MacGillivray Freeman's

CITIES OF THE FUTURE

Discover the exciting innovations transforming our world

EDUCATOR GUIDE

MacGillivray Freeman Films

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Cities of the Future is a film for IMAX® and giant screen theaters produced and distributed by MacGillivray Freeman Films in partnership with the American Society of Civil Engineers (ASCE). For more information, visit www.citiesofthefuturefilm.com.

The *Cities of the Future* Educator Guide is made possible by ASCE and the ASCE Foundation together with NCEES, educational sponsor of *Cities of the Future*.

INTRODUCTION

This educator guide was created as a companion resource to the giant-screen film *Cities of the Future*, produced by MacGillivray Freeman Films in partnership with the American Society of Engineers (ASCE). It provides multidisciplinary lesson plans and activities rich in STEM, language, and social sciences that are related to key themes in the film. Each lesson presents students with an engineering challenge inspired by the work of real engineers. To solve these challenges, students walk through the problem-solving process used by engineers in the real world and develop an understanding of the core ideas and principles that shape the world of engineering.

This guide includes lessons for students in grades 1–12 and has been written to meet Next Generation Science Standards (NGSS) as well as common state science objectives. In addition to the individual lessons, educators will find cross-curricular extension activities and a list of resources that encourage a deeper engagement with engineering and a more robust interdisciplinary experience. With such a richness of material, this guide also serves as an excellent stand-alone resource for teachers—the experts in their own classrooms—to use in ways that best support their students and align with specific state or national standards.

The importance of creating smarter, more sustainable cities

Did you know that nearly 50% of earth's population lives in cities? And that this is projected to grow to 75% by 2050? Because of this, the battle to adapt to climate change will be won or lost in cities. *Cities of the Future* brings to the giant screen the efforts of creative engineers working in concert with others to make cities more livable, sustainable and resilient starting today.

Many cities around the world are already making profound changes. The film explores ground-breaking developments in cities like Los Angeles, Amsterdam and Singapore where innovations created by engineers are already moving these cities towards a more sustainable future.

Our guide in the film is Paul Lee, an enthusiastic and passionate young civil engineer. Paul loves inspiring kids to get excited about STEM. In the film, we see him mentoring a group of middle school students as they build a model city to compete in the annual Future City Competition, an international contest that challenges more than 60,000 students to engineer their own city. Teachers and middle school students interested in the Future City Competition can find more information here: https://futurecity.org. Just as Paul mentors and inspires young students in the film, the activities in this Educator Guide will ignite inquisitive minds about creative problem-solving in areas that present complex challenges to cities globally.

Your neighborhood is always changing. Your city is ever growing. Resources are limited, the climate is stressed. Yet innovation and automation are everywhere. We will one day ride in electric flying vehicles on aerial highways in the sky. Drones will help us with deliveries. Renewable energy will meet more and more of our energy needs. The world will be transformed, but the role of cities will remain the same: to connect us and keep us safe and healthy so we can live, work, play, and learn.

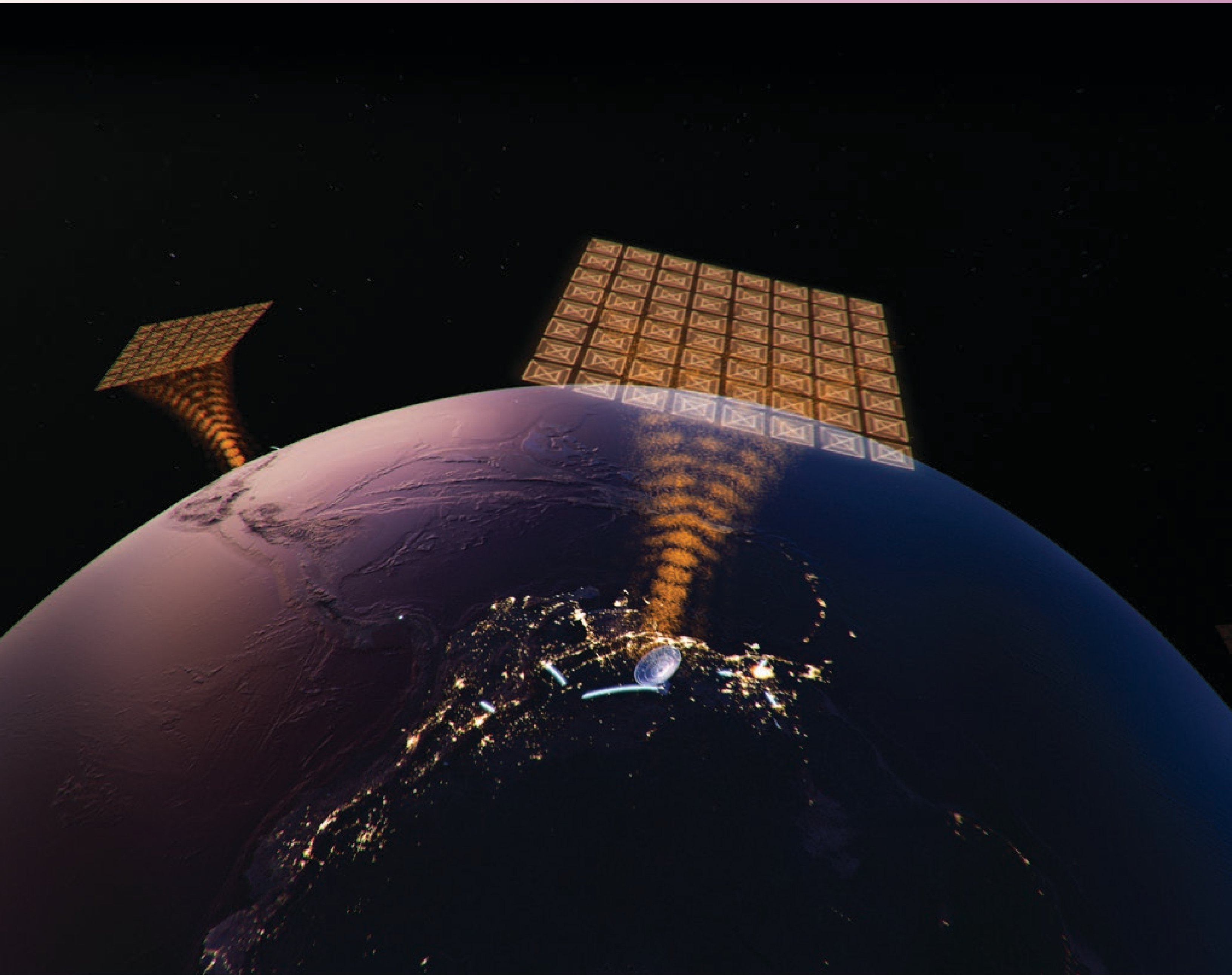
Future World Vision

Cities of the Future was inspired in part by ASCE's Future World Vision initiative (https://www.futureworldvision.org), designed to transform the way we think about our cities and help prepare engineers to lead the way in designing future infrastructure ideas, based on real engineering data and principles. Civil engineers have identified six key focal points as they seek to solve some of the world's challenges and plan for the future:

- Climate Change
- Alternative Energy
- Autonomous Vehicles
- Smart Cities
- High Tech Materials and Construction
- Public Policy

Climate Change

Humanity is in a race to manage climate change. There are daily reports of global warming, floods, droughts and other extreme weather events. Cities globally are making changes to help mitigate the impact of climate change. The planting of trees is one immediate step that all cities can take to reduce what is known as the Urban Island Heat Effect. Singapore is one place where the greening of the city space is making a difference for all citizens. One spectacular project is the Supertrees installation engineered as vertical gardens. These gardens of the future have many benefits that make the area more livable and help to combat the impact of climate change. The 162,000-plus plants on the 18 steel tree structures provide shade and cooling. Some of the trees harvest rain water and solar energy and some are integrated with nearby buildings and serve as air in-take and exhaust towers. Aesthetically, these engineered trees, some reaching up 164 feet tall, are a stunning addition to Singapore's Gardens by the Bay city park. *Cities of the Future* audiences will marvel at these artistic engineering creations on the giant screen.



Alternative Energy

In 1941 science fiction writer Isaac Asimov described the idea of collecting solar energy in space and sending it to earth. Scientists explored the concept in the 60s and 70s. And now, researchers at Caltech in Pasadena, California are working on doing just that. They recently demonstrated a prototype for collecting solar power and transmitting the energy wirelessly through microwaves. This technology will allow for power availability on earth unaffected by weather or time of day. In this manner, solar power could be continuously available anywhere on earth.

This possibility is presented in *Cities of the Future* with CGI (computer-generated images) showing huge collection panels in space. New clean sources of energy, such as solar energy collected in space, and energy storage are key to combating climate change.

Autonomous Vehicles

Artificial Intelligence will have a tremendous impact on transportation systems of the future. Better connectivity and more precise data collection will improve transportation through smart technology. *Cities of the Future* features an innovative look at transportation in the future with CGI showing a transportation system composed of three levels. On the top level is a walkway with open skies, pedestrian walkways, bikes, scooters, and street vendors. The second level features an autonomous pod track where riders use their cell phone to call for a pod to pick them up and take them to their destination. The ground level is used for heavier vehicles like trucks for deliveries and freight. All the vehicles are autonomous and the entire system runs safely with smart technology. The film also shows how Amsterdam is introducing other autonomous vehicles, like Roboats, that are already being tested. In the future, a fully autonomous transportation system will transform cities and help alleviate traffic congestion.

High Tech Materials and Construction

Infrastructure and buildings are being transformed by new materials, 3D printing and other new manufacturing approaches. These innovations are going to revolutionize the way that the infrastructure of our cities is developed in the future. Amsterdam currently boasts the world's first 3D-printed stainless-steel bridge. This bridge is fitted with sensors to track stress and wear in the structure. This beautiful bridge, shown in *Cities of the Future*, shows that artistic design is also important to making our cities of the future more livable. Changes like using new ultra-light and ultra-strong materials will make a dramatic difference in how infrastructure will be built to last longer and better withstand disasters. Technology will be woven into all facets of traditional infrastructure including real time sensors to monitor many variables.

Smart Cities

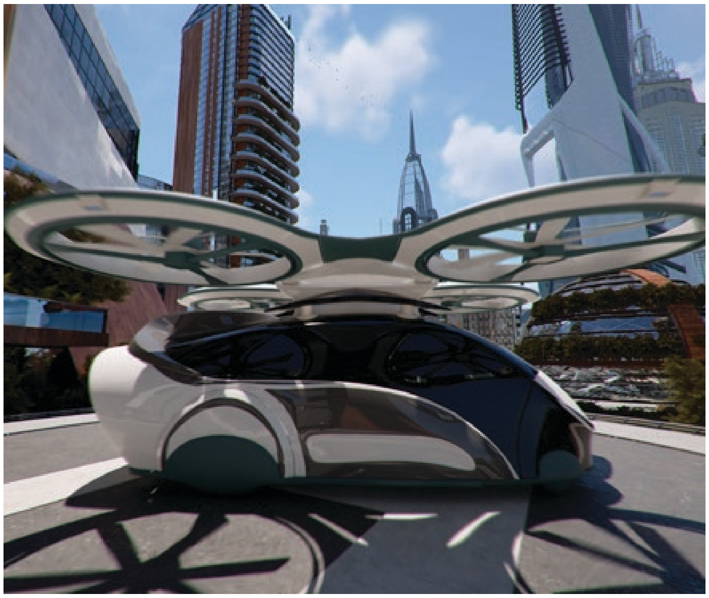
Engineers, architects, urban planners, and others are working to design highly responsive "smart cities" to adapt to life over the coming decades. While there's no official definition of a smart city, the term broadly means any municipality utilizing the latest technology including digital networks and reams of open data to manage resources, maximize space, become more energy-wise and environmentally friendly, strengthen social bonds, share vital information, increase equality, and overall make for happier, healthier places to live. But the future is now, as *Cities of the Future* dramatically shows that this is already happening across the globe. For example, in Amsterdam, an 80-year-old building has been retrofitted with sensors to "know" how many people are in any given location and adjust the heating, cooling and lighting appropriately. It is also "off the grid" with solar and other renewable sources of energy.

Public Policy

The climate change challenges that we face require interdisciplinary and multifaceted solutions. And achieving more favorable outcomes from any technology advances will depend on policy making, regulation and funding. In addition to engineers, infrastructure industry professionals, urban planners and policy makers, the public will play a key role in supporting the effort in practice and with funding. Amsterdam is a great example of this where giant contemporary wind turbines join the landscapes profile along with classic windmills and where bicycles outnumber people. A bicycle parking area that fills the giant IMAX screen in *Cities of the Future* clearly depicts the public support of green energy. It is a conscious collective decision about the sustainable and better future that they want.

An Incredible Future

The most resounding theme of *Cities of the Future* is that there is already so much creative engineering happening that will help build a more sustainable future. As filmmaker Greg MacGillivray sums up: "I'm really thankful to have discovered just how much planning and thinking is going on. A lot of it might not be visible to most of us, but behind the scenes there is a very strong push to take on the problems we are facing and not stop. Engineers and scientists are already producing results that are significant and foundational for what comes next. What we've seen happening has the potential to make all of our tomorrows not only possible but incredible."

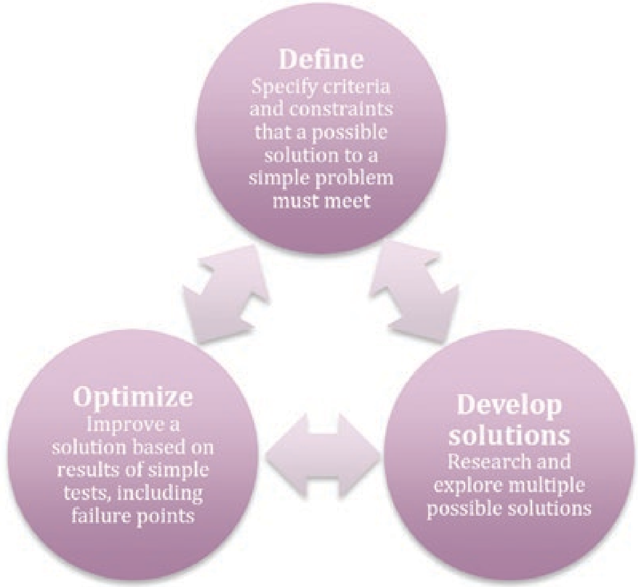


NGSS*: THE BRIDGE FROM THE FILM TO THE CLASSROOM

As engineering habits and mindsets become ever more essential for success in our technology-driven world — including for non-engineers—many states are choosing to adopt standards that introduce engineering within the science and math curriculum. The Next Generation Science Standards meet the needs of STEM educators wishing to teach engineering.

In addition to bringing the film's problem-solving strategies and many of its concepts into the classroom, all of these lessons align with the core engineering ideas and principles laid out in the NGSS framework. Specifically, each lesson includes a brief description of NGSS engineering core ideas and age-appropriate expectations for that skill. Lessons are designed to develop the student's ability to approach problems with the engineering mindset and create a solution. For more details on the specifics of age-appropriate development of the three engineering core ideas, see NGSS Appendix I at www.nextgenscience.org/resources/ngss-appendices

In the film *Cities of the Future*, we watch engineer Paul Lee rock climbing in Lake Powell, where he compares climbing to the engineering process. He says it's all about problem solving. You identify the problem, come up with different solutions and pick the best one. Much like science with its scientific method, engineering is a process of problem solving. In the scientific method, scientists attempt to answer questions about the natural world. Similarly, the engineering and design process centers around creating a solution to meet a need or solve a problem present in society.



NGSS identifies three major core ideas in the engineering problem-solving process:

1. Defining and delimiting engineering problems involves stating the problem to be solved as clearly as possible in terms of criteria for success and constraints or limits.
2. Designing solutions to engineering problems begins with generating a number of possible solutions and then evaluating potential solutions to see which ones best meet the criteria and constraints of the problem.
3. Optimizing the design solution involves a process whereby solutions are systematically tested and refined, and the final design is improved by trading off less important features for those that are more important.

Unlike steps in the scientific method, these are not sequential. Engineers move back and forth between these steps as they continue to test and refine solutions.

* Next Generation Science Standards ("NGSS") is a registered trademark of Achieve. Neither Achieve nor the lead states and partners that developed the Next Generation Science Standards were involved in the production of this product, and do not endorse it. Source: NGSS Appendix I: Engineering Design in the NGSS.

NGSS Science and Engineering Practices

Both scientists and engineers rely on a recognized set of methods to accomplish their work. NGSS defines these skills as the Science and Engineering Practices. These eight practices are defined as:

1. Asking questions (for science) and defining problems (for engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

If the engineering process is what engineers do (e.g., define problems and design solutions), then the engineering practices are the how. Engineering activities in the classroom should incorporate and develop these practices.

NGSS Engineering Practices In The Film

Cities of the Future is an excellent way to introduce these practices to students. The examples in the film help students to visualize how use of the practices plays out in the real world before they try using them in their academic work. Give students the challenge of finding examples of all eight practices in the film, and use the examples below to guide discussion afterward.

DEFINING PROBLEMS

At the beginning of the film, Paul Lee climbs a rock wall in Lake Powell. He compares rock climbing to the engineering process. Paul says, "I love climbing because it helps me problem solve. It's almost like an engineering problem. You make mistakes, you try a different solution, maybe you get a little bit stronger, maybe you get a tip from your friends. But eventually you solve the problem and you're up the wall." The constraints? Climbing a rock wall with all kinds of different crevices and holes. The solution? Try different ways to adjust your hands or the ropes or your feet. When you make mistakes, you try again, and maybe get help from a friend. Eventually you reach the top of the wall.

DEVELOPING AND USING MODELS

Paul Lee describes how the engineering team, looking for a solar energy solution for the LA100 program for the City of Los Angeles, came up with two different models. They looked at the photovoltaic solar array system and the central collector system used at Ivanpah Solar Electric Generating System. After testing, they determined that the photovoltaic solar array system was more effective.

PLANNING AND CARRYING OUT INVESTIGATIONS

Engineers at Joby Aviation test their eVTOL (Electric Vertical Takeoff and Landing) vehicle—an electric flying car!—to be sure it is safe and performs as expected. For safety reasons, the vehicle is flown by remote control instead of by a pilot during this experimental stage.

ANALYZING AND INTERPRETING DATA

Paul examines data showing progress towards reaching LA100's goal of using 100% renewable energy by 2045. Monitoring data lets engineers know if their solutions are performing as expected.

USING MATHEMATICS AND COMPUTATIONAL THINKING

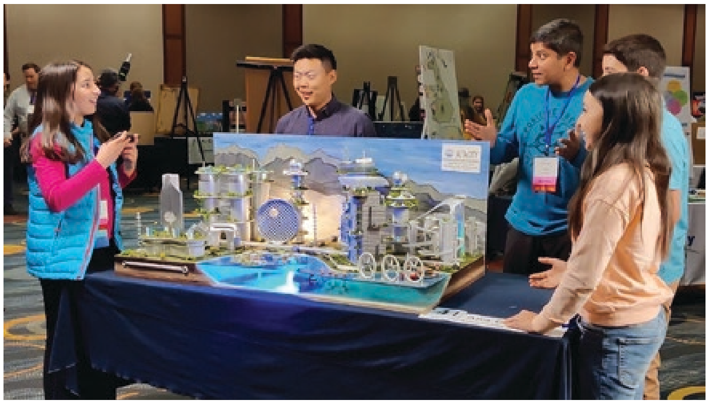
Amsterdam's high-tech autonomous ROBOAT navigates by using sensors, mathematical data and computations. It runs with smart technology—no driver needed!

DESIGNING SOLUTIONS

Singapore's engineers designed many innovative solutions to combat the intense heat, including a mirrored building facade that blocks half the sunlight from the building's windows; a park that is also a freshwater pumping station; and "trees" made of steel, concrete, and plants that cool and clean the air and generate solar power. Sometimes solutions to complex problems can be elegant and beautiful.

ENGAGING IN ARGUMENT FROM EVIDENCE

Much like engineers who must present their solutions to the city council for approval using engineering data as evidence, the middle school teams competing in the Future City Competition have to present their ideas for their future city models to the engineer judges, using evidence to back them up.



OBTAINING, EVALUATING, AND COMMUNICATING INFORMATION

At a news conference, the mayor of Los Angeles announces the release of an engineering study used to guide the city's plan to determine how long it would take for Los Angeles to operate on 100% renewable energy. They determined that the city could operate on 100% clean energy by 2045. Effective communication is critical to good engineering.

For an in-depth explanation of these eight practices, please refer to NGSS Appendix F and to Appendix I for Engineering Design: www.nextgenscience.org/resources/ngss-appendices

For more information on *Cities of the Future*, visit www.CitiesintheFuture.com

MEET THE ENGINEERS IN *CITIES OF THE FUTURE*

Introduce your students to the inspiring stories behind the engineers of *Cities of the Future*. The cast represents a diverse group of engineers who are called to work on the future of cities every day as they solve problems to create better lives for people worldwide.

PAUL LEE

Work: Former Energy Policy Analyst with the Mayor's Office of Energy and Sustainability of the City of Los Angeles and a Civil Engineering Associate at Los Angeles Department of Water and Power

Education: Master's Degree in Public Administration from University of California, Master of Science in Civil Engineering at UC Berkeley, Bachelor of Science in Civil Engineering at UCLA

Fun Fact: Paul danced competitively in breakdancing and hip hop in high school and college.

A civil engineer in Los Angeles, Paul Lee is always searching for new ways to harness energy from sustainable sources. His work involved planning resources for a 100% clean energy city for the City of Los Angeles. He has also worked on developing projects such as utility scale wind, solar, geothermal, biomass resources as well as energy storage such as batteries, pumped hydro, and other emerging technologies. In 2019, Paul was chosen as an ASCE New Face of Civil Engineering.

Paul had little idea of what starring in an IMAX movie might entail, but he was already a big fan of MacGillivray Freeman Films' work. "I absolutely loved *Dream Big*," he says, "and so did my friends, and we all enjoyed showing it to school kids all over L.A. and seeing their positive reactions. So, when they asked me if I would be part of *Cities of the Future*, I just had to say yes."

MONICA MORALES

Work: Water Resources Engineer and Project Manager for Jacobs, a global consulting firm largely focused in engineering

Education: Bachelor of Science in Civil Engineering and Master of Science in Civil Engineering with a minor in Water Resources Engineering from Oregon State University (as a first-generation college student)

Fun Fact: Monica received a City of Los Angeles Certificate of Recognition from the Former Mayor of Los Angeles, Eric Garcetti for her work inspiring students. Monica loves oil painting photos she has taken during hikes with her husband and dog using a triangulation method (a process she learned from her engineering coursework, specifically GIS).

Monica Morales, a fellow 2019 ASCE New Face of Engineering honoree along with Paul Lee, is helping Southern California face its challenges in the essential field of water and wastewater engineering. Currently working for Jacobs, she is focused on plans to create more independent and sustainable water resources within the greater Los Angeles area, especially through potable reuse and groundwater remediation. Monica previously worked at CH2M on an engineering team to help solve future drought concerns in San Diego. A passionate organizer, she also served as Dream Big Committee Chair on the Los Angeles Younger Members Forum of the ASCE.

DINIECE MENDES

Work: Director, Office of Freight Mobility at New York City Department of Transportation

ASCE Role: Transportation & Development Institute, Appointed Board of Governor

Education: Bachelor of Science in Civil Engineering from City College of New York

Fun Fact: High-school Valedictorian, Science Skills Center High School (Brooklyn, NY). Proud Afro-Caribbean immigrant, hailing from the beautiful twin isle of Trinidad and Tobago.

Diniece Mendes brings her background as a civil engineer with extensive experience in transportation to *Cities of the Future*. Currently based in New York, she serves as ensuring individuals, businesses, and communities have equitable access to the goods they need without compromising livability. Diniece is most passionate about educating, elevating, and empowering changemakers to advance humanity, as well as increasing the diversity and inclusion of underrepresented groups. She was elected to the 4-year position on the ASCE Transportation & Development Institute's (T&DI) Board of Governors and has held several leadership positions in ASCE's T&DI.

PEYTON GIBSON

Work: Senior Business Consultant for the Architecture, Engineering, and Construction sector at Autodesk in Amsterdam, Netherlands, where she specializes in using technology to improve and measure the well-being impacts, social value, and sustainability of cities. Based in Amsterdam, she works with global, European, Middle Eastern, and African companies.

Education: Bachelor of Science in Civil Engineering from Colorado School of Mines, Master of Science in Transportation Engineering and Public Policy from University of Colorado, Denver, Master of Science in Spatial and Urban Economics from VU Amsterdam

Fun Fact: Peyton is the Events Director of the Amsterdam Triathlon and Cycling Club, participates in the triathlon occasionally and also enjoys writing essays for the John Adams Institute about her life abroad.

Peyton Gibson became an engineer to help communities live higher-quality, happier lives in their built environments. She moved to the Netherlands on a Fulbright grant to study spatial, transport, urban, real estate, and environmental economics in 2021. With a unique background as an Army brat, civil engineer, and economist, she brings a unique perspective to her work.

VIGNARAJH KANESATHURAI KURUKKAL (RAJH)

Work: Senior Director, Program and Project Management at APAC & ME in Singapore

Education: Mini MBA - Executive Management Program in Engineering Leadership, Nanyang Business School, Nanyang Technological University (NTU), Singapore. Bachelor of Science in Engineering - Civil Engineering, University of Peradeniya, Sri Lanka

Fun Fact: Rajh has multiple achievements in running, including completing two marathons in a single day, running the fastest marathon in 2 hours, 57 minutes and 10 seconds, and the fastest half marathon in 1 hour, 10 minutes and 43 seconds, and the fastest 1km race in 2 minutes and 50 seconds.

Vignarajh Kanesathurai Kurukkal "Rajh" is a civil engineer and Singapore citizen who works in the construction industry across Southeast Asia and the Middle East. His focus has been on introducing innovative ways to implement sustainability in all his projects and designs. Rajh has been involved in such large-scale projects as Singapore's Marina Bay Sands, the UAE Dubai World Expo 2020, China Macau's "City of Dreams" development, Singapore's underground metro infrastructure, Malaysia's underground infrastructure, Vietnam's VietinBank Tower, Saudi Arabia's underground metro development and more.

Grades 1-3

2.5 hours

LESSON PLAN 1:

DAYLIGHT IN A BOTTLE

THE BIG IDEA

Engineers are constantly looking for ways to bring natural daylight into buildings. It saves power and fuel for everyone. This concept is called "daylighting." Students will experiment with radiant energy and the concept of refraction to develop a lighting system made out of recycled materials. Water bottle–based systems like the ones students create in this activity are in use in several impoverished areas.

IN THE FILM

In *Cities of the Future* we see how cities will no longer rely on the traditional electric grid for its energy. In Amsterdam, an 80-year-old building is now off the grid and generates its own electricity via renewable sources including solar power, thanks to innovations designed by engineers. Another approach that engineers use to save energy is to bring natural sunlight into the interior of buildings, reducing the need for electricity and making them more energy efficient. During this design challenge, students will experiment with ways to make similar devices to light the homes of those in need.

NGSS DISCIPLINARY CORE IDEAS

1-PS4.B Electromagnetic Radiation

Objects can be seen if light is available to illuminate them or if they give off their own light.

NGSS ENGINEERING PRACTICES

1-LS1-1 Crosscutting Concepts Influence of Engineering, Technology, and Science on Society and the Natural World

Every human-made product is designed by applying some knowledge of the natural world and is built by using materials derived from the natural world.

KEY WORDS/VOCABULARY

Daylighting: The idea of using skylights, mirrors, or other devices to bring natural daylight into a building.

Illumination: Lighting, or light. The light that comes into a room, or that shines on something.

Opacity: Not allowing light to pass through. If something has a high degree of opacity, no light can get through. If it has a low degree of opacity, a lot of light can get through.

Opaque: A material that light is not able to pass through. Roofs and walls made of wood or stone are opaque.

Refraction: The bending of light as it passes through one material into another. Light bends a little when it moves from the air into water, for example.

Translucent: A material that light is partially able to pass through. Ice is translucent; so is frosted glass.

Transparent: A material that light is fully able to pass through. A window is transparent.

TEACHER PREP NOTES

Before beginning this lesson, collect empty water bottles. For the research component of the activity, each pair of students will need one empty .5L water bottle and one empty water bottle that has been painted on the outside.

For the construction component of the activity, each pair will need an empty .5L water bottle marked with a black permanent marker line around the middle. The line is to indicate how far you will place the bottle into the box.

Prior to introducing the challenge to students, build the testing box using the Making the Testing Box instructions.

Be prepared to explain the vocabulary terms in this lesson. Be able to relate these terms to the students' experiments with different substances in water bottles and the way those substances affect how they see a picture.

TO DO

Determine the Problem or Question to Solve: ⏱ 15 minutes

1. Before watching *Cities of the Future*, give students an overview of what they are about to experience. This film is about engineering and the ways that engineering can inspire, challenge, and enrich our lives. Give students the following questions to think about as they are watching the film:

MATERIALS

Per class:

- Making the Testing Box instructions
- Testing box:
  - Large cardboard box
  - Box cutter
  - Piece of black cloth or felt large enough to drape over a child's head
  - Duct tape
  - 3 images
  - Means of darkening the classroom
  - Computer and projector for showing a YouTube video

Per student:

- Light in a Bottle Testing Sheet
- Pencil

Per group:

- 1 empty .5L water bottle, with cap
- 1 empty .5L water bottle, with cap, painted on the outside
- 1 empty .5L water bottle, with cap, with a line marked around the middle
- Simple black-and-white picture that students can use during testing of the light
- Flashlight
- Water
- Vegetable or olive oil
- Food coloring
- Funnel

- How do you think people used to light their houses before electricity was invented?
- Why do you think natural sunlight might be better than electricity for lighting a house during the daytime?
- If you didn't have electricity to light up your home, what would you do?
- Why do you think some people don't have electricity to light their homes?

2. Debrief as a whole class after viewing the film. Encourage students to reflect on the guiding questions you gave them.
3. Introduce the design challenge. Explain that today, students will be engineers who figure out a way to bring sunlight into a room without using electricity, and by using recycled materials.

Research and Gather Information:

⏱ **60 minutes**

1. Make the classroom as dark as possible (turn off lights, and draw shades or close blinds if possible). Ask students how well they can see. Open the shades but keep the electric lights off. Is it any better? Are there any places in the room where it's too hard to read or work? Elicit responses to what they would do if they had to get dressed, eat, or work in a dim or dark room, and then explain that this is exactly what many children and families who can't afford electricity have to do every day in countries all around the world. Today, they will try to come up with a way to make life better for people in this situation by making a room light without electricity.
2. Show the following video: https://youtu.be/hPXjzsXJ1Y0. It shows how simple plastic "light bottles" are acting as valuable indoor lamps for people who don't have access to electricity in urban slums. Ask students to explain, as best they can, how these interior lights are made. Tell students that during this engineering challenge, they will explore how to make the best "Light in a Bottle" using materials available at school.
3. Divide students into pairs. Give each pair a .5L water bottle, a black-and-white picture of something very simple, and a flashlight. Tell students to prop the picture up against some books or a wall. Distribute the Light in a Bottle Testing Sheet to each student, along with a pencil. Make sure the students understand what they are supposed to write or draw on this testing sheet. You might write down words that they could use in their descriptions, such as *wavy*, *blurry*, *fuzzy*, and *clear*.
4. Instruct students to experiment with how light travels through their soda bottle (filled only with the air inside) by turning on the flashlight and shining it through the bottle toward the picture. Ask students to describe what the black-andwhite image looks like as it is illuminated through the water bottle. Ensure that students understand the term *illuminated* as you use it in context.
5. Afterward, have the students fill the water bottles with water. Have them repeat the procedure, shining the light through the bottle and recording what they see of the black-and-white image.
6. Have students repeat the procedure three more times, once with a half-filled bottle of vegetable oil, once with a half-filled bottle of water with one drop of food coloring, and once with a bottle half filled with water and five drops of food coloring. Note: Depending on your students, you can choose to have them pour the new test material into the bottles, or you can have prefilled bottles available. Each time, have students use their testing sheet to record how the different substances affect the illumination of the blackand-white image. Finally, have students repeat the experiment using the bottles that have been painted on the outside. They should write down their findings for this step as well.
7. Talk about the terms *translucent*, *transparent*, and *opaque*. Ensure understanding by asking students to use these terms as they describe their findings. Talk about the concept of refraction and how that relates to the water bottles full of air, water, and oil. Explain that refraction is the principle behind why they were able to move light to the image in different ways.

Plan a Solution: 30 minutes

If students are unfamiliar with the concepts of criteria and constraints in engineering, take the time now to introduce these two key fundamental ideas. Engineers look at challenges through the lens of criteria (what does my device have to do?) and constraints (what are the limitations I face in making, testing, and using the device?). Spend some time as a whole class brainstorming the criteria and constraints of this particular engineering challenge.

Instruct each pair to draw a plan for what they think is the best combination and amount of materials (water, oil, paint, and food coloring) for their bottle, to make it light up a room by making use of sunlight. This plan should reflect the work conducted during the research stage and should demonstrate their understanding of light and refraction.

Make It: 15 minutes

Once students have drawn their plan, tell them to assemble the best version of their daylighting device. Visit each group and review how their experiences with the flashlight shaped their overall design and plan. If students are making obvious mistakes, allow them to continue and learn from those mistakes. Avoid offering solutions and instead encourage students to develop a secondary plan that demonstrates the evolution of their ideas and experiences.

Test: 20 minutes

Using the cardboard box you assembled beforehand, place student daylighting devices in the top hole, one at a time. Allow the students to look through the viewing hole into the box. You can either shine a flashlight onto the daylighting device while inside the classroom or take it outside to test with the sun!

Evaluate: 10 minutes

Allow students to think about and discuss the following questions:

1. Does your daylighting device illuminate the interior images of the box?
2. How does your daylighting device compare to the ones created by other teams?
3. How would you make it work better?

TAKING IT FURTHER

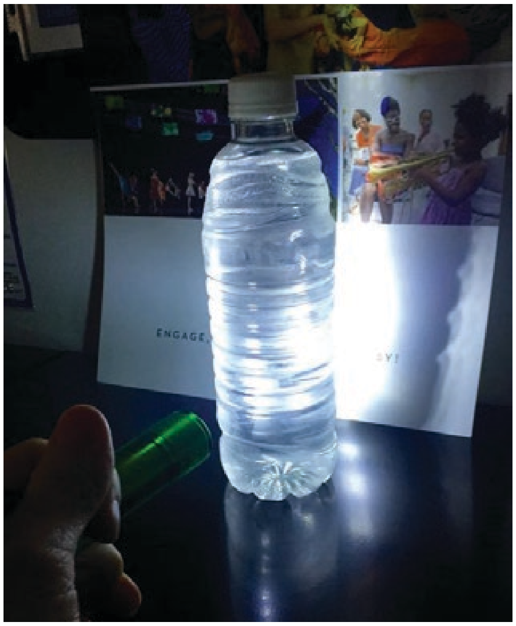
Using littleBits electronics, develop a light meter that can be used by the students to gauge the success of their daylighting device, or use a Vernier Probe Light Sensor to measure their device's output.

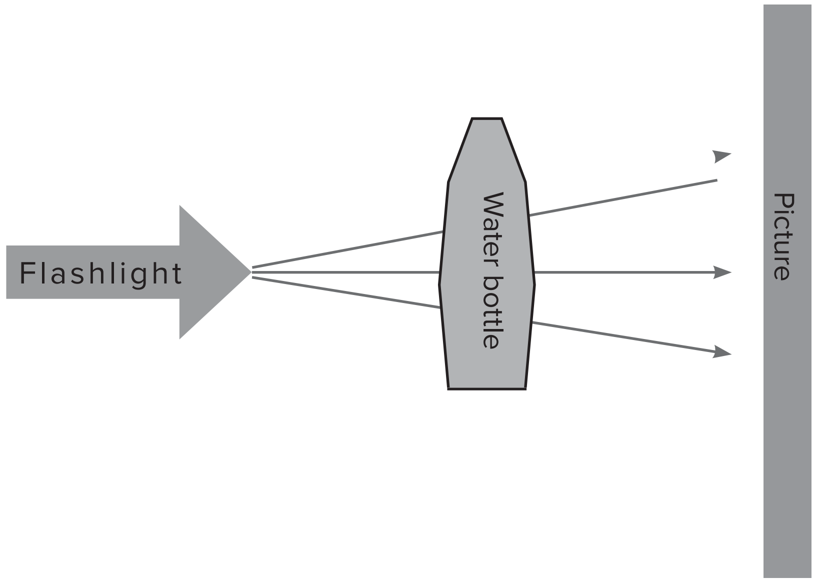
Engineers are exploring how to make current lightbulbs more efficient. Compare the new technologies that are in development to light our future: LEDs, MITs incandescent bulbs, and lasers. Explore the Liter of Light Project deeper through the following link to the My Shelter Foundation—Global Lighting Project: sculptthefuturefoundation.org/portfolio/my-shelter-foundation-global-lightingproject/.

Document your students' work through our social media outlet: #dreambigfilm

LIGHT IN A BOTTLE TESTING SHEET

Prop a black-and-white picture up against some books or tape it to a wall. Place a water bottle 6 inches in front of it. Turn off the light to the classroom and turn on a flashlight. Shine the flashlight through the water bottle and onto the picture and record what it looks like!





1. Empty bottle:

2. Full water:

3. Half full with oil:

4. Half full with water and 1 drop food coloring:

5. Half full with water and drops food coloring:

6. Painted outside of bottle:

MAKING THE TESTING BOX: INSTRUCTION SET

Prop a black-and-white picture up against some books or tape it to a wall. Place a water bottle 6 inches in front of it. Turn off the light to the classroom and turn on a flashlight. Shine the flashlight through the water bottle and onto the picture and record what it looks like!

1. Print three images of your choice to tape on the inside of the testing box. Students will use these images to determine and describe the amount of light illuminating the interior of the box when they test their device. The images can be of anything as long as they have enough detail for students to describe when light hits them. Suggestions are your school's mascot, a picture of someone's room, and so forth. Tape one picture on each interior side of the box, leaving one side blank. On the exterior of the box, mark the sides that have pictures so that you know their placement later.
2. Seal the box openings with duct tape to create a light-tight box.
3. On the top of the box, cut a 2.5-inch diameter hole. (This is the standard diameter of most .5L water bottles. If you are using bottles with a different shape or size, measure their diameter and cut a hole slightly smaller than that diameter for the bottle to fit snugly into.)
4. On the side of the box that you did not mark as containing an internal image, cut a viewing rectangle that is 6 inches wide and 2 inches high. This viewing rectangle should be about 1 inch above the bottom of the box.
5. Measure and cut a piece of black cloth that is slightly larger than the side of the box with the viewing hole.
6. Tape the cloth to the side of the box so that students must place their heads beneath it to look through the viewing hole when the box is resting on a table.

MATERIALS

- Cardboard box (the larger the better)
- Box cutter
- Black cloth or felt
- Duct tape

GRADE 1 MATH

Light Chart

15 minutes

THE BIG IDEA

In the Daylight in a Bottle activity, students experiment with making a recycled water bottle capture daylight and transmit images as clearly as possible. This math activity gives them a chance to put the classroom results into categories and to make comparisons. Students explore answers to these questions:

- Which one of my light bottles made the clearest image inside the testing box?
- How do my results compare with the results of my classmates?

LEARNING OBJECTIVES

- Demonstrate the ability to organize, represent, and interpret data in three categories
- Compare and contrast data points across three categories
- Evaluate data across three categories to determine which bottle produces the clearest image when light shines through it.

PREPARATION

This activity requires completion of the Daylight in a Bottle Activity. Students will use the data collected from the activity to create their chart.

MATERIALS

Per class

- Paper or board space for making a class chart
- Writing implements for class chart
- Daylight in a Bottle activity supplies

Per student:

- Paper cutout of a light bulb
- Daylight in a Bottle activity supplies

INSTRUCTION

1. In step 6 of the Daylight in a Bottle activity, student pairs test the quality of light as it passes through bottles half full of different substances and record their results on their testing sheets. Once they have completed all of their tests, give each pair the cutout of a light bulb. Direct each group to read through the notes they took. Then tell them to place the light bulb cutout next to the bottle that transmitted the clearest image.
2. On a large piece of chart paper or the board, create a chart with the following headings: Plain Water, 1 Drop Food Coloring, 5 Drops Food Coloring, and Oil.
3. Invite each pair to come to the board and place an x in the category that matches the one where they placed the light bulb cutout.
4. Together, count the number of x's in each category and write down the total at the bottom of each column

EVALUATION

After the counting is completed, hold a class discussion around questions such as the following:

- Did most of the teams achieve the same results? Why or why not?
- Were there other categories we could have used to compare results? What would they be?
- What other substances would be worth testing to see if they create clear illumination

ACTIVITY EXTENSIONS

- See if results are different if substances are tested in glass jars instead of plastic bottles.
- Create a bar graph displaying results from the classroom chart.
- Ask students to brainstorm reasons why they may have had different “best” outcomes. What might groups have done differently from each other? How could you fix those? Then have the students run each of the experiments again and compare their results from the first round to the second round.

OTHER IDEAS FOR MATH

Here are a few more ways to connect the Daylight in a Bottle lesson with your math curriculum.

- Have students practice measuring by placing different quantities of liquid in each container
- Use different shaped containers to explore volume. Have students predict which containers hold more water and then measure the volumes to find the results.

GRADE 1 ENGLISH LANGUAGE ARTS

Sources of Light

30 minutes

THE BIG IDEA

In the Daylight in a Bottle activity, students experimented with making a recycled water bottle capture daylight. In this activity, students become aware of the way light is written about in stories and whether the source of the light is natural or human-made. Students think about these questions:

- What kinds of light are written about in stories?
- Where do different kinds of light come from?

LEARNING OBJECTIVES

- Identify the sources of different types of light from clues in stories
- Describe the ways light is written about in stories
- Distinguish between human-made and natural forms of light

PREPARATION

Set context for students by holding a brief class discussion about the Daylight in a Bottle activity. Ask them to remember why engineers are creating ways to capture light from the sun in order to illuminate people's homes. To check understanding, ask, "What are the lights in our classroom powered by?" Make sure students grasp that their school and homes are lit by electricity, a human-made form of light, rather than by sunlight, which is natural.

Tell students that light can be the subject of stories too—all kinds of light. Ask students to share the names of stories or books they know that talk about light. In this activity, they will try to figure out how many different kinds of light they can find in one story.

MATERIALS

Per class

- The read-aloud book *The House in the Night* by Susan Marie Swanson
- Chart paper, enough for every three or four students

Per student:

- Drawing supplies

INSTRUCTION

1. Tell students that you are about to read a book called *The House in the Night* aloud to them. As you read, ask them to notice every time a kind of light is mentioned or shown in a picture.
2. Pause at each page spread to give students time to think about whether a source of light is written about or shown. For example, in the beginning of the story is a page with the text, "In the house burns a light." Students should note the word "light" in the text; they should also see the sun coming up in the picture as well as the light emanating from the windows of the house. Keep a cumulative list on the board.
3. After you read the story, ask the class to review with you all the different kinds of light that were in the story (sunlight, starlight, moonlight, as well as light from electricity).
4. Ask which of these kinds of light are made by people? Encourage students to think about how many sources of light occur naturally, even though people depend so much on light from electricity. Remind them of the engineers in Dream Big and the one in the video who was bringing sunlight to people who did not have any electricity.
5. Organize students into groups of three or four and give each group a sheet of chart paper. Distribute drawing supplies. Ask students to draw all the different sources of light that they can think of. Beyond the ones in the story, they might think of flashlights, fireflies, campfires, lightning. Ask students to write an "N" next to any natural light source on their paper and a "P" next to any light source made by people.
6. Ask each group to take turns holding up their chart papers so that the rest of the class can see how many light sources they drew. Ask students to point to the light sources that are made by people and those made by nature.

CLOSURE

Ask students to explain what "human-made" means to them. Do they think a campfire is made by people or nature? There may be some disagreement. Point out that it depends on how you think about the word "human-made." How do students think engineers use that word? What about daylight in a bottle? Maybe something can be a little bit of both!

Encourage students to see that the question is not either/or, black and white.

ACTIVITY EXTENSIONS

- Read the story *The House in the Night* again, but this time focus on the words associated with light: burn, glow, shine.
- Ask students to think of some songs that are about light and sing them together. Options include "Twinkle, Twinkle, Little Star" and "This Little Light of Mine."
- Tell students a simple version of the biography of Thomas Edison, inventor of the light bulb.

BOOK CONNECTIONS FOR ENGLISH LANGUAGE ARTS

The following books relate to the Daylight in a Bottle activity and can be incorporated into your ELA curriculum.

Day Light, Night Light by Franklyn M. Branley

I See Myself by Vicki Cobb

On a Beam of Light by Jennifer Berne

The Storyteller's Candle by Lucia Gonzalez

Burn by Darcy Patterson

Grades 3-6

2 hrs 30 mins

CITIES OF THE FUTURE

LESSON PLAN 2:

BUILDING FACADE REFLECTORS

THE BIG IDEA

One of the effects of climate change is the creation of excess heat in cities, known as the “urban heat island effect.” This is where heat from crowded city structures gets trapped, exacerbating the most extreme heat waves. Students will build and test a structure with reflective materials designed to reduce heat and the effects of rising temperatures. They will use upcycled materials and found objects in order to reduce waste and help support a healthier planet.

IN THE FILM

In *Cities of the Future*, we visit the tropical city-state of Singapore where engineers are designing clever solutions to reduce the urban heat island effect and create energy-efficient buildings. These include adding reflectors to the facades of buildings to block much of the sun’s light and reduce heat.

NGSS DISCIPLINARY CORE IDEAS

ETS1.A: Defining and Delimiting Engineering Problems

ETS1.C: Optimizing the Design Solution

MS-PS4-2: Waves and their Applications in Technologies for Information Transfer

PS4.B: Electromagnetic Radiation

When light shines on an object, it is reflected, absorbed or transmitted through the object, depending on the object’s material and the frequency (color) of the light.

LEARNING OUTCOMES

- Students will learn how various materials reduce heat.
- Students will learn to engineer a building that can hold an intricate reflective facade.
- Students will learn to create artistic forms of architecture.

KEY WORDS/VOCABULARY

Architecture: The art and technical practice of designing and constructing structures, utilizing the skills of construction. Architects employ their expertise to create designs tailored to the specific requirements of clients, ensuring that the resulting structures are aesthetically pleasing, functional and aligned with the envisioned purpose.

Circular economy: A model in which the production and consumption of materials can be used to share, reuse, repair and recycle again in another way.

Engineering: The discipline dedicated to making things operate efficiently and effectively through creation, improvement and construction, with the goal of enhancing the well-being of society. Engineers work with the architect’s design and decide what materials must be used to bring the architect’s design to completion and to make the building strong enough for use.

Engineering design process: A series of steps that engineers follow to find a solution to a problem. The steps include ask, imagine, plan, create, test and improve.

Heat: Energy that is transferred from mass to another. Heat from the sun's energy is captured in the building.

Heat island effect: When cities replace natural landscapes with concrete spaces, buildings and other surfaces absorb and retain heat.

Heat transfer: When energy is exchanged between materials in the form of heat. For example, heat from the sun is captured inside buildings, making the buildings warmer.

Light: Energy that is detected by the human eye.

Recyclable materials: Materials that can be reused for other purposes.

Reflective surfaces: Surfaces that are shiny or glossy and bounce back light. This keeps the surface cooler.

Solar radiation: Electromagnetic energy given off by the sun; it is a form of heat.

Waste: Materials no longer being used.

MATERIALS

Per class:

- Plastic snack bags – different brands
- Various reflective upcycled materials or found objects
- Pieces of metal
- Glue and hot glue gun
- Tissue and cereal boxes
- Heat lamp (non-LED source)
- Popsicle sticks
- Thermometer
- Paper
- Pencil
- Scissors

TO DO

Teacher Prep Notes: 1 hour

Collect plastic snack bags and other recycled or upcycled materials that are reflective. Reflective surfaces are shiny or glass-like reflecting the light back. Collect empty cereal and tissue boxes, which will be used for creating "buildings."

Student Prep Notes: 30 mins

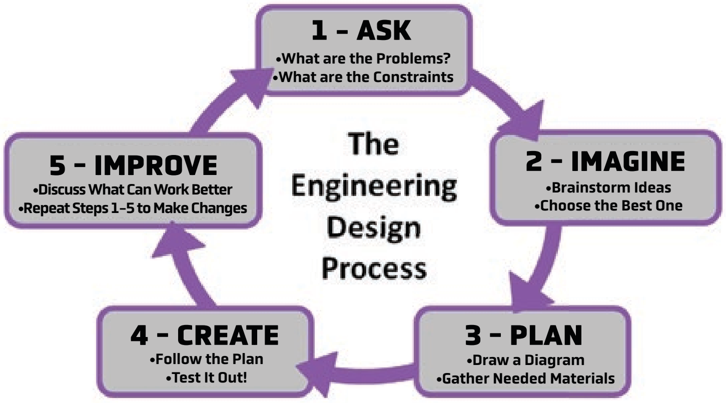
ENGINEERING DESIGN PROCESS

Discuss how climate change causes excess heat and how the heat island effects impact urban areas or cities that have less green space. Show students the files from the links below to discuss climate change and the rising levels in temperature. Discuss the engineering design process (see picture) as they think about constructing a reflective facade that bounces back light to reduce heat inside the building.

U.S. EPA: Learn About Heat Islands

U.S. EPA: Reduce Urban Heat Island Effect

13 Stunning Examples of Reflective Architecture



ASK: Prior to seeing *Cities of the Future*, students will be asked questions regarding how to design their buildings' reflective facade. The construction of the building is not the focus, but the reflective facade over the building needs to be thought about. Engineers play a crucial role in this process as they create the structure of the facade according to the architectural design. Ask them the following questions to get them thinking:

a. How will you cover as much area of your building as possible so that it reflects light?

b. How will heat be reduced?

c. What are the aesthetics that you want to see your building facade covered in?

d. How are the designs and materials attached to the building?

e. Will this attract people to your building?

f. What materials will help reflect heat?

After viewing the film, students will have a better understanding of how reflective surfaces work and how they can add beauty to a city.

PLAN: Students will develop a plan for their reflective facade by creating a drawing/sketch. Ask them to consider their favorite works of art, animations and designs. Encourage students to consider engineering materials that ensure both structural stability and effective heat reduction in the designed structures.

As a working group, students will decide what their individual role will be. Students should determine:

a. Who is the engineer designing the building and how will he/she ensure materials work together?

b. Who is the architect designing the reflective facade?

c. Who will engineer the reflective materials?

d. Who will construct/attach these materials to the building facade?

CREATE: Students will design and build their facade together. Instruct them to place designs on paper and create a template showing where they will be placed on the facade. Students should engineer materials together, such as string and popsicle sticks, to hang their designs in the same way that the reflective facade hangs over the buildings in *Cities of the Future*. Students should engineer an identical building without a reflective facade.

TEST: After students place their reflective facades on the buildings, they will turn the light source on and test the temperature. The temperature of the reflective facade on the building should be compared to a similar structure without a reflective facade. If the reflective facade building is at a lower temperature, then the deflection of heat has been successful.

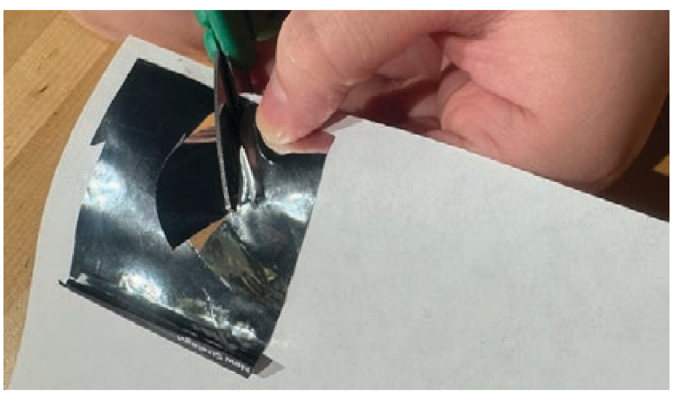
IMPROVE: Based on the results of testing, students will discuss and see how they can improve their reflective facades. They can continue the design process until their group is satisfied with its iterations of a reflective facade. The designs may need enhancements if alterations to the structure supporting the reflective facade are necessary.

Activity Part 1: 60 minutes

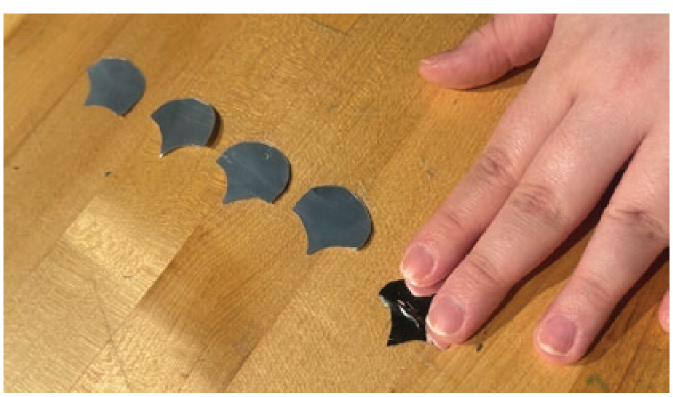
Students will be given directions to create two buildings of equal dimensions and shape. Incorporating architecture and engineering, students will receive instructions to attach reflective facades to a building as part of the design process aimed at reducing heat. The challenge and creativity are in the design of the facade and architectural design of the building to minimize heat loss.

1. Using cereal and tissue boxes, construct two similar buildings.

2. Glue the reflective materials to paper and cut them out according to the preplanned design.

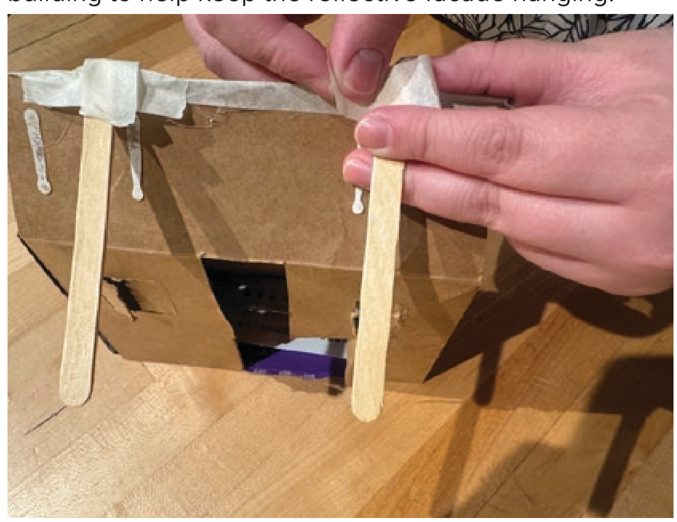


3. Arrange the cut-outs as planned.



4. Attach your designs and reflective surfaces to string, and then hang the strings from the building structure.

5. Popsicle sticks can be attached and hang off the building to help keep the reflective facade hanging.



Activity Part 2 – Test Building Facade Reflectors: ⏱ 30 minutes

Students will use a heat lamp over each of their buildings (with and without reflective facade) to see if there is a difference in temperature.

1. Place the heat lamp over the buildings (one building with the reflective facade and one without.)

2. Turn the lamp on and leave it on for approximately 10 minutes.

3. Record the interior temperature of the building without the reflective facade using the thermometer and time.

4. Repeat these three steps for the building witht the reflective facade.

If there is a difference between the temperatures, students should discuss why this occurs.

DATA TABLE

	Temperature Reading	Time Heat Lamp is on
Non-Reflective Facade		
Reflective Facade		

TAKING IT FURTHER

Cities of the Future showcases buildings that have reflective facades. In your classroom or school, choose a few outside facing windows and create a reflective facade from the inside of the classroom. Challenge the entire class to create a design and build a facade within your classroom window. Use the thermometer to test the difference between the window with a reflective facade and one without. Is there a temperature difference?

SUGGESTIONS FOR OTHER GRADE LEVELS

Lower Elementary (Grades K-2): Educators will prepare pre-constructed buildings of the same type. Students will design and cut a predetermined size of a reflective facade, attaching the reflective surface to the building. For kindergarten students, educators may provide pre-printed designs on paper for students to glue their reflective surface.

High School (Grades 9-12): After creating their buildings, students will test wind/air on the reflective facade, aiming for controlled movement to create an optical visual or illusion, similar to what is seen in *Cities of the Future*.

ACKNOWLEDGEMENTS

Lesson Plan created by the Museum of Discovery and Science, Ft. Lauderdale, FL.

GRADES 3-6

Civics

20 minutes

THE BIG IDEA

Investigate ways in which students can strengthen their cities with other solutions and community engagement. For example, students can discuss different ways that communities can offset the heat in urban areas. Direct students to incorporate additional materials to represent greenery near their buildings and test the temperature in the building. Is there a difference in the temperature?

EXTENSION ACTIVITY

Lead a discussion with students about possible heat islands in your community. What parts of their cities contain/distribute more heat? Generally, these are areas with limited economic resources and/or with a high concentration of low-income households. Work with students to develop a plan of action to reduce heat islands.

Follow the steps planners use within a city:

1. Facilitate the formation of valuable and enduring communities.
2. Provide improved options for the locations and lifestyles in which people work and reside.
3. Involve residents, businesses and civic leaders in actively contributing to the development of communities that enhance people's lives in a meaningful way.

As a class, students can host a community beautification workshop focused on improving architecture and building facades. Participants can engage in a simulated city planning exercise in which they assess locations around their city that are the hottest, strategize on effective response measures and collaborate to develop plans for safeguarding buildings against heat effects. How might this activity come to life in your city? Who are the people it will affect? How does this benefit your city economically? What buildings in your neighborhood would you like to visit, and would you go there more often if they were designed beautifully? What about park buildings or government housing?

Grades 3-6

2 hours

LESSON PLAN 3:

DRONES 101 (eVTOLs)

THE BIG IDEA

In *Cities of the Future*, electric vertical takeoff and landing (eVTOL) aircraft are used as transportation. Students will learn how these structures are engineered and will experiment with building an eVTOL drone using basic circuitry.

LEARNING OUTCOMES

- Students will learn how a simple drone is made and the directions of flight.
- Students will learn to create simple circuits.
- Students will learn about the mechanics of how the blades are placed so air moves below them.
- Students will understand Newton's third law of motion when applied to drones.

KEY WORDS/VOCABULARY

Advanced Air Mobility (AAM): Innovative air transportation solutions to address the growing demands of urban mobility.

Drone: Vehicle that moves in vertical takeoff, usually unmanned and controlled remotely from the ground.

Electric vehicle: Vehicle that uses electricity as a form of energy, unlike traditional gasoline vehicles.

eVTOLs: Electric vertical takeoff and landing aircraft.

Geofencing: Virtually created flight paths that adhere to boundaries. A geofenced drone can alert the person controlling it when it leaves the boundaries of where it is supposed to operate.

Global Positioning System (GPS): Worldwide navigational and surveying system that uses a network of satellites to locate and help guide transportation and vehicles.

Motor: A machine that converts electrical energy into mechanical energy. Motors will spin the blades in different directions to move the drone.

Newton's third law of motion: For every action there is an opposite and equal reaction.

NGSS DISCIPLINARY CORE IDEAS

ETS1.A: Defining and Delimiting Engineering Problems

PS2.B: Types of Interactions – The gravitational force of Earth acting on an object near Earth's surface pulls that object toward the planet's center.

5-PS2-1: Motion and Stability: Forces and Interactions – Support the argument that the gravitational force exerted by Earth on objects is directed down.

4-PS3-1: Energy – Use evidence to construct an explanation relating the speed of an object to the energy of that object.

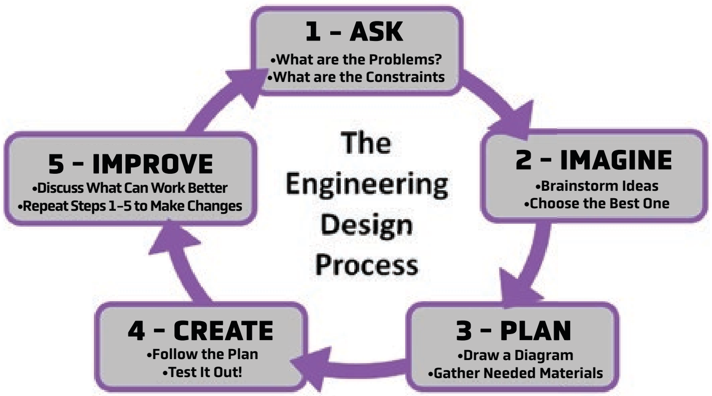
TO DO

Teacher Prep Notes: 1 hour

Depending on the students' age and dexterity skills, you may need to strip the wires ahead of time (suggested age is 12+ to use wire cutters safely.) Prepare students with videos about eVTOLs and advanced air mobility.

Student Prep Notes: ⏱ 30 mins

ENGINEERING DESIGN PROCESS



MATERIALS

Per class:

- Paper straws
- 2 DC motors. Recommended: Crazepony 3.7V @ 65,000rpm; shaft diameter: 0.8mm motor diameter: 6mm, motor length: 15mm
- 2 drone propellers, one with clockwise (CW) angle of attack, one with counterclockwise (CCW) angle of attack. Recommended: Gemfan 31mm Props 1208 3-Blade PC Propeller Micro Whoop Drone Props, 0.8mm hole diameter, 0.21g
- 4 AA rechargeable batteries (1.5V each)
- Battery holder for 4 AA batteries with switch and wire leads
- 30-gauge, two-color, electrical wire (8” piece)
- 1 plastic bottle cap
- Hot glue gun
- 30-gauge wire stripper
- Masking tape
- Electrical tape
- Scissors
- Wooden dowel, 1/8” x 12” small enough to go through the straw (can use a guide pole from Amphibious Houses)

Discussion in Advance of Activity:

⏱ 30 minutes

Discuss basic concepts of aviation, including lift, weight, drag and thrust. Explore Newton’s third law of motion and the differences between drones, helicopters and airplanes. Lead a discussion with students about eVTOLs and how they are used and how they are different from other common aircraft.

Ask: Prior to seeing *Cities of the Future*, explore the following questions:

a. What purposes do air taxis serve?

b. How do eVTOLs help society?

c. What similar modes of transportation exist?

d. How do drones move?

e. How do electrical circuits work?

f. Where are blades placed on drones, eVTOLs and helicopters?

After viewing the film, students will have a better understanding of how eVTOLs physically operate. They will be able to understand the importance that this mode of transportation has in relation to traffic, energy efficiency and economic impact.

Imagine: Before embarking on the design for a simple drone, students should think about the placement of the motors and weight distribution of materials. Is air moving upward or downward when the motors are powered on? If not, they should consider the flow of air needed to achieve vertical takeoff.

Plan: As a group, students will engineer and build a simple drone that can achieve vertical takeoff. To determine students’ role in the activity ask them the following questions:

a. Who is engineering the body of the drone?

b. Who is attaching the motors?

c. Who is wiring the electrical circuits?

d. Who is working on the vertical takeoff pole?

Create: First, students must construct the body of the drone. Second, they should consider the weight distribution of their drone and where to place the motors and blades. Next, students must create a vertical takeoff pole.

Test: Students will place their drones on their vertical takeoff pole. To do so, attach a straw to the middle of the drone body. Then, place the wooden dowel through the straw. As the drone is powered on, vertical takeoff occurs and the drone should be moving vertically. The air should be forced downward. As the blades spin, air is pushed downward toward the ground and the reaction is an upward force pushing the drone illustrated by Newton's third law of motion. Does the drone lift?

Improve: Students should reiterate the design process to make improvements or to challenge themselves further. Was the weight balanced in the drone?

Activity Part 1 – Make Drone:

60 minutes

Students will create a simple drone using basic electrical circuitry. They will work in teams to complete their drone.

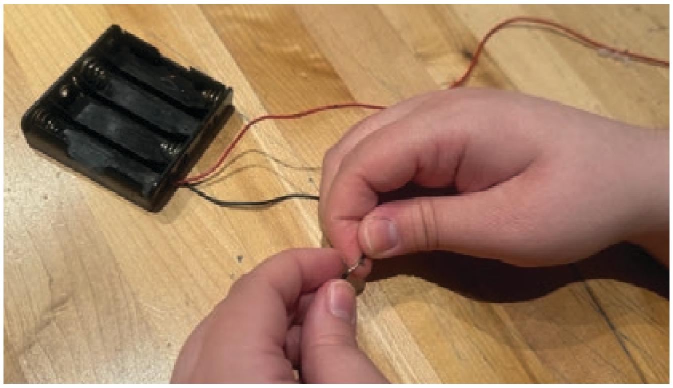
1. Cut a 4-inch piece of straw.

2. Hot glue the motors to the ends of the straw.

3. Place the right and left blades on top of the motors and across from each other at the same height to maintain balance.

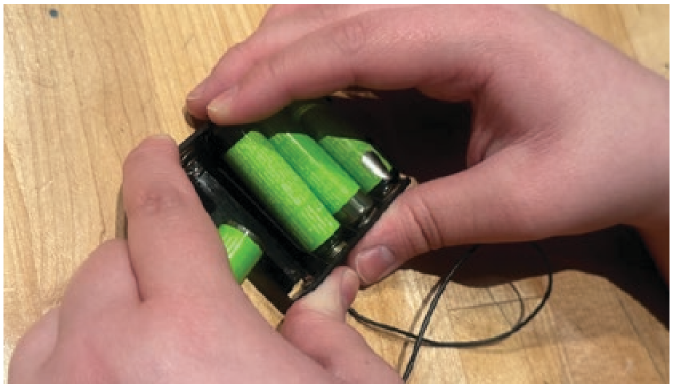
4. Cut a 1.5-inch segment of straw and attach it to the middle of the drone body, perpendicular to the body. You can use tape or hot glue to secure it.

5. Attach electrical wiring red to red and black to black. Twist the wires around each other like how you twist bread ties.



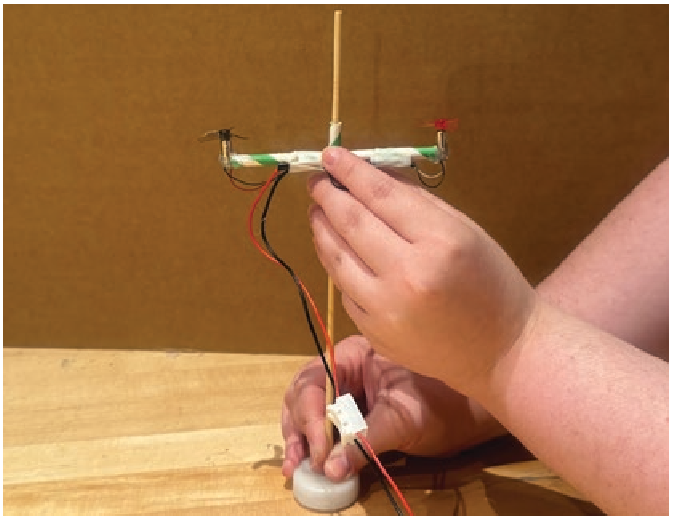
6. Wrap the exposed metal with electrical tape.

7. Place the batteries into the power supply.



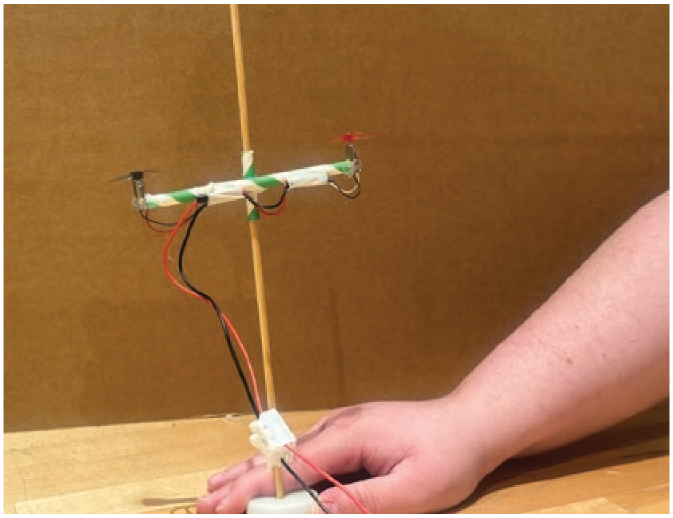
8. Using a hand drill, create a hole in the middle of the bottle cap. Attach a wooden dowel through the hole and use a hot glue gun to adhere it in place.

9. Place the wooden dowel through the straw that is attached perpendicular to the drone body.



Activity Part 2 – Test Drone: 30 minutes

1. Students will test their drones to see if they have vertical lift by attaching the blades and observing that the air is flowing downward. Try different brands of batteries with the same voltage to see if it impacts the power and vertical lift. Some brands have more power and can lift the drone with much more ease compared to others. Ask the students if their drone experienced vertical takeoff. If not, have students think about the weight and balance of their drone. Encourage students to review the design to make improvements.



TAKING IT FURTHER

In the previous activity, students constructed a drone with two blades. Take it further by having students engineer a drone with four blades. They will need to balance the blades so that right-handed blades are across from one another and left-handed blades are also across from one another.

SUGGESTIONS FOR OTHER GRADE LEVELS

Lower Elementary (Grades K-2): Educators will provide pre-constructed drones for students to test and comprehend vertical flight in movement.

High School (All Grades): Enhance the activity by having students develop a 4-motor drone.

ACKNOWLEDGEMENTS

Lesson Plan created by the Museum of Discovery and Science, Ft. Lauderdale, FL.

GRADES 3-6

Geography and Mapping

⏱ **20 minutes**

THE BIG IDEA

Students will plan an aerial highway, including vertiports and stops that eVTOLs can navigate within a city. Students can work on this activity alone or as a group, planning routes using coordinates on a map. They will develop an understanding of longitude and latitude to navigate the best route for eVTOLs.

IN THE FILM

In *Cities of the Future*, eVTOLs are featured flying around the cities, transporting people from one location to another. The eVTOL industry is predicted to take off between 2025 and 2030. Some suburban areas can have heavy traffic, and eVTOLs are one way to reduce traffic. The goal is to have people travel short distances in the air, so there are more eVTOLs and less traffic on the ground. eVTOLs are becoming more of a reality as an environmentally-friendly form of ridesharing.

KEY WORDS/VOCABULARY

Coordinates: Intersection on a grid or map that indicates location, such as (x, y).

Hop: Flight path to move passengers from one stop to another.

Latitude: Measures the distance north or south of the equator. Lines of latitude, also called parallels, are imaginary lines that divide the Earth on a map or y-plane. They run east to west but measure your distance north or south. The equator is the most well-known parallel.

Longitude: Lines of longitude, also called meridians, are imaginary lines that divide the Earth on a map or x-plane. They run north to south from pole to pole, but they measure the distance east or west. Longitude is measured in degrees, minutes and seconds.

Map: Visual representation of an area or land that shows buildings, roads and water.

Vertiport: An area in a city where eVTOLs can land and take off. Vertiports help move people and goods along and are used for charging eVTOLs.

MATERIALS

Per class

- Graph paper
- Ruler
- Pencil
- Markers
- Printed map of a city or community of choice

EXTENSION ACTIVITY

Experiment with identifying placements of a vertiport near your school. Discuss the concepts of longitude and latitude with your students. Encourage students to use maps.google.com to explore where their school is located.

1. Find your school on Google Maps (see link above) and right-click to identify the longitude and latitude location of your school at the top of the list. Right-click other locations that are on the same latitude to see how longitude changes and vice versa. Explore the location of major landmarks, especially tall buildings in relation to your school. On the printed map of your school, use one colored marker and a ruler to make vertical lines. Space them evenly and keep them about a half-inch apart. With another marker, do the same thing to make horizontal lines on the map. You can also lay the grid below over the map to make coordinates. See below for Grid Sample and click here for Printable Grid Paper.
2. Label each vertical line, starting with the number 1 and increase by single digits as you go.
3. Label each horizontal line, starting with the number 1 and increase by single digits as you go.

4. Choose a flat and open area on your map to place a vertiport. Vertiports should be on the top of a building that is flat. Look for current heliports on the map or choose buildings that are not so close to other tall buildings. Color this area with a different marker. Check to see all corner coordinates surrounding your school and check for the fences or limits to your school property. Write those coordinates down in the data table. Color in this area and use this information to create a geofence that eVTOLs should not pass through your school. Create a flight path for your eVTOL to location 3.

5. Choose five locations on your map, then color and label them with different markers.

6. Using the data table below, label the coordinates of each location, including your school.

DATA TABLE FOR COORDINATES:

Location	**X**	**Y**
School		
Vertiport		
Location 1		
Location 2		
Location 3		
Location 4		
Location 5		

8. Start at the vertiport. You want to ride an eVTOL to location 3. How many spaces do you hop to that location? If you are moving right or upward, the number stays positive. If you are moving left or downward, the number is negative. The number of spaces you move horizontally is placed in the X column and the number of spaces you move vertically is in the Y column. Record this data. Try plotting a flight path from a new starting point to additional endpoints.

Starting location	**Final location**	**Coordinates moved (X,Y)**	**Was the flight path in a straight line?**	**Was the geofenced area on the way from the starting location to the final?**
Vertiport	Location 3			
Location 3	Location 5			
Location 1	Location 2			

GRID SAMPLE

DISCUSSION

Students should discuss:

a. How does mapping and geography help you understand the movements of eVTOLs and other transportation?

b. Does hopping with coordinates on a grid help you understand how an aerial highway might work?

Grades 3

85 minutes

MacGillivray Freeman's CITIES OF THE FUTURE

LESSON PLAN 4:

MAGLEV TRAIN

THE BIG IDEA

Most forms of transportation rely on fuels that come from oil, called fossil fuels. This type of fuel can be expensive because it comes from a source that is not renewable (the less there is of it, the more precious it is, and the more expensive it becomes). Fossil fuels can threaten our environment because they must be extracted from the earth and they pollute our air.

Thus, engineers are working to make transportation systems more green. Students will learn about one method as they design a train that can move three feet without making physical contact with the track. Magnetism provides the force required to levitate the train over the tracks, reducing the energy required to move the train.

IN THE FILM

Transportation in the modern world is becoming a challenge as the population continues to grow beyond the capacity of the highways that once allowed civilization to flourish and expand. Today's engineers are working on new innovations in transportation that will reduce congestion and energy consumption, like maglev trains, bullet trains, and electric flying vehicles (eVTOLS), to move people and goods more quickly, more safely, and with less dependence on fossil fuels. Within cities there will also be a track for "autonomous pods" for affordable mass transportation through the city. The pods will be electric and use little or no energy, and will be operated by smart technology or AI.

NGSS DISCIPLINARY CORE IDEAS

3-ESS3-1 Crosscutting Concepts

Influence of Engineering, Technology, and Science on Society and the Natural World

Engineers improve existing technologies or develop new ones to increase their benefits, decrease known risks (fossil fuel consumption), and meet societal demands (greater mass transit).

NGSS ENGINEERING PRACTICES

3-PS2-3 Ask questions to determine cause and effect relationships of electric or magnetic interactions between two objects not in contact with each other.

3-PS2.B Types of Interactions

Objects in contact exert forces on each other.

Electric and magnetic forces between a pair of objects do not require that the objects be in contact. The sizes of the forces in each situation depend on the properties of the objects and their distances apart and, for forces between two magnets, on their orientation relative to each other.

KEY WORDS/VOCABULARY

Attractive force: A force that attracts objects toward each other.

Fossil fuel: An energy source that is produced through the million-year decomposition of dead organic material, such as trees and animals.

Magnetic force: The attractive or repulsive force that exists between two bodies that contain a magnetic charge.

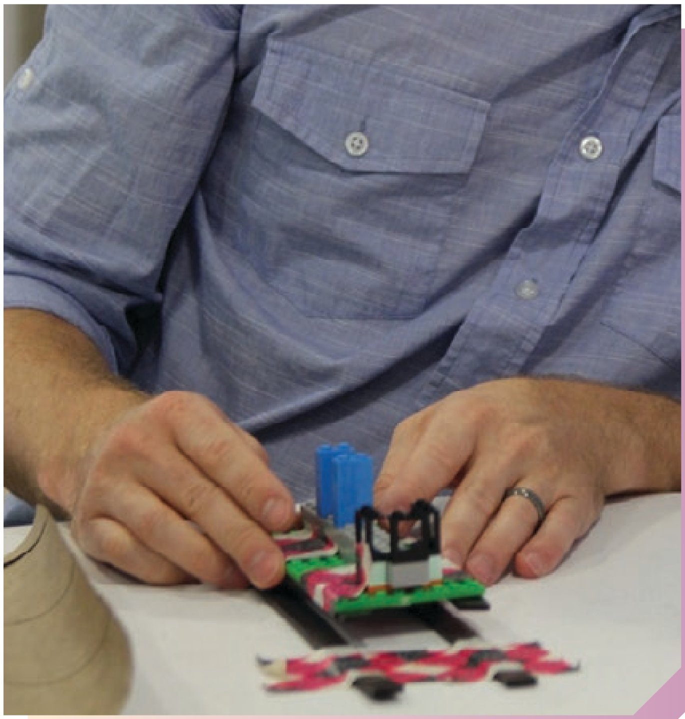
Repelling force: A force that pushes two or more objects away from each other.

TEACHER PREP NOTES

Preassemble track segments beforehand. You will find a template for tracing with the Track Assembly Instructions sheet (included later in this lesson plan). You can build just a couple as a class set for testing or build one track per group. The tracks are reusable.

Cheap and varied magnets can be sourced online from common vendors like Amazon or from your local craft store.

Be prepared to discuss how magnets work. You will also give a basic overview of how the maglev train in Japan uses magnets to float and accelerate trains. (For quick reference: web-japan.org/kidsweb/hitech/maglev).



MATERIALS

Per class:

- Track Assembly Instructions sheet
- Track template
- Video capture device (optional)

Per student:

- Bar or disc magnets
- Paper

Per group:

- Paper
- Pens or pencils
- Cardstock paper
- Scissors
- 6 inches of magnetic tape
- 4 disc magnets
- 4 bar magnets
- 1 foot of tape
- Washers for weight during testing
- Preassembled train track:
  - Cardboard
  - Track template
  - Scissors or box cutter
  - Strong tape
  - Magnetic tape
  - Glue gun or glue

TO DO

Determine the Problem or Question to Solve: 15 minutes

1. Before watching *Cities of the Future*, give students an overview of what they are about to experience. This film is about engineering and the ways that engineering can inspire, challenge, and enrich our lives. Give students the following questions to think about as they watch the film:
   - How is transportation shown and talked about in the film?
   - What role do engineers play in shaping our future modes of transportation?
   - What are some of the trends you see with future transportation?
2. Debrief as a whole class after viewing the film. Allow students to reflect on the guiding questions you gave them.
3. If necessary, remind students of some of the current challenges we face regarding transportation. These include too many vehicles on the roads, which causes traffic; safety concerns; and using fossil fuels, which pollute the air, water, and ground.
4. Introduce the design challenge. Sixty years ago, there weren't nearly as many people as there are today. When suburban neighborhoods were built around a city center, people could comfortably and safely travel back and forth to work each day. But as populations have increased, so have the number of cars on the road. Today we face long commutes in slow traffic, back and forth between our jobs and homes. Unfortunately, some public transportation services, like buses, are bogged down with the same challenges. Engineers are working now to develop solutions to these challenges. One of the methods of transportation being reimagined is trains. Imagine a train that can travel incredibly fast, yet be safe and consume very little energy from fossil fuel sources—or none at all. Today you will reimagine the way trains work and the potential they may have as a future form of public transportation.

Research and Gather Information: 20 minutes

1. First, give students time to experiment with magnets. Have bar or disc magnets available. Ask students to arrange the magnets so that they can hold a piece of paper in between them. Then ask the students to arrange the magnets so that they push away from each other. Explain the concepts of magnetic force having a negative and positive end (magnetic polarity). Demonstrate the repulsion of positive-positive and negative-negative interactions and the attraction of positive-negative interactions.
2. Students should attempt to float or hover an object with the bar or disc magnets. Note the challenges of doing this. The magnets will flip over so that the opposite sides attract and attach to each other, for example, or the magnets will fly away to the side rather than stay suspended.
3. Give a basic overview of how the maglev train in Japan uses magnets to float and accelerate trains. (For quick reference: web-japan.org/kidsweb/hitech/maglev).

Plan a Solution: 15 minutes

If students are unfamiliar with the concepts of criteria and constraints in engineering, take the time now to introduce these two key ideas. Engineers look at challenges through the lens of criteria (what does my device have to do? and constraints (what are the limitations I face in making, testing, and using the device?). Spend some time as a whole class brainstorming the criteria and constraints of this particular engineering challenge.

Divide students into groups of three. Give each group a preassembled track and basic train platform (the piece of cardstock). Based upon their experimentation and research, tell groups to design and draw a magnet configuration that they believe will allow the train to float along the track. Give students a variety of options to choose from for magnetic materials, such as disc magnets, magnetic tape, and bar magnets.

Make It: 15 minutes

Instruct students to assemble the train and test it on the track. They should start building according to their plan, but they should not be surprised if they have to keep experimenting in order to create a functional floating train. Visit each group and review how their experiments shaped their overall design and plan. If students are making mistakes, let the mistakes happen. Avoid offering solutions; instead, encourage students to keep trying and allow their ideas to evolve.

Test: 15 minutes

To test their trains, have each group float their device along the track. Allow students to add washers, one at a time, to see how much weight their train can hold. Optional: make videos of the different tests to compare the trains afterward.

Evaluate: 10 minutes

Ask students to reflect on the following questions, and talk about their responses as a class:

1. Did your train float magnetically?
2. Was your train able to carry any washers?
3. What part of your design contributed to its successes?
4. What part of your design contributed to its failures?
5. What could you change to make your train better able to carry a heavy load?

TAKING IT FURTHER

Allow students to reiterate and create a new design that they feel addresses the failure point of their previous design, and then test the new design.

Explore how civil engineers are overcoming transportation issues (mountains and inclement weather) by designing and building new tunnels like Switzerland's Gotthard train tunnel that opened in 2016.

Watch YouTube videos about magnetic tracks/trains and their capabilities.

Document your students' work through our social media outlet: #CitiesoftheFuture

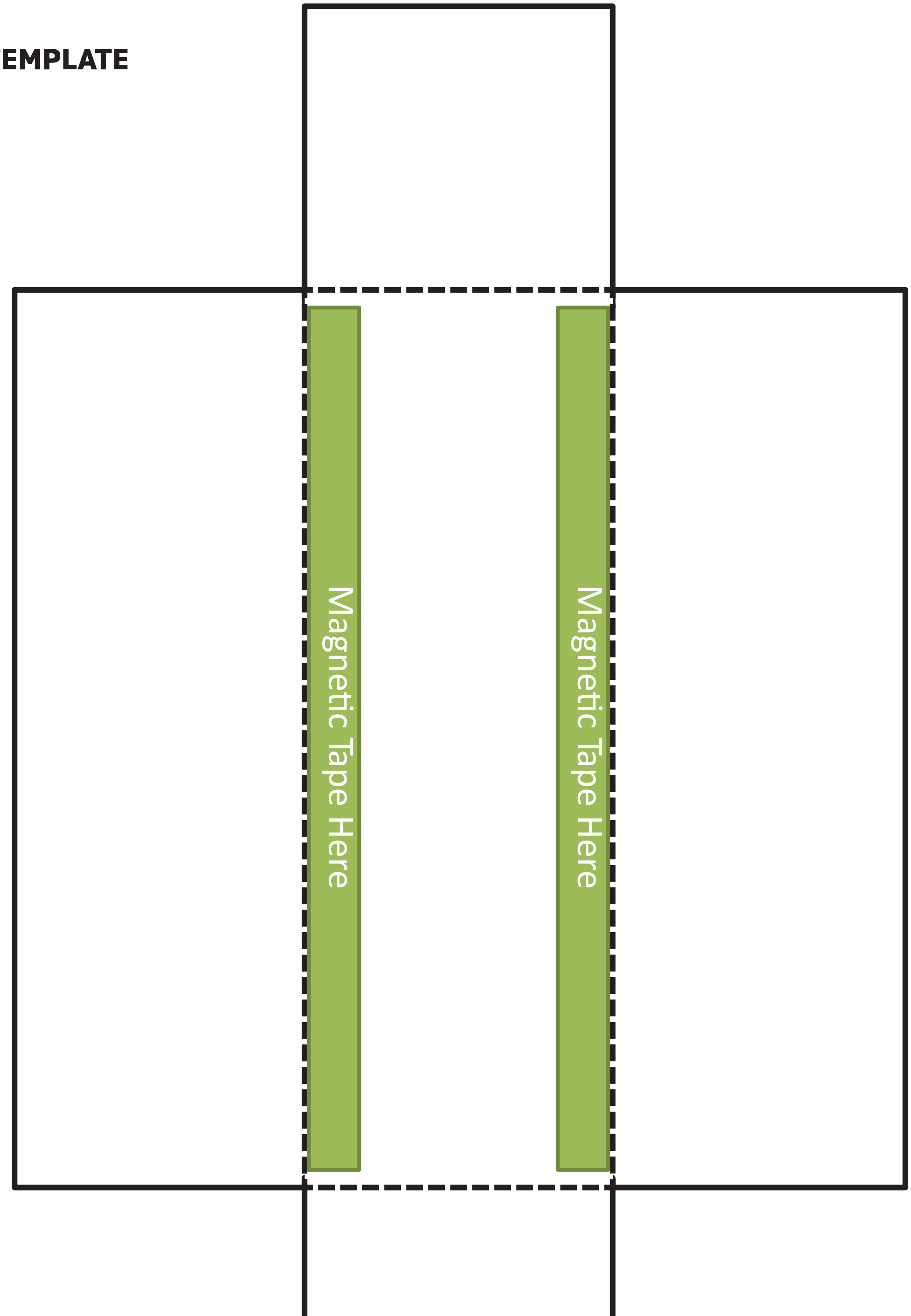
TRACK ASSEMBLY INSTRUCTIONS

Obtain cardboard. Use the template (included on the next page) for exact dimensions. Trace the cut lines with scissors or a box cutter. Fold the cardboard along the dotted lines. Tape the sides together with strong tape. On either long side of the track, measure out a length of magnetic tape that would run from end to end. Use a glue gun to glue down the magnetic tape along the leftmost and rightmost sides of the top of the track.

Give students a piece of cardstock paper cut to the size of the width of the track. This will serve as the "train" for them to tape magnets onto in order for the train to float suspended above the magnetic tape on the track.

Hints: If you would like, you can have students create an actual train boxcar to place on top of the cardstock. Another option is to place an empty paperclip box on top of the cardstock and allow students to add washers, one at a time, to see how much weight their floating magnetic train can hold.

TRACK TEMPLATE



GRADE 3 MATH

Measuring Magnetism

30 minutes

THE BIG IDEA

In the Maglev Train activity, students experimented with creating their own magnetically levitating model trains. This lesson gives them a chance to learn more about the properties of magnets by mapping and measuring a magnet's magnetic field. Students explore answers to these questions:

- How far does a magnet affect the space around it?
- If you make a map showing this distance, what would the shape look like?

LEARNING OBJECTIVES

- Determine how best to measure the effect of a magnet on the space around it
- Display understanding of area as an attribute of plane figures
- Demonstrate the ability to measure areas by counting unit squares

PREPARATION

Set context for students by holding a brief class discussion about the Maglev Train activity. Prompt students to explain what they understand about how these trains work in the real world. Ask students to summarize their own experiences with building levitating model trains using magnets.

Tell students that in this activity, they are going to find out how their magnets affect the space around them by measuring and mapping these effects.

MATERIALS

Per pair of students:

- the bar or disc magnets used in the Maglev Train activity
- graph paper
- pencils
- rulers

Per student:

- Math handout

INSTRUCTION

1. Distribute materials to each pair. Review these terms, which students learned in the Maglev Train activity, by asking students to demonstrate each type of force with their magnets:
   - Attractive force: A force that attracts objects toward each other
   - Repelling force: A force that pushes two or more objects away from each other
   - Magnetic force: The attractive or repulsive force that exists between two bodies that contain a magnetic charge
2. Ask partner A to place a magnet in the center of the graph paper and hold it there with their finger so it stays in that fixed position.

3. Ask partner B to place the second magnet along the edge of the paper. Have partner B move their magnet one square of graph paper toward the center magnet using a pencil to nudge it slowly. If nothing happens, the student should move the magnet another square toward the center magnet. The moment the students see this magnet move as a result of attractive force, they mark an x on that square of the graph paper.
4. Explain that the students' task is to work all the way around the paper, finding the spot of attractive force and marking it with an x on the graph paper. Ask partners to take turns being the person to hold the center magnet in place versus being the one to find the next spot of attractive force. Tell students to locate at least 12 points on their paper, including 1 from each corner and 2 from each side.
5. Instruct students to use a ruler to measure how far away the x's are from the center and to note these measurements on the edge of the paper. Ask several pairs to report on their findings to these questions:
   - Can you see any kind of pattern or shape made by the x's?
   - Is there any kind of pattern to the measurements of the x's from the center?
6. Have students use their rulers to connect all the x's. Ask partners to hold their papers up so that classmates can compare their findings.
7. Ask students to guess how many squares of graph paper it will take to fill in the shapes made by their x's. Then have each pair measure the area of their shape by counting graph squares. Tell them to write down how many squares they count.

CLOSURE

Once all of the pairs are done figuring out the area of their shapes on the graph paper, list them all on the board to see how similar the results were. Hold a closing discussion, asking questions such as the following:

- Why do you think all of the areas turned out to be similar? What might explain any differences among the results?
- What kind of shape do you think you could make with a repelling force? Would it be the same or different?

ACTIVITY EXTENSIONS

- Ask two pairs to double up and stack two magnets in the center of the paper. How does the area of magnetic effect change?
- Try this activity with different kinds of magnets.
- Plot different measurements in a bar graph: the class results of the first activity, the results of single versus double magnets, or the results of different kinds of magnets.

OTHER IDEAS FOR MATH

Here are a few more ways to connect the Maglev Train lesson with your math curriculum.

- Have each student group use a ruler to measure the distance their train was able to travel along the track. Make a bar graph for the whole class to show all of the results.
- Have students use a small kitchen food scale to weigh their train. Using a list of the results on the board, have students deduce the minimum and maximum weight for a train that successfully floats over the track.

Directions:

1. Partner A: Put a magnet in the center of the paper and hold it there with your finger.
2. Partner B: Put the other magnet at the edge of the paper. Mark the spot with your pencil. Slowly slide the magnet one square of the graph paper, toward the other magnet.
   - As soon as you see the magnet move, mark this spot with an X.
   - Locate at least 12 points on the paper, including 1 from each corner and 2 from each side.
3. Take turns being the one to hold the magnet in the middle and being the one to mark X's all around the paper.
4. Use the ruler to measure the distance between the center and each X. Write these numbers down.
5. Use the ruler to connect all the X's and see what kind of shape they make.

GRADE 3 ENGLISH LANGUAGE ARTS

Exploring Transportation Sounds

⏱ 50 minutes

THE BIG IDEA

In the Maglev Train activity, students experimented with creating their own magnetically levitating model trains. This lesson gives them a chance to explore the rich vocabulary associated with the sounds made by different modes of transport. They also consider which of these sounds engineers have created intentionally. Students think about these questions:

- What sounds do different trains and other kinds of transportation make?
- Which words describe the different kinds of transportation sounds?
- Which transportation sounds do you think engineers make on purpose?

LEARNING OBJECTIVES

- Compare and contrast sounds made by different kinds of transportation
- Identify the best words for describing different transportation sounds
- Write an explanatory piece that distinguishes transportation sounds that seem useful versus those that are just noise

PREPARATION

Set context for students by holding a brief class discussion about the Maglev Train activity. Prompt students to describe the Maglev Train and what it might be like to ride in one. Ask students to relay any experiences they have had with riding in trains.

Tell students that to begin this activity, they are going to explore the differences between various kinds of trains based on the sounds they make and practice describing these sounds as vividly as they can.

MATERIALS

Per class:

- A read-aloud book with descriptive words for train sounds, such as *Locomotive* by Brian Floca or *Train* by Elisha Cooper (More about these books is listed in the Book Connections section at the end of this activity.)
- Optional: YouTube video and/or audio recordings of different transportation sounds. Examples include trains sounds: youtube.com/watch?v=wqO2HC1QYuc, transportation sounds: youtube.com/watch?v=M5-eFEZ4fi8

Per student:

- pencil
- paper

INSTRUCTION

1. Tell students that you are about to read a book about trains aloud. Every time students hear a word that describes a sound a train makes, they should raise their hands. You will pick a student to say what the word is and start a list on the board.
2. After you've read the book, look at the list of words on the board. Ask, "Do you think other kinds of transportation also make these sounds? Why or why not?" Give students a moment to think and discuss with their neighbors before eliciting responses from the class. As students think of them, add more terms to the list.
3. As an option, help students to connect the words for sounds with the actual sounds by playing a YouTube video or audio recording of train and other transportation sounds. Students may come up with more words for the list on the board; encourage them to call these out and add them.

4. Explain that engineers want cars, trains, and boats to make certain kinds of sounds. They include these sounds on purpose; for example, cars have horns so that drivers can beep them to warn other drivers. Ask students to look at the list on the board. Which of these words describe sounds that engineers have designed intentionally—sounds that are helpful? Circle these terms on the list.
5. Distribute paper and pencils. Ask students to choose three sounds to write about. For each one, students should answer these questions:
   - Which kinds of transportation make this sound?
   - Is it a sound that engineers designed on purpose to be helpful? Why or why not?
   - Is it a sound that engineers are trying to reduce or eliminate? Why or why not?
6. Once students have finished writing, place them in pairs. Students should take turns telling their partners which sounds they picked and why they think they are intentionally designed or not. Note that partners may disagree, and it's okay if they do.

CLOSURE

Ask for a show of hands: which pairs had different opinions about whether or not a sound was helpful? Call on some of these students to learn the source of disagreement. Hold a brief closing discussion, asking questions such as:

- Which transportation sound annoys you the most?
- If you were an engineer, how would you try to change this annoying sound?
- Which of the describing words we listed were new to you? What other things could you describe using these words?

Encourage students to be imaginative as they think of different ways to apply transportation sound descriptors.

ACTIVITY EXTENSIONS

- Assemble train research materials, such as books, magazines, and/or age-appropriate websites. Ask students to pick two different kinds of transportation and write about their similarities and differences.
- Play train sounds and have students guess which part of the train is making the sound and why.
- Ask students what their favorite book about transportation is and read several of them aloud. Ask, if you were to make up a story, what kind of transportation would your story feature?

BOOK CONNECTIONS FOR ENGLISH LANGUAGE ARTS

The following books relate to the Maglev Train activity. They can be incorporated into your ELA curriculum or used as a warmup for the activity provided in this supplement.

Locomotive by Brian Floca, A Richard Jackson Book/Athenium, 2013. A young family boards a train in 1869, bound for California on the transcontinental railroad. It is written for a wide age group and won the *New York Times* Best Illustrated Books Award for 2013.

Train by Elisha Cooper, Orchard Books/Scholastic, 2013. This book introduces students to many kinds of trains—commuter, passenger, freight, and bullet.

Trains for Kids: A Children's Picture Book about Trains by Melissa Ackerman, CreateSpace Publishing, 2016. This book describes specific trains in detail, including the Maglev, and will especially delight the train enthusiasts in the class.

The Polar Express by Chris Van Allsburg, Houghton Mifflin Harcourt, 30th Anniversary Edition, 2015. This Caldecott Medal Winner and *New York Times* Bestseller and Best Illustrated Book is a classic that students love to hear.

Grades 4-7

2 hrs 40 mins

LESSON PLAN 5:

AMPHIBIOUS HOUSES (SMART CITY)

THE BIG IDEA

Smart city technologies play a crucial role in addressing problems caused by climate change. In this design challenge, students will create a house that adapts to rising sea levels and is resilient to the impact of storm surges by remaining afloat. Students will discuss and learn how flooding affects houses in cities.

IN THE FILM

In *Cities of the Future*, we visit Amsterdam, a city covered by waterways that is moving towards becoming a smart city by installing sensors in buildings and other locations to help monitor energy use and send important data to engineers. Autonomous boats on the city's canals have sensors that assist in navigating under bridges and avoiding other boats. Amsterdam also has the world's first 3D-printed steel bridge equipped with built-in sensors to detect fatigue and notify city engineers when the bridge requires maintenance. With increases in global temperatures causing abnormal weather conditions and storm surges, the Netherlands will also need help from smart-city technologies to monitor the impact of sea level rise. Over a quarter of the country's land is situated below sea level, intensifying the impact of rising water levels. One idea may be to build amphibious houses that respond to changes in water level by moving vertically with the water, essentially floating. These houses would be securely fastened to pillars, limiting their horizontal movement and providing protection against floods.

NGSS DISCIPLINARY CORE IDEAS

ETS1.A: Defining and Delimiting Engineering Problems

ETS1.B: Developing Possible Solutions

LEARNING OUTCOMES

- Students will engage in the engineering design process: define the problem and constraints, research the problem, develop possible solutions, imagine, plan, build a prototype, test and redesign.
- Students will understand that houses can be designed to be resilient to flooding.
- Students will understand that for an object to float, the buoyant force acting on the object must be greater than the object's weight.

KEY WORDS/VOCABULARY

Amphibious house: A house that rests on the ground but when a flood occurs can float, lifted by floodwater.

Buoyant: Able to stay afloat.

Climate change: Long-term shifts in temperatures and weather patterns.

Engineering design process: A series of steps that engineers follow to find a solution to a problem. The steps include ask, imagine, plan, create, test and improve.

Flood: An overflow of water onto land that is normally dry. Floods can happen for several reasons, including heavy rainfall or ocean waves coming to shore. Flash flooding is one of the most dangerous types of floods because they occur when water isn't being absorbed by the ground. Flash floods can be powerful and destructive.

Horizontal movement: Side-to-side movement, parallel to the horizon.

Sensors: Devices that detect and respond to some type of feedback.

Smart city: A technologically advanced urban area that uses sensors and other electronic means to help manage resources and services efficiently, so the city's operations are more efficient.

Smart city grids: Grids that use data and communication systems to enable utilities, consumers and other constituents to make informed decisions.

Storm surge: Abnormal rise in water produced by a storm such as a hurricane. The water rises above normal high-tide levels, causing coastal flooding.

Vertical movement: Movement upward at a right angle to the water/floor.

TEACHER PREP NOTES

Prior to the start of these lessons, collect cardboard boxes, plastic bottles and caps and other found objects to be used in constructing the houses. Each student group will need a plastic container to build their amphibious house. These plastic containers serve as a practical testing ground for assessing the amphibious house's resistance to rising water levels.

Begin the lessons by establishing a foundational understanding of climate change and its impact on global temperatures, leading to abnormal weather patterns such as storm surges, sea level rise and flooding. Engage students in discussions about specific examples, referencing the links provided below:

National Hurricane Center: Introduction to Storm Surge

NYC Mayor's Office of Climate and Environmental Justice: Coastal Surge Flooding

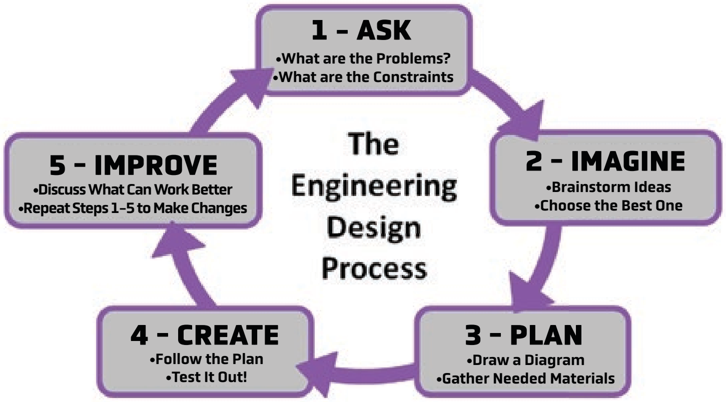
Climate Change and Sea Level Rise in Florida

MATERIALS

Per class:

- Recycled cardboard boxes
- Tape
- Scissors
- Glue and hot glue gun
- Paper straws
- Plastic bottle caps of similar size
- Wood dowels to act as pillars
- Mini hand drill to make a hole in each bottle cap for a wood dowel
- Wood pieces, popsicle sticks
- Various found objects to create a landscape around the house
- Washers to act as weights
- Floats to help lift the foundation of the house; examples include sandwich bags that zip closed
- Plastic containers/boxes in which to test the amphibious house
- Water in a jug or container

ENGINEERING DESIGN PROCESS



TO DO

Student Prep Notes: ⏱ 30 minutes

Encourage students to engage in discussions about how climate change causes abnormal heat and weather changes, potentially resulting in phenomena like storm surges and sea level rise. Supplement these discussions by presenting reports from the links above, fostering a deeper understanding of climate change and its implications for water levels. Facilitate a class dialogue on the engineering design process depicted in the image above. Connect this discussion to the students' upcoming task of building amphibious houses that can float in response to rising water levels. This integration of theory and practical application will help students grasp the real-world relevance of the design process.

ASK: Prior to seeing *Cities of the Future*, prompt students with the following questions to support the activity:

a. What is the importance of engineering a floating house?

b. Who would live in the house and what personal items would need to be protected from flooding?

c. What are current measures that are used to protect houses from flooding and other weather-related issues?

d. How do you think people protected their houses before smart city technologies were invented?

After viewing the film, students will have a better understanding of the workings of smart cities and how the grids can detect floods, water level rise and respond to protect houses. Can you think of other ways in which a smart city can make houses more resilient to the impacts of climate change?

IMAGINE: Students will imagine what an amphibious house can look like. Prompt them with "Think about what your house will look like using the materials given. Amphibious houses can be in and out of the water. Think about how your house will be structured on dry land and after the water level rises."

PLAN: As a group, students will become engineers deciding who is working on which parts of the amphibious house and foundation. Engineers have different jobs, so the students will discuss and plan, using the following as a guide:

a. Who is building the foundation that the pillars are attached to?

b. Who is building the floor of the house? The foundation will move vertically in response to floods. The actual house will then be attached to this. Think about where the floor will interact with the pillars, so movement of the house is easy when the water level rises.

c. Who will build the livable part of the house? Think about the size of the house in relation to the number of people living inside.

d. Who will help build the floats so that the house moves vertically away from the flooding? Think about the weight and balance of the house on floats.

CREATE: Students will construct the foundation (to which pillars are attached), floor and structure of the house and the house, as they have planned. Place the foundation in the test box.

TEST: Students will place their house in the test box on top of the foundation. The floor of the house (with floats attached to the bottom) should sit inside the pillars. As they pour water into the test box, students will be able to see if their house is resistant to flooding. As they pour in water, the amphibious house should move vertically, lifting the house off the foundation.

IMPROVE: Students will discuss and see how they can improve their house based on the testing. They can continue the design process until their group is satisfied with the iteration of their amphibious house.

Exploring Buoyancy and Floating Houses:

1. Buoyancy displaces water and causes the building to float on the water's surface. Test some of the materials for buoyancy in water except for the dowels. See if the materials sink or float. If an object sinks, it is too dense and cannot displace water. If it can float, then it is the opposite – able to displace water and float.

2. The vertical guidance pillars restrict horizontal movement so that the house can move up and down but not float away. The foundation should have straws glued on the corners to help guide the pillars (wooden dowels) as water level rises.

3. A new structural framework can be installed beneath the foundation to support and stabilize the building while connecting it to the vertical pillars for buoyancy. This structural framework can hold the house in place, keeping things inside mostly stable.

Activity Part 1 – Making the Foundation: 60 minutes

Students will plan the size of their foundation, engineer the foundation and insert the pillars.

1. Take four of the same bottle caps and use the hand drill to make a hole in the middle of each of them. Make sure it is the same size as the wooden dowel.

2. Using the hot glue gun, attach the wooden dowel to the hole in the bottle cap.

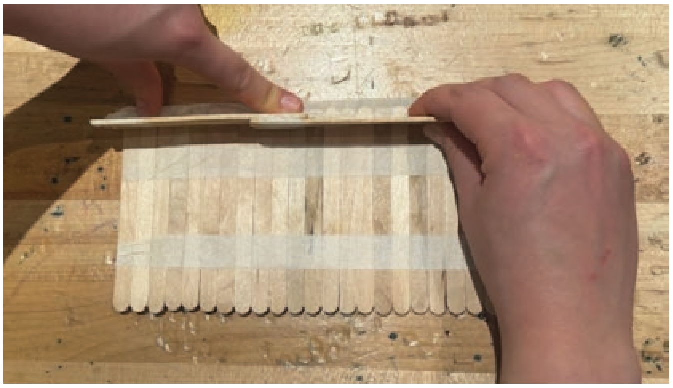
3. Once the dowels are dried, place the bottle caps in four locations on the bottom of the plastic container. Once the team agrees upon the placement, use the hot glue gun to attach the pillars to the plastic container.

4. Using found objects, fabricate your house's landscape around the four pillars (foundation) inside the plastic container.

Activity Part 2: 60 minutes

Students will plan which building materials to use; these materials will be used to create a house that will float as water rises. Students will test various materials in the process.

1. Construct the floor foundation that your house will sit on by using popsicle sticks and tape.



2. Fill sandwich zip bags with air and seal them. Tape these to the bottom of your floor foundation as a float for the house. Depending on the house's weight, the bags may need additional air. Keep in mind that your house will add weight when you place it on top of the floor foundation.

3. Looking at the foundation built in Activity Part 1, attach straws on the side of your floor foundation so that it aligns with the wooden dowels. The dowels must go through the straws as the house moves vertically.

4. Construct your house and place it on the floor foundation. Think about its size, balance and weight.

Activity Part 3 – Test Amphibious Houses: 10 minutes

Have students place their amphibious houses on the floor foundation and then onto the foundation in the bin where the pillars go through the straws. Pour water into the bin to see if the house rises above the water level. The house must lift vertically and be as stable as possible, so it does not move horizontally. Go through the design process discussed earlier to see if changes and improvements are needed for the amphibious houses.

TAKING IT FURTHER

City planners use sensors on city grids to determine which areas of their city are flooding. Once these sensors are activated, they let engineers know that the amphibious houses need to start moving vertically, so the house and people are safe from floods. Using a window and door alarm kit from a local hardware store and the video below, students can create flood sensors for their houses. The link below shows how to build on this activity.

https://www.youtube.com/watch?v=QCFzJAyx-FQ

SUGGESTIONS FOR OTHER GRADE LEVELS

Lower Elementary (Grades K-3): Educators should prepare Activity 1 in advance for students. Students in this age group can experiment with a house.

High School (Grades 9-12): Students should construct scaled model houses and furniture within the house with various found objects and materials from the list. This will allow students to test the true weight of their house as the water level rises.

ACKNOWLEDGEMENTS

Lesson Plan created by the Museum of Discovery and Science, Ft. Lauderdale, FL.

GRADES 4-7

Math

20 minutes

THE BIG IDEA

Experiment with the students to learn whether their house moves vertically or horizontally when the water level rises.

ACTIVITY

Students previously added water to their testing box to observe if their house would float.

Before adding water again, students will weigh their house and use the data table below to track their house's weight, the number of floats being used and whether it floats or not. It is important that students only change one variable at a time (either the number of floats or the weight of the house) as they run their experiments. Weights are represented by the washers, serving as a measure for the number of people and weight of things in the house. The goal is to minimize the use of floats while achieving the lightest possible house.

MATERIALS

Per class

- Washers
- Data table
- Digital scale

Engage the class in a discussion about how the house was constructed to accommodate the weight of people and their personal items, understanding that the washers represent the weight of items in the houses and discuss how their houses can be redesigned as they test out the weight. Ask: What is the ratio of floats to washers needed to keep your house safe from floods?

DATA TABLE

DISCUSSION

Test #	House Weight (grams)	Number of Floats	Float OR Fail
Test 1	237 grams	2	Fail
Test 2	237 grams	3	Float

GRADES 4-7

Civics

20 minutes

THE BIG IDEA

In *Cities of the Future*, we saw that cities around the world utilize smart city technology to solve problems and help make their city more efficient for their residents.

Discuss with the students the ways they can help their cities become more prepared and resilient through other solutions, community involvement and understanding climate change.

ACTIVITY AND DISCUSSION

Educators should gather information on their local government to facilitate discussions on city planning, specifically focusing on housing, city grids and smart city technology. Students can raise awareness about the importance of proactive urban planning in the face of sea level rise and flood challenges. Students can discuss and learn about urban planning. Here are three main things that planners do within a city:

1. Facilitate the formation of valuable and enduring communities.
2. Provide improved options for the locations and lifestyles in which people work and reside.
3. Involve residents, businesses and civic leaders in actively contributing to the development of communities that enhance people's lives in a meaningful way.

With the class, educators can facilitate a student led community resilience workshop focused on sea level rise and flood response in urban areas. Participants can engage in a simulated city-planning exercise in which they assess flood-prone areas, strategize on effective response measures and collaborate to develop plans for safeguarding houses against flooding. How might this activity come to life in your city? How does this benefit your city economically? Does your community have a climate action plan? How would you make your community more resilient?"

MATERIALS

Per class

- Paper
- Pen or Pencil

RESOURCES FOR UNDERSTANDING PROJECT

Thriving With Water: Developments in Amphibious Architecture in North America

Buoyant Foundation Project

Grades 4

2.5 hours

LESSON PLAN 6:

WINDPOWERED LED

THE BIG IDEA

The landscape is changing as we find alternative ways to meet our energy needs and rely less on fossil fuels. Hydropower from dams, wind power, solar power, wave energy, and even methane gas from sewage and anaerobic digestion processes are all examples of renewable, alternative energy sources that engineers are harnessing. Students will learn about one of these renewable energy sources as they design a wind turbine. They will test blade designs on a windmill and see if it can light an LED light bulb.

IN THE FILM

Engineers are leading the way as the world explores alternative energy sources to supplement or replace the fossil fuels we have come to rely upon. In *Cities of the Future*, we see engineers harnessing the power of the wind in large wind farms in the Netherlands, right next to the country's original, historic windmills. But the new wind turbines are part of the "smart city" approach of Amsterdam. The turbine blades have sensors that track temperature and ice and other variables. In this activity, students investigate wind energy, and discover how engineers harness the power of our atmosphere to create energy for tomorrow.

NGSS DISCIPLINARY CORE IDEAS

4-PS3-1 Use evidence to construct an explanation relating the speed of an object to the energy of that object.

4-PS3-2 Make observations to provide evidence that energy can be transferred from place to place by sound, light, heat, and electrical currents.

4-PS3-4 Apply scientific ideas to design, test, and refine a device that converts energy from one form to another.

NGSS ENGINEERING PRACTICES

4-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.

KEY WORDS/VOCABULARY

Electrical energy: Energy of the movement of electrons through a circuit.

Mechanical energy: Energy of motion.

TEACHER PREP NOTES

Though KidWind makes an excellent DC turbine that requires little to no assembly, it is not the only option. You can also buy a small DC motor, alligator clips, and an LED light. Attach the LED light to the DC motor using the alligator clips. When you spin the motor shaft, the LED light will illuminate. Similar to the KidWind motor, students' wind propellers are affixed to a cork, and the cork is pushed onto the motor shaft so that the spinning blades spin the shaft and generate light.

Before class starts, preassemble the testing devices for each team (see Research and Gather Information), according to the Windmill Blade Testing Device Instructions.

Be prepared to discuss the kinds of energy often used in society (radiant, electrical, thermal, mechanical, and so on) and have examples ready. Talk about how energy transfers convert energy to usable forms for humans. Have an explanation ready to explain how wind turbines convert mechanical energy (in the form of wind) to mechanical energy in the spinning of a turbine, to the electrical energy in the generator, to the radiant energy in a light bulb.

MATERIALS

Per class:

- Box fan
- Pencil sharpener
- One KidWind Mini Turbine Kit (can be sourced from online vendors like Amazon; see Teacher Prep Notes for alternative)
- Windmill Blade Testing Device Instructions

Per team:

- Fan template
- Paper for taking notes
- Pencil or pen
- 2 corks
- Hot glue or thumbtacks
- Windmill Blade Testing Device preassembled:
    - Half-gallon milk carton
    - Water or other weight
    - ¼-inch by 1-foot dowel
    - Small paper cup
    - 1-foot length of string
    - Scissors
    - 2 metal washers
- Materials that may be used for making turbines:
    - 1 empty water bottle
    - Other scrap materials (e.g., soda bottles) for making turbine blades
    - 4 notecards, or cardstock
    - 1 foot of tape
    - 8 paper clips

TO DO

Determine the Problem or Question to Solve: 15 minutes

1. Before watching *Cities of the Future*, give students an overview of what they are about to experience. This film is about engineering and the ways that engineering can inspire, challenge, and enrich our lives. Give students the following questions to think about as they are watching the film:
   - What forms of alternative energy did you see in the film?
   - What are the benefits of having multiple sources of energy?
   - What role are engineers playing in the future of energy?
2. Debrief as a whole class after viewing the film. Allow students to reflect on the guiding questions you gave them. If necessary, remind students of some of the current challenges we face regarding the consumption of energy: dependency on nonrenewable fossil fuels, the by-products of nuclear waste, greenhouse gas emissions, and so on.
3. Introduce the design challenge. Explain that in keeping with a worldwide initiative, many countries are exploring how they can reduce their dependency on fossil fuels such as coal, oil, and gas. Our planet provides many opportunities to harness energy with minimal impact on the planet, but so far the technology to harness energy from these sources on a massive scale has not been perfected. Out of the identified alternative sources, a few have risen to the top as showing the most promise: wind, solar, and tidal. Today students will use the provided materials—a KidWind Turbine with LED light (or similar materials as described in Teacher Prep Notes), a cork, and a turbine blade design of their choice—to design and build a wind turbine capable of generating energy.

Research and Gather Information: 60 minutes

1. Divide the class into teams of three.
2. To each group, distribute fan templates that students can use to create pinwheels. Have students cut along the solid lines and fold along the dotted ones. Instruct them to attach each pinwheel to the end of a cork with a spot of hot glue or a thumbtack.
3. Explain that the next step is to experiment with how air pressure can interact with the different predesigned wind turbine/pinwheel blades. Instruct each group to attach its pinwheels to their preassembled Windmill Blade Testing Device by poking the unused end of the cork onto the pointed end of the dowel rod. Place the windmills, with pinwheels attached, one foot away from a box fan. Turn the box fan on and let it blow on the pinwheels.

Students should record the amount of time it takes for each pinwheel design to raise the washers. Discuss with students the idea that the faster the pinwheel is moving, the more energy it is creating, and the faster it can raise the washers. For each of their three designs, students should note what worked well and what did not.

Review the kinds of energy often used in society (radiant, electrical, thermal, mechanical, and so on) and brainstorm examples of each. Talk about how energy transfers convert energy to usable forms for humans. Connect back to the wind turbines being built in class. They convert mechanical energy (in the form of wind) to mechanical energy in the spinning of a turbine, to the electrical energy in the generator, to the radiant energy in a light bulb.

Plan a Solution: 15 minutes

If students are unfamiliar with the concepts of criteria and constraints in engineering, take the time now to introduce these two fundamental ideas. Engineers look at challenges through the lens of criteria (what does my device have to do?) and constraints (what are the limitations I face in making, testing, and using the device?). Spend some time as a whole class brainstorming the criteria and constraints of this particular engineering challenge.

Guide groups to identify one factor from each pinwheel design to use as inspiration for designing the blades of their turbine. Their goal will be to develop a design that will harness the most energy by spinning the fastest when air pressure is applied. Students should draw a diagram of what they plan to build, labeling the materials they will use and describing how energy is transferred to the light bulb in the device.

Make It: 30 minutes

Give each group a baggie of materials and one cork with which to build the turbine blades. Blades can be made of paper, plastic, or another material. Allow students to build their designs, visiting each group and pushing them to fluently talk about their design, how it transfers energy, and how they will know if it is generating a lot of energy (more motion = more energy). The final blades should be attached to a cork for easy attachment to the turbine generator in the next step.

Test: 30 minutes

Attach each cork/turbine blade, one at a time, to the motor shaft of the turbine generator. Place a dot of hot glue on the cork before sticking it onto the turbine. This will ensure full contact so that it is spinning the motor as it spins from the wind. When you are switching groups, simply pull off the cork and the hot glue will easily peel off. Place the turbine at set lengths (e.g., 1 foot, 2 feet, 3 feet) from a box fan on low speed. Compare the input and output of energy from each stage.

Evaluate: 10 minutes

Ask students to reflect on the following questions and share their thoughts with the class:

1. Does your turbine spin effectively under airflow?
2. Does it hold up to the air pressure without breaking?
3. Does it produce enough electricity to light the bulb?

TAKING IT FURTHER

Retest turbines at different fan speeds for each of the suggested stages.

Students can attempt to light multiple LEDs or use a voltmeter/ammeter to measure with greater accuracy.

Search the web for other pinwheel blade designs and templates.

Explore more ways that engineers are protecting our planet through innovations in alternative energies and in designing recycling solutions and strategies for cleaning up our planet.

Document your students' work through our social media outlet: #CitiesoftheFuture

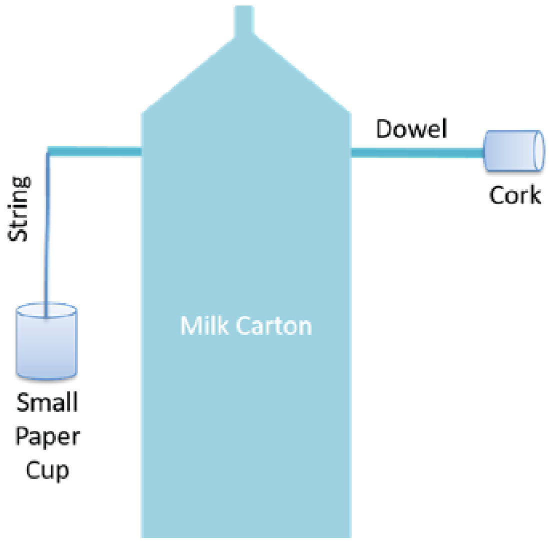
WINDMILL BLADE TESTING DEVICE

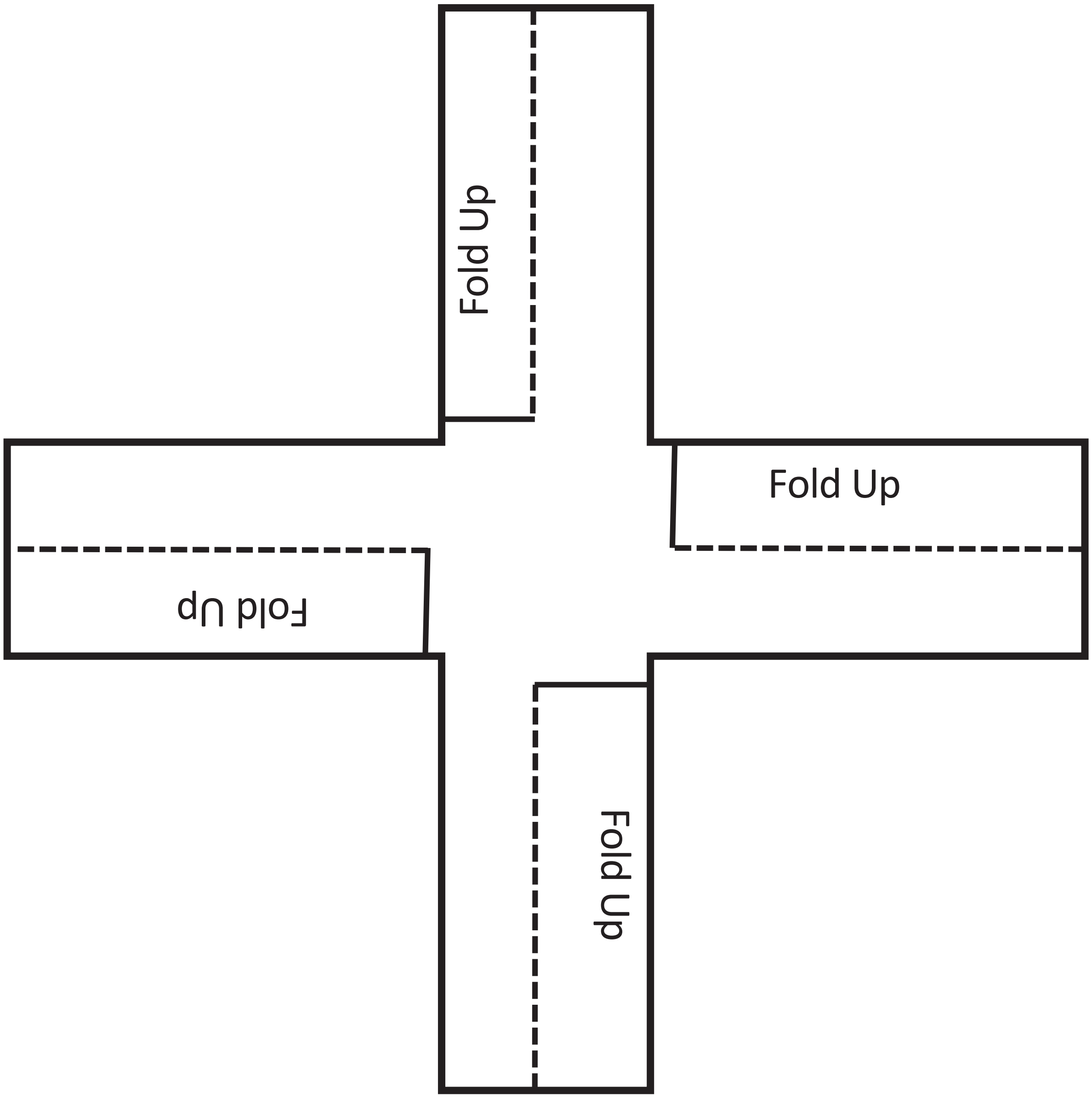
Assembly Directions:

1. Add water/weight to the milk carton (if using water, fill halfway).
2. Pierce the milk carton 2 inches beneath the top edge. Pierce the milk carton on the opposite side at the same relative location.
3. Sharpen a 1/4 inch by 1 foot wooden dowel rod by placing one end into a pencil sharpener. Place the dowel rod through the holes you made in the milk carton so that both ends are protruding on either side.
4. Tie 1 foot of string around the unsharpened end of the dowel rod.
5. At the loose end of the string, tie it to a small paper cup. This is most easily done by piercing the small paper cup with scissors near the top on either side, looping the string through, and closing with a knot.

Directions for Use:

1. Each group of students should have attached a pinwheel to one end of a cork before testing with this device.
2. Attach the blank end of the cork to the sharp end of the dowel by simply pushing the cork onto the sharp point until it is firmly stuck.
3. Place 2 metal washers in the paper cup.
4. Place the device 1 foot away from a box fan.
5. Turn the fan on and allow students to observe the turbine spinning and doing the work of raising the cup and washers!

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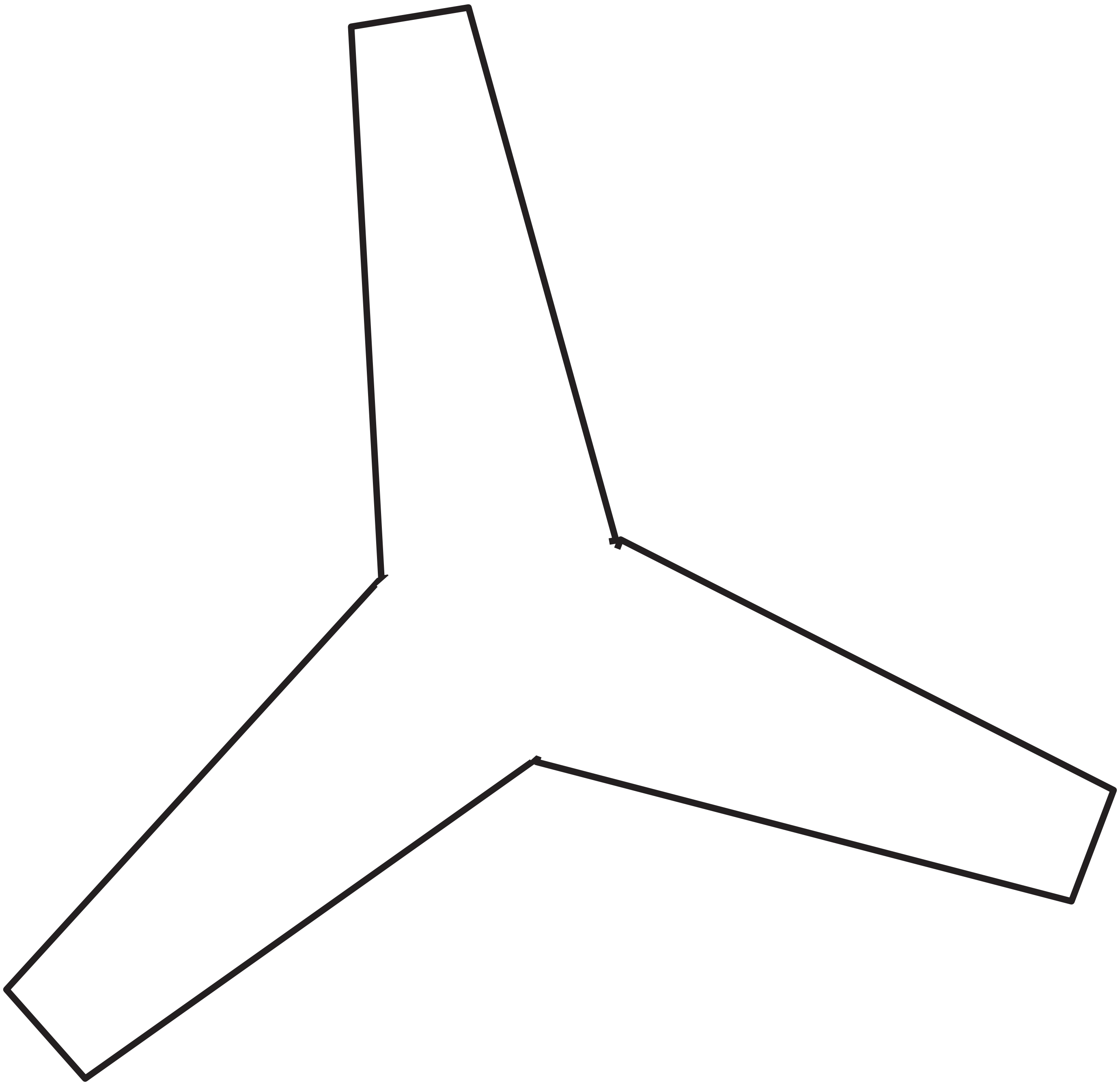

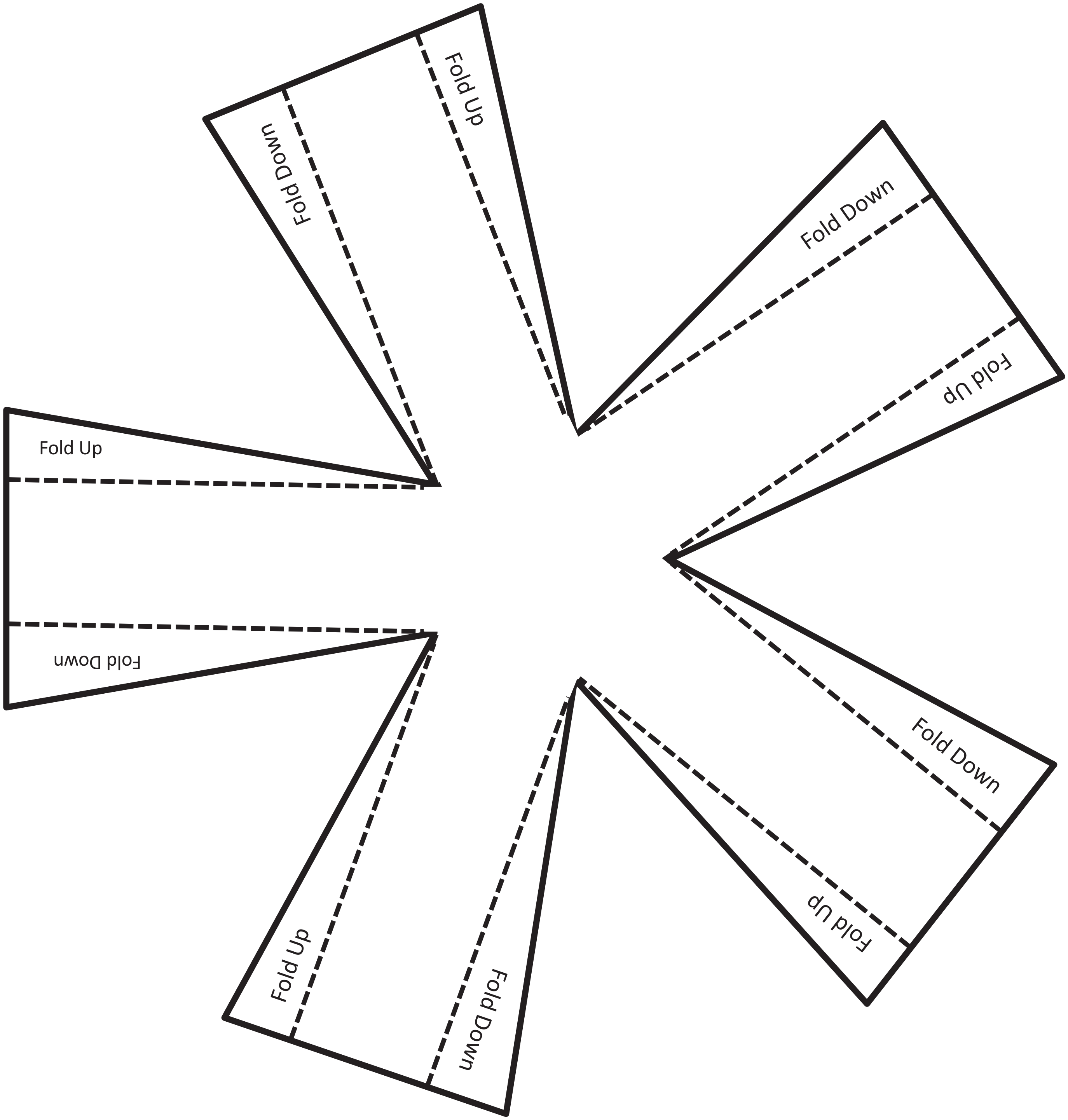
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GRADE 4 MATH

Interpreting Graphs

30 minutes

THE BIG IDEA

In the Wind-Powered LED activity, students used their observations of spinning pinwheel blades to design an improved version of a pinwheel that harnesses enough wind energy to light an LED light bulb. In this lesson, students interpret a graph that displays scientists' predictions of the impact different forms of alternative energy will have in the United States by the year 2040. Students explore answers to these questions:

- Which forms of alternative energy are expected to make more electricity than they do now?
- Why might some forms of energy be expected to generate less electricity in the future?

MATERIALS

Per class

- PDF of Alternative Energy Prediction Graph, projected on a screen

Per student:

- Student Math handout
- pencils

LEARNING OBJECTIVES

- Interpret data in a graph
- Explain which forms of alternative energy are likely to supply the most electricity in the future
- Demonstrate the ability to summarize information displayed in graphical form

PREPARATION

Before displaying the graph, review how generating electricity requires converting one kind of energy into other forms that people can use. Remind students about their experiments with wind energy. See if students can summarize how wind energy is used to light an LED (the mechanical energy of wind becomes the mechanical energy of a spinning turbine, which converts to electrical energy, which in turn converts to the radiant energy in a light bulb).

Explain that we use the term **watt** to describe a unit of electrical energy—or energy that is used up in order to light a light bulb. This unit measure makes it possible to measure and compare energy from different sources. A watt is such a small amount of energy that we talk about **kilowatts** instead. A kilowatt is 1,000 watts of electrical energy, or power. A **kilowatt hour** means that in one hour, one kilowatt of energy will be used.

Tell students that in this activity, students will see which forms of alternative energy scientists think will create the most kilowatts in the future.

INSTRUCTION

1. Display the PDF of the Alternative Energy Prediction Graph. Show students the y-axis of a billion kilowatt hours. Note that it's challenging to imagine these amounts of energy! And yet we need more and more electricity all the time to serve the billions of people on the planet.
2. Point out the other features of this graph, such as the years along the x-axis and the dividing line between history and projections. Ask students to turn to a neighbor and speculate about what the terms hydroelectric, biomass, and geothermal might mean.
3. Distribute the Student Math handout and pencils. Simple definitions of the terms on the graph are provided. Hold a brief discussion of each term to make sure students understand them.
4. Give students a few minutes to answer the questions on the handout before convening as a class to discuss them and come to consensus on the best answers.

CLOSURE

- Lead a discussion to have students share what their ideas are to explain these projections. What do they think will happen in order to create so much more wind and solar energy? What might be limiting the growth of hydroelectric, biomass, and geothermal sources of energy?
- Ask students how old they will be in the year 2040. If the projections for renewable electricity generation are correct, do they think the world will be less polluted by then? Why or why not?

ACTIVITY EXTENSIONS

- Bring in the boxes for a range of different kinds of light bulbs and distribute them to small groups. Ask students to note the number of watts of electricity the bulbs in the box generate, as well as the lumens. What do they think the difference is between a watt and a lumen? (A watt is a unit of energy, and a lumen is the degree of brightness.)
- Have small groups of students research how much of the energy in your state is generated by alternative forms of energy.
- Have students do a web search for other graphs that show predicted electricity generation for the next few decades. They will find graphs that include nonrenewable sources of energy. Have them draw further conclusions about the future of energy generation and explain those conclusions.

OTHER IDEAS FOR MATH

Here are a few more ways to connect the Windpowered LED lesson with your math curriculum.

- Have each student group note the length of time that their turbine was able to keep the LED light bulb lit and create a classroom graph of the results.
- Have students watch a film clip showing a set of turbines turning, such as the one through the link below. How would they find the speed of the turbine? Allow students to use a stopwatch to time how long it takes for the turbines to turn 20 times. Then have students use that informationto determine the length of one turn. How many turns would a turbine make in one full minute? Have students calculate their answer and then have them watch and count to see how close they are. (youtu.be/92BR9oGS8VQ)

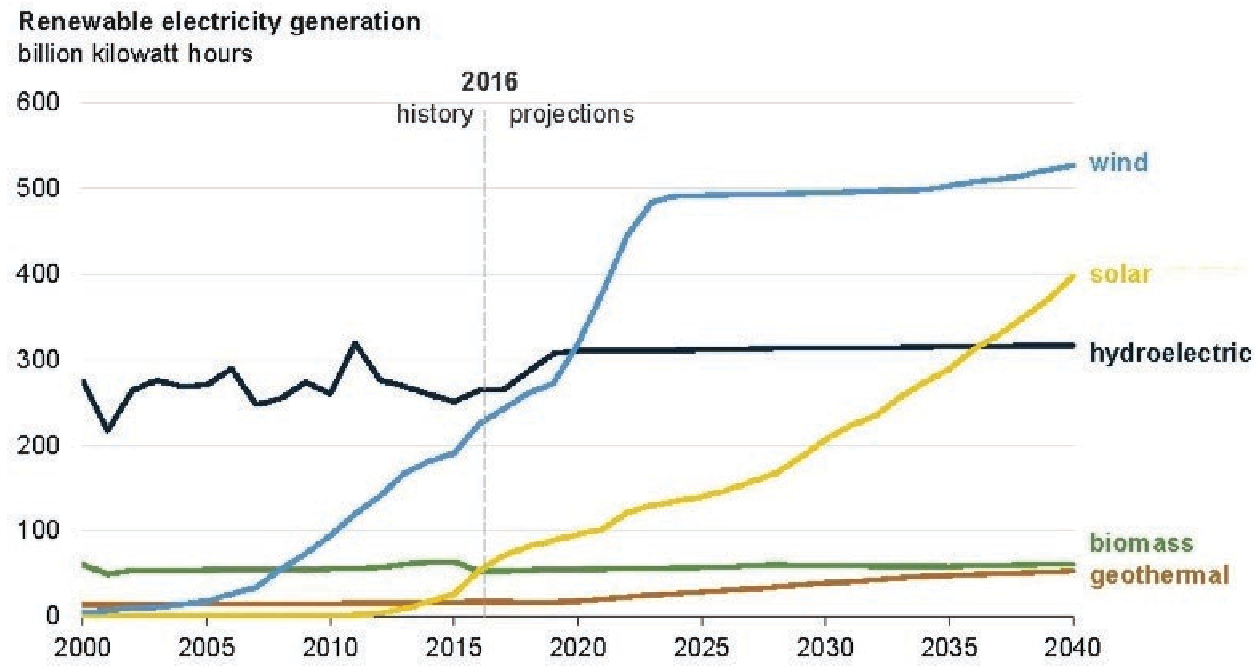
MATH: STUDENT HANDOUT

Directions: Find the answers to the following questions by using the graph below.

Hydroelectric: electricity generated from water

Biomass: energy generated from wood, crops, animal material, and garbage

Geothermal: energy from heat, hot water, or steam coming from below the Earth's surface



1. Which source had the greatest generation in 2000?

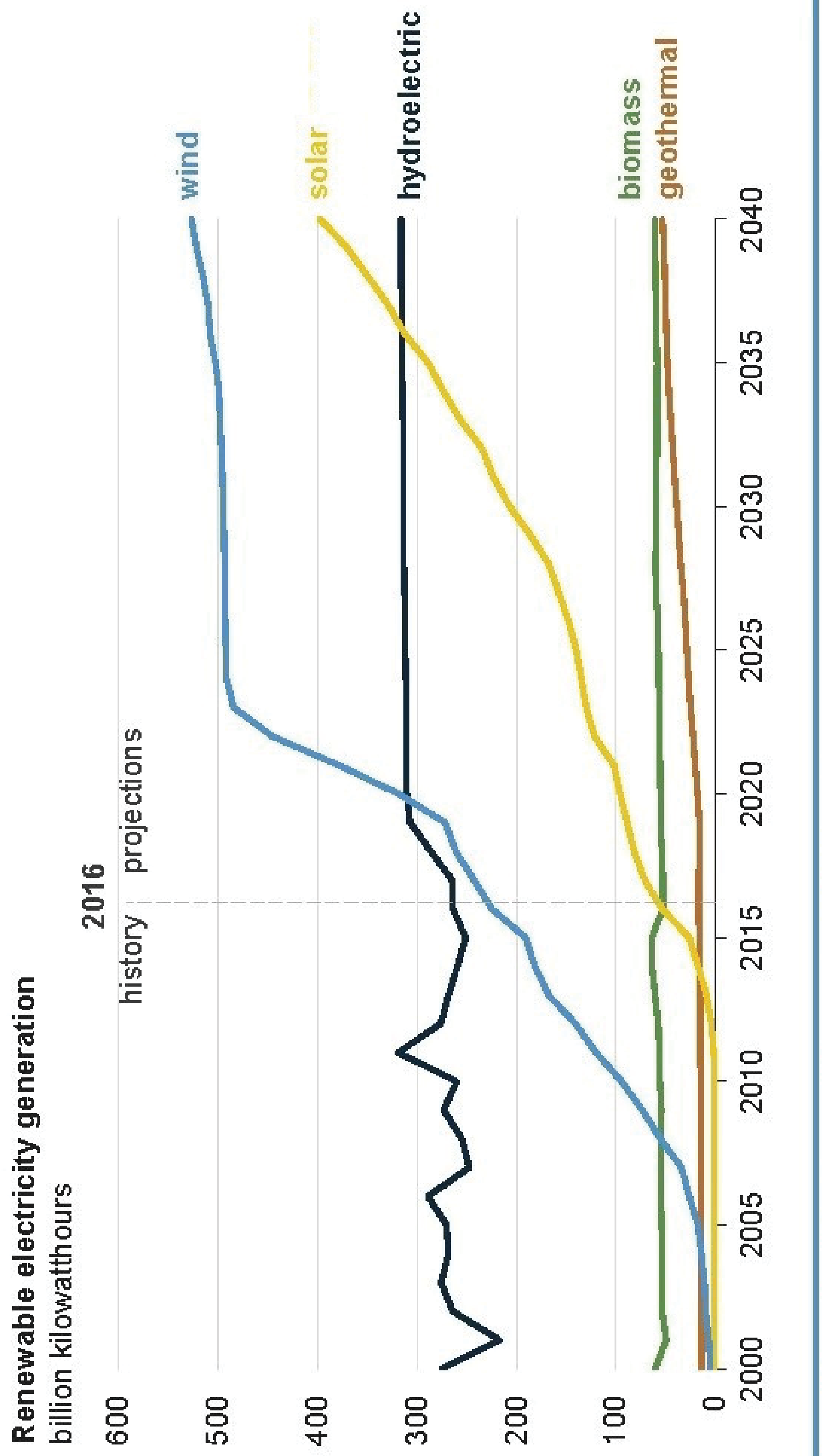
2. Which source had the greatest increase from 2000 to 2016?

3. Which source is expected to grow the most from 2016 to 2025?

4. Which source is expected to grow the most from 2025 to 2040?

5. Which sources have little growth or little expected growth?

Graph for projecting on a screen



Adapted from the U.S. Energy Information Administration

www.eia.gov/aeo

GRADE 4 ENGLISH LANGUAGE ARTS

Alternative Energy Research

90 minutes

THE BIG IDEA

In the Wind-Powered LED activity, students used their observations of spinning pinwheel blades to design an improved version of a pinwheel that harnesses enough wind energy to light an LED light bulb. This activity widens the scope of students' investigations into renewable energy sources as they work with a small group to compile information and create a poster of their findings. Students think about these questions:

- Which kinds of alternative energy work best for different places in the United States?
- How does this renewable source of energy work?
- What problems do engineers face as they make this alternative energy available?

LEARNING OBJECTIVES

- Summarize information about a type of alternative energy
- Integrate information from different sources in order to write knowledgeably about a type of alternative energy
- Decide how best to present information about a type of alternative energy in a poster format

PREPARATION

Generate a list of types of alternative energy as students call them out. The list should include wind, water (hydroelectric), solar, geothermal, tidal, and biomass. Ask volunteers to explain something about each type and fill in any major gaps in understanding.

Tell students that they are about to learn more about one of these types of energy, and their task is to present what they have learned in a poster so that they can share information with their classmates.

MATERIALS

Per group

- Grade-appropriate research materials (books, magazines, websites, printouts) on renewable energy: wind, hydroelectric, solar, geothermal, or tidal. See sources to get started with.*
- Poster-making supplies: poster board, art materials

Per student:

- Student Research handout
- Pencil

SOURCES TO GET STARTED WITH:

National Geographic, Renewables Roundup (video)
nationalgeographic.org/media/renewables-roundup

Energy Kids, U.S. Energy Information Administration
eia.gov/kids/energy.cfm?page=renewable_home-basics

Union of Concerned Scientists, Renewable Energy:
ucsusa.org/clean-energy/renewable-energy#.Wuo4YaIrLSc

National Geographic, Tidal Energy
nationalgeographic.org/encyclopedia/tidal-energy/

National Geographic, Wind Energy (video)
nationalgeographic.org/media/yes-in-my-backyard

Ted Ed, short video describing the problems to be solved with solar energy youtube.com/watch?v=RnvCbquYeIM

Burlington Vermont runs entirely on different sources of renewable energy youtube.com/watch?v=zKhzVcHrWH4

INSTRUCTION

1. Organize students into groups of three or four students, ideally according to the type of energy they are most interested in learning about. Distribute the Student Research Handout and discuss how to fill it in.
2. Show students where the research materials are located. Suggest that each member of the group find information from one source, either a book, magazine, printout, or website. Instruct them to take notes from this source by filling in their research handout. Remind them to look for interesting visuals as well as text that will make their poster both informative and interesting.
3. Once students have gathered information independently, tell them to share what they found with their group. Students can pick at least one piece of information from each of their research to include in their poster by circling it on their handouts.
4. Instruct students to make a rough draft of their poster on a separate sheet of paper. At this point they can pick visuals and decide how to organize their information. Artists should start making artwork.
5. Distribute poster board to each group and check in with groups. Show the class where the art materials are.
6. Ask each group to present their poster to the class. Then choose a place to display them.

CLOSURE

Ask students to spend a few minutes reflecting on what they learned in this activity. Tell them to write a paragraph in which they answer one or more of these questions:

- One thing I learned about renewable energy from our project is…
- One thing I learned about renewable energy from a different group's project is…
- I think the hardest part about getting people to use more renewable energy is…

ACTIVITY EXTENSIONS

- Assemble materials about how your community is making use of renewable energy.
- Ask an engineer to come to class and talk about the successes and challenges of renewable energy in your area.
- Complete relevant activities from the Discover Engineering website at discovere.org/ouractivities. Activities include creating a working water mill, designing a folding solar panel, and designing a solar water heater.

BOOK CONNECTIONS FOR ENGLISH LANGUAGE ARTS

The following books relate to the Wind-Powered LED activity. They can be incorporated in your ELA curriculum or used as a warmup for the activity provided in this supplement.

Drummond, Allan, *Energy Island: How One Community Harnessed the Wind and Changed Their World*, Square Fish, 2015. This is the true story of how the residents of a Danish island have used wind power to become energy independent.

Kamkwamba, William, *The Boy Who Harnessed the Wind*, Young Reader's Edition, Puffin Books, reprinted 2016. This true story describes how the 14-year-old author made a windmill with nothing but machine parts and metal scraps to bring electricity and water to his small, destitute African village.

Caduto, Michael, *Catch the Wind, Harness the Sun: 22 Super-Charged Projects for Kids*, Storey Publishing, 2011. The award-winning author has compiled projects with step-by-step instructions that have students learning about, making, and using renewable energy.

STUDENT RESEARCH HANDOUT

Name:

The kind of renewable energy I am researching:

The book, website, magazine, or handout where I found my information:

Information that we could put on our poster:

1.

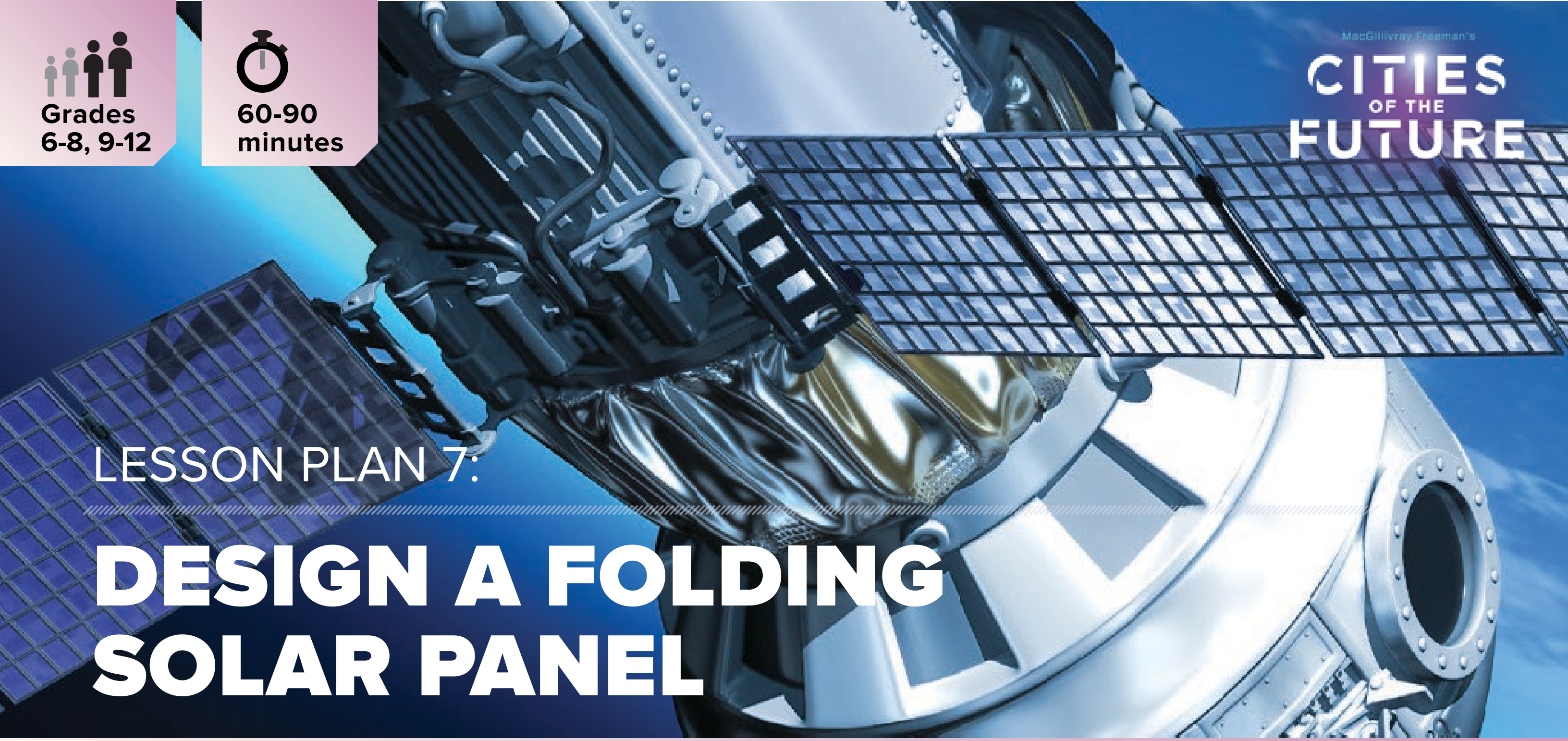
2.

3.

Descriptions of pictures that would be helpful to include on our poster:

Grades 6-8, 9-12

60-90 minutes



LESSON PLAN 7:

DESIGN A FOLDING SOLAR PANEL

THE BIG IDEA

Design and construct a foldable “solar panel” made of aluminum foil that fits in a small container and expands without tearing.

IN THE FILM

A huge source of energy that we all rely on comes from the sun. In recent years, through solar panel technology, the energy in sunlight is converted into electricity. But most of the solar panels are located on rooftops or on giant solar farms and are dependent upon clear sunny days to generate power. *Cities of the Future* features a new, revolutionary way to use solar power. It’s called the Space Solar Power Project being developed by Caltech in Pasadena. This technology gathers the sun’s energy in space, then transforms it electronically and beams it to Earth by microwave. Energy can be produced 24 hours a day, 7 days per week, whether it’s day or night or cloudy or clear. The energy will be transmitted wirelessly so it can go anywhere in the world, even to under-developed countries that may not have any other source of electricity. These space solar arrays will be over a mile long—that is a lot of specialized folding and unfolding that will need to be engineered!

TEACHER PREP NOTES

Remove rolls of foil from their boxes. Cut sheets of aluminum foil 3’ long for each team’s panel. If desired, prepare examples of origami to inspire the folding solar panel designs. Designs and instructions for origami folds of varying complexity can easily be found online.

MATERIALS

Per whole group to share:

- Aluminum foil
- 100–500 craft sticks
- 100–500 straws
- 100–500 pipe cleaners
- Examples of origami (optional)
- 100 rubber bands
- Ruler or tape measure

Per team:

- 1 aluminum foil box with metal rip bar removed
- Cardboard or chipboard from recycled boxes
- 1 roll tape
- 1 bottle glue
- 1 pair scissors
- 1–2 plastic rods or wooden dowels

GETTING STARTED

Ask questions to get participants thinking about folding and design.

- What do you have at home that folds up for storage? (Lawn chair, card table, etc.)
- Folding laundry is a chore that some people don't like. Why do we do it? (So our clothes fit in drawers and don't wrinkle.)

The large solar arrays on the International Space Station are 115 feet long by 38 feet wide. The James Webb Space Telescope is the size of a tennis court. Both of these are far too large to send into orbit without making them smaller, so they must be folded to fit. Engineers must plan how these devices will fold up to fit in the rocket and how they will unfold once they are in space. Engineers address this and many other challenges when working with objects destined for space.

INSTRUCTIONS

Get participants thinking about how much space objects take up and how they could be folded to be smaller. For example, show origami creations as well as the paper from which they were made.

Introduce the design challenge. Participants will work in teams of 3–4 to design a folding aluminum foil "solar panel" that fits in an aluminum foil packaging box and can open to its full dimensions without tearing. Give them the following constraints:

- The unfolded dimensions of the solar panel must be as close to 1' x 3' as possible.
- The solar panel must be taped to the bottom of the box.
- The solar panel can only be touched by one hand when unfolding.
- Optional: The solar panel must rigidly keep its unfolded shape without being held by a person.

Give the participants 5–10 minutes to brainstorm their designs. Suggest that they keep origami in mind; engineers take inspiration from the work of others to create a design that fits their needs. Encourage them to make drawings or small-scale models to help communicate their ideas. Each team must decide on a final design as a group, as well as the materials they will use.

Give the groups 20–40 minutes to build their designs.

- Check in with each team during the build time. If teams are frustrated, give them a hint but avoid building anything for them.

Give each team a chance to show off their design to the rest of the group by asking them to present on the following points:

- Demonstrate the solar panel's operation.
- Share inspiration and difficulties.
- Explain whether working on a team made the solar panel more successful, and how they think engineers work in teams.

Evaluate the success of each design.

- Was the solar panel able to fit into the box?
- Did the solar panel extend to 1' x 3' without tearing?
- Was the solar panel able to be unfolded with one hand?

A student designing a solar array using an accordion fold. Credit: Try Engineering.

ACTIVITY VARIATIONS

Make the design challenge more difficult by using tissue paper instead of foil.

KEY WORDS/VOCABULARY

Electricity: A form of energy caused by the flow of electrons that occurs naturally and can be transferred through conductive materials like wires.

Solar array: Another name for solar panel; made of solar cells that convert light energy or photons into electrical energy through the photovoltaic effect.

Working on the port overhead solar array wing of the International Space Station. Credit: NASA.

Guidance For Younger Children

QUESTIONS TO ASK AFTER THE ACTIVITY

- What were you looking for when selecting materials for your solar panel?
- What did you learn by testing your solar panel after designing it?
- After testing your solar panel, did you make any changes to your design? (Explain that engineers test and retest designs and are always looking to make things better.)
- What examples or ideas did you consider when designing and folding your solar panel?

ENGINEERING CONNECTIONS

Mechanical engineering is a field of engineering that requires knowledge of engineering, physics, and different materials to create machines or parts for them. And sometimes engineers need to know about art, as well! For example, Brian Trease, a mechanical engineer at NASA, designed solar panels based on the Japanese art of folding paper called origami. Solar panels used in space already were designed to fold up, but Brian believes that by folding solar panels like paper is folded in origami, it's easier to get these panels into space.

One type of origami fold that he uses is called the Miura fold. This allows the panel to be folded and fit into a small space while being carried into space, but then opened into a big checkerboard that can catch the sun and power the satellite. The Miura fold also makes the launch of a solar panel easier because there is only one way to open or close it: pull on one corner. Brian used the Miura fold to design a solar panel prototype that looks like a blooming flower and, when opened, forms a big, flat, circular surface to catch sunlight and generate electricity.

SCIENCE CONNECTIONS

Plants use the energy in sunlight to create their own food in a process called photosynthesis. Solar power is generated through a similar process. Energy in sunlight is converted into electricity using solar panels, which are also called photovoltaic cells. These solar panels are a necessary part of every satellite in orbit. However, they are far too big to launch on a rocket without folding them up in some way.

Folding is an important feature of human-made and natural structures. Nature folds objects to fit them into a small space. For example, a butterfly's wings are folded until it hatches from its chrysalis. Petals fold inside a flower bud. Products like bicycles and chairs can be designed to fold for storage in small spaces. Folding bridges allow cars and boats to share waterways. Folding stents that are inserted into veins and arteries allow doctors to treat weakened blood vessels. Even DNA is folded. The DNA in a single cell of your body is six feet long! However, because it is folded by special proteins, it can fit into a microscopic cell. Folding is one way to make efficient use of space.

Guidance for Older Youth and Adults

QUESTIONS TO ASK AFTER THE ACTIVITY

- Why is it so important for solar panels to be foldable when going into space?
- How did you go about selecting materials for designing your folding solar panel?
- After testing your prototype, what refinements did you make to your design?
- What designs did you use as inspiration when folding your solar panel?

ENGINEERING CONNECTIONS

To deliver payloads (cargo and satellites) during the Space Shuttle program years, a device called the Canadarm was used. This series of robotic arms was built into each shuttle cargo bay and was used to load, unload, capture, and move cargo and satellites when in orbit. In order for the shuttle to both take off and land, the arm needed to fit into the cargo bay along with the payload so that the cargo doors could close. To accomplish this, NASA engineers designed the Canadarm to be 50 feet long with six joints that are similar to a shoulder, elbows, wrists, and fingers.

SCIENCE CONNECTIONS

For engineers to design objects that can be folded up to fit into constrained spaces, they need a strong understanding of the mathematics of shapes. This area of study is called geometry. The most basic shapes in that field that most everyone knows about are ones like squares, rectangles, circles, and triangles. However, those are all known as two-dimensional shapes.

When folding objects to fit into three-dimensional spaces such as a rocket's cargo bay, engineers must be able to understand how their two-dimensional shapes can be attached to one another and then folded or unfolded to form three-dimensional shapes. This can be very complex and often requires the assistance of computers. Basic three-dimensional shapes include spheres (like a ball), cylinders (like a soup can), and cones (like a birthday hat). However, NASA engineers are likely to deal with much more complex shapes that go by names like *oblate spheroid*, *truncated tetrahedron*, and *disphenoid*. No matter the name, geometry is a necessary field of study for engineers wishing to fit big objects into small spaces!

ACKNOWLEDGMENTS

Activity courtesy of IEEE TryEngineering.org All rights reserved.

Supplemental content adapted by the Carnegie Science Center.

Grades 6-8, 9-12

45-90 minutes

LESSON PLAN 8:

ROBOT CHALLENGE

THE BIG IDEA

Program a humanoid robot to successfully navigate an obstacle course.

IN THE FILM

In *Cities of the Future*, robots can be seen to offload supplies on trucks and deliver packages to buildings. What are some other ways that robots could be used in the future? Robots could deliver the mail, write parking tickets and act as traffic guards at crosswalks, help in construction work and handle dangerous materials at garbage sites. In the film, an autonomous boat called the “Roboat” is seen being tested along the canals in Amsterdam for a variety of tasks, including transporting people and collecting trash along the canals at night.

TEACHER PREP NOTES

An area of at least 400 square feet is recommended for this activity. Set up the obstacle course before participants arrive by placing tables, chairs, trash cans, and whatever else you’re using throughout the space. Design the obstacle course so that participants must make at least one left turn and one right turn to complete it. The course does not need to be too complex but should have enough obstacles so that there is more than one path to the goal.

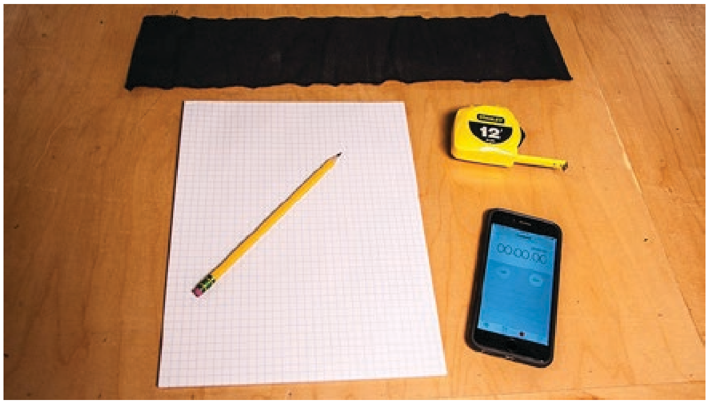
MATERIALS

Per whole group:

- Obstacles for obstacle course (chairs, desks, tables, trash cans, books, etc.)
- Stopwatch

Per team:

- Measuring tools: tape measure, ruler, or meter stick (at least 1 per team)
- 1 blindfold
- Graph paper
- Writing utensil



GETTING STARTED

Explore these questions as a group:

What is a robot? (You will probably get a wide variety of answers from the group; this is good!)

Let the group know that if we asked a bunch of robotics experts what a robot is, we would get a wide variety of answers as well. Because of the complexity and variety of robots, it is nearly impossible to agree on one standard definition of what a robot is. Instead, we can talk about how a robot works.

According to the Robot Institute of America (1979), a robot is "a reprogrammable, multifunctional manipulator designed to move material, parts, tools, or specialized performance of a variety of tasks."

Most machines do the same job over and over. To do it differently means building a different machine. Robots, on the other hand, can be made to do many different jobs by changing their programming.

How does a robot work?

Input: Robots use sensors to gather information about their surroundings. Sensors are devices that detect some type of information from a physical environment such as light, heat, pressure, motion, or sound. A robot's sensors act just like our human senses, which give us information about our surroundings.

Program: Robots have a brain called a microcontroller. Humans create programs—instructions—that tell a robot how to respond to the input from its sensors.

Output: This refers to how the mechanical system, including motors, responds to accomplish the task(s) the robot has been programmed and sent to do, such as navigating around obstacles, picking up an object, or building a car.

INSTRUCTIONS

1. **SET UP TEAMS**
   Divide participants into teams of 3 or 4. Have them come up with a team name.

2. **INTRODUCE THE DESIGN CHALLENGE**
   You've been chosen to work with a team of engineers to explore a shipwreck, deep underwater on the ocean floor. The location is very treacherous and has a number of obstacles, so your team will be using a robot for this mission. Your team will need to program a robotic explorer to navigate through these obstacles to a specific point of interest. But be careful! The wreck is full of obstacles that can damage your robot. Avoid them and reach the destination for mission success.

3. **INTRODUCE THE OBSTACLE COURSE**
   - Identify the starting point and the ending point (the point of interest on the ocean floor). You can mark these using masking tape.
   - Identify the obstacles on the course that the robots need to avoid

4. **DESIGNATE TEAM ROLES**
   Have each team assign roles to each participant:
   - **Humanoid Robot:** One participant from each team is the robot. This team member will walk the course following the instructions from a programmer. The robot will only be able to hear the instructions; it will not be able to see the course or talk with the other team members during the mission.
   - **Programmer:** The programmer is the person who will call out the instructions to the robot. The programmer will only be able to call out the program. He or she will not be able to see the robot move.
   - **Observer(s):** The observer(s) watches the movement of the robot through and around the obstacles. The observer cannot talk to the other team members during the mission but should note how the team can improve the program.

5. **PLAN THE PATH**
   Instruct the teams to plan their path through the obstacle course using graph paper and measuring tools. During this phase of the mission, teams can use tools to create a map of the layout of the ship and determine the best path. Note to participants that in real life, engineers could do this by creating a life-size replica of the ship, by working with another ship that has a similar layout, or by working from a blueprint.

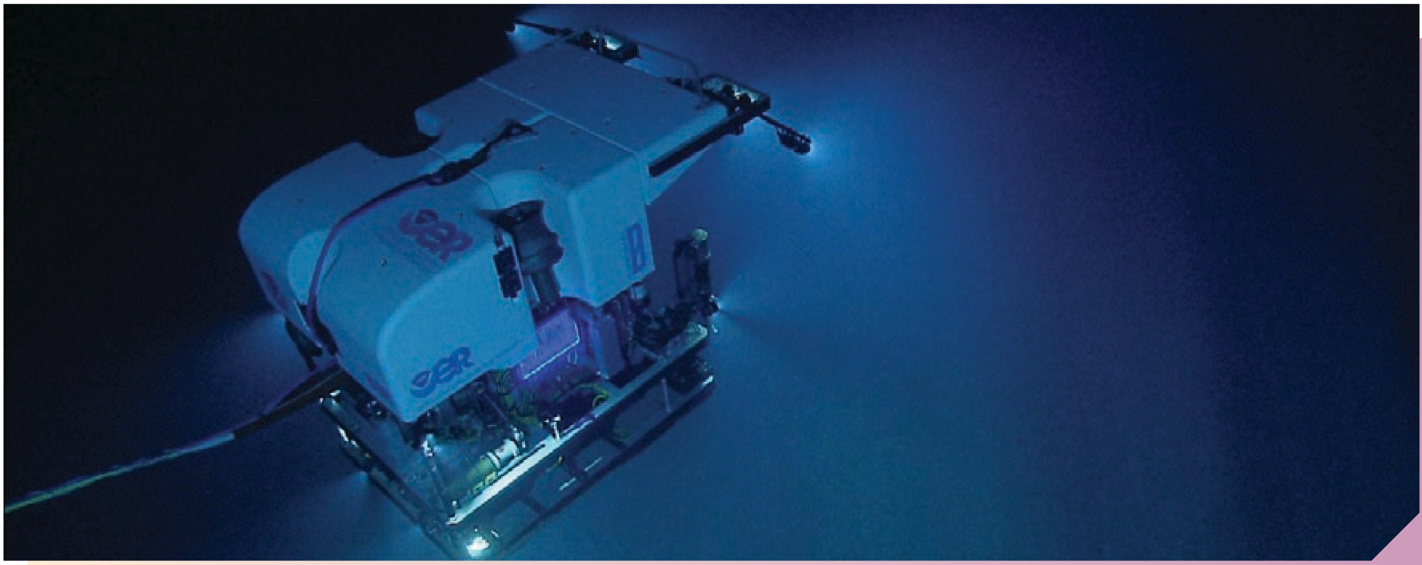
6. **PROGRAM AND CALIBRATE THE ROBOT**
   Now that teams have determined their path, they should program their robot to move through the path by writing a series of instructions. Encourage teams to use simple words and to be very specific in their directions.
   - **Moving Forward:** Encourage teams to measure their robot's step length to begin to determine how many steps forward the robot should move along the path. Teams can determine the number of steps using this formula:
     Distance Needed to Travel ÷ Step Length = Number of Robot Steps

- **Calibrating Rotation:** Encourage teams to calibrate their turns by testing and refining their robot's rotational movement. Simple rotations are encouraged: 45-degree and 90-degree turns work best.

7. **EXECUTE THE MISSION**
Tell teams that it is time to execute their deep sea robotic exploration mission! One team at a time, teams should execute their mission. Blindfold the robot, and turn the programmer away from the obstacles so that he/she can't see the robot's movement. Only the observer(s) should be watching the robot as it moves through the course. If the robot is damaged by colliding with any obstacle, the team must stop the mission immediately and return to their planning area to "recalibrate" their robot's program. Using the stopwatch, see which team can complete the challenge in the fastest time.

ACTIVITY VARIATIONS

- **Trade roles:** Have team members change roles during the exercise.
- **Remotely Operated Vehicle:** Allow the programmer to see what the robot is doing and adjust instructions according to what is seen. In this variation, the robot acts as a Remotely Operated Vehicle (ROV), which is controlled more directly by humans.
- **Scaling up:** Have teams work from a scaled blueprint rather than the actual course to plan the robot's route.
- **Exploration location:** Change the location theme that your robot is exploring (e.g., to a volcano, another planet, a cave, etc.).
- **Environment change:** This activity can be done in a smaller area by using masking tape to create an outer border. To make it more challenging, design the course in an irregular polygon. You can also use different items for obstacles and change the rules for each obstacle. For example, "participants can/cannot crawl under tables or interact with objects."
- **Competition:** Vary how teams win the challenge (first team to complete, farthest distance traveled during tests, most accurate, shortest program, etc.).



Underwater robot called Deep Discoverer exploring the Atlantic Ocean. Image courtesy of NOAA Okeanos Explorer Program, Our Deepwater Backyard. Exploring Atlantic Canyons and Seamounts 2014.

TROUBLESHOOTING

- If teams are having trouble calibrating their robot's steps, encourage them to walk their steps by placing one foot directly in front of the other. This will help control the variations between strides.
- If a team's instructions are too complex, suggest they take a different path through the course, or help them simplify their terminology.

KEY WORDS/VOCABULARY

Calibration: The process of carefully assessing, setting, or adjusting an instrument to ensure accuracy.

Humanoid robot: A robot with its body shape built to resemble that of the human body.

Iteration: The process of repeatedly testing and refining to reach a desired target or result.

Map: A representation of features of an area that shows them in their relative forms, sizes, and relationships.

Programmer: A person who creates and tests programs for devices including robots.

Programming: Creating a plan or schedule of activities and procedures to be followed.

Guidance For Younger Children

QUESTIONS TO ASK AFTER THE ACTIVITY

- How did your team choose a path? Were there other paths you could have chosen?
- How did your team decide how the robot would move? Were there other ways your robot could have moved that would have been faster?
- Did your program work perfectly the first time? If not, how did your team improve the program?
- Why did or didn't you give the robot each instruction separately?
- Were there programs that worked better than other programs? Why?
- How well did your team work together? How could you have improved your teamwork?

ENGINEERING CONNECTIONS

Robots are machines that help humans with tasks that are considered dirty, dull, dangerous, or distant. Engineers design, build, and program robots to work in specific environments, perform particular tasks, and conduct research.

Dirty tasks suitable for robots include cleaning up chemical spills or inspecting the insides of sewer pipes. Mowing the lawn or vacuuming are examples of dull jobs perfect for robots. Dangerous robotic tasks include bomb disposal and exploring harsh environments. Distant tasks include those at the bottom of the ocean or in outer space.

Robots are seen as perfect tools for deep sea exploration, which is both dangerous, due to the extreme pressure and temperature, as well as distant—sometimes more than a mile below sea level. Robots are also much cheaper to send into the deep ocean than humans, who need support systems such as air and heat to survive.

SCIENCE CONNECTIONS

Scientists study the properties of materials. At what temperature do they melt? How do they react under pressure? What happens when they freeze? Knowing this information is vital in designing robots that can hold up in extreme environments such as the bottom of the ocean. The pressure in the deep sea is 1,000 times that experienced at sea level, and the temperature varies from just above freezing to 750 degrees Fahrenheit at hydrothermal vents.

Materials scientists conduct a wide range of experiments designed to test the durability of metals and plastics under extreme conditions. Some types of steel and rubber become brittle at low temperatures, making them unsuitable for deep ocean exploration.

devices through various programmed motions for the

Guidance for Older Youth and Adults

QUESTIONS TO ASK AFTER THE ACTIVITY

- How did your team decide which path was the best? (Shortest? Fewest turns?)
- If the same robot/programmer team repeated the activity, would the path be exactly the same? Why or why not?
- What were the results of your first test? Did your team improve the program in between tests?
- Did you learn from any of the other teams' strategies? Did you add any elements of their program into your own?
- How well did your team work together? How could you have improved your teamwork?

ENGINEERING CONNECTIONS

Some robots must work with a high degree of precision. They are able to repeat dull, repetitive tasks over and over again with no variation. These robots function well in controlled environments such as a factory or lab.

Robots used in exploration, whether it is underwater or on another planet, must be programmed with a higher degree of flexibility. Currents can shift the position of the robot, or the robot can encounter unexpected conditions. Engineers program in suggested responses, such as telling the robot to back up or change direction when an obstruction is encountered. If this doesn't work, the robot may be programmed to wait for the humans to figure out a new set of directions.

SCIENCE CONNECTIONS

Understanding how animals are well adapted for a harsh environment can inform decisions made by engineers in designing robots for that environment. Scientists are using biomimicry to develop robots that look and act like living animals. Biomimicry develops solutions to human problems by imitating animals or biological processes. For example, Robolobster, a robot with 8 plastic legs, fiber-optic antennae, and a sturdy plastic shell, was originally used to study how a lobster's nervous system controlled its movements in the water. A lobster's body shape, weight, and buoyancy make it able to adjust to the changing currents, crashing waves, and low visibility of a coastal environment. By studying lobsters, scientists have been able to gain insight into how robots can be programmed to respond to similar conditions.

ACKNOWLEDGMENTS

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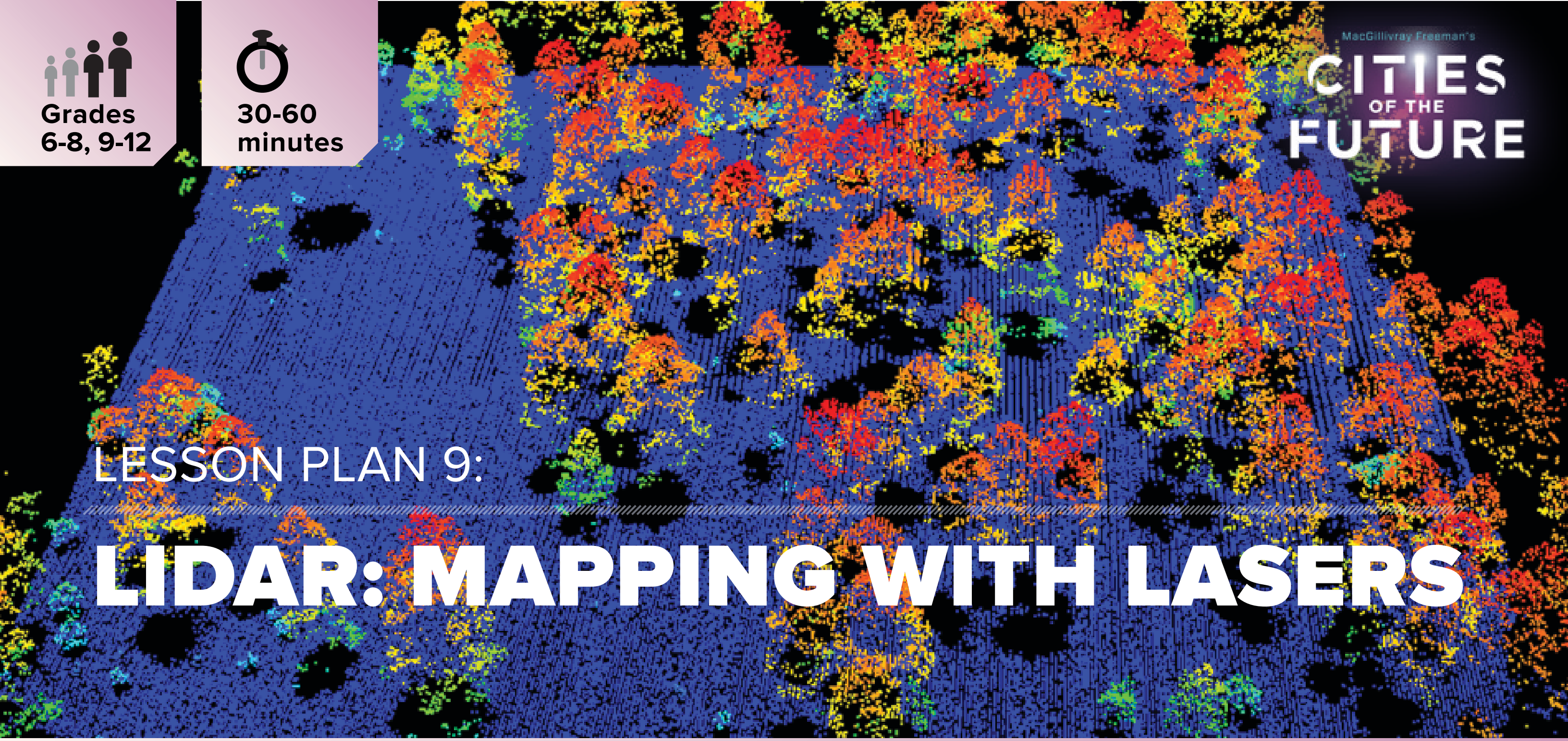


Grades
6-8, 9-12

30-60
minutes

LESSON PLAN 9:

LIDAR: MAPPING WITH LASERS

THE BIG IDEA

Create and map a three-dimensional landscape using a lidar laser measuring device.

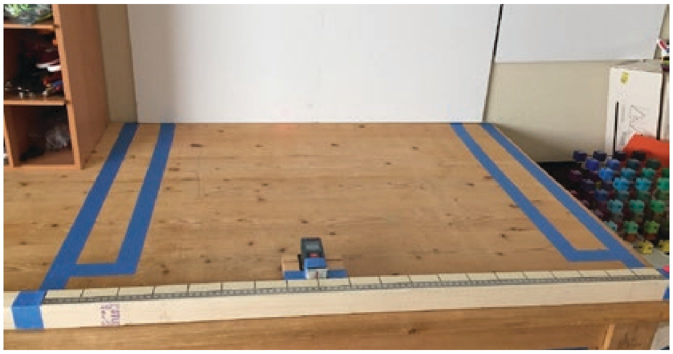
IN THE FILM

In *Cities of the Future*, a high-tech, autonomous boat known as the "Roboat" uses lidar to drive itself around the canals in Amsterdam. The lidar uses a sensor that points infrared lasers at nearby surfaces. A specialized GPS receiver measures how long the light takes to bounce back, allowing the boat to steer safely. This new kind of smart technology could revolutionize the way we get around in the city and how we use it to deliver packages and even pick up trash.

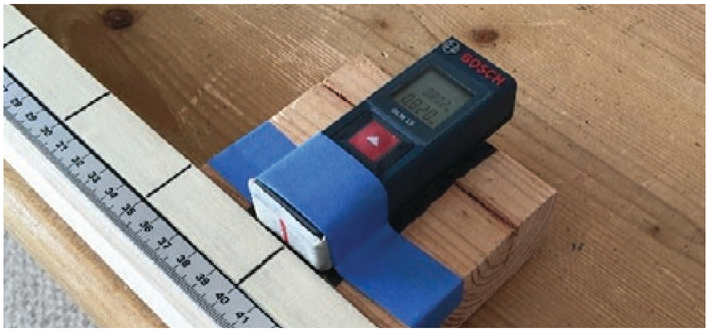
TEACHER PREP NOTES

1. Attach the laser measuring device to a block of wood so that its rear end is flush with the edge of the block. On the rear end of the device, place a red reference line. Set the laser device so that it displays metric units.

2. Set up work area as in the photo.

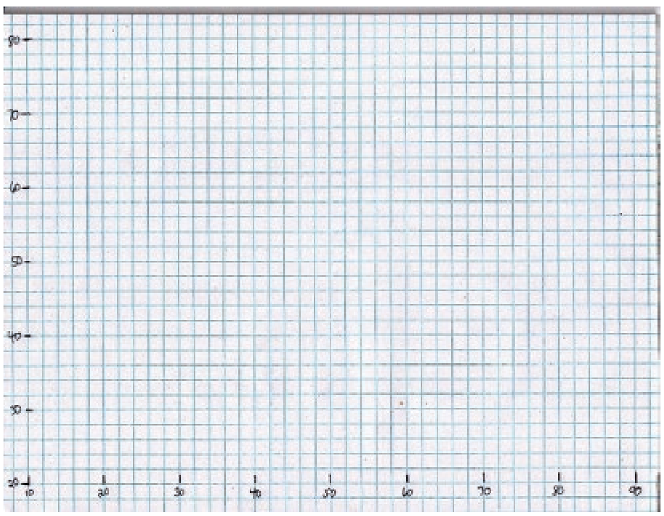


- Create a back wall with foam core or use an actual wall.
- Attach the reference track (2" x 2" x 40" board) to the table edge closestto you. It must be parallel to the back wall.
- Attach a meter stick to the reference track. Optional: Add lines every 5cm to make measuring easier.
- Use tape to mark off the work area, which will be determined by the labeling on your graph paper. (In the example here, because of the size of the graph paper, the work area extends from 10 cm to 90 cm left and right, and the back wall is about 80 cm from the reference track.)



Notice that the block and laser device slide against the reference track.

3. Prepare graph paper by labeling it to match your work area. (In these instructions, the horizontal axis goes from 10 cm to 90 cm and the vertical goes from 20 cm to 80 cm. Each square represents 2 cm.) Print these graph sheets so that each participant gets one.



4. Prepare data recording sheets as shown here and print a supply. Include about 20 rows.

Reference mark	Lidar reading (mm)	Round off to nearest cm

5. Provide a supply of cardboard boxes for visitors to use to make their own landscape.

MATERIALS

Supplies and Equipment

This is a tabletop-sized activity, so multiple stations could be set up.

Each station needs:

- Tabletop work area approx. 4' x 4'
- Laser measuring device such as Bosch GLM-15 Laser Measure (be sure it's rated "eye-safe")
- Wooden block to mount laser measuring device (approx. 4" x 4" x 2")
- Backdrop wall (an actual wall or one constructed from foam core)
- Wooden board (2" x 2" x 40") to serve as reference track
- Meter stick
- Ruler
- Rubber ball for bouncing
- For the concluding "hidden landscape" option: A foam core sheet approx. 2' x 3' to block participants' view, plus stands to hold this sheet in place

Consumables:

- A variety of cardboard boxes, approximately shoebox-sized
- Masking tape
- Supply of pre-printed graph paper, 4 squares/inch, with labeling (see Getting Ready)
- Supply of pre-printed data recording sheets (see Getting Ready)
- Colored pens or pencils

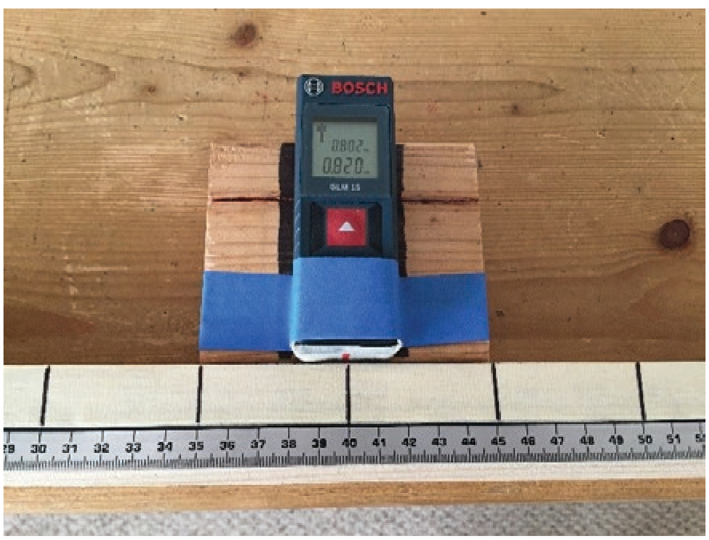
INSTRUCTIONS

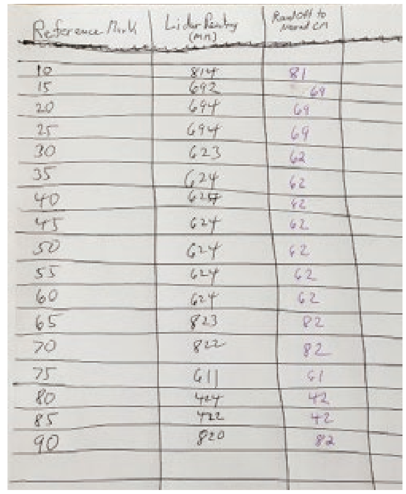
Explain to participants that they will be bouncing laser light to map a "landscape" that they will construct. To demonstrate, use a rubber ball and bounce it several times on the floor. Point out how long it takes for the ball to return to your hand. Now bounce the ball off of a tabletop or bench to show that it takes less time for the ball to return to your hand, because the ball has less distance to travel. Explain that you could walk along bouncing a ball and sort of figure out the heights of objects that you bounce it off of by seeing how long it takes for the ball to get back to your hand.

Demonstrate how to use the laser measuring device by pointing it at various objects and reading the distances. (It should be set to display metric units for measuring ease.) Remind participants never to point the laser at anybody, even though the lasers are rated eye-safe.

Have the participants set up a simple landscape consisting of three or four cardboard boxes. It is best if the boxes are pushed flush with the back wall. Be sure that the boxes stay within the work zone that you have marked with tape.

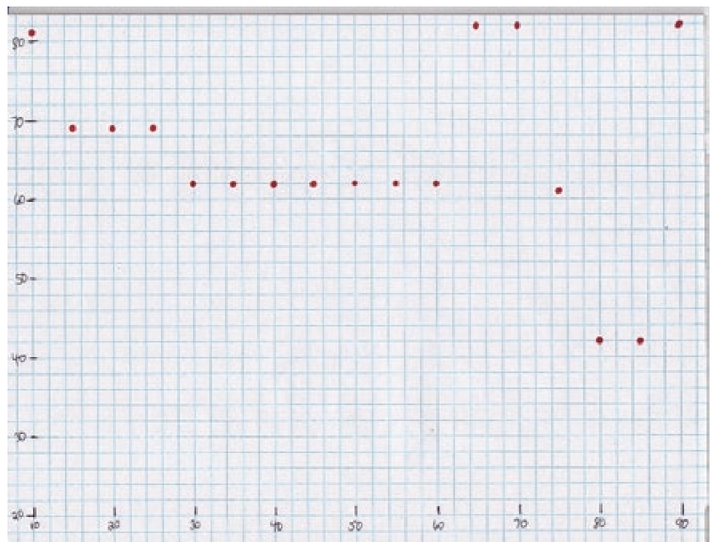
Next, show how to slide the laser device on its block along the reference track, lining up the red line on the laser device with the numbers on the meter stick. Show how to read the display on the device to see the distance from the reference track to the front of each box.





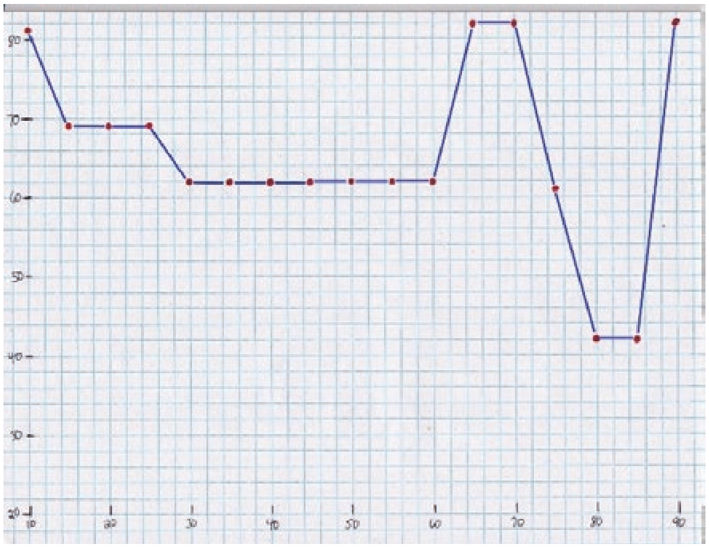
Reference Mark	Lidar Reading (MM)	Round off to nearest CM
10	814	81
15	692	69
20	694	69
25	694	69
30	623	62
35	624	62
40	624	42
45	624	62
50	624	62
55	624	62
60	624	62
65	823	82
70	822	82
75	611	61
80	424	42
85	422	42
90	820	82

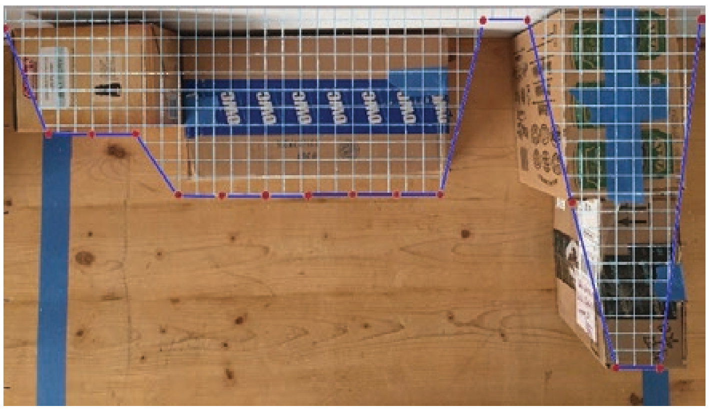
Participants should now slide the laser device every 5 cm and then take and record their readings on their data recording sheet. In the center column, they record the readings as they are on the device display (i.e., in millimeters). In the next column, they round off to the nearest centimeter.



Next, tell participants to transfer the data from their table to the graph paper. Depending on participants' age and skill, assist with graphing as needed.

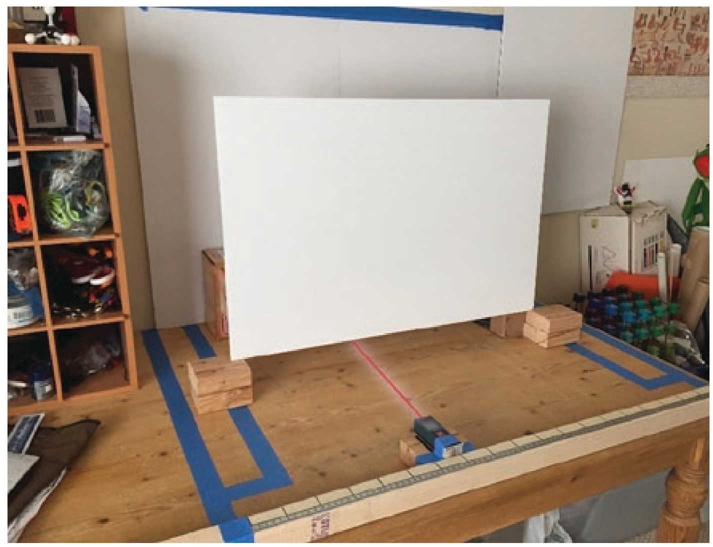
Connect the dots. This will give a general shape for the boxes that they measured. They can see how their graph approximately represents the shape of the boxes on the table. They can even sketch the shapes of the boxes onto the graph paper to see the relationship.





As time allows, conclude the activity with this more challenging step:

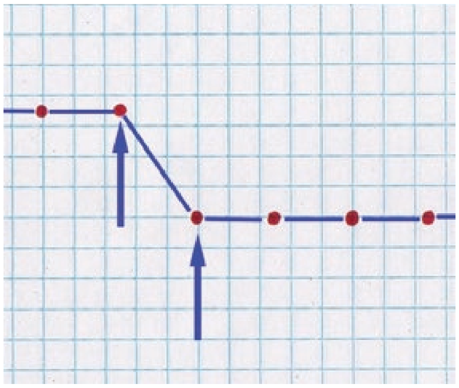
Explain that in a real-life situation, lidar data points are taken without actually seeing the objects or landscape being imaged. In fact, data collection may be completely automated, with nobody actually looking at the landscape. Invite participants to try their hand at mapping a landscape that they cannot see: Place a piece of foam core in front of the boxes as shown. The foam core must be mounted with a gap at the bottom so that the laser can shine underneath it to the boxes. Have one participant secretly set up the boxes to make a landscape, and a second participant take lidar measurements and do the graphing to try to construct an image of the landscape.



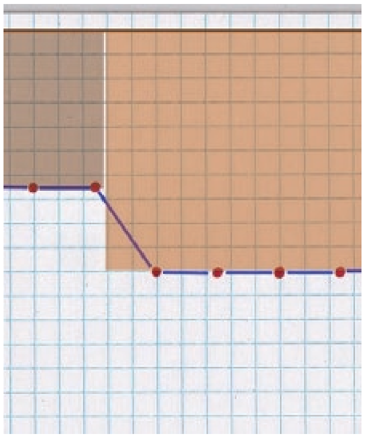
ACTIVITY VARIATIONS

More data points: One major problem arises when you measure two data points right next to each other that have different values. It is impossible to know what happened in between those two data points.

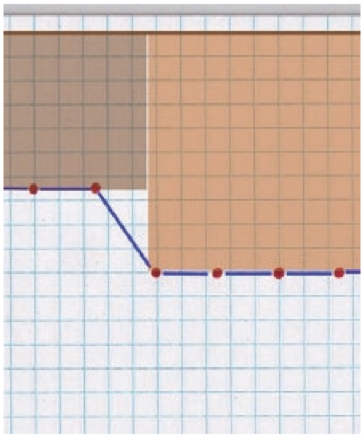
It could mean that the boxes were pushed to the left, pushed to the right, or even have a gap in between them…maybe even something else! The truth is that it is impossible to know. To find a possible answer, engineers increase the resolution—that is, they take measurements closer together. Have participants take measurements every 1 cm in these areas.



What does this graph represent?



OR



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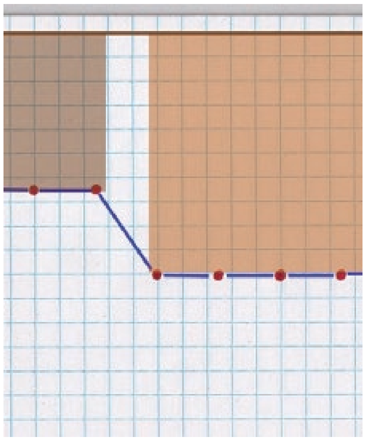


TROUBLESHOOTING

Be sure that the laser measuring device that you purchase is rated "eyesafe." Even with that, caution participants not to look directly at the laser or point the laser at anybody else.

The autonomous "Roboat" seen in *Cities of the Future* uses lidar to self-navigate.

KEY WORDS/VOCABULARY

GPS: Global Positioning System. A system of satellites and receiving units that accurately tells you where you are on (or above) the Earth's surface.

Laser: Light that is of a pure color and whose waves are all in phase. It is a very focused type of light that is used to measure distances in lidar units.

Lidar: Light detection and ranging. A system that measures the time it takes for light to bounce off a remote object and return to the sensor to calculate the distance to that object.

Remote imaging: Any technique that creates a picture or map of an object from a distance.

Resolution: The number of data points that you take in a certain area. The more data points, the higher the resolution, and the more accurately your map reflects the actual object you are imaging.

Guidance For Participants

QUESTIONS TO ASK AFTER THE ACTIVITY

- How did your graph compare to the shape of the cardboard boxes?
- If you had a laser measuring device like the one in the activity, what types of things would you want to measure?
- How would you have to change things in order to measure round or other shaped objects?
- In this activity, all of the boxes were pushed against the back wall. If some of the boxes were instead away from the wall, how would that change things?

ENGINEERING CONNECTIONS

Lidar is very useful for capturing information about a building. The laser signals are sent out at a much higher resolution than the 5 cm used in the activity. This allows an engineer to capture an exact record of a building, either on the inside or the outside. The detail becomes a record of the current condition. This threedimensional detail can even be printed out using a 3-D printer to provide an exact scale model of a building. On a larger scale, lidar can be used to give a digital representation of an area that includes several buildings.

Lidar is being used for some amazing things, such as mapping landscapes to make maps, checking the health of forests, determining where water might go in a flood, planning new neighborhoods, monitoring coastlines to see the effects of global climate change, searching for oil, discovering ancient Mayan cities, making virtual objects for video games, tracking the weather, checking the speed of cars, and guiding self-driving cars.

MATH AND SCIENCE CONNECTIONS

The main principle that lidar works on is this mathematical formula:

Distance = Rate x Time

For example, if a person is walking at a rate of 3 miles per hour and they have been walking for 4 hours, you can figure out how far they have walked. Their distance equals 3 miles per hour times 4 hours, which is 12 miles.

The same idea works with lidar, only much, much faster. The speed of light is about 300,000,000 meters per second. That is so fast that a laser pointed at the moon would reach there in less than 1.5 seconds! At that speed, light takes only a little more than 3.3 billionths of a second to travel one meter. The laser measuring device that you used in your activity is measuring the time it takes for light to go from the device, to the cardboard box, then back again. So, if the device measures that the light took 3.3 billionths of a second to make the round trip to the box, it means that the round trip is 1 meter, and the distance from the device to the box is half of that, or 0.5 meters.

Lidar measurements are often made by airplanes flying over a landscape. The laser sweeps back and forth, and computers use all of the data gathered to piece together a map of the ground beneath. Trigonometry must be used to account for the fact that lidar sweeps back and forth at an angle and not always straight down.

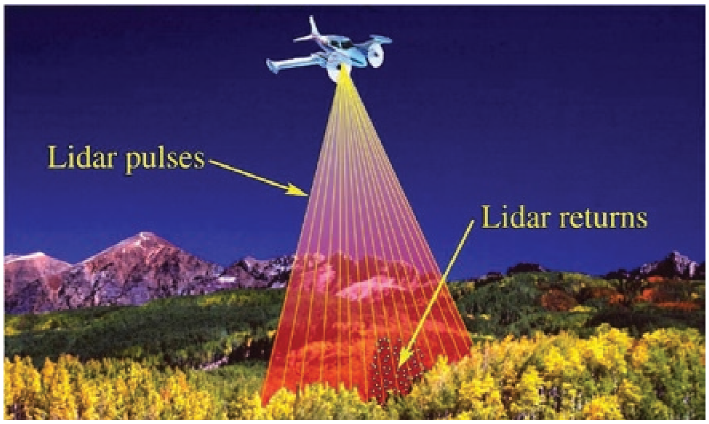
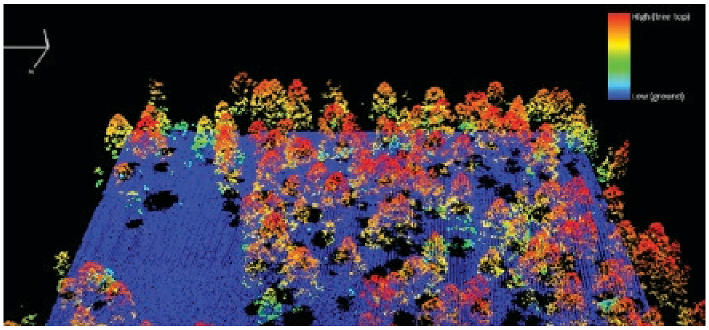


Illustration showing how the laser beam sweeps back and forth as the plane flies forward. Credit: USGS.

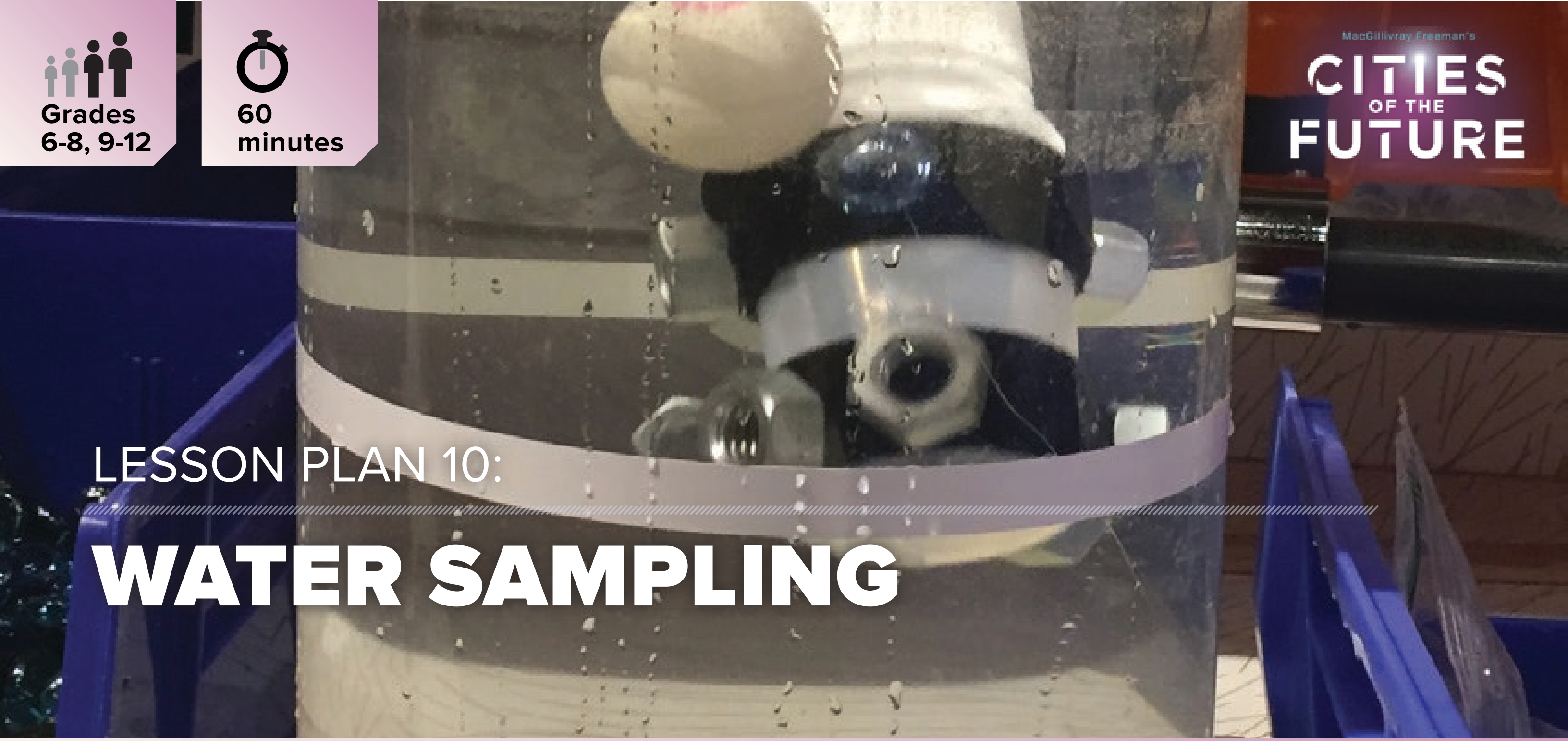


An actual lidar image of trees in a forest. Credit: Zhuoting Wu, USGS.

ACKNOWLEDGMENTS

Created by Eddie Goldstein, Alchemy Studio, for the American Society of Civil Engineers.

Supplemental content adapted by Carnegie Science Center.



Grades 6-8, 9-12

60 minutes

MacGillivray Freeman's CITIES OF THE FUTURE

LESSON PLAN 10:

WATER SAMPLING

THE BIG IDEA

Participants design bottles that can float, sink, or remain suspended to hold simulated sensors that would monitor the health of a river.

IN THE FILM

From ancient times until the present, cities have worked to develop adequate water sources. The Romans built aqueducts and the Mayans had underground storage systems. Because of climate change, droughts are increasing in frequency and severity. For the cities of the future, engineers are working on creative solutions to help conserve water and “re-use” it. Ideas include using waste water for watering gardens, harvesting rainwater, and designing better meters to measure consumption so that users can modify their behaviors. In your home, would you consider adding a meter to your shower that let you know how much water you were using?

TEACHER PREP NOTES

Designate a table for building and a space for the testing basins or buckets. Make sure that these areas are safe to get wet.

Designate a space where a facilitator can introduce the activity to participants; this is where teams can receive their water bottles. The materials should be available on an array of tables where participants construct their water sensor holders.

GETTING STARTED

Introduce the activity to participants by saying the following, adapted for your audience:

Environmental engineers and scientists design tools and develop solutions to environmental problems, such as pollution in rivers. River pollutants accumulate at different depths. How might you design an apparatus that can hold a sensor to test for oily pollutants on the surface of the river? How might you design one to test for salt or heavy metals at the bottom of the river? Today you will design bottles that can be attached to sensors and be used to collect a sample from the surface, middle, or bottom of a river.

INSTRUCTIONS

Divide participants into teams of two or three at most. Introduce the design challenge: to design bottles that can have sensors attached outside them to collect samples from the surface, middle, or bottom of a river in order to test for different types of pollutants that accumulate at each of these levels.

Point out the materials participants can use and the water containers that they will use for testing. The first step for each team will be to experiment with their water bottle to determine its initial buoyancy. Does it tend to float or sink with nothing but the simulated sensor attached?

Distribute three water bottles to each team. Instruct them to sketch their designs and take notes, so that they keep track of their ideas for each of the three levels. Remind participants of the steps of the engineering design process:

1. Plan. With your team, sketch ideas and select materials to change the buoyancy of the bottle to make it float, hover midway down the water column, or sink to the bottom. To adjust buoyancy, you may use water and/or weights.
2. Create. Construct your prototypes by adding floats and/or weights to your bottles, in addition to the simulated sensors (which are attached by a rubber band to the outside of each bottle).
3. Test. Place your bottles in the water and observe the results. Record your findings in your notes.
4. Improve. Try to improve your bottles by changing one variable at a time; then test again. What did you learn from your tests? How does your new design compare to the previous version?

As time allows, invite teams to demonstrate their apparatuses and discuss how they made their decisions.

MATERIALS

Per whole group:

- Basins or buckets deep enough for bottles to float, sink, or be neutrally buoyant (at least 1 basin per every 3 teams)
- Water to fill the basins or buckets
- Nuts, metal clips, washers, and other weight sources
- Fishing bobbers, ping-pong balls, and other floating objects
- Velcro, string, and twist ties to connect weights and floats to water bottles

Per team:

- 3 identical plastic water bottles (1 or half liter size)
- 3 identical placeholders for sensors (such as metal spoons)
- 3 rubber bands for attaching the sensor placeholders to bottles
- Paper and pen or pencils for sketching and taking notes
- 1–2 plastic rods or wooden dowels

ACTIVITY VARIATIONS

Each team makes only one water bottle sensor holder that can be used to test one level of the river.

Design two different sensor holders that float or hover at the same depth. Design a sensor holder that floats horizontally.

Design a sensor holder that floats vertically.

Try a different object to represent the sensor and attach it to the bottle. How do you need to change your design to compensate?

KEY WORDS/VOCABULARY

Buoyancy: An object's ability to float in water or other fluid.

Iteration: The process of repeatedly testing and refining to reach a desired target or result.

Prototype: An initial model of something from which other variations or innovations are developed.

Guidance For Younger Children

QUESTIONS TO ASK AFTER THE ACTIVITY

- Which water level was it hardest to develop an apparatus for: surface, submerged, or sunk to the bottom? Why do you think that is?
- What might work better than a water bottle to create a sensor holder?
- If your sensor holder worked horizontally, how could you make it work vertically? Or vice versa?

ENGINEERING CONNECTIONS

Engineers work with scientists to find ways to monitor our waterways and make them as clean as possible. This is very important work: the Environmental Protection Agency has determined that over half of the streams and rivers in the United States are in poor condition due to pollution or sediment from erosion.

Engineers who are working on projects that might affect the water quality of a nearby river also have to monitor the river, to make sure their project isn't creating pollution. For example, if a construction project requires dredging—scooping out mud or weeds—a lot of dirt and buried chemicals can swirl up and stay suspended. This cloudy, dirty water kills fish and can make people sick too. Engineers have ways to monitor the situation and to filter the water to make it clean again.

SCIENCE CONNECTIONS

Why does a bottle filled with water sink, while a capped bottle filled with air will float? The laws of buoyancy are known as Archimedes' principle, after the Greek scientist who discovered them. Buoyancy is the upward force of the fluid against the object. One of the laws of buoyancy is that something that floats must weigh less than the liquid that it is floating in. If an object has low density, such as wood, cork, or a sponge, it weighs less than water and it will float. If an object has higher density than the water and weighs more, it counteracts this upward force and sinks. Gravity pulls the object downward.

Guidance for Older Youth and Adults

QUESTIONS TO ASK AFTER THE ACTIVITY

- What factors influence your water bottle's buoyancy?
- How might changing your design affect the way the bottle floats or sinks?
- Did figuring out how to make a sensor holder for one level of the river help you design one for the other two levels? How so?
- Why is it important to make only one modification to a prototype at a time?

ENGINEERING CONNECTIONS

Environmental engineers use the principles of engineering, soil science, biology, and chemistry to develop solutions to environmental problems. Among the many tools that they have developed are stream gauges, which transmit data that can warn people of impending flooding. Engineers use a device called a sonde to measure water quality and characteristics such as temperature, pH, dissolved oxygen, and other indicators of water health. These devices, which often require sensors at different levels of the river, must take advantage of the laws of buoyancy to achieve the correct depth.

ACKNOWLEDGMENTS

Activity created by the Museum of Science, Boston. All rights reserved.

Supplemental content for this activity adapted by Mindful Solutions.

SCIENCE CONNECTIONS

The science of monitoring water is becoming increasingly accurate and sophisticated. The Lawrence Berkeley National Laboratory, for example, has created a DNA-based method of detecting and distinguishing sources of microbial contamination in water. They call it the PhyloChip. Being able to pinpoint exactly what is in the water helps engineers, local governments, and ordinary citizens figure out where the contamination is coming from so that they can put a stop to it. Scientists at the Berkeley Lab have created a reference library of the microbes from a huge range of sources, such as sewage and the excrement of birds and animals. Right now, the PhyloChip can detect the presence of more than 60,000 species of bacteria.

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