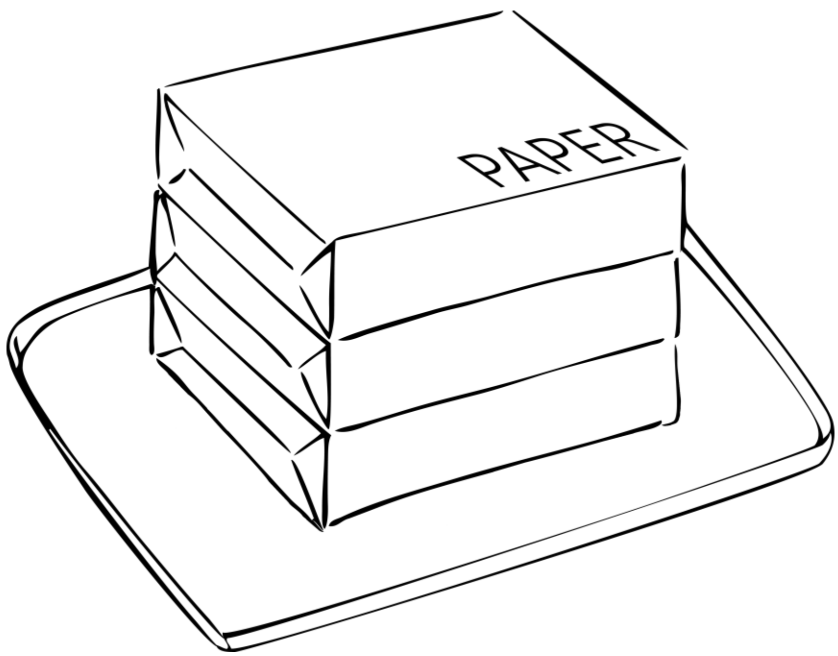


Figure 3: Paper tower set up.

INTRODUCTION

10 minutes

Let students speculate before offering answers to any questions. The answers given are provided primarily for the instructor's benefit.

Suggested script is shaded. Important points or questions are in **bold**. Possible answers are shown in *italics*.

What are some things people need to worry about during and after earthquakes?
Buildings collapsing, bridges/roads breaking, tsunamis, water supply contamination.

Think about the effect of earthquakes on houses and other buildings. In a big earthquake, the ground will shake and ripple in waves. That is bad news for buildings connected to the ground through their foundations – usually a big block of concrete poured under the base of a building that is firmly attached to the frame (think "skeleton") that holds the walls, roof, and everything else.

What happens to the house when this big block of concrete starts shaking and rippling?
The house walls crack, windows break, things fall off walls and shelves, etc.

If you have a projector and internet access, show one of the following videos to introduce the topic:

Wired Science 8 - "High Tech Quake Survival" (2008)
http://youtu.be/Il1M8o0BHPc
(Duration 4:05)

Seeker – "How We Design Buildings to Survive Earthquakes" (2016)
https://youtu.be/c4fKBGsllZI
(Duration 3:58)

One way engineers can protect buildings is to use base isolation. Base isolation means separating the base of the building from the ground so that the building can remain in place while the ground moves back and forth underneath it. This helps protect the structure from major damage or collapse during an earthquake.

Today we are going to use what we know about base isolation to design and test different ways to make buildings safer during earthquakes.

GROUP ACTIVITY

Paper Tower Testing

35 minutes

First demonstrate how the students will be testing their structures and what they are looking to prevent. Shake the cookie sheet with the paper reams for 10 seconds.

These three reams of paper represent a three-story building. Notice when I shake the cookie sheet (the foundation) they quickly separate and fall off. The challenge today is to invent a way to isolate the base of your three-story building so it can survive the earthquake.

Demonstrate how the tower moves when there are bouncy balls underneath it to show successful base isolation.

How can we decide if our design worked? *The paper reams stayed stacked, they did not wobble as much during the shaking, etc.*

While you are testing, record your results on the data sheet. You can rate the different materials you tried based on how much the building separated or fell apart while shaking.

Divide students into groups of 3–5.

Round 1:

For the first round, each group must choose **one** material box at a time to test as a base isolator (e.g., just tennis balls, just marbles, or just wine corks). See Figure 4. Instruct them to return materials to the center area as they finish testing each one so that other groups can try them out. Each group must only have **one** supply box at their table at a time.

Remind the students to make sure the paper is neatly stacked before testing and to shake for a full 10 seconds to obtain the best data.

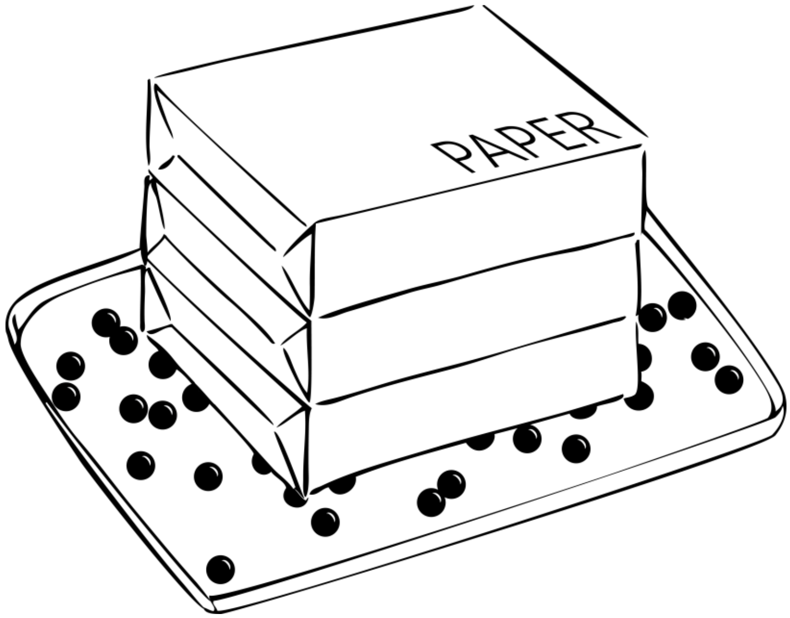


Figure 4: Paper tower testing example.
This model includes marbles as a base isolation method.

Once students have had a chance to try each material separately, lead discussion on what worked or what didn't work as well. Use the worksheet as a guide for the discussion.

Round 2:

Now, you will take what you learned about each material and begin to get creative! You will be able to test combinations of each material to find the most effective way to protect the building. There is one catch: You will have fewer numbers of each item. How will you keep the testing material in the right spot underneath the tower? I will pass out some additional supplies so that you can improve on your creations.

Pass out the additional materials (sticky tack, paper cups, scissors, craft wax sticks, cardboard tubes, and/or magnets). Groups may have a difficult time keeping the testing materials from scattering out from underneath the paper reams while testing. The paper cups, cardboard tubes, or craft wax sticks are helpful for containing the objects so they don't roll away (see Figure 5). Allow the students to cut their containers to whatever size they think is necessary. Sticky tack or magnets will add traction to keep the containers from moving away with the testing material.

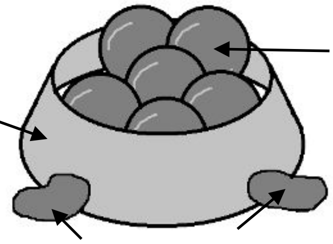


Figure 5: Marbles held in place using a modified paper cup.

Depending on the group, you may present various challenges: limit the number of materials they can use, shake the tray in more than one direction, shake intermittently to replicate aftershocks, etc.

What is happening? Does the paper tower move differently with different-sized balls? What happens when you use a cylindrical object instead of a sphere? How does the paper stack move differently when there are more or fewer objects in the tray? What happens if you mix and match? Did the tower fall off the shake table completely even though the stack stayed together?

GROUP ACTIVITY

Dollhouse Testing (Optional)

15 minutes

A building is not just the outside structure. Think about what you see in the building you are in (other people, furniture, hanging ceiling lamps, etc.). What happens to the interior of a building when an earthquake hits?

For this round, you will work in your group to discuss what objects worked best as base isolators. We will pick our top three and see if they work in making an earthquake-safe base isolation method for this miniature house. There are objects inside, and we will take note of how much everything moves around. The catch is you only get one try.

Show the students the dollhouse so they know what size it is. Ask each group which base isolators worked best in the previous activity, and choose your top three (or more, depending on time) as a class.

What will you have to consider as you plan?
House is larger, so you can't stack balls under entire base. Heavier, etc.

When the groups are finished, have a final showcase to test all of the designs. Before testing, let each group point out the notable aspects of their designs to the rest of the class.

When students are ready, put the dollhouse on the shake table and test each group's design, resetting the objects inside the house every time.

What happened to the house? Did the house stay on the table? Did anyone fall down or fall completely out of the house? What stayed put? What fell over? What sort of base worked best?

Would it be different if your house were built on a slope or on a hill?

What happens when buildings are near each other?

WRAP-UP

5 minutes

From this activity, we learned that just by adding something to separate the building and the ground we could make a building safer during an earthquake. No matter what type of base isolation we used, the building still moved a little during the earthquake. However, we were able to notice big differences in having a fixed versus an isolated base.

If time allows, you can show one of the other videos from the introduction if you were not able to do so at the beginning.

CLEAN UP

10 minutes

- Have students sort the materials and put them back in their separate bins

BACKGROUND INFORMATION

During an earthquake, intense ground shaking causes buildings to sway and vibrate, resulting in structural damage. A powerful earthquake may result in the complete collapse of buildings, bridges, and other structures—resulting in billions of dollars of losses, not to mention human death and injury.

Engineers are trying to find different ways to make buildings more earthquake safe, especially in urban areas near fault lines. One technique is base isolation. In a base-isolated building, rollers, sliders, elastic feet, or other elements physically separate the foundation of a building from the main structure. In the event of a quake, the base of the building can roll or slide back and forth, but the primary structure doesn't sway or bend. This technology dramatically reduces the amount of structural damage a building suffers during an earthquake (see Figure 6).

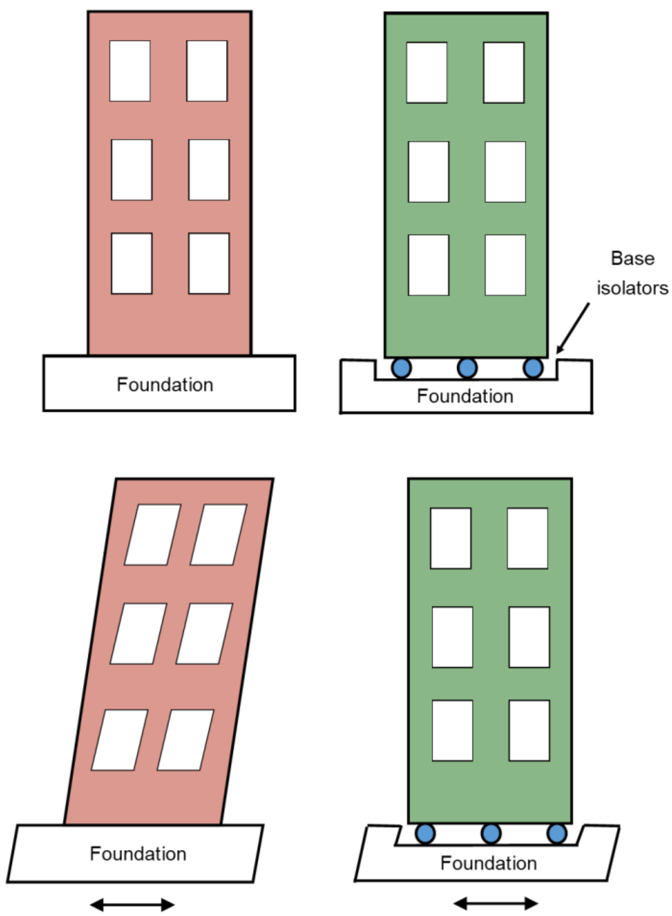


Figure 6: Simplified diagram illustrating base isolation in buidlings.

Figure 7 shows an aerial view of Apple Park, corporate headquarters of Apple Inc. in Cupertino, CA. This seven-story, ring-shaped building sits atop 700 base isolators. For more information on Apple Park and other base-isolated buildings around the world, see:

Lewis, Scott. "The 10 Largest Base-Isolated Buildings in the World." *Engineering News-Record,* 2017, www.enr.com/articles/42366-the-10-largest-base-isolated-buildings-in-the-world.

Figure 7: Aerial view of Apple Park, corporate headquarters of Apple Inc. (Image: Michael Estigoy, www.flickr.com).

For more information on engineering earthquake-proof buildings, see:

Wired Science 8 - "High Tech Quake Survival" (2008)
http://youtu.be/Il1M8o0BHPc
(Duration 4:05)

Seeker – "How We Design Buildings to Survive Earthquakes" (2016)
https://youtu.be/c4fKBGsllZI
(Duration 3:58)

GLOSSARY

Base isolation	Separating the base of a building from the ground to protect the structure from major damage or collapse during an earthquake.
Fault line	A fracture in one of the Earth's tectonic plates.
Tectonic plates	Sections of the Earth's crust that move and whose interactions cause earthquakes, volcanoes, and mountains.
Aftershocks	The series of earthquakes that come after a seismic event. The number of aftershocks and their duration depends on the magnitude of the initial earthquake, but they usually decrease in magnitude over time.

NEXT GENERATION SCIENCE STANDARDS

	Practices
✓	Asking questions and defining problems
✓	Developing and using models
✓	Planning and carrying out investigations
	Analyzing and interpreting data
	Using mathematics and computational thinking
✓	Constructing explanations and designing solutions
	Engaging in argument from evidence
✓	Obtaining, evaluating, and communicating information

	Crosscutting Concepts
✓	Patterns
✓	Cause and effect
	Scale, proportion, and quantity
✓	Systems and system models
	Energy and matter
✓	Structure and function
	Stability and change

	Disciplinary Core Idea	3	4	5	MS
	Physical Science				
PS1	Matter and Its Interaction	n/a	n/a		
PS2	Motion and Stability: Forces and Interactions		n/a		
PS3	Energy	n/a			
PS4	Waves and Their Applications in Technologies for Information Transfer	n/a		n/a	
	Life Science				
LS1	From molecules to organisms: Structures and processes				

LS2	Ecosystems: Interactions, Energy, and Dynamics		n/a		
LS3	Heredity: Inheritance and Variation of Traits		n/a	n/a	
LS4	Biological Evolution: Unity and Diversity		n/a	n/a	
Earth & Space Science					
ESS1	Earth's Place in the Universe	n/a			
ESS2	Earth's Systems				
ESS3	Earth and Human Activity	✓			
Engineering, Technology, and Applications of Science					
ETS1	Engineering Design	✓	✓	✓	✓

DCI Grade Band Endpoints

3-5 ETS1.A: Defining and Delimiting Engineering Problems

- Possible solutions to a problem are limited by available materials and resources (constraints). The success of a designed solution is determined by considering the desired features of a solution (criteria). Different proposals for solutions can be compared on the basis of how well each one meets the specified criteria for success or how well each takes the constraints into account. (By the end of Grade 5)

3-5 ETS1.B: Developing Possible Solutions

- Research on a problem should be carried out before beginning to design a solution. Testing a solution involves investigating how well it performs under a range of likely conditions. (By the end of Grade 5)
- At whatever stage, communicating with peers about proposed solutions is an important part of the design process, and shared ideas can lead to improved designs. (By the end of Grade 5)
- Tests are often designed to identify failure points or difficulties, which suggest the elements of the design that need to be improved. (By the end of Grade 5)

3-5 ETS1.C: Optimizing the Design Solution

- Different solutions need to be tested in order to determine which of them best solves the problem, given the criteria and the constraints. (By the end of Grade 5)

MS ETS1.A: Defining and Delimiting Engineering Problems

- The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that are likely to limit possible solutions. (By the end of Grade 8)

MS ETS1.B: Developing Possible Solutions

- A solution needs to be tested, and then modified on the basis of the test results, in order to improve it. (By the end of Grade 8)
- There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. (By the end of Grade 8)
- Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors. (By the end of Grade 8)
- Models of all kinds are important for testing solutions. (By the end of Grade 8)

MS ETS1.C: Optimizing the Design Solution

- Although one design may not perform the best across all tests, identifying the characteristics of the design that performed the best in each test can provide useful information for the redesign process—that is, some of those characteristics may be incorporated into the new design. (By the end of Grade 8)
- The iterative process of testing the most promising solutions and modifying what is proposed on the basis of the test results leads to greater refinement and ultimately to an optimal solution. (By the end of Grade 8)

3-5 ESS3.C: Human Impacts on Earth Systems

- Human activities in agriculture, industry, and everyday life have had major effects on the land, vegetation, streams, ocean, air, and even outer space. But individuals and communities are doing things to help protect Earth's resources and environments. For example, they are treating sewage, reducing the amounts of materials they use, and regulating sources of pollution such as emissions from factories and power plants or the runoff from agricultural activities. (By the end of Grade 5)

Performance Expectations

3-5-ETS1-1	Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.
3-5-ETS1-2	Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.
3-5-ETS1-3	Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.
MS-ETS1-1	Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.
MS-ETS1-2	Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.
5-ESS3-1	Obtain and combine information about ways individual communities use science ideas to protect the Earth's resources and environment.

Shake, Don't Break
Appendix

Names: ____

Shake, Don't Break Data Sheet

Instructions: How well did the materials separate, or isolate, the base from the building and prevent the paper reams from separating and falling? Fill out the chart, rating each testing material by circling a number on the scale from 1 to 10. Use the pointers below as your guidelines.

1: All three paper reams collapsed immediately
3: Most reams fell after the shaking began
5: The reams started separating and falling after a few seconds of shaking
7: The paper reams separated some, but stayed mostly in place
10: The paper reams stayed stacked neatly on top of one another

Testing Material	Effectiveness
	1 2 3 4 5 6 7 8 9 10
	1 2 3 4 5 6 7 8 9 10
	1 2 3 4 5 6 7 8 9 10
	1 2 3 4 5 6 7 8 9 10
	1 2 3 4 5 6 7 8 9 10
	1 2 3 4 5 6 7 8 9 10

Nombres: ____

Hoja de información
Shake, Don't Break (Sacúdete, no te rompas)

Instrucciones: ¿Qué tan exitosos fueron los materiales en separar (aislar) la base del edificio y prevenir que se cayeran las resmas de papel? Llena la tabla, calificando cada material en la escala del 1 al 10. Utiliza los indicadores a continuación como referencia.

1: Las tres resmas de papel se cayeron inmediatamente
3: La mayoría de las resmas se cayeron cuando empezó el movimiento
5: Las resmas comenzaron a separarse y caerse unos segundos después que empezó el movimiento
7: Las resmas se separaron un poco, pero por la mayor parte quedaron igual
10: Las resmas quedaron bien apiladas una encima de la otra

Material de prueba	Eficacia									
	1	2	3	4	5	6	7	8	9	10
	1	2	3	4	5	6	7	8	9	10
	1	2	3	4	5	6	7	8	9	10
	1	2	3	4	5	6	7	8	9	10
	1	2	3	4	5	6	7	8	9	10
	1	2	3	4	5	6	7	8	9	10

FACILITATION GUIDE

Shake, Don’t Break

Description: Students will determine the effectiveness of various materials at isolating the base of a structure during a simulated earthquake.

Promoting collaboration and organization

- Have students take turns choosing a material, shaking the tray, and rating the material.
- Students should discuss with their teammates why they think these materials worked well or why they failed.
- Facilitate a conversation about working together and combining different materials for each base isolation technique.

Encouraging iteration

- Encourage students to find different materials they can combine to improve their original designs.
- Ask students why certain materials seem to work better at base isolation than others. Discuss shape, size, material composition, etc.
- To extend the challenge, ask:
  - *“Is there a way to keep the building in the center of the cookie sheet?”*
  - *“What if there’s an aftershock? Shake it again and see if it still stands.”*
  - *“Can you use fewer materials?”*
  - *“How high can you get the building off the ground and still make it safe? How low? Which one do you think is safer for the people inside?”*

Helping those who are stuck

- Ask some leading questions to build curiosity and confidence to try again:
  - *“What shape do you think would be the best base isolator?”*
  - *“What materials have you not tried yet?”*
  - *“Try combining round materials with non-round ones.”*
  - *“Pause after putting your building on the shake table to test. Do you have to spend time balancing the building just right? If so, maybe it’s a sign it is unstable to start with.”*
  - *“Are the materials shifting to one spot? What does that do to the building?”*
  - *“How can you keep the building balanced?”*
  - *“Is there a way to keep the testing materials in the corners of the building?”*

Real-world applications

- Relate the testing materials to real-life building/engineering tools and materials.
- A commonly used base isolation is lead rubber bearings (LRBs), which are a combination of lead, rubber, and steel. This base isolation was developed in the early 1970s.
- Extremely strong magnets can be used to levitate buildings just enough so there is a separation between the base of the building and the foundation. This prevents the building from shaking during an earthquake.

Smooth Travels

Program Type: Classroom Program	**Audience Type:** Grades 3–8

Description: Students design an accessible path that will allow for the slowest, safest route possible down a mountain.

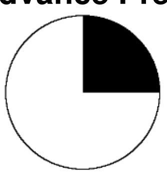
LEARNING OBJECTIVES

For Next Generation Science Standards alignment, see end of outline.

- Students will design a ramp to decrease the speed of a rolling object
- Students will test and improve their design route to achieve the slowest speed possible

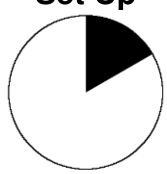
TIME REQUIRED

Advance Prep



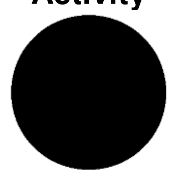
15 minutes

Set Up



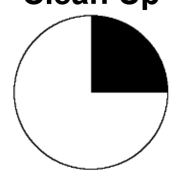
10 minutes

Activity



60 minutes

Clean Up



15 minutes

SITE REQUIREMENTS

- Standard size classroom
- Tables or grouped desks with chairs for each student, or a large floor space with room for all students to sit and work in groups of 3–4

PROGRAM FORMAT

Segment	Format	Time
Introduction	Large group discussion	10 min
Design, Test, Improve	Group activity	45 min
Wrap-Up	Large group discussion	5 min

SUPPLIES

Supplies	Amount	Notes
Choose a base: pegboard, foam board, or cardboard 24"x18" or larger	1/group	Pegboard can be found at hardware stores and cut to size **See "Note on Supplies" below*
Materials to secure ramp to about a 60^{o} angle from the table or floor (see diagram in "Set Up")		Wooden blocks and/or books can be used to prop up pegboard
String	8 ft./group	For prototyping paths
Scissors	1/group	
Container	1/group	For holding building supplies
Small bouncy ball	1/group	
Small paper viewpoint signs	1/group	*(Optional)* See *Advance Prep* and *Appendix*
Photos of switchbacks		Photos in *Background Information* section
Stopwatch	1/group	*(Optional)* For Extension activity
Blank paper or notebook	1/group	*(Optional)* For Extension activity. To record times for different iterations
Ping pong balls	1/group	*(Optional)* For Extension activity
Marbles	1/group	*(Optional)* For Extension activity
Golf balls	1/group	*(Optional)* For Extension activity

Note on Supplies: The supplies for the base are flexible. If the activity will be done often with multiple groups, using pegboard as a base is recommended. If this activity is used less frequently, cardboard or foam board is cheaper. If using pegboard, you will find large 4'x8' sheets at your local hardware store. Often, store employees are able to cut it on-site. To make things easy, cut the sheet once the long way, to make two long strips, each 24" wide. Then cut each strip into five pieces approximately 19" wide, for a total of 10 pieces. **You can reuse the same pieces of pegboard for Energetic Ocean, another engineering activity in the Designing Our World curriculum.**

Suggested Building Materials:
Common classroom supplies and recyclables can be used as building materials in this activity. Listed below are a few suggestions.

- Golf tees
- Wooden craft sticks
- Rubber bands
- Brads
- Rulers
- Binder clips
- K'NEX®
- Toilet paper/paper towel rolls
- Pipe cleaners
- Pencils (to poke holes)
- Twist ties
- Straws
- String or yarn
- Toothpicks
- Cardstock
- Craft foam

ADVANCE PREPARATION

- Collect all materials
- Cut pipe cleaners in half
- Cut string or yarn into 8-ft. lengths for each group
- *(Optional)* Print and cut out "Viewpoint" signs (see Appendix).

SET UP

- Assemble an assortment of ramp-building supplies in a container for each group.
- Set a ramp base at an angle of about 45-60° at each table. The exact angle is not important, but all ramps should be at the same angle. See Figure 1.
- *(Optional)* Attach one "Viewpoint" sign to the top corner of each ramp, using tape, a binder clip, or similar.

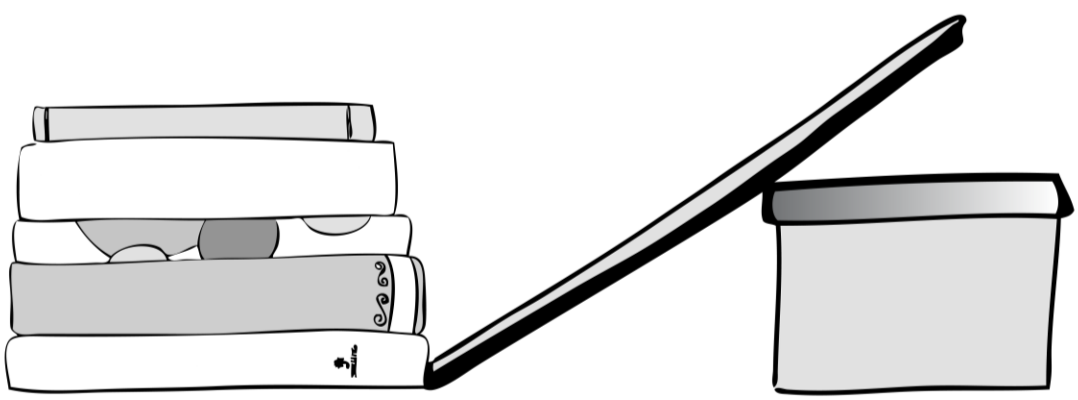


Figure 1: Ramp setup, propped up by common household items.

INTRODUCTION

10 minutes

Let students speculate before offering answers to any questions. The answers given are provided primarily for the instructor's benefit.

Ask the students the following questions in **bold**.
Suggested script is shaded. Possible answers are shown in *italics*.

Imagine a time that you went up or down a steep hill or mountain. Maybe you were riding your bike, hiking, or in a car. What did you notice about these roads or paths?

Allow students to tell some short stories about their experiences. The goal is to determine the types of roads and/or paths that engineers design to traverse steep slopes. The back and forth zigzag pattern is known as a switchback.

Why do you think steep paths are designed differently than straight, flat paths?

Facilitate a short discussion about some of the benefits of zigzags, switchbacks, or long, windy paths for going down steep inclines. The primary goal of these designs is to decrease the amount of slope, which makes climbing easier, prevents users from going too fast downwards, and prevents erosion. See the *Background Information* section in this outline for more detailed information.

Today, our engineering firm has been asked to design a safe path that people in wheelchairs can use to get to a viewpoint that only hikers can access. How would we do that? What characteristics will this path need to have?

Have students "pair-share" ideas for a minute. They may suggest lowering the inclined plane to decrease the slope. Tell them this change is not an option because it would mean tearing down the whole mountain.

GROUP ACTIVITY

Design, Test, Improve

45 minutes

Split students into groups of 3–5 and pass out the 8-ft. lengths of string or yarn to each group.

Our first step is planning! Now is the time for your group to start talking about what your ramp will look like. Use the string to plan a path down the mountain. Using more string to get from the top to the bottom means you are creating a longer path, which will be less steep for people in wheelchairs. Try out a few different paths with your group.

Give groups 3–5 minutes to experiment with the string. Encourage students to try different paths and encourage switchbacks. For groups that are struggling, suggest specific points of entry and exit on opposite sides of the base.

Pass out the building materials to each group.

Start talking with your team and come up with a plan for your wheelchair ramp to get up and down the mountain. When you've come to an agreement on the design plan, you can start building. Remember to test early and test often! The ball must roll all the way to the bottom in order for your path to work- it can't get stuck!

See Figure 2 for a visual illustration of what a ramp might look like.

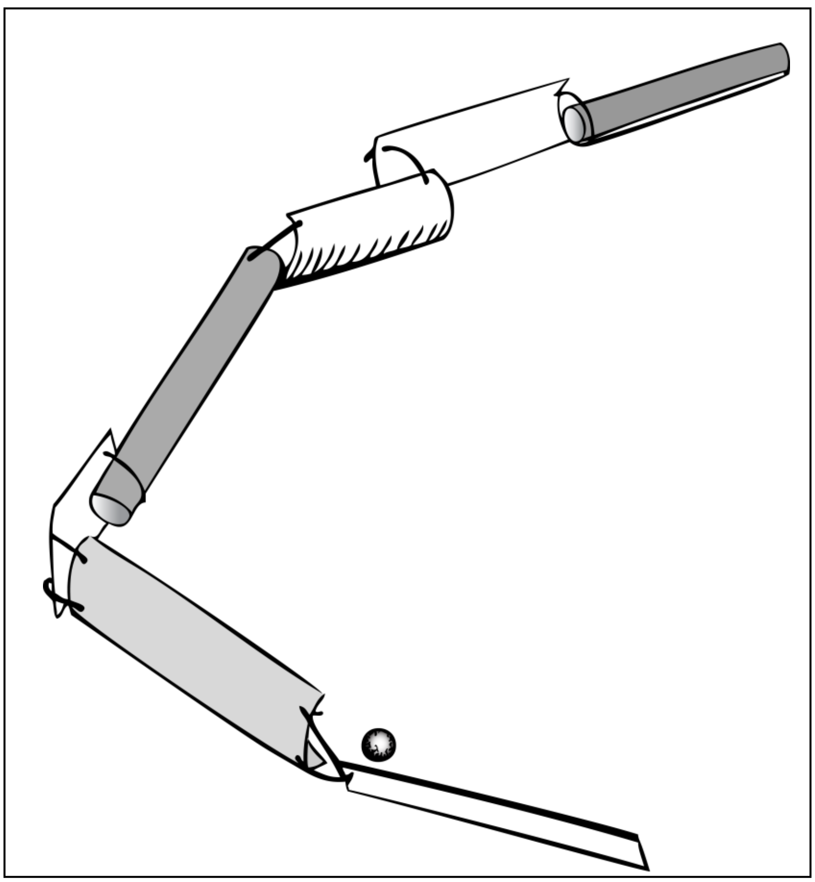


Figure 2: An example ramp.

After about 10 minutes, when groups have made ramps that are at least halfway complete, do a “hands-off” trial run (students can’t interfere with ball) with a facilitator.

You may wish to use a stopwatch to time the ball as it rolls down their path. Have students test their prototype ramps. Be consistent with the number of trials each team gets, how and where they release the ball, and when you start and stop the stopwatch.

Have all groups watch as each test occurs. Encourage struggling groups to look for ideas on how to improve their design.

If time allows, have all students watch each group’s trial runs in order to get additional ideas for their own designs. Encourage the group to discuss what they need to improve or change as they continue building. Students should aim to have many rounds of iteration, including several “hands-off” trials.

Younger or inexperienced students may need some hints on how to use the building materials to create pathways. Encourage them to think about the wheelchair-accessible ramps they have seen in malls, parks, and restaurants, to look at other groups, and to remember the path they planned with string.

WRAP-UP

5 minutes

Ask for student observations. There is no correct answer. Let students guide the discussion and present their hypotheses before discussing explanations.

Tell us about your design.
Be ready to dig deeper by asking specific questions about the number of switchbacks they created or how they decided on a specific design. Now is also a good time to talk about how the students used the materials.

What would you have done if you had more time to work on your path?
Answers will vary from adding more paths to fixing parts that didn’t work during testing. Groups testing later in the order may reference other teams’ designs. Use this opportunity to talk about how engineers share their designs.

What made your designs more or less successful?
Answers will vary depending on your class’ designs.

CLEAN UP

- Ask the groups to disassemble their design, return all usable materials to their containers, and recycle or throw away any trash

OPTIONAL EXTENSIONS

- **Measurement**
  Was the group with the longest time really the group that had the slowest ball? Maybe, but not necessarily. We did not measure the speed of the ball—just how long it could stay on the pegboard. To see which group actually had the slowest average velocity for their ball, have students measure the length of the path the ball followed on its way down the slope using strings and rulers. Divide the distance by the amount of time to determine the average velocity of their ball.

  Speed (velocity) = distance ÷ time

  For added challenge, convert to meters per second, feet per minute, miles per hour, or any other unit.

- **Multi-use**
  Add the criteria that several different types of balls must be able to travel down their designed path. Balls of the same size will be easy; balls of different sizes will be more challenging. Try adding a marble, a golf ball, or a ping-pong ball. These balls may represent different types of wheelchairs.

- **Math Extension**
  Use the pegboard to simulate a coordinate graph and have students create a map of their pathway. They can determine the slope of each pathway on the board as well. Advanced students can determine what the slope is when the board is then placed at an angle. Make a graph of the teams' times versus the length of their paths.

BACKGROUND INFORMATION

Often, engineers work to make things faster. However, there are also times when they wish to design a system that makes things move more slowly or more easily. One such situation is when designing roads to ascend and descend a steep slope. Too steep, and the road will be exhaustingly slow on the way up—and dangerously fast on the way down!

People who design roadways are typically known as civil engineers. Nearly all roadways have some degree of slope, and engineers must pay careful attention to make sure it's safe to go up and down. By creating switchback patterns, engineers decrease the slope of a roadway, making it easier to climb and safer to descend. However, civil engineers must balance cost and safety, designing their paths to be effective with the least amount of resources. Users will complain if roadways are too long and winding, slowing them down far more than necessary.

Engineers keep the same principles in mind when designing paths for wheelchair users. Buildings, parks, and other public spaces often use ramps with switchbacks to make paths and entryways accessible to all users.

Figure 3: A wheelchair-accessible trail allows all visitors to safely explore Mammoth Caves National Park in Kentucky. (Image: National Park Service).

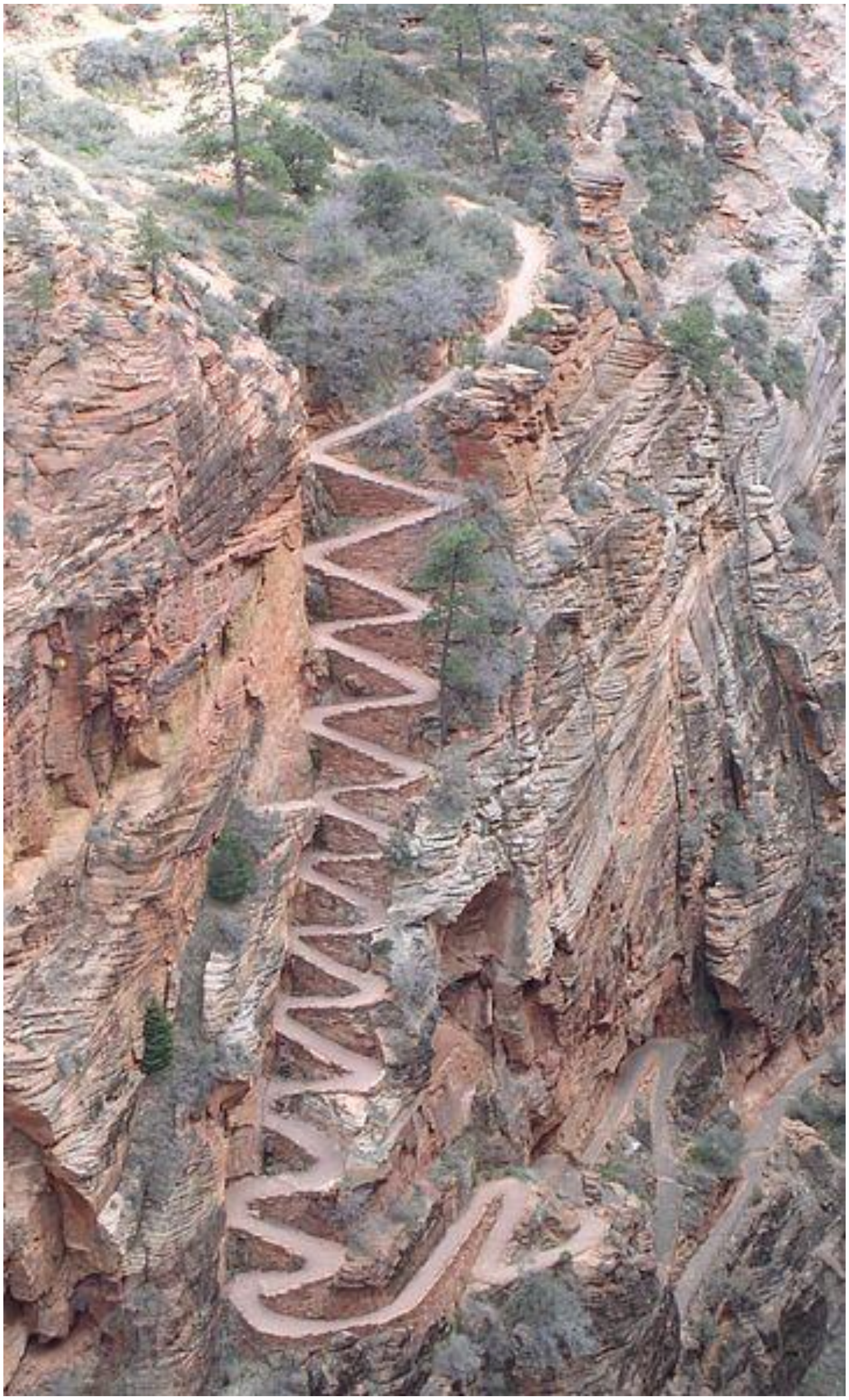


Figure 4: An impressive series of switchbacks allows hikers to safely ascend and descend a steep rock face on the West Rim Trail in Zion National Park. (Image: National Park Service).

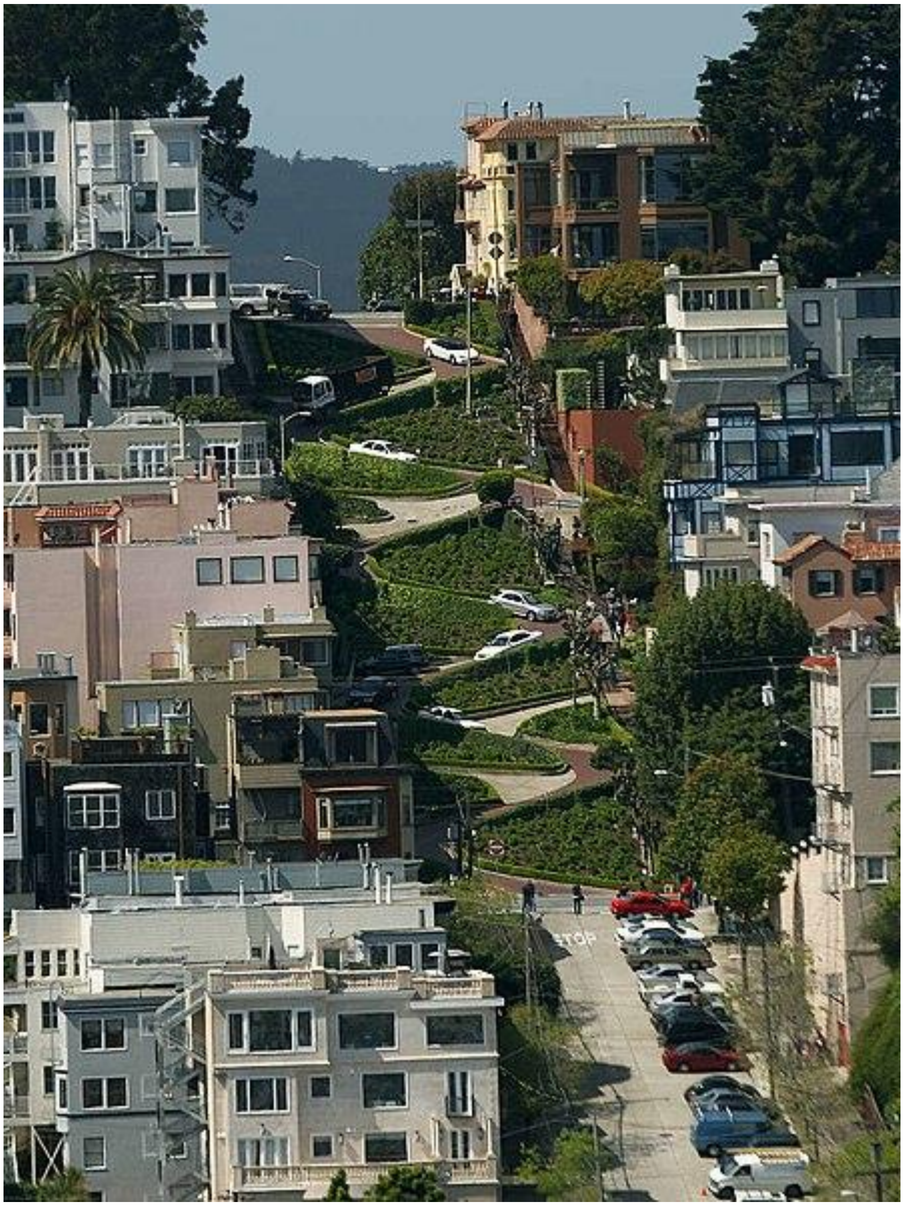


Figure 5: Lombard Street in San Francisco utilizes sharp switchbacks to make a steep hill accessible to cars. (Photo: Wikimedia Commons).

GLOSSARY

Slope	A measurement of change in height divided by distance traveled.
Switchback	A method of switching direction at certain intervals when climbing a slope to make ascension and descension safer and easier.

NEXT GENERATION SCIENCE STANDARDS

	Practices
✓	Asking questions and defining problems
✓	Developing and using models
✓	Planning and carrying out investigations
	Analyzing and interpreting data
	Using mathematics and computational thinking
✓	Constructing explanations and designing solutions
	Engaging in argument from evidence
✓	Obtaining, evaluating, and communicating information

	Crosscutting Concepts
✓	Patterns
✓	Cause and effect
	Scale, proportion, and quantity
	Systems and system models
✓	Energy and matter
	Structure and function
	Stability and change

	Disciplinary Core Idea	3	4	5	MS
	Physical Science				
PS1	Matter and Its Interaction	n/a	n/a		✓
PS2	Motion and Stability: Forces and Interactions	✓	n/a	✓	✓
PS3	Energy	n/a	✓		✓
PS4	Waves and Their Applications in Technologies for Information Transfer	n/a		n/a	
	Life Science				
LS1	From molecules to organisms: Structures and processes				
LS2	Ecosystems: Interactions, Energy, and Dynamics		n/a		
LS3	Heredity: Inheritance and Variation of Traits		n/a	n/a	
LS4	Biological Evolution: Unity and Diversity		n/a	n/a	

Earth & Space Science					
ESS1	Earth's Place in the Universe	n/a			
ESS2	Earth's Systems				
ESS3	Earth and Human Activity				
Engineering, Technology, and Applications of Science					
ETS1	Engineering Design	✓	✓	✓	✓

DCI Grade Band Endpoints

3-5 ETS1.A: Defining and Delimiting Engineering Problems

- Possible solutions to a problem are limited by available materials and resources (constraints). The success of a designed solution is determined by considering the desired features of a solution (criteria). Different proposals for solutions can be compared on the basis of how well each one meets the specified criteria for success or how well each takes the constraints into account. (By the end of Grade 5)

3-5 ETS1.B: Developing Possible Solutions

- Research on a problem should be carried out before beginning to design a solution. Testing a solution involves investigating how well it performs under a range of likely conditions. (By the end of Grade 5)
- At whatever stage, communicating with peers about proposed solutions is an important part of the design process, and shared ideas can lead to improved designs. (By the end of Grade 5)
- Tests are often designed to identify failure points or difficulties, which suggest the elements of the design that need to be improved. (By the end of Grade 5)

3-5 ETS1.C: Optimizing the Design Solution

- Different solutions need to be tested in order to determine which of them best solves the problem, given the criteria and the constraints. (By the end of Grade 5)

MS ETS1.A: Defining and Delimiting Engineering Problems

- The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that are likely to limit possible solutions. (By the end of Grade 8)

MS ETS1.B: Developing Possible Solutions

- A solution needs to be tested, and then modified on the basis of the test results, in order to improve it. (By the end of Grade 8)
- There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. (By the end of Grade 8)
- Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors. (By the end of Grade 8)
- Models of all kinds are important for testing solutions. (By the end of Grade 8)

MS ETS1.C: Optimizing the Design Solution

- Although one design may not perform the best across all tests, identifying the characteristics of the design that performed the best in each test can provide useful information for the redesign process—that is, some of those characteristics may be incorporated into the new design. (By the end of Grade 8)
- The iterative process of testing the most promising solutions and modifying what is proposed on the basis of the test results leads to greater refinement and ultimately to an optimal solution. (By the end of Grade 8)

3-5 PS2.A: Forces and Motion

- Each force acts on one particular object and has both strength and a direction. An object at rest typically has multiple forces acting on it, but they add to give zero net force on the object. Forces that do not sum to zero can cause changes in the object's speed or direction of motion. (By the end of Grade 8)
- The patterns of an object's motion in various situations can be observed and measured; when that past motion exhibits a regular pattern, future motion can be predicted from it. (Boundary: Technical terms, such as magnitude, velocity, momentum, and vector quantity, are not introduced at this level, but the concept that some quantities need both size and direction to be described is developed.) (By the end of Grade 5)

MS PS2.A: Forces and Motion

- The motion of an object is determined by the sum of the forces acting on it; if the total force on the object is not zero, its motion will change. The greater the mass of the object, the greater the force needed to achieve the same change in motion. For any given object, a larger force causes a larger change in motion. (By the end of Grade 8)

Performance Expectation

3-5-ETS1-1	Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.
3-5-ETS1-2	Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.
3-5-ETS1-3	Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.
MS-ETS1-1	Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.
MS-ETS1-2	Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.
MS-ETS1-3	Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that

	can be combined into a new solution to better meet the criteria for success.
MS-ETS1-4	Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.
3-PS2-1	Plan and conduct an investigation to provide evidence of the effects of balanced and unbalanced forces on the motion of an object.
3-PS2-2	Make observations and/or measurements of an object’s motion to provide evidence that a pattern can be used to predict future motion.
4-PS3-1	Use evidence to construct an explanation relating the speed of an object to the energy of that object.
MS-PS2-2	Plan an investigation to provide evidence that the change in an object’s motion depends on the sum of the forces on the object and the mass of the object.
MS-PS3-2	Develop a model to describe that when the arrangement of objects interacting at a distance changes, different amounts of potential energy are stored in the system.

Smooth Travels
Appendix


VIEWPOINT

VIEWPOINT

VIEWPOINT

VIEWPOINT

VIEWPOINT

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VIEWPOINT

FACILITATION GUIDE

Smooth Travels

Description: Students design an accessible path that will allow for the slowest, safest route possible down a mountain.

Promoting collaboration and organization

- During the introductory discussion, have students "pair-share" with a neighbor before the large group discussion. Doing so will ensure that all students share their ideas in some way.
- Allow each team member to use the long string to show his or her proposed plan for the path down the mountain.
- You may choose to create a "budget" for materials and give teams an allowance. This will teach students about planning wisely and reducing waste of materials.
- Consider assigning roles for collaborative groups. Possible roles can include group leader, recorder, materials manager, timekeeper, and ambassador.

Encouraging iteration

- Remind students that the "wheelchair" must go down at a slow and safe speed. Is there anything they can do to slow the ball down even more? How can you make your path even longer?
- Iteration means taking things apart sometimes! It's okay to alter parts of your ramp if your group has a better idea.
- Remind students about the purpose of this challenge: "Is your path safe and smooth for the person in the wheelchair? How can you make it more comfortable?"
- Test early and often! Encourage groups to test every few minutes to make sure their path is working.

Helping those who are stuck

- Show pictures of switchback roads and ask students about what they notice.
- Encourage students to visit each group and see if they can gather more ideas for building ramps.
- Do a test run with the group and discuss each point where the ball falls or gets stuck. Ask specific questions to work toward a solution:
  - What could you do to widen this ramp so the ball won't fall?
  - Are there other building materials that may work better/be stronger?
  - Where does the ball lose control? How can you reinforce the ramp here?

Real-world applications

- On real wheelchair ramps, engineers have to make the ramp no more than a five-degree incline so that it's safe for people in wheelchairs to go up and down. That means for every twelve inches of length the ramp can only go up one inch.
- In 2017, the project "Pompeii for All: Accessibility Paths Overcoming Architectural Barriers" was launched. This path made Pompeii, a unique World Heritage site, accessible to all visitors, and is considered to be the longest barrier-free accessible path in Italy.

Sounds of the Sea

Program Type: Classroom Program	***Audience Type:*** Grades 3–8

Description: Students will engineer carriers to hold different objects underwater at particular depths.

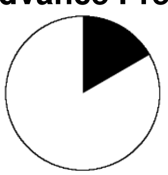
LEARNING OBJECTIVES

For Next Generation Science Standards alignment, see end of outline.

- Students will create different models to test the concept of buoyancy.
- Students will learn about engineers that study marine mammals.

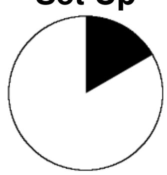
TIME REQUIRED

Advance Prep



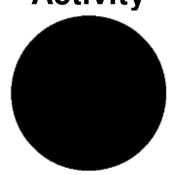
10 minutes

Set Up



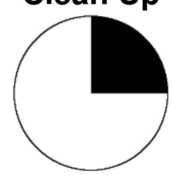
10 minutes

Activity



60 minutes

Clean Up



15 minutes

SITE REQUIREMENTS

- Table space for each group of 3–5 students
- Access to a water source
- Easy clean-up area in case of water spills (i.e., non-carpeted flooring)

PROGRAM FORMAT

Segment	Format	Time
Introduction	Large group discussion	15 min
Design, Test, Improve	Group activity	40 min
Wrap-Up	Large group discussion	5 min

SUPPLIES

Permanent Supplies	Amount	Notes
Clear container	1/group	At least 8’’ deep
Ping pong ball	1/group	Or balls of similar size and density Metal ball bearings can be found online or at hardware stores
Bouncy ball	1/group	
Large metal ball – 1” diameter	1/group	
Craft foam	1–2 sheets/group	Cut into approximately 2-inch squares
Rubber bands	8–10/group	
Craft wax sticks	5–6/group	Wikki Stix® or similar
Paper clips	10/group	
Binder clips	8/group	
Scissors	1/group	
Washers	8/group	a variety of washers between 1/4” and 1/2’’ works best
Hand towels or rags	1/group	
Interview with an Engineer printout	1/student	See the *Appendix* for the transcript. Alternatively, you can display the document using a projector and screen
Additional clear container(s)	1-3	*(Optional)* See Extension
Table salt	About ¼ cup	*(Optional)* See Extension
Ice	About ½ cup	*(Optional)* See Extension
Hot water		*(Optional)* See extension

ADVANCE PREPARATION

- Draw three marks on the side of each container: one 2” from the bottom, one 2” below where the water line will be, and one halfway in between both those lines. See diagram below.

Figure 1: Example markings on a clear container.

- Print out the Interview with an Engineer sheets (see Appendix) for students to “meet an engineer.” Alternatively, you may choose to display the document on a screen using a projector.

SET UP

- Fill each of the clear containers with water 2” above the top mark
- Each group should receive:
  - 1 ping pong ball
  - 1 bouncy ball
  - 1 ball bearing
  - 1 pair scissors
  - Variety of building materials such as:
    - 1–2 sheets craft foam
    - 8–10 rubber bands
    - 5–6 craft wax sticks
    - 8 washers
    - 10 paper clips
    - 8 mini binder clips
- Place a hand towel or rag at each table, with the container of water on top

INTRODUCTION

15 minutes

Let students speculate before offering answers to any questions. The answers given are provided primarily for the instructor's benefit.

Suggested script is shaded. Important points or questions are in **bold**. Possible answers are shown in *italics*.

Today we are going to learn about an engineer who studies the sounds in the ocean to learn about animals.

Pass out the Interview with an Engineer printout or display it using a projector and screen. You can have students take turns reading aloud. For example, have two student volunteers play the role of interviewer and interviewee, respectively, while other students read the introduction.

What does Elizabeth study? What does she do? *Elizabeth studies the sounds marine mammals make. She records the sounds and measures how many animals are in different parts of the ocean.*

How does she record these sounds? *She uses underwater robots.*

What are some challenges you think she faces in her job? *Students' answers will vary, but may include: How to design the underwater robots, how to make something electronic work underwater, how to know where to send the robots, etc.*

The biggest challenge in designing these underwater robots is engineering them so they do not float above the water or sink all the way down to the bottom of the ocean. They have to remain neutrally buoyant so they can work and record all the sounds.

Has anyone heard the word buoyant before? What do you think it means? *Answers will vary but some may be: It means to float, not sink, or be underwater.*

Buoyancy is the force that causes objects to float. If something is *positively buoyant* it floats, if it's *negatively buoyant* it sinks, and if it's *neutrally buoyant* it will neither sink nor float.

(Optional): Show video on buoyancy:

Kids Want to Know - "Buoyancy: What Makes Something Float or Sink?" (2005) https://www.youtube.com/watch?v=nMIXU97E-uQ (Duration 3:28)

GROUP ACTIVITY

Design, Test, Improve

40 minutes

If students are not already sitting in groups, divide them into groups of 3–4 students.

Today, you are going to design a case that can carry different objects ("sensors") underwater without floating to the surface or sinking to the bottom. You will be engineering a carrier for three different objects that represent the sensors: a ping pong ball, a bouncy ball, and a ball bearing.

Hold the objects up one at a time.

These objects are of slightly different size and density, so you will need to modify your design to fit each one.

In order for your design to be successful, your carrier will need to remain neutrally buoyant in between the two lines marked on the container.

Show a container and point out the lines.

You will be working in teams to engineer three different carriers, one for each round object. These are the materials you may use to build your marine sensor carriers.

Show and quickly describe the materials.

Start with your design plan for building the "robot" carrier for your ball "marine sensor." Work as a team and make sure everyone's ideas are being heard. Once you have drawn/discussed a final plan, gather your materials and begin building! Please keep any wet materials on the towel.

If groups get all three "sensors" between the lines, have them try to get it to float at exactly the middle point. You can also gently shake the container with each iteration to simulate waves and see if the object remains neutrally buoyant despite the movement.

Faster-working groups can also be challenged to design a carrier that can hold all three sensors at the same time. Or they can try testing their carrier in salt water, hot water, and/or ice water (see Extension).

WRAP-UP

5 minutes

If time allows, hold a final showcase to test all of the designs. Before testing, let each group point out the notable aspects of their designs to the rest of the class.

Test one design from each group and note what works and what could be improved.

Did the size of the sensor matter? Which sensors were easier to work with? Which ones were more difficult? Which materials were the most useful?

CLEAN UP

15 minutes

- Place all of the wet materials on the towel to dry
- To prevent mold, allow the materials to dry before returning them to storage
- Dump the water out

EXTENSION

As an optional extension, let students test their carriers in “ocean” water. Remind them that, so far, they have been testing their carriers in room-temperature fresh water, but in reality, these devices are meant to go in the ocean, which is salty.

In the front of the room, have an extra clear container filled with water. Add salt and stir until you can’t dissolve any more. Invite students to test their carriers again. Do the carriers tend to float more or sink more? What does that tell you about the density of salt water versus fresh water?

You can try the same extension with ice water and very hot water.

BACKGROUND INFORMATION

Buoyancy is an object's ability to float, and it is directly related to density. If an object is more dense than the fluid it is placed in, it will sink to the bottom. If it is less dense, it will float on the surface of the fluid. The density of water varies with salinity and temperature. Saltwater is more dense than freshwater and; therefore, an object will float in saltwater more readily than in freshwater. Likewise, cold water is more dense than warm water.

For an introductory video about buoyancy, see:

Kids Want to Know - "Buoyancy: What Makes Something Float or Sink?" (2005)
https://www.youtube.com/watch?v=nMlXU97E-uQ
(Duration 3:28)

Bioacoustics is a type of science in which researchers study the sounds organisms make and how outside sounds affect those organisms.
Marine biologists may study whale sounds to understand how those animals communicate, mate, and migrate. They also study how humanmade sounds from boats and sonar affect whales and other marine mammals.

In order to study the bioacoustics of marine animals, scientists place marine sensors underwater. To use a sensor in the ocean, researchers must submerge it in water and have it stay neutrally buoyant at a certain height—neither sinking to the ocean floor, nor floating to the surface—to collect data.

Accomplishing neutral buoyancy is a real engineering challenge! Submarines and underwater robots are designed to be able to change their density by opening and closing ballast tanks; if a tank fills with water, the submarine becomes more dense and moves downward in the water column. By expelling water from the same hatch, the submarine becomes less dense and moves upward in the water column.

Figures 2 and 3: The Hawai'i Institute of Marine Biology uses Ecological Acoustic Recorders to study coral reefs. The devices are placed at different depths, depending on the kinds of sounds they are hoping to detect. (Images: NOAA Fisheries https://www.pifsc.noaa.gov/cred/ear.php).

GLOSSARY

Buoyancy	The ability and tendency for something to float in a fluid.
Bioacoustics	The field of acoustics concerned with sounds produced by or affecting living organisms, especially as relating to communication.
Density	Weight (mass) per unit volume used as a measure of the compactness of a substance.
Neutrally buoyant	The state of not moving up or down within a fluid.

NEXT GENERATION SCIENCE STANDARDS

	Practices
✓	Asking questions and defining problems
✓	Developing and using models
	Planning and carrying out investigations
	Analyzing and interpreting data
	Using mathematics and computational thinking
✓	Constructing explanations and designing solutions
	Engaging in argument from evidence
✓	Obtaining, evaluating, and communicating information

	Crosscutting Concepts
	Patterns
✓	Cause and effect
	Scale, proportion, and quantity
✓	Systems and system models
	Energy and matter
✓	Structure and function
	Stability and change

	Disciplinary Core Idea	3	4	5	MS
	Physical Science				
PS1	Matter and Its Interaction	n/a	n/a		
PS2	Motion and Stability: Forces and Interactions		n/a		
PS3	Energy	n/a			
PS4	Waves and Their Applications in Technologies for Information Transfer	n/a		n/a	
	Life Science				
LS1	From molecules to organisms: Structures and processes				
LS2	Ecosystems: Interactions, Energy, and Dynamics		n/a		

LS3	Heredity: Inheritance and Variation of Traits		n/a	n/a	
LS4	Biological Evolution: Unity and Diversity		n/a	n/a	
Earth & Space Science					
ESS1	Earth's Place in the Universe	n/a			
ESS2	Earth's Systems				
ESS3	Earth and Human Activity				
Engineering, Technology, and Applications of Science					
ETS1	Engineering Design	✓	✓	✓	✓

<u>DCI Grade Band Endpoints</u>

3-5 ETS1.A: Defining and Delimiting Engineering Problems

- Possible solutions to a problem are limited by available materials and resources (constraints). The success of a designed solution is determined by considering the desired features of a solution (criteria). Different proposals for solutions can be compared on the basis of how well each one meets the specified criteria for success or how well each takes the constraints into account. (By the end of Grade 5)

3-5 ETS1.B: Developing Possible Solutions

- Research on a problem should be carried out before beginning to design a solution. Testing a solution involves investigating how well it performs under a range of likely conditions. (By the end of Grade 5)
- At whatever stage, communicating with peers about proposed solutions is an important part of the design process, and shared ideas can lead to improved designs. (By the end of Grade 5)
- Tests are often designed to identify failure points or difficulties, which suggest the elements of the design that need to be improved. (By the end of Grade 5)

3-5 ETS1.C: Optimizing the Design Solution

- Different solutions need to be tested in order to determine which of them best solves the problem, given the criteria and the constraints. (By the end of Grade 5)

MS ETS1.A: Defining and Delimiting Engineering Problems

- The more precisely a design task’s criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that are likely to limit possible solutions. (By the end of Grade 8)

MS ETS1.B: Developing Possible Solutions

- A solution needs to be tested, and then modified on the basis of the test results, in order to improve it. (By the end of Grade 8)

- There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. (By the end of Grade 8)
- Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors. (By the end of Grade 8)
- Models of all kinds are important for testing solutions. (By the end of Grade 8)

MS ETS1.C: Optimizing the Design Solution

- Although one design may not perform the best across all tests, identifying the characteristics of the design that performed the best in each test can provide useful information for the redesign process—that is, some of those characteristics may be incorporated into the new design. (By the end of Grade 8)
- The iterative process of testing the most promising solutions and modifying what is proposed on the basis of the test results leads to greater refinement and ultimately to an optimal solution. (By the end of Grade 8)

3-5 ESS3.C: Human Impacts on Earth Systems

- Human activities in agriculture, industry, and everyday life have had major effects on the land, vegetation, streams, ocean, air, and even outer space. But individuals and communities are doing things to help protect Earth's resources and environments. For example, they are treating sewage, reducing the amounts of materials they use, and regulating sources of pollution such as emissions from factories and power plants or the runoff from agricultural activities. (By the end of Grade 5)

Performance Expectations

3-5-ETS1-1	Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.
3-5-ETS1-2	Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.
3-5-ETS1-3	Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.
MS-ETS1-1	Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.
MS-ETS1-2	Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.
5-ESS3-1	Obtain and combine information about ways individual communities use science ideas to protect the Earth's resources and environment.

Sounds of the Sea
Appendix

Inspiration from the Ocean Sound

Interview with an Engineer

By Raquel Stewart

Elizabeth Küsel at work with her underwater robot.

Elizabeth Küsel, originally from Brazil, is an engineer with a background in oceanography and mathematics. She designed a robot that goes underwater and records whale and dolphin sounds, and with those sounds and some math she is able to figure out how many of those animals live in certain parts of the ocean.

We asked Elizabeth some questions so we could give you a glimpse into the life of this engineer.

Do you remember when you first learned about engineering? How did it make you feel?
In my family, my father and three uncles are all engineers in the fields of electrical, mechanical, and computer engineering. I don't think engineering was something I learned about –it was already present in my life. I always had an inquisitive mind and was drawn to science. The thing about engineering is that it gives you tools to build things and fix things.

What do you study and research?
My research focuses on developing methods to estimate whale and dolphin population density from recorded sounds they produce.

How does your work help others?
My work helps understand whale and dolphin populations and create other means of managing and studying them. It contributes to our understanding of wild animals, and how we can help their populations be and stay healthy.

Who do you look up to, in your career and in your personal life?
We meet all sorts of interesting people in our lives, and I have been trying to learn something from everyone that crosses my path.

What do you do in your free time?
I like to be active, run, hike, travel, and take pictures. Sometimes though, all I want is to watch movies or cook a good meal at home.

What is your favorite part about being an engineer?
I can build and understand the instruments I use, and because I understand how they work, I can think of ways to improve them.

What advice would you give to your younger self?
Don't be so hard on yourself.

Even though Elizabeth inherited her passion for the ocean from her father, an Officer in the Navy, she credits both her mother and her father as being big influences in her life because they always supported her decisions and endeavors.

Elizabeth encourages young students to be open to every opportunity that may arise. "Try everything you can, so you can decide what is best for the life you want." As far as what influences her own life decisions, she says, "I don't want to be like anyone else. I want to do what I like, which is study acoustics and the oceans."

Inspiración de los sonidos marinos

Entrevista con una ingeniera
Por Raquel Stewart

Elizabeth Küsel es una ingeniera brasileña con estudios en oceanografía y matemáticas. Diseñó un robot que navega bajo el agua y graba los sonidos que emiten las ballenas y los delfines. Usando esos sonidos, y algo de matemáticas, Elizabeth logra determinar cuántos de esos animales viven en ciertas partes del océano.

Entrevistamos a Elizabeth para poder darles un vistazo en la vida de esta ingeniera.

¿Te acuerdas de la primera vez que aprendiste sobre la ingeniería? ¿Cómo te sentiste?
En mi familia, mi papá y tres tíos son ingenieros eléctricos, mecánicos, e informáticos. No creo que la ingeniería haya sido algo sobre lo que aprendí –ya era parte de mi vida. Siempre tuve una mente curiosa y me atraía la ciencia. Lo que tiene la ingeniería es que te da herramientas para construir y arreglar cosas.

¿Qué estudias y en qué te especializas?
Investigo métodos para estimar la densidad demográfica de ballenas y delfines, basado en los sonidos que emiten.

¿De qué forma el trabajo que haces logra ayudar a otros?
Mi trabajo nos ayuda a entender las poblaciones de ballenas y delfines y nos ayuda a crear otros medios de estudiarlos. Mi trabajo contribuye a nuestro entendimiento de animales salvajes, y cómo podemos ayudar a esas poblaciones a mantenerse en buen estado.

¿A quién admiras, en tu vida profesional y privada?
En nuestras vidas conocemos a un sinfín de personas interesantes, y yo he estado tratando de aprender algo de cada persona que cruza mi camino.

Elizabeth Küsel trabajando con su robot marino.

¿Qué te gusta hacer en tu tiempo libre?
Me gusta mantenerme activa –correr, hacer senderismo, viajar, tomar fotos. Sin embargo, a veces lo único que quiero hacer es ver películas o cocinarme una buena comida en casa.

¿Qué es lo que más te gusta de ser ingeniera?
Puedo construir y entender los instrumentos que uso, y ya que entiendo cómo funcionan, puedo inventar maneras de mejorarlos.

¿Qué consejo te darías a ti misma cuando eras más pequeña?
No seas tan dura contigo misma.

Aunque Elizabeth heredó su pasión por el océano de su padre (era un oficial marino), ella agradece tanto a su madre como a su padre por ser grandes influencias en su vida ya que siempre apoyaron sus decisiones y proyectos.

Elizabeth anima a jóvenes estudiantes a que estén abiertos a cualquier oportunidad que pueda surgir. "Intenta todas las cosas que puedas, para que decidas qué es lo mejor para la vida que tú quieres". En cuanto a lo que influye sus propias decisiones, dice que "No quiero ser como nadie más. Quiero hacer lo que me gusta, que es estudiar la acústica y los océanos".

FACILITATION GUIDE

Sounds of the Sea

Description: Students will engineer carriers to hold different objects underwater at particular depths.

Promoting collaboration and organization

- Circulate the room as student teams are discussing and drawing their carrier. Encourage all students to provide input regarding the design plan.
- You may choose to create a "budget" for materials. Each team will have a certain allowance, which will teach students about planning wisely while reducing material waste.

Encouraging iteration

- Discuss different designs of the carriers:
    - Can you use fewer materials and achieve the same result?
    - Can the carrier be brought to the surface and dropped in the water multiple times?
    - Does it bounce and hit the bottom before settling in the middle?
    - Is there a side that is always pointed to the surface?
    - Can you devise a way to pull the carrier out of the water without dipping your hands in?
    - Can you change how high or low the carrier floats?

Helping those who are stuck

- Try putting the sensor in by itself before putting it in a carrier. Then add one material at a time to make a carrier and do a trial after each building material is added.
- Drop the building materials into the water by themselves to see if they sink or float.
- If the carrier is falling apart try securing or fastening the materials differently.
- Is the sensor completely encased? Are there water bubbles escaping as it sinks?

Real-world applications

- Marine sensors can be used to collect a variety of data. One company developed sensors called *Argo floats* that collect temperature, salinity, current velocity data, and oxygen levels. The probes go down as deep as 2 kilometers and relay data by satellite link when they surface. The data are publicly available within 24 hours.

Surgical Solutions

Program Type: Classroom Program	***Audience Type:*** Grades 3–8

Description: Students will develop, build, and test a surgical tool to use in various model medical challenges.

LEARNING OBJECTIVES

For Next Generation Science alignment, see end of outline.

- Students will use the engineering design process to design tools for performing different types of surgery.
- Students will use creative problem solving and the iterative process to improve their designs.

TIME REQUIRED

Advance Prep	Set Up	Activity	Clean Up
1 hour	**15 minutes**	**60 minutes**	**10 minutes**

SITE REQUIREMENTS

- One horizontal space (6’ × 3’) for each group. Desks can be clustered together or students can work on the floor.

PROGRAM FORMAT

Segment	Format	Time
Introduction	Large group discussion	10 min
Design, Test, Improve	Group activity	45 min
Wrap-Up	Large group discussion	5 min

SUPPLIES

Permanent Supplies	Amount	Notes
Felt fabric or butcher paper	1/group	For body cutouts, approximately 60” × 24”
Scissors	1/group	
Dominoes or blocks	Approx. 8/group	Wooden or plastic, all the same size
Pennies	2/group	
Marbles	1/group	
Metal washers	6/group	Approx.. ¾” or smaller
Toothpicks	1/group	
Popsicle sticks or dowels	1/group	
String or yarn	8”/group	
Craft foam	1–2 sheets/group	
Magnets	2/group	½” diameter or smaller
Thin plastic storage containers	3/group	1- approx. 3” × 6” × 3” 2- approx. 2” × 3” × 2” Must be thin enough to be cut using scissors and/or a razor knife
X-Acto® knife	1	Only used for advance preparation
Sticky tack	1 pack	*(Optional)* For advance preparation only
Clear disposable plastic cups	1/group	
Opaque disposable paper cup	1/group	
Surgery Design Challenge cards	1 set/group	Templates in the *Appendix*
Laminated organ images	6/group	Found in the *Appendix*
Meet a Scientist Video – Nancy Yen Shipley	1	*(Optional)* Found on USB flash drive provided with manual and website listed in *Advanced Prep*
Computer with screen and internet connection	1	*(Optional)* To show videos
Velcro	6 pieces/group	*(Optional)* To secure organs to body cut out

Suggested Building Materials	Amount
Paper clips	12/group
Wooden craft sticks	12/group
Rubber bands	12/group
Binder clips	12/group
Paper straws	4/group
Yarn	4 ft. length/group
Cardboard or Tack board	4/group
Pipe cleaners	8/group
Wooden skewers	8/group
Aluminum foil	6” × 8” sheet/group
Craft foam	5–6 sheets
Play dough	1 small piece/group
Twist ties	4/group
Magnets	1/group
Sticky tack	1 small piece/group

Note on Activity Set-Up Option: This activity can be easily adapted to “rotation stations.” If your group size is small or if you have minimal materials, this option may be a good choice. In this case, you will only need to build one of each type of model challenge (one for each station). When gathering permanent and suggested supplies from the lists above, you will need 5–6 felt or paper body outlines (one for each station) and only one set of the rest of the materials. These will then be distributed to each station rather than having all of the model challenges occurring with each group.

ADVANCE PREPARATION

Videos

- Prepare the projector and computer to show one or more of the following videos:
  - *Meet a Scientist Video – Nancy Yen Shipley* found on the USB flash drive provided with this manual (if applicable), or at https://vimeo.com/296710292/3257a06d06
  - YouTube – Michigan Engineering - “FlexDex: A Revolutionary Surgical Tool” https://www.youtube.com/watch?v=x6Wl4MFEXeY (Duration 4:40).

Body Outlines

- Trace and cut out one human body shape from each piece of felt or butcher paper (approximately 60” × 24”). You can trace a friend (or yourself) as a model for the felt cut-out.

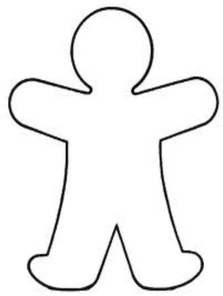


Figure 1: Shape suggestion for felt human body outline

Organ Cutouts

- Print, cut out, and laminate images of individual organs for each group. Images can be found in the *Appendix* section. Add a small piece of Velcro to the back of each laminated image to hold it in place on top of the body cut out.

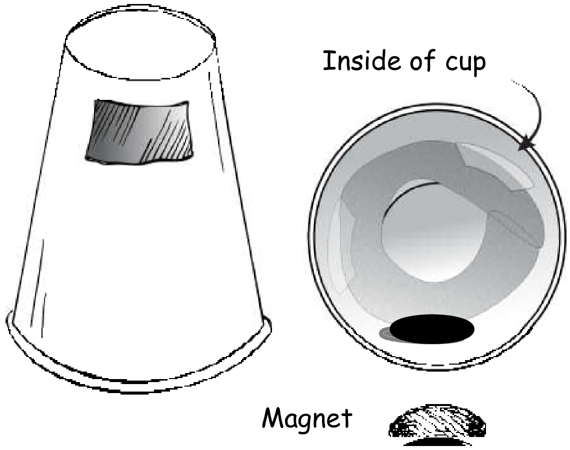
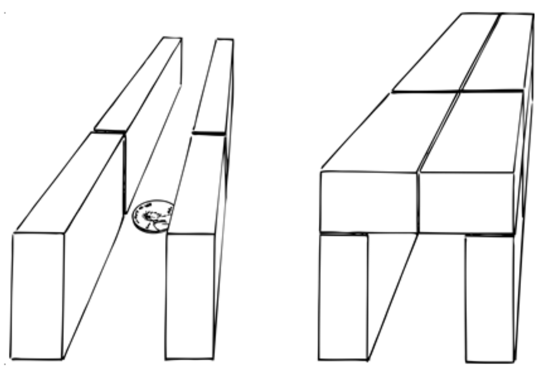
Surgery Design Challenge cards

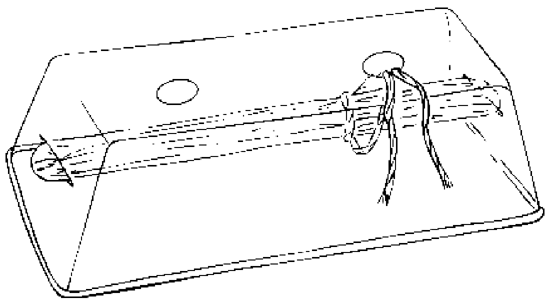
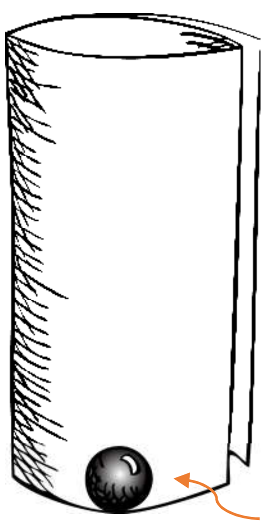
- Print and cut out a set of the Surgery Design Challenge cards for each group. Laminating the cards makes them easier to reuse.

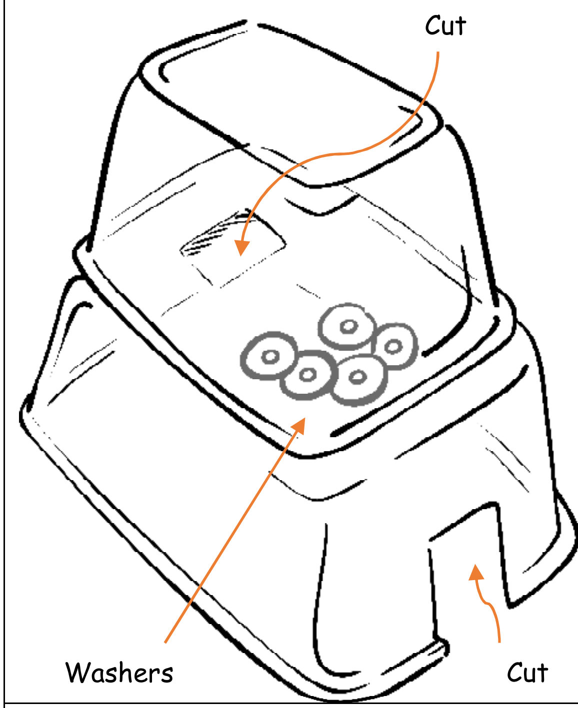
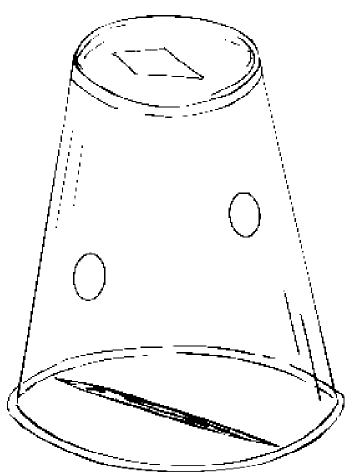
Model Surgery Challenges

- Use the table below and assemble one of each of the surgery challenges for each group. (Or, if you are doing rotation stations, assemble one challenge per station). The obstacles shown are just examples; you can alter them depending on what materials you have. Feel free to choose which ones to do, as some may be too difficult or too simple for your students.

Model Surgery Challenge	Goal and Instructions	Difficulty (out of 5)

<table>
<tr><td>Remove a Kidney Stone
</td><td>Goal: create a tool to pull the magnet out through both holes.
• Cut a hole on the side near the base of an opaque paper cup
• Cut a 1” round hole in a piece of craft foam
• Fold and insert the foam in the cup below the first hole and tape it in to make the cup opening smaller
• Place the cup over a small magnet</td><td>★★</td></tr>
<tr><td>Place a Patch on a Lung
</td><td>Goal: place a penny on top of another without disturbing the blocks.
• Place four small wooden blocks in two parallel rows
• Place a penny in the middle
• Glue together four blocks to place across the top to create a tunnel</td><td>★★</td></tr>
<tr><td>Model Surgery Challenge</td><td>Goal and Instructions</td><td>Difficulty (out of 5)</td></tr>
</table>

Model Surgery Challenge	Goal and Instructions	Difficulty (out of 5)
Tie-off an Artery in the Heart 	**Goal: tie the string in a knot around the wooden craft stick using only tools and the top two holes to reach inside.** • Cut two slits on the side of a clear rectangular container slightly shorter than a wooden craft stick • Cut two ½" holes at the base of the container • Cut a piece of string 8" long • Insert the wooden stick horizontally through the side slits and place the container face down	★★★★★ *This challenge is particularly difficult. Consider saving it as a bonus!*
Remove a Brain Tumor  	**Goal: remove the marble without knocking the tube over.** • Roll a tube of craft foam 6" tall and 1 ½" in diameter and seal it with hot glue (alternatively, you may use a paper towel tube) • Balance the tube vertically so there is only one opening facing up and place a marble inside	★★★

Remove Objects from Stomach 	**Goal: build a tool that can remove the washers through both holes without lifting the plastic containers.** • Stack a smaller rectangular plastic container on top of a larger rectangular one. Glue the rim of the small one to the base of the large one • Cut a passage to the small container through the base of the large container • Cut a 1” square notch from the lip of the large container on the side opposite the hole in the base • Insert a few metal washers into the small container and then invert them	★★★
Remove a Shard of Bone from a Leg 	**Goal: remove the toothpick through the holes in the cup.** • Cut three ½” holes in a clear plastic cup: one on the base and two on the sides mid-way up • Place cup upside down over a toothpick	★★★★

SET UP

Provide to each student group:

- A felt body shape outline
- Six laminated organs
- Six obstacles
- One set of the Surgery Design Challenge cards
- Building supply kits
- A table large enough to accommodate the entire length of the felt body; otherwise, students can work on the floor

Set up instructions:

- Place the body outline on the table. If necessary, secure the felt bodies to the floor or table
- Place organs in their respective places on the felt body
- Place the model surgery challenges on the appropriate organs. Use Velcro® and/or sticky tack to secure them to the laminated organs

INTRODUCTION

10 minutes

Let students speculate before offering answers. The answers given are primarily for the instructor's benefit.

Suggested script is shaded. Important points or questions are in **bold**. Possible answers are shown in *italics*

Welcome! Today we are going to be designing tools for doctors that will help save people's lives. We'll be making tools that can help make surgery safer.

Can you think of some tools that doctors use when they do surgery?
Knives, scalpels, scissors, tweezers, cameras.

Not very long ago, doctors didn't have a lot of surgical tools. They had to make really big holes when they cut people open, and sometimes other organs and muscles would get hurt. That meant that surgery could be dangerous and it took a long time to recover from it.

Engineers called biomedical engineers work with doctors to develop tools that make surgery safer. One of the big changes that has made surgery safer is the invention of tools and special tiny cameras that allow doctors to see and perform surgery through very small holes in the body, which is a lot less dangerous than having to cut somebody wide open. But if a surgical hole is small, like only half an inch wide, you need to have tools that will fit inside and can be moved around remotely.

(Optional) Show video(s) highlighting the use of specialized tools in surgery:

- *Meet a Scientist Video – Nancy Yen Shipley*
- YouTube – Michigan Engineering - "FlexDex: A Revolutionary Surgical Tool"

Today we will be biomedical engineers designing tools that can be used to do operations on a human.

Hold up the felt body outline. Then hold up each organ as you introduce it.

We have six model surgery challenges for you that represent different types of surgery. In one of the challenges, you'll have to remove a tumor from the brain. A tumor is tissue inside the body that is growing where it shouldn't be. In other challenges, you'll need to take out other things out, like metal from a stomach that someone swallowed by accident, a shard of bone from a broken leg, or a kidney stone. But then there are other challenges where you have to put things *inside* the body in just the right way. In one, you'll need to put a patch on the breathing tube that leads to the lungs. In another one you will need to make a knot around an artery in the heart.

Hold up the surgery challenge cards.

These challenge cards explain what the goal of each surgery is. You will need to read the cards very carefully to understand exactly what type of tool you will need to design for a successful surgery.

GROUP ACTIVITY

Design, Test, Improve

45 minutes

Divide the class into groups of 3–5 students. Groups should sit at their previously set up "operating room" workspace (either a large table or the floor). Let each student choose or draw a Surgery Design Challenge card.

Give students a moment to orient themselves to the body and where their organ/model surgery challenge is located. Encourage them to help one another and remind them that they are all sharing the same "person."

What are some things we'll have to be careful about when trying out our tools?
We can't bump, shake, or move the body or the obstacle. The tool is the only thing that can go inside, no fingers.

Is it okay to use neighbors' ideas?
Yes! Engineers rely on other engineers to continue inspiring new ideas while developing their own.

Hand out a container of building materials to each group.

Use these materials to design your surgical tool. Think carefully about the challenge and observe the model carefully before you start designing your tool.

You can instruct groups to work on one challenge at a time together, or have each group member work on their own challenge separately.

When you've designed your tool, go ahead and test it on your surgery challenge. Call me over to your group when you've successfully tested your tool so you can share how your design works. Remember, you are designing your tool for a surgeon, so it should be easy for others to use. I will try out some of your tools to see how easy they are for others to use.

As you try out students' tools, give them specific feedback on how well their design works, and suggest how they could improve it to make it easier for you to use.

WRAP-UP

5 minutes

Ask for student observations. There is no correct answer. Allow students to guide the discussion.

Tell us about your design.

Is there anything you had to change to make the tool work well?

Which challenge was hardest to complete?

What would you do differently if you had more time?

If time allows, ask the groups to share their designs, either as a whole-class showcase or by partnering with another group.

Were all of the designs similar, or very different?

CLEAN UP

10 minutes

- Collect the laminated body part images, Challenge cards, obstacles, unused building supplies, and body outlines for future use
- Ensure play dough is returned to an airtight container for re-use

OPTIONAL EXTENSIONS

- Draw your ideal surgical tool that you envision would work best. How does it differ from the design your group came up with? What extra materials would you need to construct it?

- Try using the surgical tool while watching through a cell phone camera, similar to how surgeons perform a type of surgery called endoscopic surgery. Is it more difficult now to use your tool?

- Try to make one tool that can complete all challenges as quickly as possible

BACKGROUND INFORMATION

Bioengineers apply the principles of engineering to solve problems related to health and medicine. Bioengineers develop all kinds of products and devices, including drugs and drug delivery systems, prosthetics, mobility devices, surgical tools, and more. Many of the products we take for granted—like contact lenses or thermometers—were once new biomedical innovations.

Surgery is one area where biomedical engineering has made a particularly significant contribution. The earliest surgeries in history were performed without anesthesia, and with relatively imprecise tools that made large wounds, which were susceptible to infection and tissue damage. The development of anesthesia in the mid-1800s and antibiotics in the early 1900s dramatically reduced surgical mortality and made many more kinds of surgery feasible. The last 100 years has seen amazing innovations in surgery, including:

- Laser surgery – Lasers can make finer—and therefore more precise—cuts than even the smallest razor. As such, they are often used in eye surgery.
- Robot-assisted surgery – Robots are used in a variety of surgical applications. The da Vinci robotic surgical system, for example, can assist in prostate surgery and coronary artery bypass.
- Laparoscopic surgery – Instead of cutting the patient wide open to access internal tissue, the surgeon makes a small hole and performs the work by inserting long, flexible tools into the hole.
- Endoscopic surgery - Instead of cutting a hole, the surgeon enters the body through an existing opening, like the nostril.
- Computer-assisted surgery – Often used in conjunction with laparoscopic or endoscopic surgery, the surgeon inserts a tiny camera, which can be snaked around inside the body to better view the surgical site.

GLOSSARY

Endoscopic surgery	A type of surgery in which very small incisions are made and tools are inserted into the body through those incisions
Surgery	The treatment of injuries or disorders of the body by incision or manipulation, especially with instruments.
Tumor	Abnormal growth of cells, which may be cancerous

NEXT GENERATION SCIENCE STANDARDS

	Practices
✓	Asking questions and defining problems
	Developing and using models
✓	Planning and carrying out investigations
	Analyzing and interpreting data
	Using mathematics and computational thinking
✓	Constructing explanations and designing solutions
	Engaging in argument from evidence
	Obtaining, evaluating, and communicating information

	Crosscutting Concepts
	Patterns
✓	Cause and effect
	Scale, proportion, and quantity
	Systems and system models
	Energy and matter
✓	Structure and function
	Stability and change

	Disciplinary Core Idea	3	4	5	MS
	Physical Science				
PS1	Matter and Its Interaction	n/a	n/a		
PS2	Motion and Stability: Forces and Interactions		n/a		
PS3	Energy	n/a			
PS4	Waves and Their Applications in Technologies for Information Transfer	n/a		n/a	
	Life Science				
LS1	From molecules to organisms: Structures and processes				
LS2	Ecosystems: Interactions, Energy, and Dynamics		n/a		
LS3	Heredity: Inheritance and Variation of Traits		n/a	n/a	

LS4	Biological Evolution: Unity and Diversity		n/a	n/a	
Earth & Space Science					
ESS1	Earth's Place in the Universe	n/a			
ESS2	Earth's Systems				
ESS3	Earth and Human Activity				
Engineering, Technology, and Applications of Science					
ETS1	Engineering Design	✓	✓	✓	✓

<u>DCI Grade Band Endpoints</u>

3-5 ETS1.A: Defining and Delimiting Engineering Problems

- Possible solutions to a problem are limited by available materials and resources (constraints). The success of a designed solution is determined by considering the desired features of a solution (criteria). Different proposals for solutions can be compared on the basis of how well each one meets the specified criteria for success or how well each takes the constraints into account. (By the end of Grade 5)

3-5 ETS1.B: Developing Possible Solutions

- Research on a problem should be carried out before beginning to design a solution. Testing a solution involves investigating how well it performs under a range of likely conditions. (By the end of Grade 5)
- At whatever stage, communicating with peers about proposed solutions is an important part of the design process, and shared ideas can lead to improved designs. (By the end of Grade 5)
- Tests are often designed to identify failure points or difficulties, which suggest the elements of the design that need to be improved. (By the end of Grade 5)

3-5 ETS1.C: Optimizing the Design Solution

- Different solutions need to be tested in order to determine which of them best solves the problem, given the criteria and the constraints. (By the end of Grade 5)

MS ETS1.A: Defining and Delimiting Engineering Problems

- The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that are likely to limit possible solutions. (By the end of Grade 8)

MS ETS1.B: Developing Possible Solutions

- A solution needs to be tested, and then modified on the basis of the test results, in order to improve it. (By the end of Grade 8)
- There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. (By the end of Grade 8)

- Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors. (By the end of Grade 8)
- Models of all kinds are important for testing solutions. (By the end of Grade 8)

MS ETS1.C: Optimizing the Design Solution

- Although one design may not perform the best across all tests, identifying the characteristics of the design that performed the best in each test can provide useful information for the redesign process—that is, some of those characteristics may be incorporated into the new design. (By the end of Grade 8)
- The iterative process of testing the most promising solutions and modifying what is proposed on the basis of the test results leads to greater refinement and ultimately to an optimal solution. (By the end of Grade 8)

Performance Expectations

3-5-ETS1-1	Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.
3-5-ETS1-2	Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.
3-5-ETS1-3	Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.
MS-ETS1-1	Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.
MS-ETS1-2	Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.

The Perfect Present

Program Type: Classroom Program	***Audience Type:*** Grades 3–8

Description: Students will design and improve a gift for their class partner based on their individual needs and unique interests.

This activity is adapted from Stanford Design School's "Gift Giving Project." See https://dschool-old.stanford.edu/groups/designresources/wiki/ed894/The_GiftGiving_Project.html

LEARNING OBJECTIVES

For Next Generation Science Standards alignment, see end of outline.

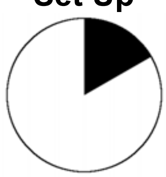
- Students will use the engineering design process to design, test, and improve upon an object that will be a perfect present for a unique individual.
- Students will interview their partner and actively listen to their partner's specific needs and wants.

TIME REQUIRED

Advance Prep

20 minutes

Set Up

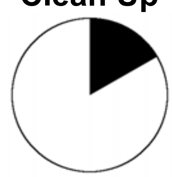


10 minutes

Activity

60-120 minutes

Clean Up



10 minutes

SITE REQUIREMENTS

- Table space for partner groups.

PROGRAM FORMAT

Segment	Format	Time
Introduction	Large group discussion	5 min
Design, Test, Improve	Partner activity	50-85 min
Wrap-Up	Large group discussion	5-30 min

*This class can be altered to fit many different schedules. A minimum of 90 minutes is recommended for the full experience. For a shorter class, you may eliminate the showcase at the end, use drawings instead of physical prototypes, and only have one round of designing. For a longer class, you may include more rounds of iteration on the designs, or even have students go through the same process with different partners.

SUPPLIES

Supplies	Amount	Notes
Booklet: Engineering the Perfect Gift for your Friend	1/student	Found in the *Appendix*
Colored pencils, crayons, or markers	1 set/group	
Object cards	3–4 cards/group	Found in the *Appendix*
Suggested Building Materials	**Amount**	**Notes**
K’NEX® rods and connectors	Amounts may vary, but distribute enough for each student to build his or her own design.	If building materials are not available, you may choose to let students draw their designs instead.
Rubber bands		
Cotton balls		
Foam sheets		
Wooden craft sticks		
Paper clips		
Binder clips		
Metal washers		
Straws		

ADVANCE PREPARATION

- Print or photocopy one *Engineering the Perfect Gift for your Friend* booklet per student. The booklet can be found in the *Appendix*. Fold and staple the booklets, ensuring the page numbers are in order.
- Print and cut out the object cards found in the *Appendix*. You may also choose to write your own prompts for objects on index cards or slips of paper.

SET UP

- Place one set of colored pencils, crayons, or markers on each table.
- Distribute a variety of building materials to each group.

INTRODUCTION

5 minutes

Let students speculate before offering answers. The answers given are primarily for the instructor's benefit.

Suggested script is shaded. Important points or questions are in **bold**. Possible answers are shown in *italics*.

Engineers create many wonderful things for all kinds of people! Different groups of people, or audiences, have different needs and wants.

Can you think of things that were designed for a certain person or group of people? *A bridge, handicap ramps, aerial trams, science equipment, heavy machinery, etc. There will be many acceptable answers here.*

The smaller the audience, the more an engineer can focus on making something even more personalized. It is also helpful to the engineer when the audience can give their opinions, or feedback, about the design.

Today you are going to design a gift just for your partner. And they will design a special present for you too! The gift you design will be an object that your partner needs or wants. When asking them questions to help plan your design, make sure you listen carefully to what they have to say.

PARTNER ACTIVITY

Design, Test, Improve

50-85 minutes

Assign one person in each pair the number 1 and the other person number 2. Make sure the students remember their numbers. Person #1 will interview their partner first.

Follow the suggested script below as the students work through the booklet. Let students know that when you give the signal, it will be time to stop and listen for the next instruction. They should wait for instructions before moving forward in their booklet. It is recommended to use a timer with an alarm to keep on track and allow both participants an equal amount of time to speak.

<table>
<tr><th>Page in Book</th><th>Suggested Script</th><th>Time</th></tr>
<tr><td>
</td><td>Pass out 3–4 object cards to each pair of students. Allow one minute for everyone to choose a card that represents the object they would like their partner to design for them. Students can also just think of something on their own.

Look through the cards and pick what object you'd like your friend to design for you. Maybe choose something that you think could be improved in your life, something that you want to change the appearance of and make work better for you.

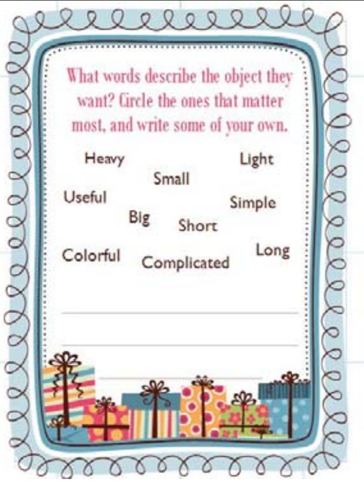
Think about the questions on the page. What did you envision the gift to look like when you picked the object card? How can you improve an existing version of that object? Your idea doesn't have to make complete sense or even be technologically possible right now. Dream big!

Once each student chooses an object, have them give their card to their partner so the partner knows what they will be designing.</td><td>5 min</td></tr>
<tr><td>
</td><td>Time to interview your partner so you can start designing their gift! Use the questions on the back of the object card to get you started, or come up with your own.

Be sure to ask "why" often. Try to uncover stories, feelings, and emotions from your partner. Figure out what he or she will be using the object for and when. Is it for sharing, playing with, or using at home? Take notes about what your partner says

Partner #1 will start interviewing partner #2. You each get 4 minutes, and I will let you know when it's time to switch.

Keep a timer to let students know when to switch.</td><td>9 min</td></tr>
</table>

<table>
<tr><th>Page in Book</th><th>Suggested Script</th><th>Time</th></tr>
<tr><td>
</td><td>Circle some of the words your partner used to describe the object. Write down any other words they said that seemed important to them.

Check with your partner to see if there are any other words they would like to add.</td><td>3 min</td></tr>
<tr><td>
</td><td>Make a plan about what your partner needs! Fill in the blanks to make a statement about what the gift will be.

This statement will explain the reason your gift is unique to your partner and addresses his or her wants and needs.

*At this point, partners can return to Step # 1: Pick Your Gift, this time switching roles. Once both students have had a chance to interview their partner about their perfect gift, both students can proceed to Step #3.</td><td>3 min</td></tr>
<tr><td>
</td><td>Sketch at least five different ideas that could be the perfect present for your partner! Don't worry about the quality of the idea or the drawings. Just come up with as many different "wild" ideas as you can!

Remember to try changing all parts of the object for each design sketch: color, shape, size, how it's used, etc. Give your partner lots of options to choose from!

Both partners can work on this step at the same time.</td><td>8 min</td></tr>
</table>

Page in Book	Suggested Script	Time
	Show your sketches to your partner and listen to his or her feedback! As you give feedback, focus on what you like about each idea, and what parts you think could be improved. Try not to defend your ideas, but instead listen to what your partner likes and doesn't like as much. Take notes on his or her feedback. This time partner #2 will start. You have 4 minutes discuss the ideas before switching. Give the signal to switch after 4 minutes.	8 min
	Consider what you learned about your partner and sketch a new idea. It might be a variation of one of your first ideas, or it might be something completely new. Don't be afraid of starting over if you don't think any of your ideas are working, but keep in mind what your partner wanted from the gift in the first place, and what parts of your original ideas they liked. Both partners can work on this step at the same time.	8 min
	Build your idea! It doesn't have to be realistic, but it will give your partner a design to interact with. You can build the whole item or just focus on one part of it. Both partners can work on this step at the same time.	15 min

Page in Book	Suggested Script	Time
	Present your perfect present! Let your partner interact with the prototype, or model, you built for them. Watch how they use it or misuse it. Capture their feedback on the next page. Starting with partner #1, take 5 minutes to share and get feedback and then switch. Give the signal to switch after 5 minutes.	10 min
	Continue improving your designs! If time allows, you may want to have students continue the improving, redesigning, and testing steps –all part of the Engineering Design Process!	(Time will vary)

WRAP-UP

5-30 minutes

If time allows, host a final showcase to share all of the gifts. Encourage students to share one part of the design that they changed based on their partner's feedback and one thing that they created to make their gift even unique for their partner.

From this activity, we learned how important it is to listen to the ideas and feedback of the person who will be using something we design. You also problem-solved to make your design better and used your partner's feedback to work with your own vision. Engineers do these same steps all of the time since the people who hire them don't always have the exact same ideas or understand the project at the same level. Engineers usually work in teams to create the best designs possible for the problem they are trying to solve.

What were some good questions you asked your partner that helped you make a design plan?

Which answers were most helpful with inspiring your design?

Were there times when you realized that your partner's ideas wouldn't work with your design ideas? What did you do?

CLEAN UP

5 minutes

- If there are enough materials, let students keep the gifts. If not, have students disassemble the gifts and separate the materials back into separate bins.

BACKGROUND INFORMATION

The process used in this activity is based on human-centered design, a way of developing solutions to problems that involves the human perspective in all steps of the problem-solving process. One interesting application of human-centered design is 3D-printed prosthetics. Companies have managed to design and put together kits for prosthetic limbs at a much lower cost than traditional prosthetics. Of course, this process took longer than the one in this activity, but the idea is similar: People were able to create an object that was customized to solve their unique problem.

Many people need prosthetic limbs, and people need different fits depending on their size. Using 3-D printers results in designs for prosthetics for people of various sizes and needs. Just like our gifts, the idea started because of a need to create something for someone. Engineers then worked on a design until it met the needs of their target audience.

Figure 1: A 3D-printed leg is designed based on a user's needs and preferences (Photo: art-vibes.com)

GLOSSARY

Prototype	An early sample or model product built to test a concept or process or to act as a thing to be replicated or learned from.

NEXT GENERATION SCIENCE STANDARDS

	Practices
✓	Asking questions and defining problems
✓	Developing and using models
	Planning and carrying out investigations
	Analyzing and interpreting data
	Using mathematics and computational thinking
✓	Constructing explanations and designing solutions
	Engaging in argument from evidence
✓	Obtaining, evaluating, and communicating information

	Crosscutting Concepts
	Patterns
	Cause and effect
	Scale, proportion, and quantity
	Systems and system models
	Energy and matter
✓	Structure and function
	Stability and change

	Disciplinary Core Idea	3	4	5	MS
	Physical Science				
PS1	Matter and Its Interaction	n/a	n/a		
PS2	Motion and Stability: Forces and Interactions		n/a		
PS3	Energy	n/a			
PS4	Waves and Their Applications in Technologies for Information Transfer	n/a		n/a	
	Life Science				
LS1	From molecules to organisms: Structures and processes				
LS2	Ecosystems: Interactions, Energy, and Dynamics		n/a		
LS3	Heredity: Inheritance and Variation of Traits		n/a	n/a	
LS4	Biological Evolution: Unity and Diversity		n/a	n/a	

Earth & Space Science					
ESS1	Earth's Place in the Universe	n/a			
ESS2	Earth's Systems				
ESS3	Earth and Human Activity				
Engineering, Technology, and Applications of Science					
ETS1	Engineering Design	✓	✓	✓	✓

DCI Grade Band Endpoints

3-5 ETS1.A: Defining and Delimiting Engineering Problems

- Possible solutions to a problem are limited by available materials and resources (constraints). The success of a designed solution is determined by considering the desired features of a solution (criteria). Different proposals for solutions can be compared on the basis of how well each one meets the specified criteria for success or how well each takes the constraints into account. (By the end of Grade 5)

3-5 ETS1.B: Developing Possible Solutions

- Research on a problem should be carried out before beginning to design a solution. Testing a solution involves investigating how well it performs under a range of likely conditions. (By the end of Grade 5)
- At whatever stage, communicating with peers about proposed solutions is an important part of the design process, and shared ideas can lead to improved designs. (By the end of Grade 5)
- Tests are often designed to identify failure points or difficulties, which suggest the elements of the design that need to be improved. (By the end of Grade 5)

3-5 ETS1.C: Optimizing the Design Solution

- Different solutions need to be tested in order to determine which of them best solves the problem, given the criteria and the constraints. (By the end of Grade 5)

MS ETS1.A: Defining and Delimiting Engineering Problems

- The more precisely a design task’s criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that are likely to limit possible solutions. (By the end of Grade 8)

MS ETS1.B: Developing Possible Solutions

- A solution needs to be tested, and then modified on the basis of the test results, in order to improve it. (By the end of Grade 8)
- There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. (By the end of Grade 8)
- Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors. (By the end of Grade 8)
- Models of all kinds are important for testing solutions. (By the end of Grade 8)

MS ETS1.C: Optimizing the Design Solution

- Although one design may not perform the best across all tests, identifying the characteristics of the design that performed the best in each test can provide useful information for the redesign process—that is, some of those characteristics may be incorporated into the new design. (By the end of Grade 8)
- The iterative process of testing the most promising solutions and modifying what is proposed on the basis of the test results leads to greater refinement and ultimately to an optimal solution. (By the end of Grade 8)

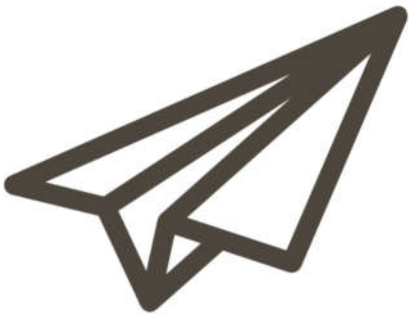
3-5 ESS3.C: Human Impacts on Earth Systems

- Human activities in agriculture, industry, and everyday life have had major effects on the land, vegetation, streams, ocean, air, and even outer space. But individuals and communities are doing things to help protect Earth's resources and environments. For example, they are treating sewage, reducing the amounts of materials they use, and regulating sources of pollution such as emissions from factories and power plants or the runoff from agricultural activities. (By the end of Grade 5)

Performance Expectations

3-5-ETS1-1	Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.
3-5-ETS1-2	Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.
3-5-ETS1-3	Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.
MS-ETS1-1	Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.
MS-ETS1-2	Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.
5-ESS3-1	Obtain and combine information about ways individual communities use science ideas to protect the Earth's resources and environment.

The Perfect Present
Appendix



A Form of Transport

Something to Carry Things In

A Communication Device

Something to Sit On

Shoes

Something to Wear

- Where and with whom would you need to communicate?
- How could you improve existing communication devices?
- What else would it do?
- How does it help you?
- How is it powered?

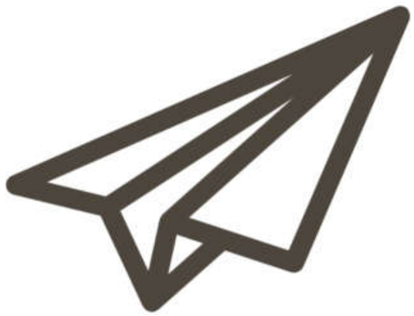
- What type of things would it carry?
- What else would it do?
- How does it help you?
- How would you carry it?

- How could you improve existing modes of transportation?
- What else would it do?
- How does it help you?
- What is your favorite and least favorite mode of transportation?
- Where would you go?
- How would it be powered?

- Why do you need it?
- What is your favorite thing to wear?
- What else would it do?
- How does it make you feel?
- How does it help you?

- Why do you need them?
- When would you wear them?
- What else would they do?
- Describe your favorite shoes.

- Where would you use it?
- Where is your favorite place to sit?
- What else would it do?
- How does it help you?



Un modo de transporte

Algo para llevar cosas

Un dispositivo de comunicación

Algo en donde sentarse

Zapatos

Algo para ponerse

- ¿Dónde y con quién necesitarías comunicarte?
- ¿Cómo podrías mejorar dispositivos de comunicación que ya existen?
- ¿Qué más haría?
- ¿Cómo te ayudaría?
- ¿Cómo se activa?

- ¿Qué tipo de cosas llevaría?
- ¿Qué más haría?
- ¿Cómo te ayudaría?
- ¿Cómo lo llevarías?

- ¿Cómo podrías mejorar modos de transporte que ya existen?
- ¿Qué más haría?
- ¿Cómo te ayudaría?
- ¿Cuál es tu modo de transporte favorito y menos favorito?
- ¿Adónde irías?
- ¿Qué tipo de energía usaría?

- ¿Para qué lo necesitas?
- ¿Cuál es tu prenda favorita para ponerte?
- ¿Qué más haría?
- ¿Cómo te hace sentir?
- ¿Cómo te ayudaría?

- ¿Por qué los necesitas?
- ¿Cuándo lo usarías?
- ¿Qué más harían?
- Describe tus zapatos favoritos.

- ¿Dónde lo usarías?
- ¿Cuál es tu lugar favorito para sentarte?
- ¿Qué más haría?
- ¿Cómo te ayudaría?

Note: To correctly print the Perfect Present booklet, use the following printer settings:

- Only print pages 23-32 (English version) or 33-42 (Spanish version)
- Select “Duplex” or “Print on both sides” and “flip on SHORT edge.”

Once printed, the entire stack of pages can be placed together, folded in half to form a booklet, and the pages will be in the correct order.

Engineer the Perfect Gift!

→ Pair up

→ Interview

→ Design a gift for your partner

Depending on time, these steps can be done over and over and over again...

It's all part of the Engineering Design Process!

Step #8:
Improve!

Improve your design even more based on the last bit of feedback your partner provided.

Step #1:
Pick your gift

What object do you need?
Is there an object you would like to improve?

Choose your card and give it to your partner.

Step #2:
Interview your partner

What does he/she need?

Read the questions on the back of your partner's card and take notes on their answers.

Feedback

What worked well:

What could be improved/changed:

Questions:

New ideas:

Step #7: Share and get feedback

Share your creation with your partner and get feedback about the gift you made for them.

Take notes here:

What words describe the object they want? Circle the ones that matter most, and write some of your own.

Heavy
Light
Small
Useful
Simple
Big
Short
Colorful
Complicated
Long

Building Time.

Have fun!

Step #6:
Build your gift!

Use the materials at your table and make something your partner can interact with.

My partner ______________
(name)

needs ______________
(object)

____

that ______________
(what it does)

____

____

____

because/but/and ______________

____
(reason or constraint)

____

____

____

Step #3:
Design your gift!

Sketch at least 5 wild new ways to meet your partner's needs (they don't have to be good sketches!)

Sketch Here!

Step #5:

Sketch your new idea based on the feedback you received.

Sketch Here!

Step #4: Share your ideas

Share your ideas with your partner and capture his or her feedback on your designs.

Feedback

What parts my partner liked:

What parts they didn't like:

¡Crea el regalo perfecto!

→ Encuentra un/a compañero/a

→ Entrevístalo/a

→ Diseña un regalo

Dependiendo de cuánto tiempo tengan, estos pasos se pueden repetir una y otra y otra vez...

¡Todo es parte del proceso de diseño de ingeniería!

Paso #8:
¡Mejora!

Mejora tu diseño aún más de acuerdo a las sugerencias que tu compañero/a te acaba de dar.

Paso #1:
Escoge tu regalo

¿Qué necesitas?

¿Tienes un objeto que quisieras mejorar?

Escoge tu tarjeta y dásela a tu compañero/a

Paso #2:
Realiza tu entrevista

¿Qué necesita tu compañero/a?

Lee las preguntas en la parte de atrás de su tarjeta y escribe sus respuestas.

Sugerencias

Qué funcionó:

Qué puede mejorar/cambiar:

Preguntas:

Nuevas ideas:

Paso #7: Comparte y escucha sugerencias

Comparte la creación con tu compañero/a y escucha sus sugerencias.

Toma apuntes aquí:

¿Qué palabras describen el objeto que quiere? Marca las más importantes, y escribe otras que se te ocurran.

Pesado

Liviano

Pequeño

Útil

Simple

Grande

Corto

Colorido

Complicado

Largo

Hora de construir.

¡Diviértete!

Paso #6:
¡Construye tu regalo!

Usa los materiales en la mesa para crear algo que tu compañero/a pueda usar.

Mi compañero/a ______________________
(nombre)

necesita ______________________
(objeto)

____

que ______________________
(¿qué hace el regalo?)

____

____

porque/pero/y ______________________

____
(razón o limitación)

____

____

Paso #3:
¡Diseña tu regalo!

Dibuja al menos 5 ideas diferentes que pudieran satisfacer las necesidades de tu compañero/a (¡los dibujos no tienen que ser perfectos!)

¡Dibuja aquí!

Paso #5:

Dibuja tu nueva idea de acuerdo a las sugerencias que recibiste.

¡Dibuja aquí!

Paso #4:
Comparte tus ideas

Comparte tus ideas con tu compañero/a, y captura sus sugerencias en tus diseños.

Sugerencias

Qué le gustó a mi compañera:

Qué no le gustó a mi compañera:

FACILITATION GUIDE

The Perfect Present

Description: Students will design and improve a gift for their partner based on their individual needs and unique interests.

Promoting collaboration and organization

- Encourage students to provide kind but honest feedback to their partner. Their perfect present depends on this input!
- Remind students that criticism on their design is not meant to be taken personally. Rather, it's to help them improve their design. Try giving one compliment along with each suggestion.
- Make sure both students in the partner team get time to speak.

Encouraging iteration

- Motivate students to think outside the box with their design. Dream big! Wild ideas are encouraged!
    - Is this object design too similar to something you have seen before? Try making it more unique. If you can buy it online, redesign it to be more original.
    - Can you change the function, material, or size?
    - What other problems does your partner want their gift to solve?

Helping those who are stuck

- Use object cards to inspire ideas, but the design does not have to be one of the objects on the cards.
- If partners are having difficulty compromising, then remind the engineer (i.e., the person designing) that their partner is their customer. Engineers want to make their customers happy.
- Ideas for an object don't have to be similar. A fork and chopsticks look nothing alike, but you can eat with either one.
- Have the designer go back to the object card and determine the function of the object. Then have the engineer visualize how it can work and what it may look like based on the preferences of their partner.

Real-world applications

- A popular way to make custom human-centered designs is using 3D printing. This process, also known as additive manufacturing, uses computer controls to create a 3D object in which layers of material are formed to make a specific object.
- Custom-designed gifts are gaining popularity. Many companies let you design your own custom products from phone cases to bath mats to clothes.

Zip Line Rescue

Program Type: Classroom Program	**Audience Type:** Grades 3–8

Description: Students will design and build a zip line carrier that will move an injured or stranded person safely and quickly out of danger.

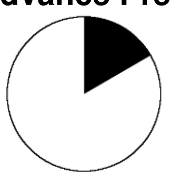
LEARNING OBJECTIVES

For Next Generation Science Standards alignment, see end of outline.

- Students will design a zip line carrier using the engineering design process, including creating, testing, and re-designing a prototype.
- Students will explore varying environmental constraints that affect the zip line carrier, including the presence of a person, adverse weather, and the need to make multiple trips.

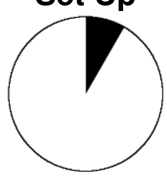
TIME REQUIRED

Advance Prep



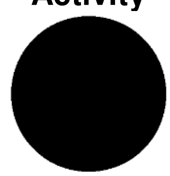
10 minutes

Set Up



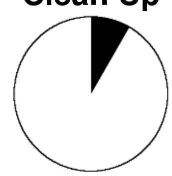
5 minutes

Activity



60-100 minutes

Clean Up



5 minutes

SITE REQUIREMENTS

- A separate space (approximately 6’×4’) for each group to set up a zip line.
- Each space needs to be near a wall, bookcase or chair capable of holding a clamp, with a table or open floor for students to design and build.
- *(Optional)* Access to a whiteboard and projector/document camera.

PROGRAM FORMAT

Segment	**Format**	**Time**
Introduction	Large group discussion	10 min
Design, Test, Improve	Group activity	40 min
Wrap-Up	Large group discussion	10 min

Levels

This activity is leveled to accommodate different class lengths and abilities of participants. Each level is an extension of the previous one and increases the complexity of the design challenge. The additions for materials and delivery are shown in each section. Instructors should choose the challenge level that is appropriate for their students and the length of the activity.

Level 1: Basic activity (good for younger participants and shorter classes).

Level 2: Introduces a bad weather element to the activity (additional 10–15 minutes).

Level 3: Additional challenge of using the carrier multiple times and creating a system to bring the carrier to the top of the zip line (additional 15-25 minutes).

SUPPLIES

Permanent Supplies		
Level 1 Supplies	**Amount**	**Notes**
Scissors	1/group	
Kite string or fishing line	6 ft./group	
Gallon jug	1/group	fill with water or sand
2” spring clamp (or larger)	1/group	Anything that attaches firmly but can be easily moved
Small human play figures	1/group	Ex: Playmobil® or Lego®
Meter stick or measuring tape	1	
Zip line rescue photos	2	*(Optional)* See *Appendix.*
Additional Level 2 Supplies	**Amount**	**Notes**
Fan	1	Can be 1/group if supplies are not limited
Spray Bottle	1	Can be 1/group if supplies are not limited
Additional Level 3 Supplies	**Amount**	**Notes**
Kite string, fishing line, or yarn	12 ft./group	
Stopwatch	1/group	
Additional human figurines	2/group	

The items below are suggestions for zip line carrier building materials. These can be added or removed as needed.

Suggested Supplies	Amount
Paper clips	12/group
Wooden craft sticks	12/group
Rubber bands	12/group
Binder clips	12/group
Drinking straws	12/group
Yarn	4 ft./group
Pennies or metal washers	4/group
Tack board (cereal boxes)	4/group
Pipe cleaners	8/group
Wooden skewers	8/group
Aluminum foil	6”×8” sheet/group
Brass brads	4/group
Craft foam sheets	1/group

ADVANCE PREPARATION

- Cut kite string into 6-ft. sections.
- Fill the gallon jugs with sand or water.
- Tie one end of the kite string to the neck or handle of the bottle and the other end to the clamp.
- *(Optional)* Print or create a slideshow of photos showing various zip line rescues (see Appendix for two examples).

Additional Level 3 Prep:
- Cut 12-ft. sections of string or yarn.

SET UP

- Divide the building materials (pipe cleaners, paper clips, foam, etc.) into equal piles for each group.
- Tie one end of each kite string to a clamp and the other end to the weighted bottle. Use the clamp to attach the string to a stable surface higher than the end of the string attached to the bottle.If the weighted bottle is on a table then the clamp can be attached to a bookshelf or windowsill. Alternatively, if the weighted bottle is on the floor then the clamp can be attached to a table or chair. Keep in mind the smaller the angle, the more of a challenge this activity will be.
- Set the weighted bottle on the floor or table so the string is taut.
- If possible, place the zip line set up over a table or other object to prevent anyone from tripping or walking into the thin, hard-to-see line.
- Place a small human play figure on each clamp.

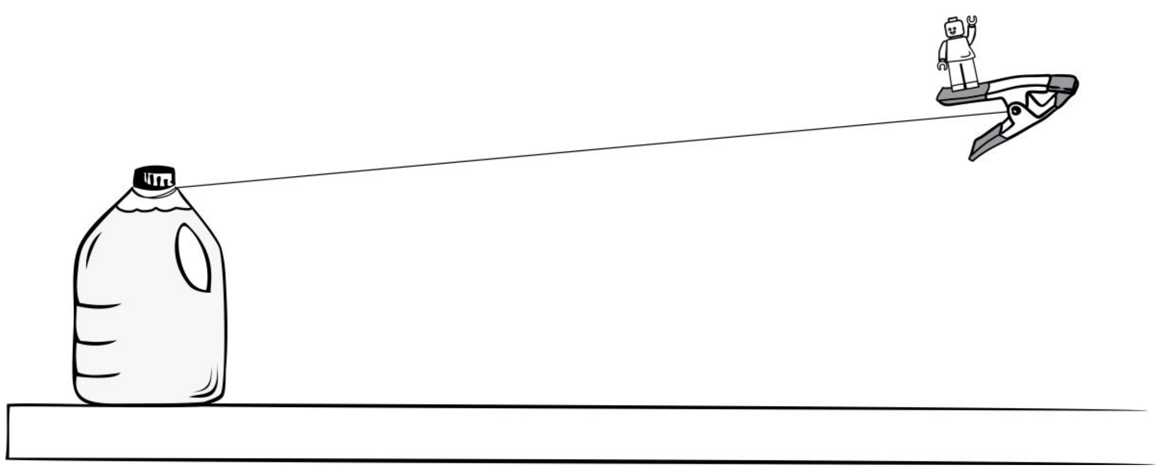


Figure 1: Zip line apparatus using a weighted gallon jug, fishing line, and a clamp. Adding the small human play figure emphasizes the altruistic nature of engineering.

<u>SAFETY WARNING</u>
If using the floor or an open space for this activity, keep in mind that the fishing line is difficult to see and can be a **tripping hazard**. You may wish to use cones or tape to mark these hazard zones.

Additional Set-up Levels 2 & 3:

- Fill spray bottle with water.
- Set up a station with a fan pointing at the zip line. This is where each group can bring their carrier for weather testing.

INTRODUCTION

10 minutes

Let students speculate before offering answers to any questions. The answers given are provided primarily for the instructor's benefit.

Suggested script is shaded. Important points or questions are in **bold**. Possible answers are shown in *italics*.

We are going to be designing, building, and testing an exciting new way to help people in trouble. There are times when people are hurt or stranded in places where it can be hard to get them to safety, like high up on a mountain, in a tram or gondola, or on the far side of a flooded river.

Show photos and diagrams illustrating these situations.

What are some ideas you have for how to get these people to safety?
Helicopters, climbers, parachutes…

One way rescue workers help people in hard to reach places is by using zip lines.

Have any of you heard of zip lines before? Have any of you used a zip line? How do they work?

Zip lines are often used for recreation—that is, for fun! However, they can also be helpful in emergency situations to get people to safety when there are no roads or easy path to take. Today, you will design a zip line attachment system to help a person who is stranded get to saftey.

LEVEL 1 INTRODUCTION

Your challenge today will be to create a carrier that will slide smoothly down the zip line. Your rig must be able to clip on and off the line easily and slide all the way to the bottom of the zip line without anyone controlling it. It is up to you to think creatively and come up with a great design. Once you have a working design, continue to work on the rigs so they can safely carry a person in trouble down the line.

Show zip line set-up, and model person. If desired, show an example of a carrier that doesn't work well and discuss what the problems are with it (doesn't move smoothly, gets stuck halfway down, is hard to get on and off of the zip line, etc).

LEVEL 2 and LEVEL 3

You may run into additional challenges as you create your design. Be prepared to make changes to your carrier as your rescue conditions change.

GROUP ACTIVITY

Design, Test, Improve

40 minutes

Divide students into groups of 3-4. Each group should sit around a space for working (either at a table, grouped desks, or on the floor). Hand out the materials to each group.

What are some factors that will affect if, or how quickly, the rig slides?
How steep the line is will affect how quickly it slides. How heavy the rig is will affect if it slides at all.

Move the bottle forward to make the line slack, showing how the carrier gets stuck.

When you've designed your carrier, go ahead and test it on your zip line. Each person in your group should have a chance to try it out and make any improvements. Call me over to your group when you've successfully tested your rig so you can show me how it works.

If groups are having problems getting a rig to slide, remind them about friction between the rig and the line. Which of their materials might have less friction? How might they incorporate those materials into their design?

LEVEL 2 ADDITIONS

A storm just rolled in! You will need to design a zip line carrier that can work in strong winds and rain. How will you keep the person you are rescuing dry and safe?

Show fan and squirt bottle at the weather testing station. Turn on the fan with medium airflow pointed at the zip line and use the squirt bottle to simulate rain. Test each group's carrier again.

How can you protect your passenger from the rain and the wind? Is it safe even in the high wind conditions?

If their carrier is unstable in the wind and flips, or gets stuck and doesn't travel all the way down the zip line, suggest adding weight or lowering the center of mass.

LEVEL 3 ADDITIONS

There are more people that need to be rescued! You will need to redesign the rig so that it can be used again and again, and so that people can be loaded and unloaded quickly. You will have to figure out a way to pull your carrier back to the top of the zip line without touching it.

In addition to the wind and rain (use level 2 additions), groups must also be able to demonstrate that their rig can carry a person down the zip line more than once without being pushed by hand up the line. Groups should use the extra string to create a system that can be controlled from one end of the zip line to raise the rig back up for another passenger.

To encourage carriers that emphasize easy entrance and exit for the passenger, you can challenge groups to safely rescue as many people as they can in a set amount of time (e.g., 3 minutes).

WRAP-UP

10 minutes

Ask for student observations. There is no correct answer. Let students guide the discussion and present their hypotheses before discussing explanations.

What designs worked best for your rigs? What were some troubles you had? How did you work through those troubles?

Save time at the end for each student group to share their carrier with their classmates and demonstrate its features.

CLEAN UP

10 minutes

- Collect and disassemble the zip line set-ups and carriers.
- Place any unused materials back in their storage containers.

OPTIONAL EXTENSIONS

- Challenge students to see how quickly their rig goes down the line. Can they get it to complete the trip in fewer than 3 seconds?
- Challenge them to slow the rig down. Can they get it to take more than 5 seconds to make the trip?
- Can they complete the challenge with a less steep line? Try lowering the high end to only a few inches above the low end.
- Can they get their rig to carry other objects (ping-pong balls, pennies, etc.) down the line?
- Challenge students to modify their design to fit a variety of different needs, such as a carrier for recreation, for someone who can't stand up, for someone who is afraid of heights, or for a young child or a pet.

BACKGROUND INFORMATION

A zip line is a long cable suspended between two high points, along which people or cargo can slide, often using a pulley. Zip lines have been engineered for all different kinds of uses, including:

- **Ancient transportation** – Before the advent of modern roads and bridges, people living in mountainous areas utilized ziplines to cross steep valley and rivers.
- **Biological research** – Scientists studying the forest canopy often use zip lines to efficiently travel from tree to tree.
- **Recreation** – Today, tourists can explore the forest canopy and other aerial environments all over the world via zip line. Zip lines also satisfy thrill-seekers at theme parks and challenge courses.
- **Emergency situations** – Zip lines have been used to safely transport people down from a broken chairlift, out of a burning building, across a flooded river, and out of other dangerous situations. NASA has even piloted a zip line system to evacuate astronauts from the Starliner crew capsule before launch, in the event that something go awry during the launch sequence.

For photos of ziplines in action, see Appendix.

For a short article on the history of zipline use, see:
Fagaly, Steve. "Zipping Through History: The Origins of the Zipline." Oahu, Zipline, 2016, https://oahuzipline.com/zipping-through-history-the-origins-of-the-zipline/.

GLOSSARY

Zip line	An inclined cable or rope with a suspended harness, pulley, or handle, down which a person slides.
Rig	An apparatus, device or piece of equipment designed for a particular purpose.
Friction	The resistance that one surface or object encounters when moving over another.
Balance	An even distribution of weight enabling something to remain steady.
Weight	An item's relative mass or the quantity of matter contained by it, in a given measurement, as determined by a downward force.
Center of gravity	The point at which the weight of a body is concentrated; if supported at this point, the body would remain balanced.

NEXT GENERATION SCIENCE STANDARDS

	Practices
✓	Asking questions and defining problems
✓	Developing and using models
✓	Planning and carrying out investigations
	Analyzing and interpreting data
	Using mathematics and computational thinking
✓	Constructing explanations and designing solutions
	Engaging in argument from evidence
	Obtaining, evaluating, and communicating information

	Crosscutting Concepts
	Patterns
✓	Cause and effect
	Scale, proportion, and quantity
	Systems and system models
	Energy and matter
✓	Structure and function
	Stability and change

	Disciplinary Core Idea	3	4	5	MS
	Physical Science				
PS1	Matter and Its Interaction	n/a	n/a		✓
PS2	Motion and Stability: Forces and Interactions	✓	n/a	✓	✓
PS3	Energy	n/a	✓		✓
PS4	Waves and Their Applications in Technologies for Information Transfer	n/a		n/a	
	Life Science				

LS1	From molecules to organisms: Structures and processes				
LS2	Ecosystems: Interactions, Energy, and Dynamics		n/a		
LS3	Heredity: Inheritance and Variation of Traits		n/a	n/a	
LS4	Biological Evolution: Unity and Diversity		n/a	n/a	
Earth & Space Science					
ESS1	Earth's Place in the Universe	n/a			
ESS2	Earth's Systems				
ESS3	Earth and Human Activity				
Engineering, Technology, and Applications of Science					
ETS1	Engineering Design	✓	✓	✓	✓

DCI Grade Band Endpoints

3-5 ETS1.A: Defining and Delimiting Engineering Problems

- Possible solutions to a problem are limited by available materials and resources (constraints). The success of a designed solution is determined by considering the desired features of a solution (criteria). Different proposals for solutions can be compared on the basis of how well each one meets the specified criteria for success or how well each takes the constraints into account. (By the end of Grade 5)

3-5 ETS1.B: Developing Possible Solutions

- Research on a problem should be carried out before beginning to design a solution. Testing a solution involves investigating how well it performs under a range of likely conditions. (By the end of Grade 5)
- At whatever stage, communicating with peers about proposed solutions is an important part of the design process, and shared ideas can lead to improved designs. (By the end of Grade 5)
- Tests are often designed to identify failure points or difficulties, which suggest the elements of the design that need to be improved. (By the end of Grade 5)

3-5 ETS1.C: Optimizing the Design Solution

- Different solutions need to be tested in order to determine which of them best solves the problem, given the criteria and the constraints. (By the end of Grade 5)

MS ETS1.A: Defining and Delimiting Engineering Problems

- The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that are likely to limit possible solutions. (By the end of Grade 8)

MS ETS1.B: Developing Possible Solutions

- A solution needs to be tested, and then modified on the basis of the test results, in order to improve it. (By the end of Grade 8)
- There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. (By the end of Grade 8)
- Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors. (By the end of Grade 8)
- Models of all kinds are important for testing solutions. (By the end of Grade 8)

MS ETS1.C: Optimizing the Design Solution

- Although one design may not perform the best across all tests, identifying the characteristics of the design that performed the best in each test can provide useful information for the redesign process—that is, some of those characteristics may be incorporated into the new design. (By the end of Grade 8)
- The iterative process of testing the most promising solutions and modifying what is proposed on the basis of the test results leads to greater refinement and ultimately to an optimal solution. (By the end of Grade 8)

3 PS2.A: Forces and Motion

- Each force acts on one particular object and has both strength and a direction. An object at rest typically has multiple forces acting on it, but they add to give zero net force on the object. Forces that do not sum to zero can cause changes in the object’s speed or direction of motion. (By the end of Grade 5)
- The patterns of an object’s motion in various situations can be observed and measured; when that past motion exhibits a regular pattern, future motion can be predicted from it. (Boundary: Technical terms, such as magnitude, velocity, momentum, and vector quantity, are not introduced at this level, but the concept that some quantities need both size and direction to be described is developed.) (By the end of Grade 5)

MS PS2.A: Forces and Motion

- The motion of an object is determined by the sum of the forces acting on it; if the total force on the object is not zero, its motion will change. The greater the mass of the object, the greater the force needed to achieve the same change in motion. For any given object, a larger force causes a larger change in motion. (By the end of Grade 8)

<u>Performance Expectations</u>

3-5-ETS1-1	Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.
3-5-ETS1-2	Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.
3-5-ETS1-3	Plan and carry out fair tests in which variables are controlled and failure

	points are considered to identify aspects of a model or prototype that can be improved.
MS-ETS1-1	Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.
MS-ETS1-2	Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.
MS-ETS1-3	Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.
MS-ETS1-4	Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.
3-PS2-1	Plan and conduct an investigation to provide evidence of the effects of balanced and unbalanced forces on the motion of an object.
3-PS2-2	Make observations and/or measurements of an object's motion to provide evidence that a pattern can be used to predict future motion.
4-PS3-1	Use evidence to construct an explanation relating the speed of an object to the energy of that object.
MS-PS2-2	Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.
MS-PS3-2	Develop a model to describe that when the arrangement of objects interacting at a distance changes, different amounts of potential energy are stored in the system.

<u>Zip Line Rescue</u>
Appendix

Test of a space shuttle zip line escape system for NASA astronauts. ***Credit: NASA. (Image from: https://www.space.com/36344-zip-line-emergency-escape-system-astronauts.html).***

Rescue dog crossing a river on a zip line to help in the search and rescue of victims of a landslide in China. Credit: Reuters. (Image: http://metro.co.uk/2017/06/25/rescue-dog-takes-zip line-to-help-victims-of-devastating-landslide-in-china-6733520).

FACILITATION GUIDE

Zip Line Rescue

Description: Students will design and build a zip line carrier that will move an injured or stranded person safely and quickly out of danger.

Promoting collaboration and organization

- Each student in a team can design his or her own zip line carrier on paper, labeling each material used. Then, the team can collaborate and come up with a design that combines ideas from all of its members.
- Encourage students to work on and improve different parts of the zip line carrier: attachment to the line, a seat belt, the material of the carrier, etc.
- Suggest that students take turns launching the carrier from the top.
- Suggest that students use drawings or demos to communicate their ideas more clearly.
- As a class, try to create the ultimate carrier by incorporating different ideas from each group.

Encouraging iteration

- There will be many rounds of trial and error—facilitate the engineering design process of improvement and re-testing. Some good questions to ask may include:
    - Does the carrier get all the way to the bottom of the zip line? What could you change to make it go all the way?
    - Does your carrier seem comfortable? Can the person see? What if he or she is afraid of heights?
    - How is the person strapped in? Is it easy to get in and out? Does your person fall out?
    - Would your design work if the person was injured?
    - Can you control which way the person goes down? Head first? Sideways?
    - What other sorts of difficulties might you have? How could you adapt your zip line to overcome them?
    - Does the landing seem like it would be gentle for the passenger?

Helping those who are stuck

- Do a test run with the group and discuss specific points where the rig is not working. Ask specific questions about how they could change the weight, size, center of mass, and the point of contact between the zip line and the carrier.
- Show photos of zip line rescue equipment and ask students what they notice about the designs.
- Invite students to go and observe the designs of other groups.

Real-world applications

- NASA has created a zip line that would help astronauts escape a space shuttle from the launch pad.