Auxiliary Resource Provided by the Film Producers

MacGillivray Freeman's

DREAM BIG

ENGINEERING OUR WORLD

EDUCATOR GUIDE

MacGillivray Freeman Films

ASCE American Society of Civil Engineers

Bechtel

Dear Teacher,

Dream Big aims to educate students on the inspiring work of engineers around the globe, igniting in them a passion for engineering at an early age that can carry through their school years and beyond. We also want students to understand how engineers work together to solve the major challenges of our time and shape the world of today and tomorrow.

I'm proud that both of my daughters have followed my footsteps into engineering. But as an engineering educator, I know that without personal role models to lead the way, many students will never discover the joy of engineering.

Teachers like you are the key to kindling a passion for engineering. Please use these lessons to inspire your students to use their curiosity, creativity, and problem-solving skills to engineer the future.

We hope you enjoy teaching these lessons to your students as much as we've enjoyed putting them together.

Norma Jean Mattei, Ph.D., P.E., F.SEI, F.ASCE

ASCE 2016 President

ASCE®
AMERICAN SOCIETY OF CIVIL ENGINEERS

Dear Teacher,

Bechtel is committed to inspiring the next generation of engineers by introducing students to science, technology, engineering, and math (STEM) educational opportunities. Today's young girls and boys are tomorrow's leaders—they will engineer and build the extraordinary, help solve the world's greatest challenges, and improve the quality of life in communities worldwide. We're proud of the role Bechtel colleagues play in mentoring and inspiring young people to dream big.

Brendan Bechtel

CEO, Bechtel Corporation

Dream Big: Engineering Our World is a film and educational project produced by MacGillivray Freeman Films in partnership with the American Society of Civil Engineers and presented by Bechtel Corporation. The centerpiece of the project is a film for IMAX and other giant screen theaters that takes viewers on a journey of discovery from the world's tallest building to a bridge higher than the clouds and a solar car race across Australia. For a complete suite of *Dream Big* hands-on activities, educational videos, and other materials to support engineering education, visit discovere.org/dreambig. The *Dream Big* Educator Guide was developed by Discovery Place for the American Society of Civil Engineers.

TABLE OF CONTENTS

Lesson Plans in this Guide

Grade K: Reach for the Skies

Grade 1: Daylight in a Bottle

Grade 2: Surviving Storm Surge

Grade 3: Maglev Train

Grade 4: Wind-powered LED

Grade 5: Take Out the Trash: Cleaning Our Rivers

Grade 6: Desert Island Desalination

Grade 7: Building Pyramids

Grade 8: Water Purification Device

Chemistry: Making an Impact on Habitat

Life Science: Endangered Species

Physics: LED Holiday Card

We Welcome Your Feedback

Your input is invaluable to help us improve the educational materials we provide. Please tell us what you think of this Educator Guide at tinyurl.com/DreamBigTG

EDUCATIONAL GOALS OF *DREAM BIG*

Introduction

“Scientists study the world as it is; engineers create the world that never has been.”

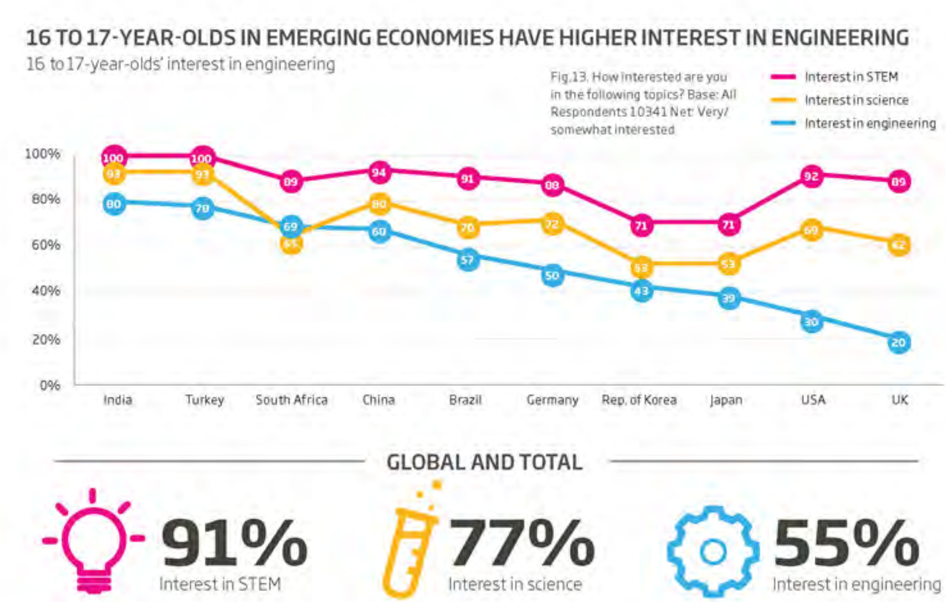
—Theodore von Kármán, Aerospace Engineer

This educator guide, created by the Discovery Place Education Studio for MacGillivray Freeman Films, is a companion resource to the giant screen film *Dream Big*: *Engineering Our World*. It provides multidisciplinary activities rich in math, language, and social sciences that tie directly to the film. Each lesson presents students with an engineering challenge inspired by the work of real engineers featured in the *Dream Big* film. 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 K–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 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.

Why *Dream Big*?

The world agrees that engineering has shaped our past and is critical to defining our future. Our success as a nation and as a global society is contingent upon how well we design and invent. But students consistently rank engineering of lower interest than science or other STEM topics.



Source: Create the Future, QEII Prize for Engineering Report, 2015

Although much has been done in the last two decades to pique interest in engineering and address gender gaps within the field, there is still work to be done. To capture the interest of tomorrow's engineers, educators must find a way to make engineering more appealing and accessible to students globally. *Dream Big* is a step in the right direction, highlighting the passion, creativity, and diversity within the field. In a global society where education, design, and innovation fuel our economy, we must strive to inspire the next generation of engineers to dream big!

Dream Big's Mission

Dream Big: Engineering Our World celebrates the engineering wonders of the world. This film aims to inspire today's youth, inform the public about the important work engineers do, and change perceptions about the profession. Viewers will learn of cutting-edge engineering innovations that enhance and improve our everyday lives. From Australia to Haiti, from China to France, this film dives into the extraordinary design of our most treasured civil wonders to better understand their purpose and function and their ability to withstand the tests of time.

Dream Big Lesson Plan Summaries

Below is a brief description of the 12 lessons included in this guide. By viewing the film *Dream Big*: *Engineering Our World* and incorporating the lessons, extension activities, and resources found here, teachers can build a robust way to talk about and experiment with engineering in the classroom.

Kindergarten
Reach for the Skies
Investigate the force of gravity on buildings in natural disasters.
Topics: Natural hazards, forces and motion, weather, climate

1st Grade
Daylight in a Bottle
Harness solar energy to light a room.
Topics: Electromagnetic radiation, refraction, use of recycled materials

2nd Grade
Surviving Storm Surge
Build a paper-based house to withstand a storm surge.
Topics: History of Earth, Earth's materials and systems, tides, weather

3rd Grade
Maglev Train
Design a magnetic train.
Topics: Transportation, conversion of energy from one form to another, magnetic objects

4th Grade
Wind-powered LED
Design a wind turbine to power on an LED.
Topics: Energy transfer, alternative energy sources

5th Grade
Take Out the Trash: Cleaning Our Rivers
Design a way to eliminate trash that threatens a river.
Topics: Relationships in an ecosystem, water filtration

6th Grade
Desert Island Desalination
Turn salt water into fresh water through desalination.
Topics: Electromagnetic radiation, structures and properties of matter, model development

7th Grade
Building the Pyramids
Determine how Egyptians moved giant stones.
Topics: Teamwork, forces and motion, ancient cultures and mythologies

8th Grade
Water Purification Device
Design a portable water purification device.
Topics: Natural hazards, natural resources, water filtration, the water cycle

High School Chemistry
Making an Impact on Habitat
Create a safe way to neutralize the byproduct of a factory.
Topics: Engineering in the real world, runoff from pollution, impact of human civilization

High School Life Sciences
Endangered Species
Engineer a method to support a local species and its future sustainability.
Topics: Ecosystem dynamics, function, resilience, biodiversity and humans, environmental niches, adaptive biology

High School Physics
LED Holiday Card
Design a greeting card that illuminates two LED lights.
Topics: Conversion of mechanical energy into radiant energy, aesthetics, design, electromagnetic fields, circuits, electricity

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 12 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 nextgenscience.org/resources/ngss-appendices

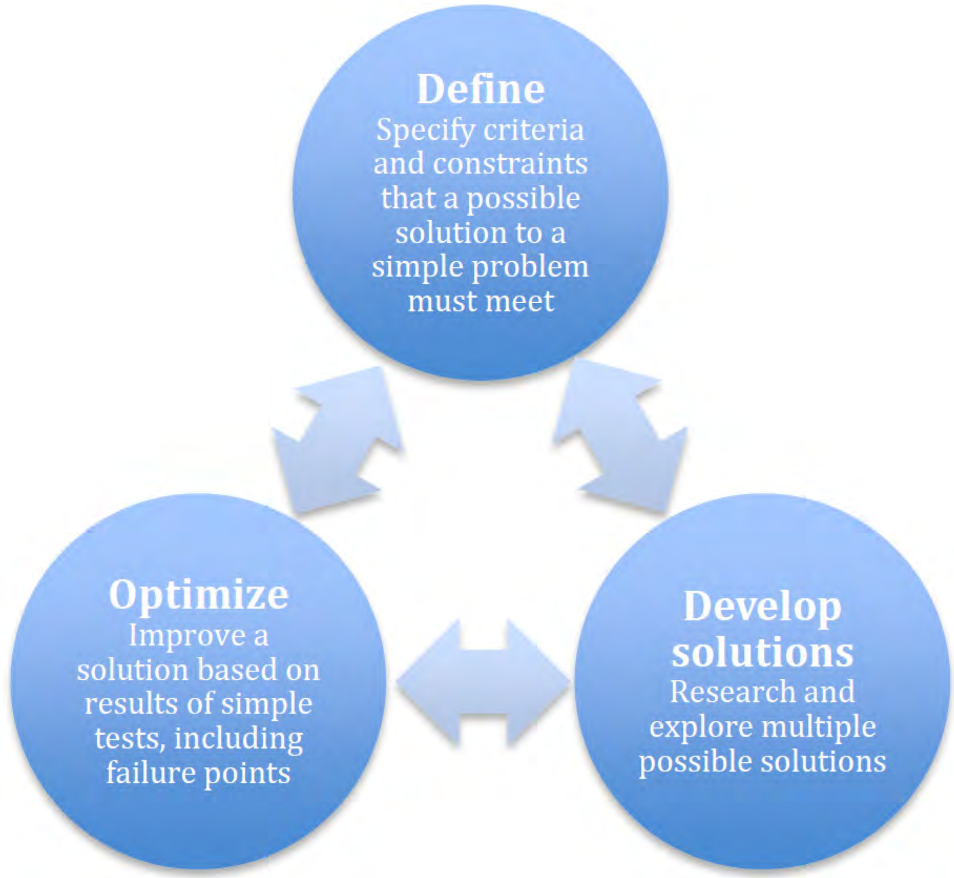
NGSS Engineering Core Ideas

Photo credit: MacGillivray Freeman Films

In the film *Dream Big*, Angelica Hernandez says that in robotics club, teacher Fredi Lajvardi "taught us a system: Define 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.

* 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 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.

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:

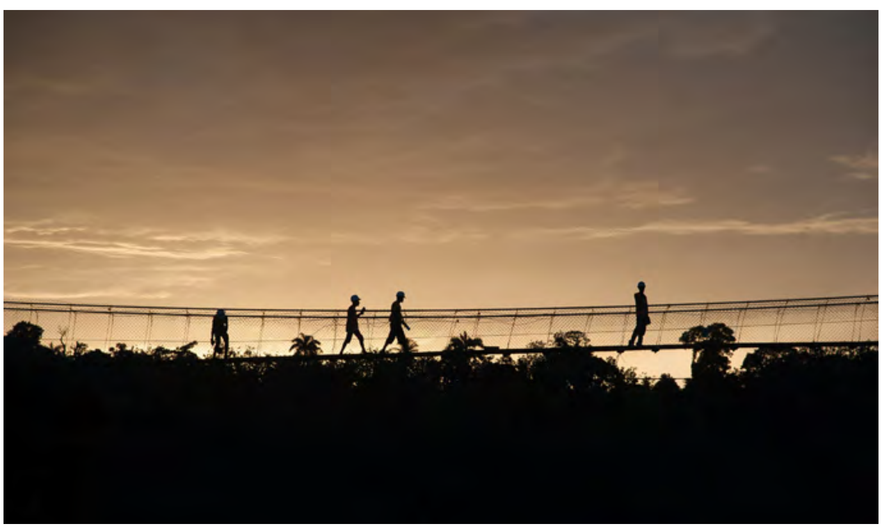
1. Asking questions (for science) and defining problems (for engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations (for science) and designing solutions (for 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

Dream Big 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



In Haiti, Avery's team defined the problem: Children needed to wade across a treacherous river to get to school. The constraints? High winds due to hurricanes and tropical storms, and limited access to building materials and skilled labor. The solution? A large suspension pedestrian bridge, built with teams of local and volunteer engineers, using local and recycled materials. The benefits of this solution include building local capacity for future projects.

Developing and using models

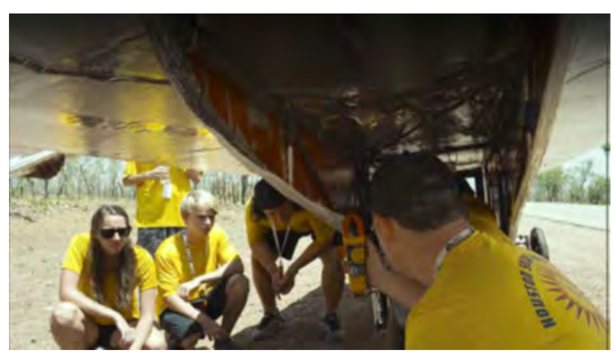
The computer models used by the Shanghai Tower's wind engineering consultants allowed them to run multiple simulations with different designs and wind forces. Physical models of the designs were tested in wind tunnels to further optimize the design.

Planning and carrying out investigations

Both the students in the classroom and the engineers at San Diego's giant outdoor shake table are planning and carrying out investigations to test their design's ability to withstand earthquake forces. These investigations allow engineers to improve their designs before selecting the best solution.

Analyzing and interpreting data

Collecting and analyzing data helped Mississippi's solar car team better understand their problem: their car was not getting the power it needed. Interpreting the data allowed them to isolate the source to the lithium batteries, which were not holding a charge. Because the solar panels were operating properly, the team optimized the angle toward the sun to eke out the extra power needed to finish the race!



Using mathematics and computational thinking

Instead of photovoltaic solar panels, the Ivanpah Solar Electric Generating Station uses over 175,000 synchronized mirrors that pivot to track the sun. The reflected sunlight is focused on a central boiler where the solar energy is converted to steam power and finally electrical power. Engineers relied on complex geometric and mathematical computations to determine the proper angles for the mirrors, the number of mirrors needed, and the total conversion of solar energy to electricity.

Designing solutions

Once the problem is defined and the constraints are known, it's time to unleash the creativity. Engineers brainstorm and test a number of solutions before selecting the best option. As Carl Hayden High School's robotics team learned, engineers also need to expect the unexpected! When Stinky sprang a leak and there wasn't time to find the source, the team brainstormed a new set of possible solutions, with surprising results. This iterative process is a hallmark of engineering design.

Engaging in argument from evidence

How do engineers know that ancient Chinese builders added sticky rice to their mortar? Unlocking the mysteries of ancient structures isn't easy. Lidar laser imaging is used to survey and map remote sections of the wall, documenting portions that withstood time with remarkable integrity. Engineering studies further confirmed that adding sticky rice increases the mortar's elasticity. This evidence helped engineers prove that the simple addition of sticky rice was in fact a major technological advance.

Obtaining, evaluating, and communicating information

Whether it's for working with the community in Haiti to define the problem and constraints for explaining the unique engineering of the Salesforce Tower to other engineers, or for presenting new ideas to the profession through journal articles or conference presentations, 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: nextgenscience.org/resources/ngss-appendices

DREAM BIG IN THE CLASSROOM

Teachers can take advantage of the enthusiasm generated by watching *Dream Big* to introduce the engineering mindset into their classroom. These strategies set the stage for successfully implementing the lessons in this guide and keeping the momentum building for learning about engineering.

Role Models Matter

Dream Big exposes students to a diverse group of interesting engineers. To make an even bigger impact, invite an engineer from your community to visit your class. The guest engineer can help lead an engineering activity or talk about how engineers in your area are "dreaming big." Request engineers who can connect with your students and expand their sense of the diversity that represents the new face of engineering.

Role models like these make a big difference. For example, according to research from Techbridge, fewer than 60% of high school girls know someone in a STEM career. Classroom guests and field trips to places where women are excelling in STEM-based careers open up entirely new possibilities for teenaged girls. Among Techbridge program participants, 93% say that those experiences made them more interested in science, technology, or engineering careers.

Many engineering companies, public agencies, engineering organizations, and universities have engineers as members or staff. Many have a commitment to student outreach and community service. To find an engineer in your area, contact the public relations office of one of these organizations and ask for an engineer to visit your classroom. The local chapters of engineering societies are a good place to start.

The list below provides excellent references to engineering groups that are engaged in outreach:

Discovere.org/about-us A national coalition of engineering companies and organizations dedicated to promoting engineering and engineering careers. Use the web links to the members to find engineers from a variety of disciplines.

Societyofwomenengineers.swe.org/page/4758-link-up-with-an-engineer-in-your-area The Society of Women Engineers offers a "find an engineer" service.

Engineergirl.org/default.aspx?id=246 This site has a comprehensive list of engineering organizations.

The Engineering Mindset: Reversing the Fear of Failure

For most students, failure is perceived as a direct reflection of their intellectual abilities rather than a stepping stone to success and a natural part of the learning and creating process. Apprehension, frustration, disappointment, and a sense of defeat are all natural responses to failure. Harnessing these emotions to drive grit and perseverance is critical to the success of these activities and is a valuable life skill reaching far beyond a student's academic career. Educators can expunge the stigma students associate with failure by modeling positive responses to it—by perceiving failures as opportunities to explore new ideas and try alternative methods, while practicing the art of persistence.

Overcoming a fear of failure is particularly important in encouraging girls and minorities to pursue careers in engineering. According to US News and World Report, girls and boys with similar interests, test scores, and confidence levels in 10th grade have drastically different views of physics in 12th grade. Boys are more likely to pursue a class that interests them, no matter how well they tested in math, while girls who are interested in physics may shy away if they feel that their math test scores aren't high enough, even if their test scores are on par with boys'.

Engineers see failure very differently. They intentionally look for the failure points of their design and use them as points to strengthen and improve their solutions.

To develop a culture of inquiry and resilience, both of which are characteristics of every engineer, consider the following tips:

- Acknowledge mistakes with a smile. Inquire about what can be done differently to produce the desired result.
- Implement a system that encourages students to share ideas for improvement.
- Empower students to make decisions, and reward creativity regardless of how extravagant the idea.
- Explore every suggestion even if success has already been achieved.
- Educate students on how to use new tools, and encourage them to use these tools during their investigations.

Dream Big Hands-on Activities and More

In addition to the lesson plans provided here, the *Dream Big* educational website features an extensive set of downloadable resources. These include 50 additional *Dream Big* hands-on activities that are suitable for lesson extensions, science fairs, family science and engineering nights, and clubs. You'll also find downloadable handouts, graphics, and more.
Visit discovere.org/dreambig

Dream Big Video Series

Take a deeper dive into the engineering stories featured in the film with this series of 11 five-minute educational videos. Each lesson plan includes one of these suggested videos, which can also provide an excellent introduction to a particular topic for students who have not seen the film.

The video series includes the following:

1. **Holding Sway: Wind Engineering**
   On a breezy day, a skyscraper might move a few inches back and forth near its top. But in a typhoon with high winds, a skyscraper could sway two feet or more! Discover how engineers tricked the wind when they designed the super-tall Shanghai Tower in China, where typhoons roar.

2. **Quake Takes: Earthquake Engineering**
   Nobody wants to experience an earthquake or tsunami in a building that can't keep them safe. That's why engineers study these high-impact, natural forces in controlled settings. Visit a giant shake table in San Diego and a tsunami wave basin in Oregon to learn how engineers work to protect people from nature's powerful punch.

3. **Virtual Modeling: Engineering the Future**
   Not only do engineers create the tools that produce virtual environments, but they also use virtual worlds to study and build the real world. Learn how engineers are changing the worlds we imagine and live in.

4. **Who's in the Driver's Seat: Autonomous Vehicles**
   Go behind the scenes at Google X and other companies to discover how self-driving cars are engineered, and meet the team who loves the creative problem solving this challenge requires.

5. **Quenching a Thirsty World: Water Engineering**
   With limits on our freshwater supply and a planet with more than 7 billion people, we need the ingenuity of engineers who are producing drinking water from improbable sources. Discover how engineers create clean water through desalination and water recycling programs.

6. **Lessons from the Great Wall: Reverse Engineering**
   Will your home or your school still be here in 100 years...or 1,000? Today's engineers still marvel at the ancient engineers who built the now 2,000-year-old Great Wall of China, the largest structure on Earth.

7. **Water Wishes: Engineering for Those in Need**
Student engineers from Princeton University worked with a village in the mountains of Peru to build a safe drinking water system that will keep families there healthy. All around the world, Engineers Without Borders and other organizations are helping people build better, safer communities.

8. **Incredible Structures: Extreme Engineering**
If we can dream it, we can build it. Take a tour of some amazing structures designed by engineers, such as a 1,000-foot glass elevator built on a cliff in China, and a fire-breathing dragon that serves as a bridge in Vietnam. Visit the engineers who work from ropes suspended high above the Colorado River near Hoover Dam.

9. **Lean and Green: Engineering Alternative Energy**
Because fossil fuels create harmful emissions and are nonrenewable, engineers are harnessing alternative energy sources to power our planet. Tour the world's largest solar thermal plant, Ivanpah in California, which reduces CO_2 emissions by over 1,000 tons every day. Learn how wind and ocean waves can generate clean power too.

10. **Innovative Engineers: Our High-Tech Future**
Engineers look for problems and try to solve them. See how Bechtel engineers, who have worked on mega projects all around the world, use today's technologies—virtual and augmented reality, drones, and massive interactive touch screens—to collaborate, test big ideas, and create a world of innovations.

11. **A License to Engineer: Let's Get Professional**
To design a building that can protect the public during an earthquake or a bridge that can be safe to cross for decades is a challenge engineers face every day. But as licensed engineers, they come prepared. Learn why having a license to engineer protects us all.

TO OUR FUTURE ENGINEERS

In this section, teachers will find information to share with students: a behind-the-scenes look at the engineers in the film, 10 great reasons to become an engineer, and how to actually do it!

Meet the Engineers in *Dream Big*

On each of the next four pages is a profile of an engineer in *Dream Big*. We encourage you to share these profiles with your students, as inspiration for their future careers.

Menzer Pehlivan

Work: Geotechnical engineer, CH2M in Seattle

Education: Ph.D. from the University of Texas-Austin, master's and bachelor's degrees from Middle East Technical University in Ankara, Turkey

Fun Fact: Menzer was a Turkish national youth champion in snowboarding

Menzer's career path is no random coincidence. Growing up in Turkey, she awoke one night to a massive earthquake rattling her hometown of Ankara.

> *"I think anyone who lived through the earthquake in Turkey will always remember that night. I know it had a great impact on who I am."*

She was inspired to become a civil engineer.

> *"The earthquake was a reality check for me. I just wanted to help reduce the risk and increase our resiliency against natural disasters."*

Menzer flew to Katmandu, Nepal, last year to do reconnaissance earthquake research.

> *"Every earthquake, every extreme event, teaches us something new. It's very important to capture that data and learn from it. The 1999 earthquake just made all of us living in Turkey, I think, realize how important the profession of civil engineering is and how much of an impact it has on our daily lives."*

Avery Bang

Work: President/CEO, Bridges to Prosperity

Education: Master's degree from the University of Colorado at Boulder, bachelor's degree from the University of Iowa; currently working toward a second master's degree at the Skoll Centre for Social Entrepreneurship at the University of Oxford

Fun Fact: Avery is a former Big 10 soccer standout for the University of Iowa

Avery spent most of her early life playing soccer. She earned a Division I scholarship and starred at the University of Iowa. But as her playing career wound down, she went looking for a new passion to fill the void and found her calling while volunteering in Fiji.

> *"One of the communities had recently opened a footbridge development project, and I was able to see firsthand how a simple bridge was transforming their everyday world. People could get to the doctor, to schools and to markets they could never have reached before. I directly experienced how structures change people's lives. That's when I really started taking engineering seriously."*

Avery became Bridges to Prosperity's first paid employee in 2008 and took on the role of CEO in 2011—while still just in her 20s. She has helped Bridges to Prosperity serve more than a million people in need in 20 different countries.

> *"Engineers need to think of ourselves as global problem-solvers. I think we have an obligation to society to not only be thinking about people who live with the most but to work for the people who don't have potable water, who don't have electricity, who don't have access to some of the common human rights that we all deserve every day."*

Steve Burrows

Work: Executive vice president, WSP Parsons Brinckerhoff in San Francisco

Education: Bachelor's degree in civil engineering from Liverpool (England) Polytechnic (now Liverpool John Moores University)

Fun Fact: Honored by Her Majesty the Queen of England as a Commander of the Order of the British Empire (CBE)

Steve is one of the world's most accomplished structural engineers and is the engineer behind several world-class building projects, including the famous Beijing National Stadium, known as the Bird's Nest, in China.

> *"I like the idea of dreaming big, because that's what engineers do. We're allowed to dream in the daytime while we're awake. Who else gets to do that?"*

But as a college freshman, he still didn't know what career he wanted to pursue. He only tried civil engineering because a friend of his was studying it.

> *"I stumbled into engineering. I didn't honestly know what I was doing, but by the end of the first year I was completely passionate about engineering. I've had an amazing career, been to amazing places, met amazing people, been a part of amazing projects, left a mark on the planet that will outlive me, my children, and my grandchildren. I've been so lucky."*

Angelica Hernandez

Work: Engineer, Nexant Inc. in Chandler, AZ

Education: Master's degree from Stanford University and bachelor's degree from Arizona State University

Fun Fact: Angelica was the valedictorian of her high school class

Angelica moved to the United States from Zacatecas, Mexico, as an undocumented immigrant at age 9. Two decades later, she is a professional engineer working to develop clean energy.

> *"I think the most exciting part of being an engineer is that every day you're helping to change the world. You might be working to solve our energy challenges, or maybe you're saving someone's life with biomedical engineering, or maybe you're working in developing countries, or you're making safer buildings. No matter what you focus on, as an engineer you feel like you are part of creating our world's future."*

Angelica discovered her talent and love for engineering as a high school student in a robotics club. She helped design a robot—named Stinky—that won a national competition for her school, Carl Hayden High.

> *"It's one thing to be working on a robot in a classroom, but the competitions took me into a world I'd never had any exposure to. It was a place where I was meeting real inventors and scientists and everyone was so excited about all the different designs. I learned about working in teams and the fun of experimentation, and I realized: this is what I want to do with my life."*

10 REASONS TO LOVE ENGINEERING

1. LOVE YOUR WORK, AND LIVE YOUR LIFE TOO! Engineering is an exciting profession, but one of its greatest advantages is that it will leave you time for all the other things in your life that you love!

2. BE CREATIVE. Engineering is a great outlet for the imagination—the perfect field for independent thinkers.

3. WORK WITH GREAT PEOPLE. Engineering takes teamwork, and you'll work with all kinds of people inside and outside the field. Whether they're designers or architects, doctors, or entrepreneurs, you'll be surrounded by smart, inspiring people.

4. SOLVE PROBLEMS, DESIGN THINGS THAT MATTER. Come up with solutions no one else has thought of. Make your mark on the world.

5. NEVER BE BORED. Creative problem solving will take you into uncharted territory, and the ideas of your colleagues will expose you to different ways of thinking. Be prepared to be fascinated and to have your talents stretched in ways you never expected.

6. TRAVEL. Fieldwork is a big part of engineering. You may end up designing a skyscraper in London or developing safe drinking-water systems in Asia. Or you may stay closer to home, working with a nearby high-tech company or a hospital.

7. EARN A BIG SALARY. Not only do engineers earn lots of respect, but they're highly paid. Even the starting salary for an entry-level job is impressive!

8. ENJOY JOB FLEXIBILITY. An engineering degree offers you lots of freedom in finding your dream job. It can be a launching pad for jobs in business, design, medicine, law, and government. To employers or graduate schools, an engineering degree reflects a well-educated individual who has been taught ways of analyzing and solving problems that can lead to success in all kinds of fields.

9. MAKE A DIFFERENCE. Everywhere you look you'll see examples of engineering having a positive effect on everyday life. Cars are safer, sound systems deliver better acoustics, medical tests are more accurate, and computers and cell phones are a lot more fun! You'll be giving back to your community.

10. CHANGE THE WORLD. Imagine what life would be like without pollution controls to preserve the environment, lifesaving medical equipment, or low-cost building materials for fighting global poverty. All this takes engineering. In very real and concrete ways, engineers save lives, prevent disease, reduce poverty, and protect our planet.

Source: DiscoverE.org

Becoming an Engineer

We need more engineers! According to the U.S. Bureau of Labor statistics, the field of engineering is expected to grow as much as 10% in the coming decade. Engineers are found in a variety of careers outside of pure engineering. More than half of the people with engineering degrees work in other areas like medicine, law, investment banking, and consulting, prompting many experts to call engineering the new liberal arts degree.

What do you do to become an engineer?

- **High School:** Pursue a well-rounded course of study in high school, including four years of math, science, and language arts. Take higher level courses, including calculus and physics. Engineers need to communicate effectively to team members and clients, so language skills are essential as well. For more detailed information, see discovere.org/discover-engineering/preparing-for-college

- **College:** There are a number of different routes you can take. If you're looking into a four-year engineering program, it should be accredited by ABET. For more information see discovere.org/discover-engineering/researching-schools

- **Licensed Professional Engineer (P.E.):** After graduating with a four-year degree in engineering, you can pursue professional licensure. This license means that you meet the standards required to perform your job, and the public can have confidence in your work. Licensure requirements vary by state, but typically involve a combination of exams as well as a certain number of years of on-the-job experience. Once you have your license, you'll take continuing education credits every year, including a course on ethics, in order to maintain your license. Given how fast the world is changing, it makes sense that you need to keep learning. It's one of the perks of the job: you'll be continuing your education throughout your career!

MACGILLIVRAY FREEMAN'S
DREAM BIG
ENGINEERING OUR WORLD

GRADE K:

REACH FOR THE SKIES

Grade level: Kindergarten

Lesson length: 75 minutes (can be broken into smaller parts)

> Students investigate shapes and material properties as they build the highest structure they can. They also learn about the ways natural disasters such as typhoons and hurricanes create powerful forces that push and pull on buildings.

In the Film

Shanghai Tower looms 128 floors tall. It is the second tallest building in the world. When engineers built it they had to make sure that its structure could support that great height. But they also had to make it capable of withstanding extremely high winds: the tower is in an area of frequent typhoons, with winds that can reach 215 miles per hour.

NGSS Disciplinary Core Ideas

K-ESS3.B Natural Hazards

Some kinds of severe weather are more likely than others in a given region. Weather scientists forecast severe weather so that the communities can prepare for and respond to these events.

K-PS2.A Forces and Motion

Pushes and pulls can have different strengths and directions.

NGSS Engineering Practices

K-ETS1.A Defining and Delimiting Engineering Problems

Asking questions, making observations, and gathering information are helpful in thinking about problems.

Before beginning to design a solution, it is important to clearly understand the problem.

K-ETS1.B Developing Possible Solutions

Designs can be conveyed through sketches, drawings, or physical models. These representations are useful in communicating ideas for a problem's solutions to other people.

Dream Big: Engineering Our World is a film and educational project produced by MacGillivray Freeman Films in partnership with the American Society of Civil Engineers and presented by Bechtel Corporation. The centerpiece of the project is a film for IMAX and other giant screen theaters that takes viewers on a journey of discovery from the world's tallest building to a bridge higher than the clouds and a solar car race across Australia. For a complete suite of *Dream Big* hands-on activities, educational videos, and other materials to support engineering education visit discovere.org/dreambig. The *Dream Big* Educator Guide was developed by Discovery Place for the American Society of Civil Engineers.

Key Words/Vocabulary

Structural engineers: Engineers who design and build bridges, buildings, dams, and other structures.

Structurally sound: What we call a building that is safe for people to be in and that doesn't have anything wrong with it, such as big cracks in it or a tendency to lean over.

Three-dimensional shape: An object that has height, width, and depth, like an apple or a person.

Typhoon: The name used in Asia for a hurricane.

Materials

Per class:

- ☐ Images of Shanghai Tower
- ☐ Ruler or tape measure
- ☐ Box fan

Per student:

- ☐ My Tall Tower Plan handout

Per pair of students:

- ☐ 20 pieces of uncooked fettuccine
- ☐ 1 large piece of newspaper
- ☐ 5 straws
- ☐ 1 yard of transparent tape
- ☐ 20 marshmallows

Teacher Prep Notes

Use uncooked noodles and marshmallows to make some shapes ahead of time to show students before you begin the research phase. Make two triangles and two squares. When it's time to demonstrate how to make three-dimensional shapes out of two-dimensional ones, add the two triangles together vertically so that they join at their apex to create a pyramid. Place two squares vertically and add two horizontal pieces to the top and bottom to create a cube.

Prepare information about typhoons and other natural disasters to share with your students, especially in terms of the pressure such events put on buildings.

Clear a large space so that students can put together their towers on the floor. Alternatively, make sure that pairs have lots of flat surface area on tables to build.

To Do

Determine the Problem or Question to Solve: 15 minutes

1. Before watching the film *Dream Big*, 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:
   - **a.** Of all the structures engineers created in this film, such as bridges, towers, and dams, which one amazed you the most?
   - **b.** Why was this structure so special to you?
2. Debrief as a whole class after viewing the film. Allow students to reflect on the guiding questions you gave them.
3. Remind students about the Shanghai Tower featured in the movie and display the pictures of it. Ask students what they remember about this building.
4. Introduce the design challenge: students will work with a partner to build the tallest building they can, just like the engineers did in *Dream Big*. They will learn how engineers use shapes and materials to support tall buildings and to keep them strong in high winds.

Research and Gather Information: 20 minutes

1. Hand out bags of prepared materials to pairs of students. **Caution:** For safety, be sure to inform participants not to taste or eat any of the materials during this activity.
2. Have students make a triangle and a square with the noodles as the sides and marshmallows as the joints. Ask students to stand the shapes up vertically, and apply pressure to the top. What are the students' observations?
3. Tell students that they can make three-dimensional shapes by adding together two-dimensional shapes. Show students how to make a pyramid and a cube with the shapes you have already made. Have them take turns applying pressure to the pyramid and triangle and reflect on the strength of each.
4. Remind the students that what makes the Shanghai Tower special, other than its tall height, is its ability to stand up in the strong winds of typhoons. Teach about natural disasters such as typhoons and the resulting high-speed winds that blow on buildings and other structures built by engineers, causing them to fall or rip apart if they aren't strong enough.
5. Have students blow on the three-dimensional noodle structure to see how the wind they create affects it.

Plan a Solution: 10 minutes

Ask pairs to look at their My Tall Tower Plan handout, which gives them a place to draw. Instruct students to make a drawing that will guide them as they build their own tower. Show them how tall 2' is and let them know that their own tower needs to be that tall!

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.

Make It: 15 minutes

Once students have drawn their plan, it's time to begin building. Encourage students to use the noodles and marshmallows to make the frame and to use the newspaper and straws to add structural support and strength. As students are building, visit each pair, reviewing what they learned about the strengths of different shapes and how they are using shapes in their design. Allow students to make mistakes along the way and struggle. When they do, ask questions about what the students are observing and ask guiding questions accordingly to lead them to a solution. Avoid offering solutions yourself. Instead, encourage students to test ideas as they build.

Test: 10 minutes

- ☐ Have students remove their hands from the building. Ask, can it stand up on its own?
- ☐ Show students how to measure their building to see if it reaches 2'. Then tell each pair to measure the height of their building.
- ☐ Place a fan in front of the buildings and turn it on low. Ask students what they see happening to their building.

Evaluate: 5 minutes

Allow students to reflect on the following questions:

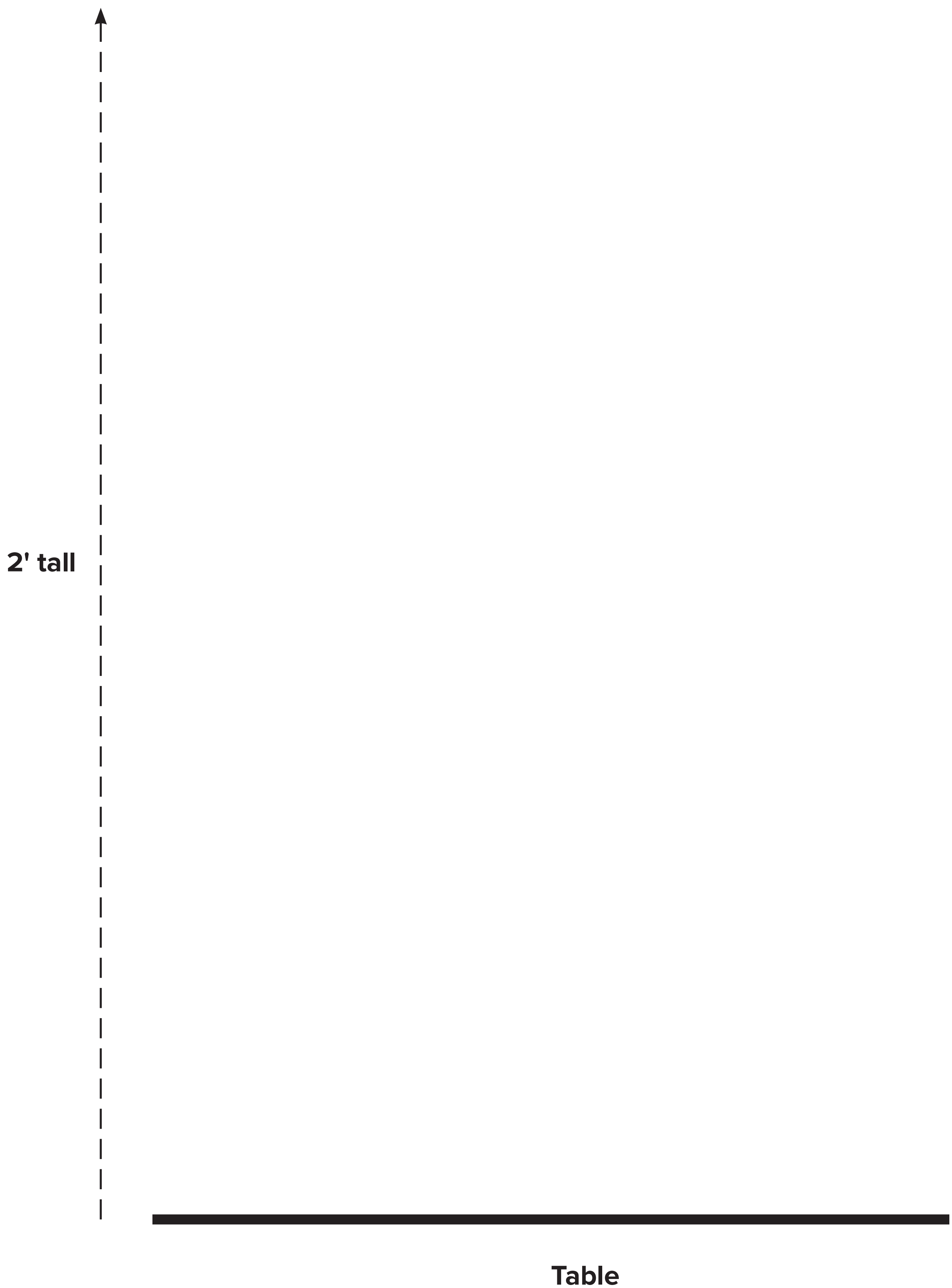
1. What do all the tallest towers have in common?
2. What do you think made them strong?

Taking It Further

Practice shape and number sense by challenging students to count the number of triangles and squares within the frame of their building.

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

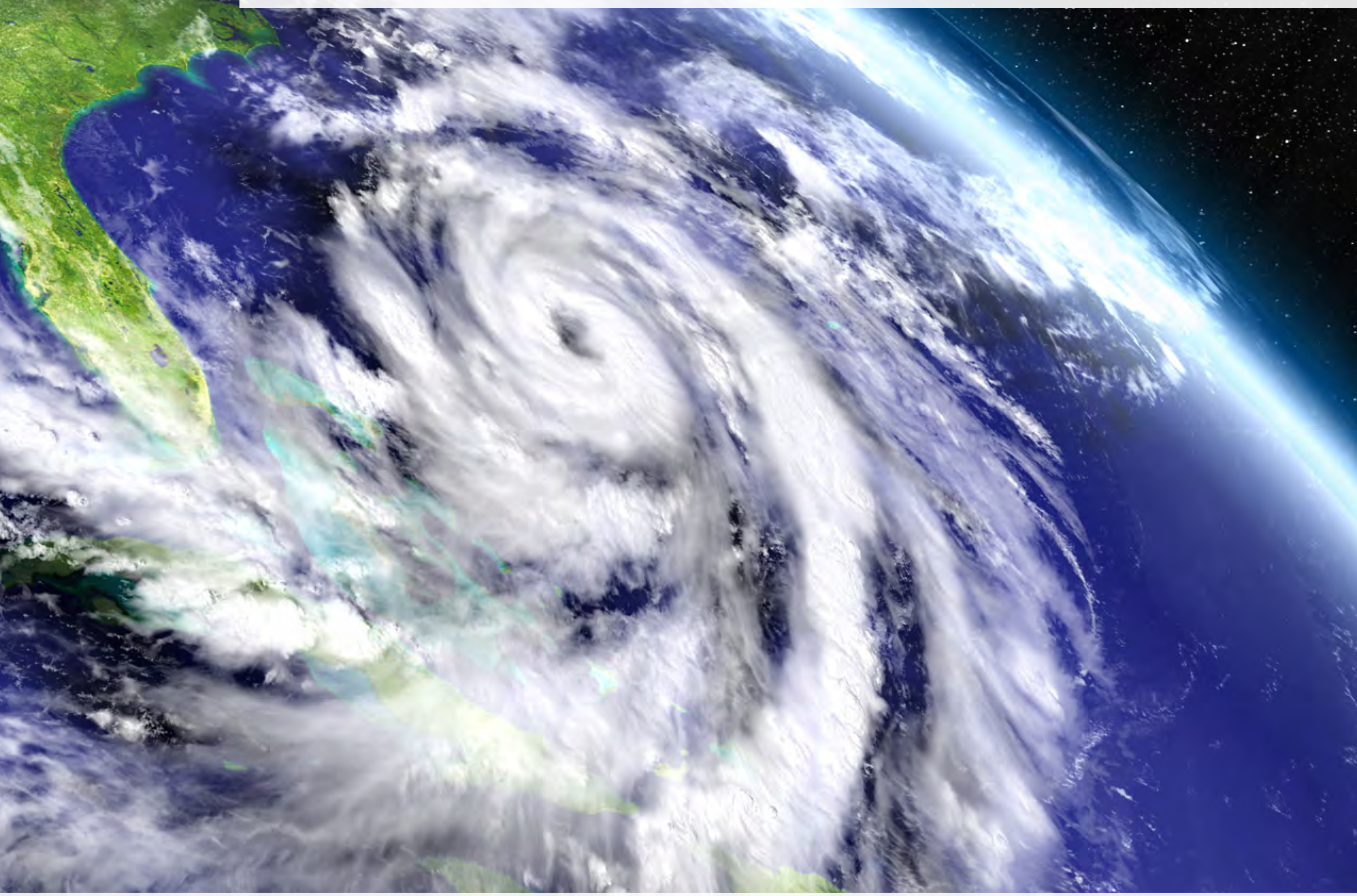
MY TALL TOWER PLAN



DREAM BIG VIDEO SERIES

WATCH *HOLDING SWAY: WIND ENGINEERING*

On a breezy day, the top of a skyscraper might move a few inches back and forth. But the high winds of a typhoon can make a skyscraper sway two feet or more! Discover how engineers tricked the wind when they designed the super-tall Shanghai Tower in China, where typhoons roar. Go to discovere.org/dreambig/media-assets and visit Educational Webisodes.



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DREAM BIG
ENGINEERING OUR WORLD

GRADE 1:

DAYLIGHT IN A BOTTLE

Grade level: 1

Lesson length: Lesson length: 2.5 hours (can be broken into smaller chunks)

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 *Dream Big*, we see ways that engineers are bringing light to the interior of buildings without the need for electricity. In the Transbay Transit Center, engineers have designed a way to bring natural sunlight into the station in order to make it more energy efficient. During this design challenge, students 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.

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 pair:

- ☐ 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

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.

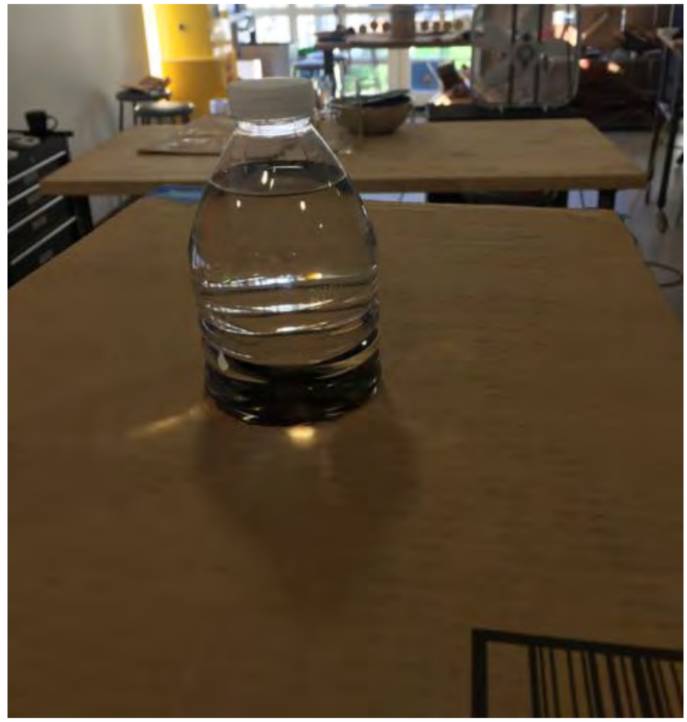
Prior to introducing the challenge to students, build the testing box using the Making the Testing Box instructions.

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 the IMAX movie *Dream Big*, 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:
   a. How do you think people used to light their houses before electricity was invented?
   b. Why do you think natural sunlight might be better than electricity for lighting a house during the daytime?
   c. If you didn't have electricity to light up your home, what would you do?
   d. 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: youtube.com/watch?v=C5XCRg_I4IE. 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-and-white 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 black-and-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.

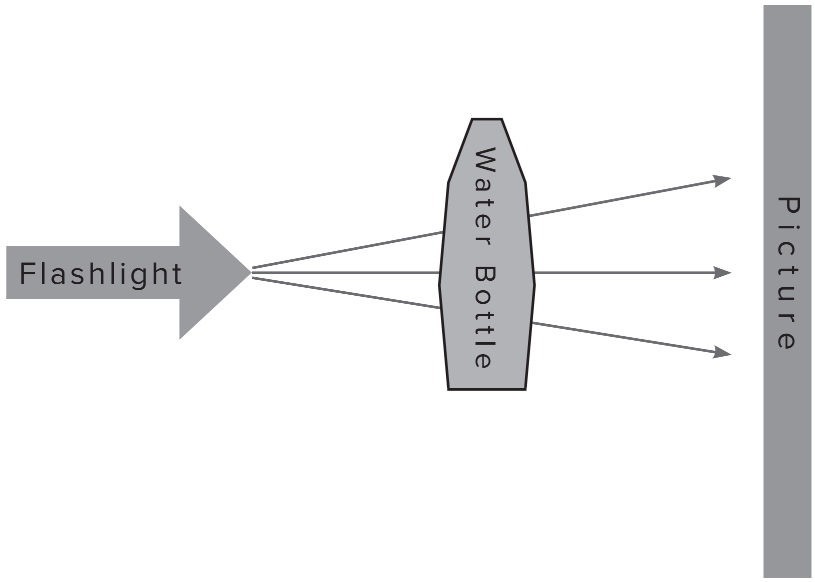
Engineers are exploring how to make current lightbulbs more efficient. Compare the new technologies that are in development to light our future: LEDs, MITs incandescent bulbs, and lasers.

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-lighting-project/.

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 5 drops food coloring:

6. Painted outside of bottle:

MAKING THE TESTING BOX

Instruction Set

Materials

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

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.

DREAM BIG VIDEO SERIES

WATCH *LEAN AND GREEN: ENGINEERING ALTERNATIVE ENERGY*

Alternative energy sources are one method engineers are using to grapple with the supreme challenge of slowing or halting climate change. Tour Ivanpah in California, the world's largest solar thermal plant: it reduces CO_2 emissions by over 1,000 tons every day. Learn how engineers are generating power through other sources too, like wind and ocean waves. Go to discovere.org/dreambig/media-assets and visit Educational Webisodes.

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DREAM BIG

ENGINEERING OUR WORLD

GRADE 2:

SURVIVING STORM SURGE

Grade level: 2

Lesson length: 80 minutes (can be broken down into multiple parts)

This activity gives students an understanding of how storm surges and rising waters affect people's homes and how important it is for engineers to design houses that withstand flooding. Students play the role of engineers as they build a model scene of a paper house on a play dough coast and inundate it with flood water to see if the house they made can withstand the rising tide.

In the Film

In the film *Dream Big*, we see how engineers create innovative ways for tall buildings like the tower of Shanghai to resist strong winds from typhoons. However, most of the damage occurs before and after the storm, when waters rapidly flood coastal areas. Buildings must have a strong enough base to resist the powerful, swiftly flowing water. In this engineering challenge, students investigate ways to engineer buildings that resist flood waters.

NGSS Disciplinary Core Ideas

2-ESS1-1 The History of Planet Earth

Some events happen very quickly; others occur very slowly, over a time period much longer than one can observe.

2-ESS2.A Earth's Materials and Systems

Wind and water can change the shape of the land.

2-ESS2-1

Compare multiple solutions designed to slow or prevent wind or water from changing the shape of the land.

NGSS Engineering Practices

ETS1.C: Optimizing the Design Solution

Because there is always more than one possible solution to a problem, it is useful to compare and test designs.

Key Words/Vocabulary

Storm surge: a bulge of water created by hurricane-type storms that moves along the surface of oceans.

Flooding: The rising level of bodies of water that invade areas that are otherwise dry.

Erosion: The slow breaking down of material by mechanical and chemical forces.

Typhoon: The name used in Asia for a hurricane-style storm.

Materials

Per class:

- ☐ Testing bin instructions (included below)
- ☐ Plastic tub, preferably 15" long x 12" wide x 6" high
- ☐ Jug or pitcher for water
- ☐ Play dough or clay
- ☐ Optional: hot glue at teacher station during the student CREATE phase.

Per pair of students:

- ☐ Popsicle Sticks
- ☐ Paper
- ☐ Glue Sticks
- ☐ Masking tape
- ☐ Beach home paper template
- ☐ Scissors
- ☐ Building a Flood Safe Home handout

Teacher Prep Notes

Prepare to discuss why people throughout history have built their homes near bodies of water, despite the dangers of flooding. Teach students about what causes flooding, including a simple, age-appropriate introduction to the science of global warming.
Tell students about the ways people have tried to prevent damage to their houses and communities from rising water and floods.

Be ready to show students how to cut out a house from the beach home template and how to put it together.

To Do

Determine the Problem or Question to Solve: 10 minutes

1. Before watching the IMAX movie *Dream Big*, 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:
   - **a.** How did nature affect engineering projects in the film? For example, what did hurricanes, floods, and earthquakes do to the projects engineers were working on?
   - **b.** How did engineers deal with these storms, floods, and earthquakes? Did the engineers use some new and exciting material to build with? Did they change their design?
2. Debrief as a whole class after viewing the film. Allow students to reflect on the guiding questions you gave them.
3. Remind students of the obstacles the engineers faced in the film. Review how large a role nature played in determining the engineers' plans. Specific examples you could bring up: building storm-resistant towers, crossing dangerous rivers, and designing ways for cities to fight against the rising sea levels.
4. Introduce the design challenge. Students will create models of a community along a coast. They will design and build homes for this shoreline community that can withstand flooding from heavy rains, hurricanes, and even the melting of the polar ice caps.

Research and Gather Information: 20 minutes

1. Teach students about different types of flooding and the cause-effect nature that supports flooding. Students should understand that most forms of flooding are caused by bursts of rainwater from storms that increase the amount of water found on land and in bodies of water. Other forms of flooding take place over a longer period of time and are caused by events such as the melting of the polar ice caps via global warming.
2. Show students the images of homes built on shorelines and in flood prone areas in the "Building a Flood Safe Home" handout. Talk about how those homes are built to withstand surges of water and what materials are used. Identify ways that humans add to or change the building of the houses themselves by adding support structures to raise the house. Also discuss ways that humans add shore-stabilizing structures like sea walls to prevent water and erosion from reaching their homes.

Plan a Solution: 15 minutes

Organize students into pairs. They will start by building a paper home as the base of their engineering and design challenge. We suggest that the teacher model for the class how to cut, fold, and assemble a home before allowing the students to do their own. A cut and tape template can be found later in this lesson or students may create their own.

As a team, they will collaborate on a design and drawing to plan what their house will look like and what their strategy will be to protect their new home. Will they raise the house on stilts or try to redirect the waves using a wall? Review from what they learned during the Research and Gather phase that engineers can change the way the home is built and/or add structures to the ocean and shoreline to prevent water and erosion from reaching their home. In addition to the paper house, provide a sample of the materials they will be allowed to use for their modifications, such as 2 popsicle sticks and 1 inch of tape so that they can physically experiment. Note: only provide a limited amount of materials at this phase. This is NOT intended as a building phase.

Make It: 10 minutes

Once students have finalized their plan, allow students to build their home and/or flood protective structures using the materials you have provided. Optional: At one safe location in the room, the teacher or teachers' assistant can operate a hot glue gun for students to use in adhering materials together.

Visit each group and review how its research shaped the overall design and plan for the home. If students are making obvious mistakes based upon your experiences and knowledge, allow them to continue and learn from their mistakes. Avoid offering solutions and instead encourage students to develop a secondary plan that demonstrates the evolution of their ideas and experiences.

Test: 15 minutes

Using the provided graphic in the resources for this lesson, set the stage for the experiment. In a tub, add a play dough base to about ½ - ⅓ of the tub's base to represent the shoreline. Students should add a group's house and any additional structure to the shore. The teacher will then pour water steadily into the bucket to replicate flooding water.

Evaluate: 10 minutes

Allow students to reflect on the following questions:

1. Did your house stay erect?
2. Did it get wet or retain water?
3. Did it stay in the same location?
4. After viewing the flooding experiment, would you want to live there?

Taking It Further

Show videos of hurricane/storm surge/flooding

Discuss the role civil engineers are playing within the arena of disaster prevention with special sub-disciplines such as hurricane engineering. Hurricane engineering aims to keep people and their property safe through the lens of our natural and constructed environments.

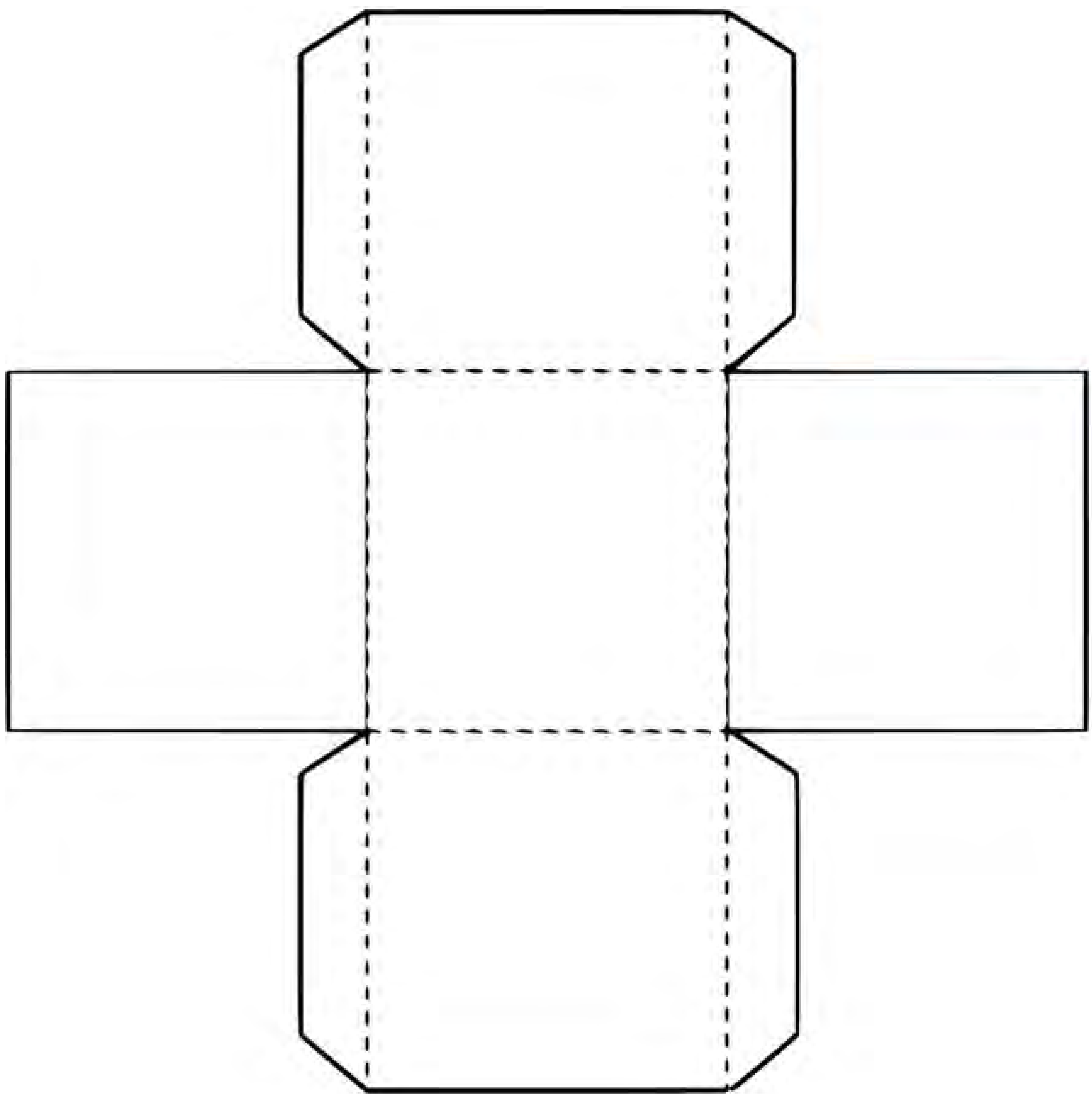
Can you build something in the water to prevent the flooding from impacting your house/property?

- Review the situations that face Venice, Italy, and the human-made barrier they are creating as a solution.

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

Beach Home Template and Instructions

1. Cut along the solid lines.
2. Fold along the dotted lines to create a box.
3. Tape or glue the flaps to secure.



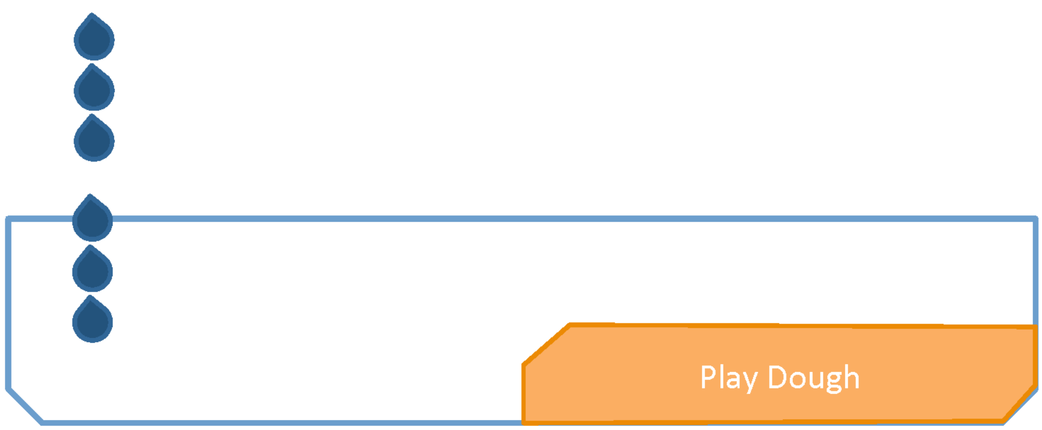
TESTING BIN INSTRUCTIONS

Assembly Directions:

1. Obtain a medium-sized plastic storage bin. Preferably a clear and shallower bin.
2. Fill half of the bin with play dough or soft clay until it is about half way full.
3. Obtain a gallon jug and fill with tap water.

Directions for Use:

1. Have students place their structure on the land portion of the device.
2. Once you are ready, pour the water into the opposite side of the plastic bin and allow the water level to rise until it is 1–2 inches above the play dough level.



DREAM BIG VIDEO SERIES

WATCH *QUAKE TAKES: EARTHQUAKE ENGINEERING*

Nobody wants an earthquake or tsunami to hit while they're in a building that can't keep them safe. In the specially controlled settings of a giant shake table in San Diego and a tsunami wave basin in Oregon, engineers study the impact of these natural forces. Watch how engineers are making buildings stronger and safer to protect people from nature's powerful punch. Go to discovere.org/dreambig/media-assets and visit Educational Webisodes.

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GRADE 3:

MAGLEV TRAIN

Grade level: 3

Lesson length: 85 minutes

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, like bullet trains and the futuristic Hyperloop, to move people and goods more quickly, more safely, and with less dependence on fossil fuels.

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

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

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.

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

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).

To Do

Determine the Problem or Question to Solve: 15 minutes

1. Before watching the IMAX movie *Dream Big*, 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: #dreambigfilm

TRACK ASSEMBLY INSTRUCTIONS

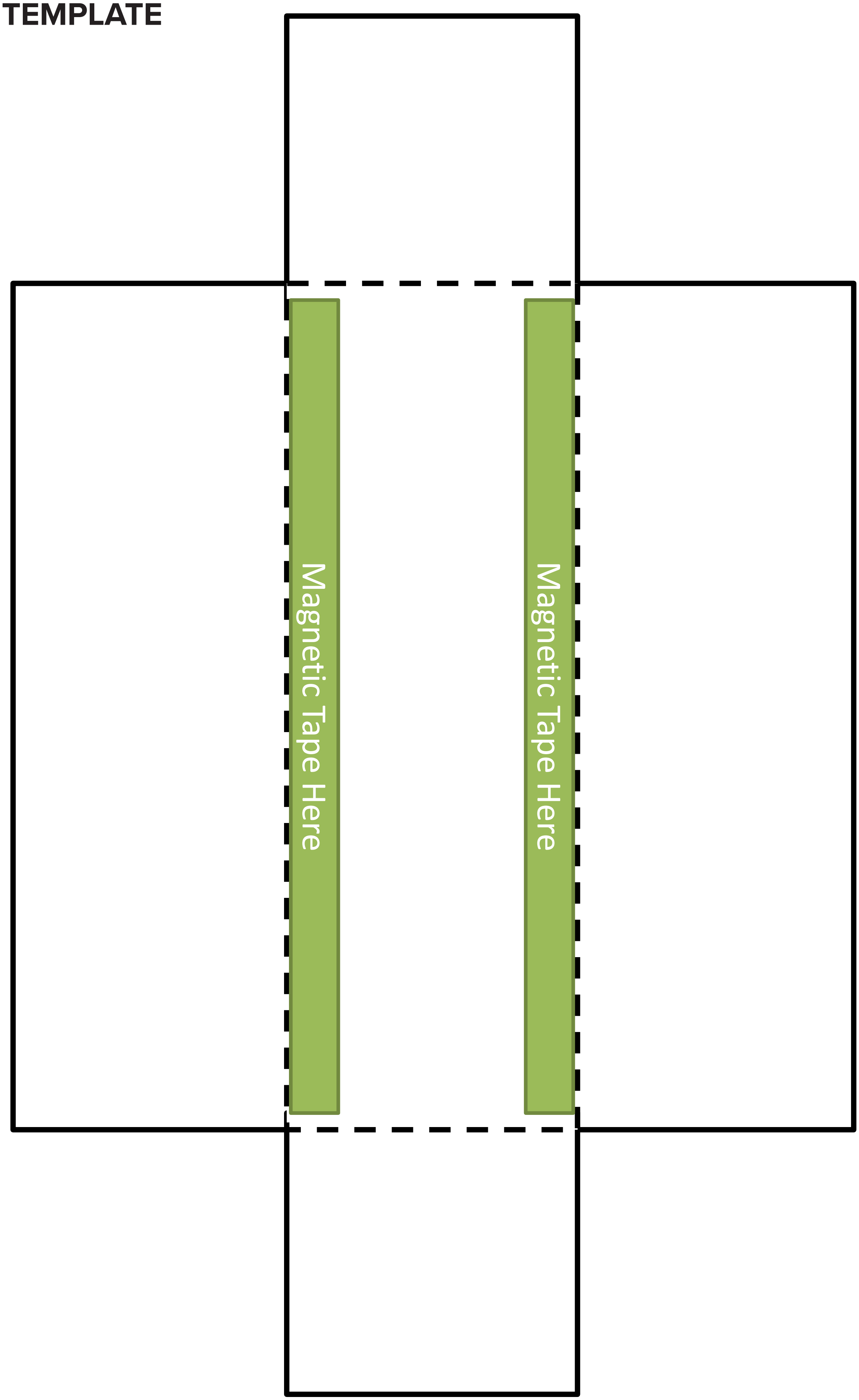
Obtain cardboard. Use the template (included as a separate sheet) for exact dimensions. Trace the cut lines with scissors or a box cutter. Fold the cardboard along the dotted lines. Tape the sides together with strong tape.

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



DREAM BIG VIDEO SERIES

WATCH *WHO'S IN THE DRIVER'S SEAT: AUTONOMOUS VEHICLES*

Go behind the scenes at Google X and other companies to discover how self-driving cars are engineered. Meet the teams who love the creative problem solving this challenge requires. Go to discovere.org/dreambig/media-assets and visit Educational Webisodes.

MACGILLIVRAY FREEMAN'S
DREAM BIG
ENGINEERING OUR WORLD

GRADE 4:

WIND-POWERED LED

Grade level: 4

Lesson length: 2.5 hours

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 lightbulb.

In the Film

Engineers are leading the way as the world explores alternative energy sources to supplement or replace the fossil fuels humankind has come to rely upon. In the *Dream Big* film, we see engineers harnessing the power of the sun in the Ivanpah Solar Facility. In this facility, engineers have developed a system that converts the radiant energy from the sun into thermal, mechanical, and ultimately electrical energy. In this activity, students investigate another form of renewable energy, 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.

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

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 lightbulb.

To Do

Determine the Problem or Question to Solve: 15 minutes

1. Before watching the IMAX movie *Dream Big*, 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 byproduct 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 lightbulb.

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 lightbulb 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., one foot, two feet, three 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

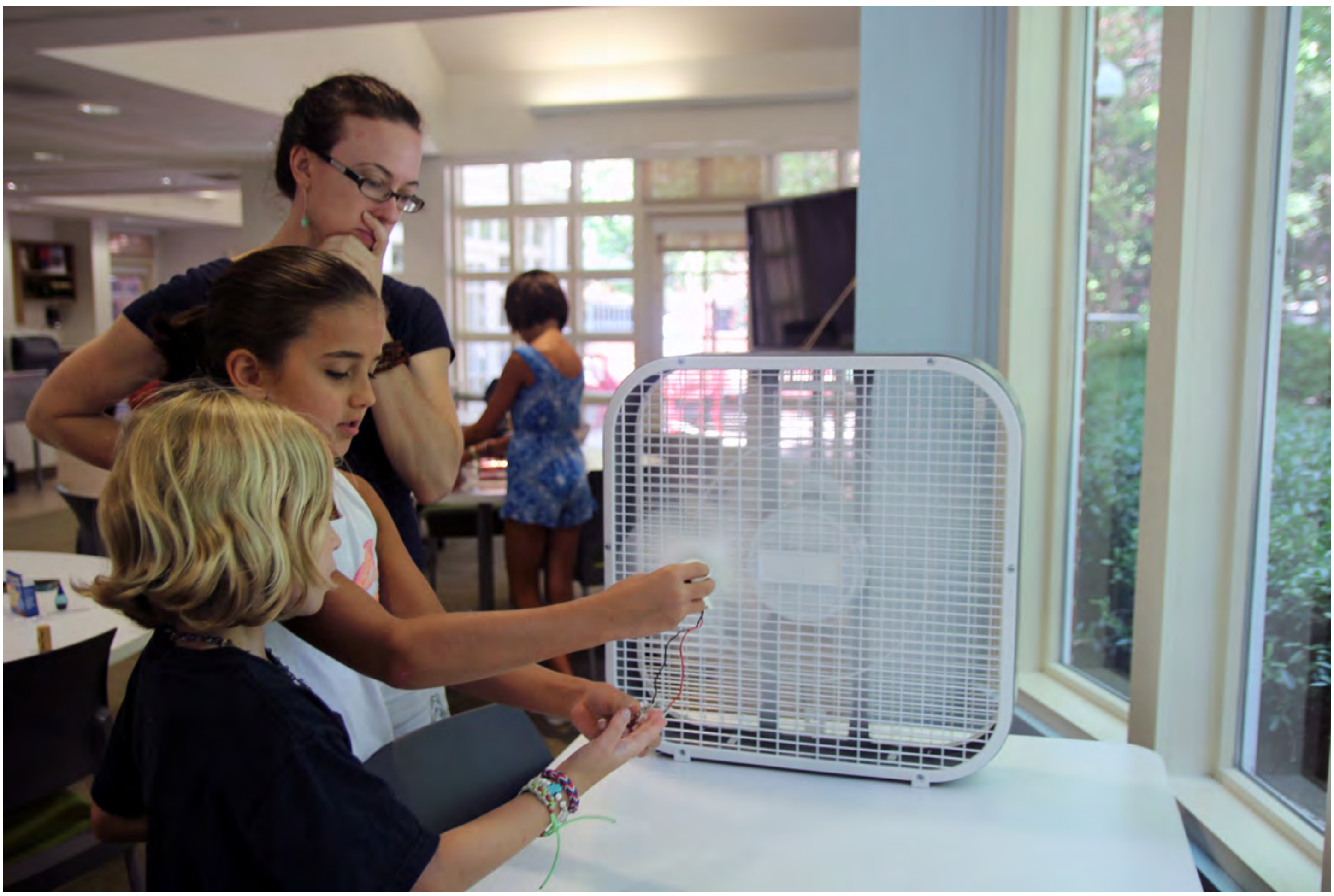
Retest turbines at different fan speeds for each of the suggested stages.

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: #dreambigfilm



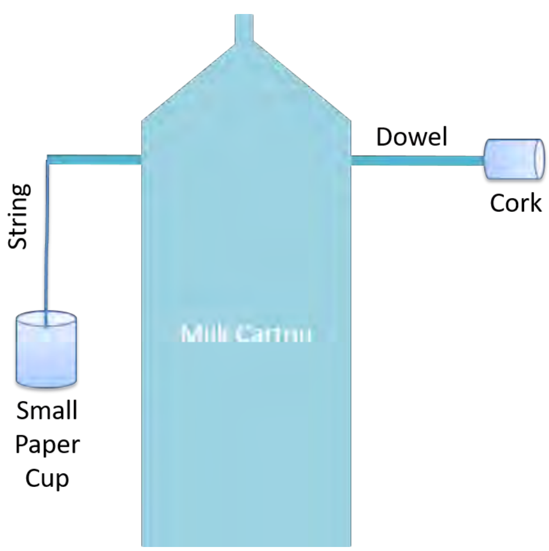
WINDMILL BLADE TESTING DEVICE

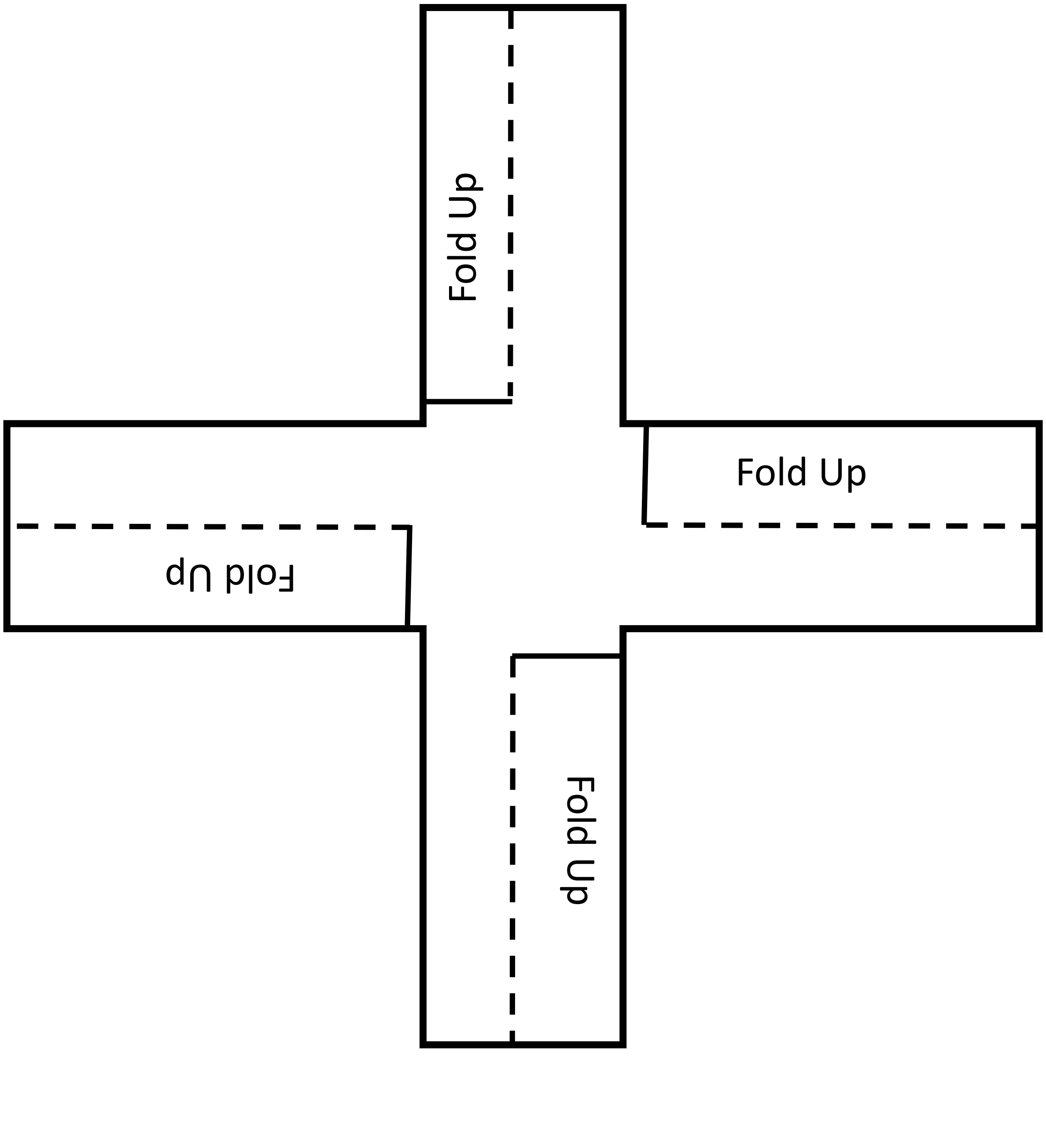
Assembly Directions:

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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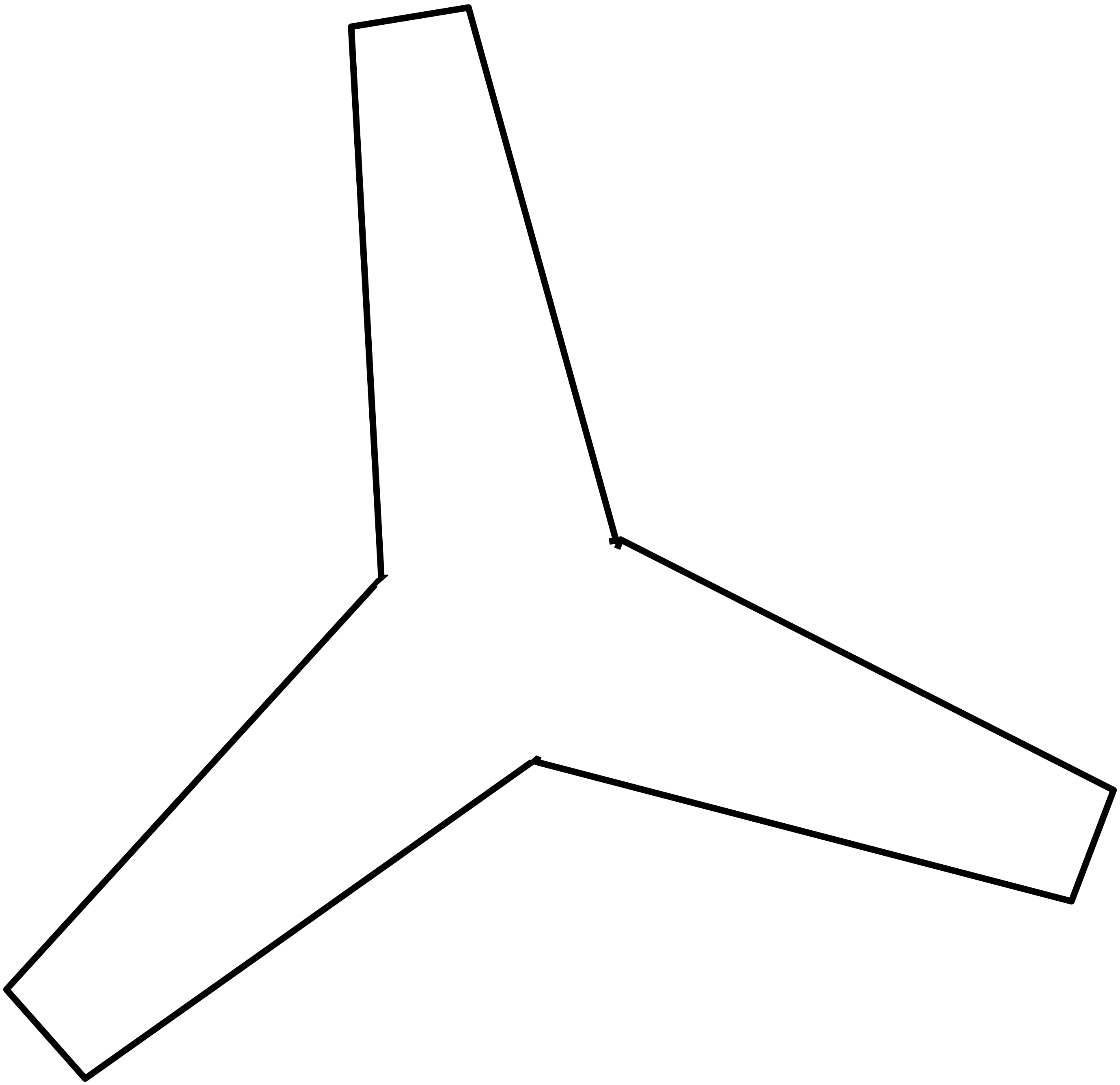

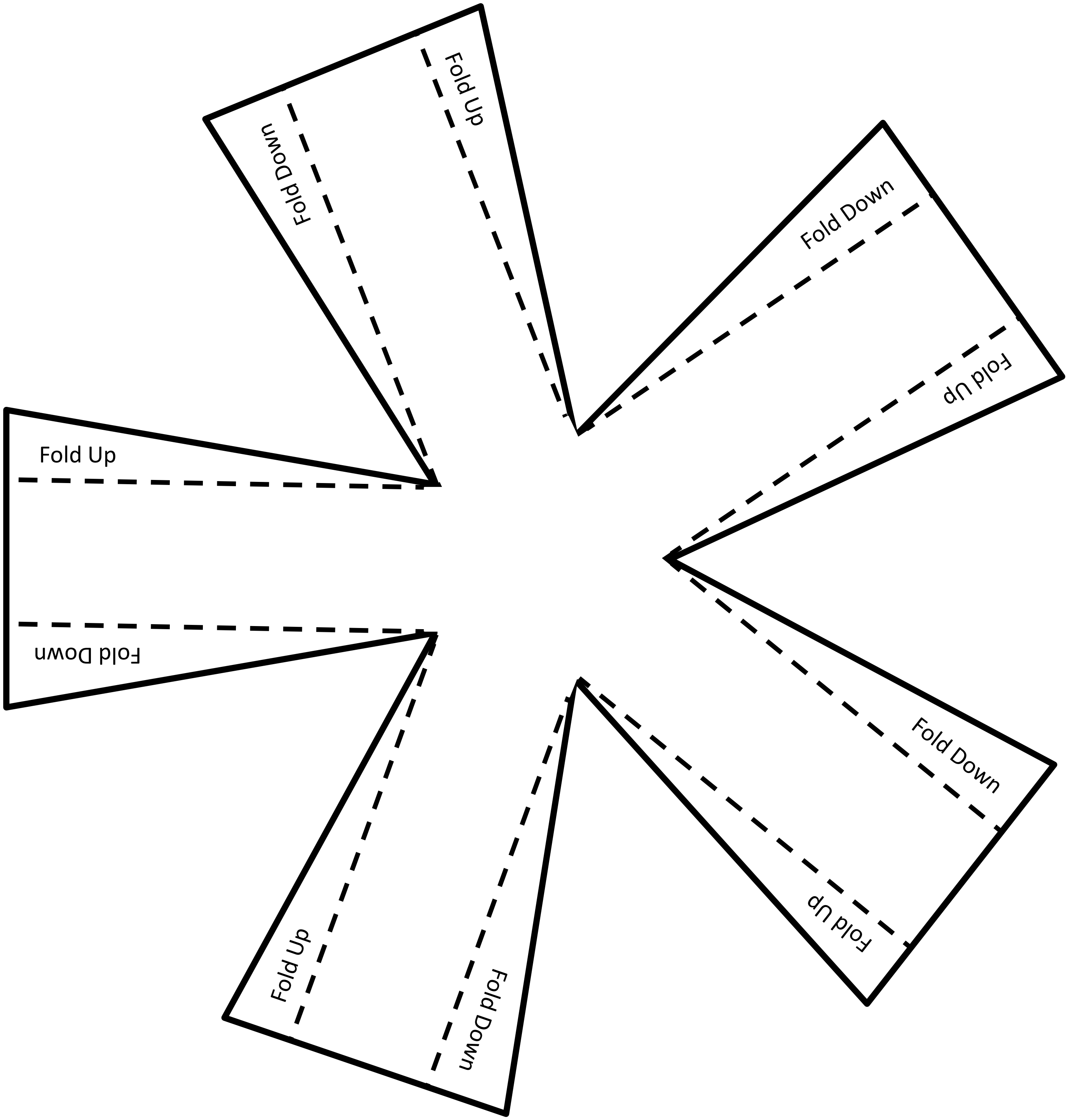
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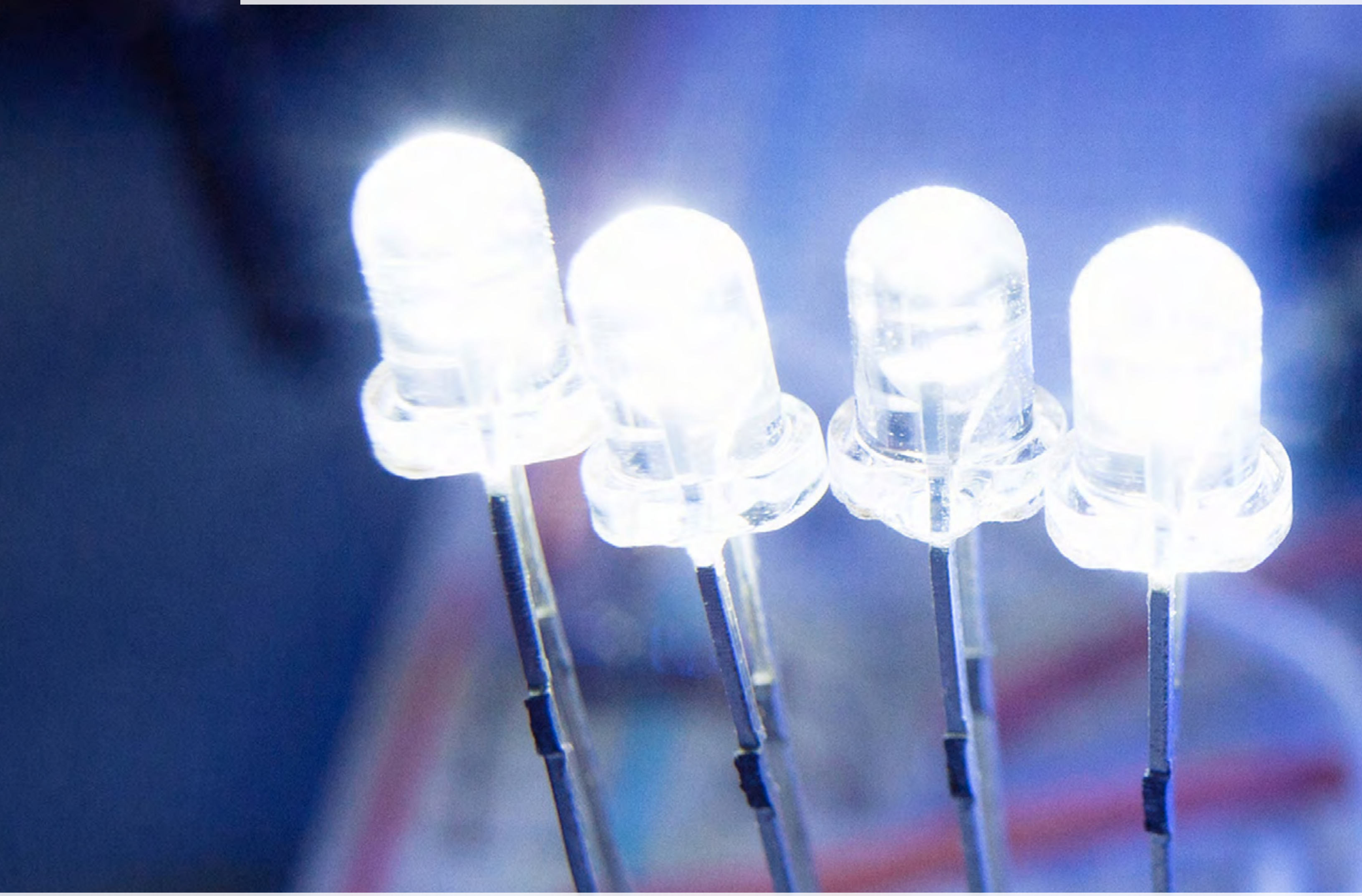
DREAM BIG VIDEO SERIES

WATCH *INCREDIBLE STRUCTURES: EXTREME ENGINEERING*

If we can dream it, we can build it. Take a tour of some amazing structures designed by engineers, like a 1,000-foot glass elevator built on a cliff in China and a fire-breathing dragon that serves as a bridge in Vietnam. Visit the engineers who work from ropes suspended high above the Colorado River near Hoover Dam. Go to discovere.org/dreambig/media-assets and visit Educational Webisodes.



MACGILLIVRAY FREEMAN'S DREAM BIG ENGINEERING OUR WORLD

GRADE 5:

TAKE OUT THE TRASH: CLEANING OUR RIVERS

Grade level: 5

Lesson length: 2.5 hours, with optional follow-up excursions to nearby river

As students learn about the components of a river ecosystem, they design a means of eliminating the trash that threatens the health of a river system. Students build their devices entirely out of recycled materials in order to understand the challenges engineers face as they try to minimize the amount of raw material used in their work.

In the Film

As our population grows exponentially, raw materials become more and more limited—so engineers are becoming imaginative in how they recycle and repurpose materials already available to them. Just as the engineers in Haiti, as seen in *Dream Big*, worked under the constraint of using only immediately available materials, all engineers work under resource constraints. In this engineering challenge, students will create a device that cleans plastic pollution from a river system by using only reclaimed plastic from that very system.

NGSS Disciplinary Core Ideas

5-LS2.A Interdependent Relationships in an Ecosystem

Organisms can only survive in environments in which their particular needs are met.

A healthy ecosystem is one in which multiple species of different types are each able to meet their particular needs in a relatively stable web of life.

5-ESS3.C Human Impacts on Earth Systems

Human activities in agriculture, industry, and everyday life have had major effects on the land, vegetation, streams, ocean, air, and even outer space.

NGSS Engineering Practices

5-ETS1.A Defining and Delimiting an Engineering Problem

Possible solutions to a problem are limited by available materials and resources (constraints). The success of a designed solution is determined by considering the desired function of a solution (criteria).

5-ETS1.B Developing Possible Solutions

Research on a problem should be carried out before beginning to design a problem. Testing a solution involves investigating how well it performs under a range of likely conditions.

At whatever stage, communicating with peers about proposed solutions is an important part of the design process, and shared ideas can lead to improved designs.

Tests are often designed to identify failure points or difficulties, which suggest the elements of the design that need to be changed.

Key Words/Vocabulary

Ecosystem: Everything living and nonliving in an area.

Abiotic: Nonliving. Examples of abiotic factors include soil, water, temperature, and bedrock.

Biotic: Living. Examples include producers, consumers, and decomposers.

Consumers: Animals; must eat other organisms to survive.

Producers: Plants; make their own “food” via photosynthesis.

Materials

Per group:

- ☐ Materials collected from recycle bins at school for 1–2 weeks prior to lesson (plastic bottles, soda cans, plastic bags, cups, paper, straws, etc.)
- ☐ Nylon string or fishing line
- ☐ Scissors
- ☐ Lego pieces or pool toys that are less buoyant to represent fish
- ☐ Inflatable children’s pool
- ☐ Video “Boyan Slat Unveils the Ocean Cleanup Prototype”: youtube.com/watch?v=RLAq19hGTBw
- ☐ Means of showing video to class
- ☐ Water Pollution Engineering Sheet

Teacher Prep Notes

To test the student devices, inflate the pool and fill it with water. Place materials in it to represent typical human pollution in a water system (plastic straws, fast food cups, and so on).

Place materials in the pool to represent healthy parts of the ecosystem that should remain undisturbed and not be caught in the pollution cleaning solution (e.g., Lego blocks to represent fish).

Optional: Dye some vegetable oil with black oil-soluble food coloring and place it in the pool to represent industrial oil spills and waste.

To Do

Determine the Problem or Question to Solve: 15 minutes

1. Before watching the IMAX movie *Dream Big*, 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:
    - **a.** Which engineers wished they had more or different materials to work with as they built their creations?
    - **b.** How did these engineers find a way to come up with materials that they needed?
2. Debrief as a whole class after viewing the film. Allow students to verbally reflect on the guiding questions you gave them.
3. Introduce the design challenge: Today in class we are going to learn about local river ecosystems and the human actions that threaten their health. Then we are going to get creative in designing a solution to solve the problem of pollution in rivers. We are going to recycle and repurpose the very same pollution that goes into rivers to create a system to clean them. We will test our devices in a small kiddy pool. After, we will decide what parts of the designs in each group worked well to determine a class design to make for a local stream or river. We will then make it and try it in that river system to judge its effectiveness at cleaning a real water system.

Research and Gather Information: 45 minutes

1. Give an overview of biotic and abiotic factors of ecosystems, in which students learn about the components of a healthy river ecosystem by examining typical river food webs. Guide students to identify the producers, consumers, and decomposers of the river system. Ask students to predict what would happen if one of the members of the food web were removed.
2. Teach students about human factors that can threaten the health of a river ecosystem. Examples are overfishing, animals ingesting plastic debris, and animals being caught in discarded fishing line.
3. Describe the innovative ideas that young engineers are devising to clean water ecosystems. Before watching the Boyan Slat video, explain to students that it's about a teenager who engineered a way to clean up the plastic pollution from the oceans. Though his design is for an ocean ecosystem, we can identify parts of his design that will also work for us in our river system cleanup device. Play Boyan Slat's video on the revealing of his prototype to clean the ocean. Ask students how his device worked and what similar things we could use to collect trash from a river.
4. Show students what recycled materials you have collected over the past few weeks for them to use. Also give them fishing wire that is typically left behind by fishers to use in their designs. Allow students time to use the "brainstorm" part of the Water Pollution Engineering Sheet and come up with ideas for how each material could be used.

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 with students as a whole class brainstorming the criteria and constraints of this particular engineering challenge.

Organize students into small groups. Show them the materials that they will use and instruct them to begin designing their prototype. The prototype should include a drawing as well as a written description of its functionality. Tell students to use the Plan section of their Water Pollution Engineering Sheet for this step. On their diagram, they should label the material they will use and the amount of that material they will need. Students should write a step-by-step process for how the device will be built and deployed.

Make It: 30 minutes

Once students have drawn their plan, tell them to begin building their device. As students are building, visit each group, reviewing what they learned about river ecosystems and how the device will capture plastic without capturing members of the food web. Allow students to make mistakes along the way and struggle. When they do, ask questions about what the students observed and what they could change to fix the problem. Avoid offering solutions and instead encourage students to test ideas as they build.

Test: 20 minutes

Part 1:

- ☐ Prep: Inflate a children's pool and fill it with water and different forms of garbage (Styrofoam cups, soda bottles or cans, straws, Styrofoam peanuts). Also add in a few sinkable items to represent fish and other living organisms.
- ☐ Instruct students to use their device in the pool to remove whatever garbage is accessible. Ask students what the failure point of the system was (where it broke, where it failed to do its job) and what they could do to fix it.

Optional Part 2 (multiple field trips to nearby stream):

If you have a local stream or river nearby, have students improve their device and test it in a true stream environment. Students can leave the device in place for 1–7 days, visiting the device each day and recording the state of the device (is it holding up in the stream environment? Where is it failing?). Students should collect and assess if they were able to gather any plastic or pollution with the device they created.

Evaluate: 10 minutes

Allow students to reflect on the following questions and to write their answers in the Evaluate section of the Water Pollution Engineering Sheet:

1. How much of the plastic or oil pollution were you able to gather with your device?
2. Did your device interfere with the ecosystem by damaging or capturing animals as bycatch? If so, how?
3. Did your device interfere with the ecosystem by permanently changing any of the abiotic factors in the ecosystem? If so, how?

As time allows, discuss students' thoughts about the success of their devices and what they would do to improve them.

Taking It Further

Extend the impact of your device: Test within real streams or rivers, increasing the scope and scale of the project as a citizen science/entrepreneurism experiment. Have students educate the public on what they learned. Display the amount of plastic taken out of the river system each week. Have students estimate how much plastic could be taken out of the river if the device lasted all year.

Learn about this engineering in the real world: As we learned about in this lesson, the plastic pollution that enters our riverways eventually drains into the ocean. Our oceans contain a large percentage of plastic that collects in the center of circular currents called gyres. Engineers are challenged with devising a plan to clean the oceans that will work in a timely manner as well as operate without the environmental stress of using fossil fuels. Learn about the machines they are engineering, the tests they are conducting, and the challenges they face by visiting this site: theoceancleanup.com

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

WATER POLLUTION ENGINEERING SHEET

Name: ____

Problem to Be Solved

Create a system that is capable of catching the plastic and trash from a water system without damaging the ecosystem.

Research and Gather Information

1. What do we know about river ecosystems?

2. What do we know can threaten river ecosystems?

3. How have other people cleaned water ecosystems?

4. Brainstorm: What could each of the available materials do?

Material	Purpose
Example: plastic water bottles	☐ When the bottle is filled with air and capped, it could float, keeping the device at water level. ☐ If the bottle is cut in half, it could create a barrier to catch plastic floating by.

Plan

☐ The criteria of the engineering and design challenge are:

☐ The constraints of the engineering and design challenge are:

- ☐ Draw a picture of what you plan to make.

- ☐ Write a step-by-step process of how to create your design.

Make It!

Evaluate

1. How much of the plastic or oil pollution were you able to gather with your device?

2. Did your device interfere with the ecosystem by damaging or capturing animals as bycatch? If so, how?

3. Did your device interfere with the ecosystem by permanently changing any of the abiotic factors in the ecosystem? If so, how?

DREAM BIG VIDEO SERIES

WATCH *WATER WISHES: ENGINEERING FOR THOSE IN NEED*

What can an engineering student in New Jersey do to help mountain villagers in Peru who lack clean water to drink? Building a safe water system for people halfway across the globe is an example of how Engineers Without Borders and other organizations are helping people build healthier communities. Go to discovere.org/dreambig/media-assets and visit Educational Webisodes.

MacGillivray Freeman

ASCE American Society of Civil Engineers

Bechtel

NCEES advancing licensure for engineers and surveyors

MACGILLIVRAY FREEMAN'S

DREAM BIG

ENGINEERING OUR WORLD

GRADE 6:

DESERT ISLAND DESALINATION

Grade level: 6

Lesson length: 160 minutes (can be broken down into multiple class periods)

Testing phase of lesson: At least 5 hours

Students are challenged to create a source of freshwater on a desert island using only the material and energy resources available to them.

In the Film

As the human population continues to increase, engineers are challenged to create structures that help our community adapt to limited space and limited resources. In the film *Dream Big*, we see ways that engineers adapt our energy systems to no longer rely on limited fossil fuels. In this challenge, we will build on this foundation. We will produce clean, fresh, drinkable water from salt water using only the energy from the sun.

NGSS Disciplinary Core Ideas

MS-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.

MS-PS1.A Structure and Properties of Matter

Different kinds of matter exist and many of them can be either solid or liquid, depending on temperature. Matter can be described and classified by its observable properties.

MS-ESS2-4 Develop a model to describe the cycling of Earth's water through Earth's systems driven by energy from the sun and the force of gravity.

NGSS Engineering Practices

MS-ETS1.A Defining and Delimiting Engineering Problems

The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will work. Specification of constraints includes consideration of scientific principles and other relevant knowledge likely to limit possible solutions.

MS-ETS1.B Developing Possible Solutions

A solution needs to be tested, and then modified on the basis of the test results.

There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem.

Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors.

Dream Big: Engineering Our World is a film and educational project produced by MacGillivray Freeman Films in partnership with the American Society of Civil Engineers and presented by Bechtel Corporation. The centerpiece of the project is a film for IMAX and other giant screen theaters that takes viewers on a journey of discovery from the world's tallest building to a bridge higher than the clouds and a solar car race across Australia. For a complete suite of *Dream Big* hands-on activities, educational videos, and other materials to support engineering education, visit discovere.org/dreambig. The *Dream Big* Educator Guide was developed by Discovery Place for the American Society of Civil Engineers.

Key Words/Vocabulary

Evaporation: The process whereby liquids absorb energy and change to a gas. Like condensation, this process also occurs most often due to a rapid change in temperature and/or pressure.

Condensation: The process whereby vapor loses energy and changes from a gas to a liquid. This usually occurs due to a rapid change in pressure and/or temperature.

Solution: A mixture of at least two pure substances where one is dissolved in another.

Pure substance: A substance that cannot be broken down into simpler components without undergoing a chemical change.

Precipitation: Any form of water that falls from clouds and reaches Earth's surface. In order for precipitation to occur, water must undergo a phase change from vapor to liquid.

Phase change: Any time there is a transition in a substance between solid, liquid, or gas.

Materials

Per group:

- ☐ Clear plastic painter's drop cloth or clear sheet of plastic, 3' x 3'
- ☐ Miscellaneous recycled objects (plastic water bottles, 2L bottles, plastic/paper cups, plastic bags)
- ☐ 6 dowel rods (36" long each)
- ☐ 10 rubber bands
- ☐ 1L beaker of water dyed with food coloring to represent salt
- ☐ 1 collection beaker for freshwater (Note: make sure it's clean, as students may be tasting their product)

Per student:

- ☐ Solar Desalination Device Engineering Sheet

Extension Materials:

- ☐ Cardboard
- ☐ Aluminum foil

Teacher Prep Notes

Before students build the frame to collect evaporated water, have them practice building frames using the rubber bands and dowel rods. For ideas on how to do this and designs that students could make, check out this video from COSI: learnxdesign.org/learnxdesign_record/dowels-and-rubber-bands-ii

Make enough copies of the Solar Desalination Device Engineering Sheet for each student. Note that students will fill in different sections as they work through the steps of this activity.

Prepare to teach students about the Earth's water cycle (note that there are educational videos online).

You will need to explain how the sun provides the energy for water to change phase, covering the evaporation of water as a pure substance and its precipitation as freshwater into the surface water system.

Decide how you want students to research desalination plants. They will be comparing what they learn to the workings of the water cycle to help them create their devices.

Optional: Gather images and suggestions of ways to distill freshwater using the sun for students to use as inspiration.

To Do

Determine the Problem or Question to Solve: 15 minutes

1. Before watching the film *Dream Big*, 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 question to think about as they are watching the film:
   - How are engineers solving the issues that humanity faces as our population continues to grow at a faster and faster rate?
2. Debrief as a whole class after viewing the film, touching on the question you gave them to think about.
3. Introduce the design challenge: In groups, students will design a device that provides clean drinking water from salt water through a process called desalination.
   - This process will use the same basic process that the Earth's water cycle uses to provide clean and fresh water, using only energy from the sun.
   - Each group will receive 1 liter of water (dyed with food coloring to represent salt) in a beaker to place in the sun.
   - The device students create must catch the evaporated water, allow it to condense, and collect it in a separate container.

Research and Gather Information: 60 minutes

1. Give an overview of the Earth's water cycle. Describe, or show, how the sun provides the energy for water to change phase, how water evaporates as a pure substance, and how it precipitates as freshwater into the surface water system.
2. Organize students into small groups. Instruct students to research and examine current desalination plants. Tell students to note in their group the similarities between desalination plants and the water cycle. Then discuss as a class, making sure students understand these comparisons: Both use heat to change the phase of water to a gas, and both condense the water vapor as a pure, drinkable substance. Review this key difference: Desalination plants use fossil fuels instead of the sun as an energy source.
3. Review the materials available for this challenge: plastic sheeting, dowel rods, and rubber bands. Give students time to brainstorm ways that they could put the materials together to catch the evaporated water, allow it to cool, and send it to a collecting beaker.
4. Optional: Do a web search for images or ways to distill freshwater using only the sun and share these with students. Tell groups to use these images or ideas to help them imagine how they could make something similar with their materials. Push students to use the scientific knowledge they gained in studying the water cycle, phase change, and desalination plants.
5. Ask students to reflect on their research and information gathering and to write their thoughts in the "Research and Gather Information" section of their Solar Desalination Device Engineering Sheet. Have students share their thoughts and concerns about the challenge, criteria, and constraints of the design as the project moves forward. 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 with students as a whole class brainstorming the criteria and constraints of this particular engineering challenge.

Plan a Solution: 15 minutes

After brainstorming shapes that they can make with the dowel rods and plastic, tell students to fill in the Plan section of their Solar Desalination Device Engineering Sheet, which involves drawing an image of what they plan to create. Groups should also write a step-by-step process for how their device will be built and deployed. Based on their knowledge of the desalinization process and the water cycle, students should be able to describe how water can change phases within their device and how that mimics the phase changes of the global water cycle.

Ask each group to share their plan with the class and discuss these questions:

- Which elements of your design are you most confident about?
- Which elements of your design might fail?

Make It: 30 minutes

Once students have drawn their plan, it's time to begin building. As students are building, visit each group, reviewing what they learned about evaporation and condensation in the water cycle. Ask students questions about how they are trapping the water vapor to keep it from escaping into the atmosphere, how they are cooling it, and how they are having it flow down into one specific area, the collection beaker. Allow students to make mistakes along the way and struggle. When they do, ask questions about what they observed and what they could change to fix the problem. Avoid offering solutions and instead encourage students to test ideas as they build.

Test: 20 minutes

Test Timeframe: At least 5 hours

Each group will start the project with a bowl or container of one liter of water dyed with food coloring to represent the salt. Students should place that container inside of their device, outside the school, on a sunny day, and likely over a long period of time. The recommended timeframe is at least 5 hours, depending on exterior temperature. Students should gather the freshwater that has been accumulated through the experiment in a separate, clean container, "the collection beaker".

Evaluate: 20 minutes

Have students assess their device by answering the questions in the "Evaluate" section of the Solar Desalination Device Engineering Sheet.

If students are feeling adventurous, have them taste their water and reflect on its palatability.

Taking It Further

Extend the impact of your device: Students should be given the opportunity to reiterate their original design and develop a successful desalinization model. Prompt students to reflect on the information you learned as a class regarding which parts of each model were useful, in order to create a new, more effective design. Engineers are constantly refining designs based on experience and new information. Students can develop reflective surfaces to increase the solar radiation that hits their salt water and speed up its output of clean water. Use cardboard and aluminum foil to create reflective surfaces for them to integrate into their design.

Learn about this engineering in the real world: Cities along the coast are not the only areas that are challenged with desalinating their water. In the central valley of California, farmers and residents are facing one of the worst droughts in history. Additionally, the soil content of this area of the United States is unusually high in salt content. When it rains, the fresh rainwater mixes with the salt in the soil to create an unusable saltwater source. Engineers are working on ways to use the solar energy from this area to desalinate the rainwater runoff. Learn about the machines they are engineering, the tests they are conducting, and the challenges they face by visiting this site: waterfx.co

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

SOLAR DESALINATION DEVICE ENGINEERING SHEET

Name: ____

Problem to Be Solved

Create a device that can desalinate water using only the energy from the sun.

Research and Gather Information

1. What do we know about how the Earth naturally desalinates salt water to make freshwater?

2. How are desalination plants similar to the Earth's natural process?

3. How are desalination plants different from the Earth's natural process?

4. Brainstorm: How can you use only dowel rods, plastic sheeting, and rubber bands to capture the vapor from a bowl of salt water, condense it, and force it to flow into a collection beaker?

Plan

☐ The criteria of the engineering and design challenge are:

☐ The constraints of the engineering and design challenge are:

☐ Draw a picture of what you plan to make.

- ☐ Write a step-by-step process of how to create your design.

- ☐ Describe how water changes phases within your device and how that mimics the phase changes of the global water cycle.

Make It!

Evaluate

Did your device meet the constraints of the engineering challenge?

Did your device meet the criteria of the engineering challenge?

Did it create fresh, drinkable water?

- What was the volume of water it created?
- What volume of salt water was still left in the original basin?
- What volume of water escaped into the atmosphere? (The original volume of 1 liter, minus the volume of water created and minus the volume of water still left in the original basin)

What was the major failure point of your device?

- Where was it the weakest?
- Did it fall over?
- Did it let too much evaporated water escape?

What would you do differently next time?

DREAM BIG VIDEO SERIES

WATCH *QUENCHING A THIRSTY WORLD: WATER ENGINEERING*

With limits on our freshwater supply and a planet with more than 7 billion people, we need the ingenuity of engineers to produce drinking water from improbable sources. Discover how engineers are quenching the world's thirst with creative solutions. Go to discovere.org/dreambig/media-assets and visit Educational Webisodes.

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ENGINEERING OUR WORLD

GRADE 7:

BUILDING THE PYRAMIDS

Grade level: 7

Lesson length: 140 minutes (can be broken down into multiple class periods)

> Analyzing primary sources, students assess the claims of how ancient Egyptians moved large-scale stones across a desert, as described in hieroglyphic accounts.

In the Film

In *Dream Big*, we see that engineers build their ideas and techniques on the previous work of others. Engineers are fascinated by the past and by the ways humans have been solving problems similar to ours for millennia. Just as engineers study the Roman construction of the aqueducts and the Chinese construction of the Great Wall of China, engineers are still investigating how the ancient Egyptians were capable of moving stones large enough to build the pyramids.

NGSS Disciplinary Core Ideas

MS-PS2.A- Forces and Motion

For any pair of interacting objects, the force exerted by the first object on the second object is equal in strength to the force that the second object exerts on the first, but in the opposite direction (Newton's third law).

NGSS Engineering Practices

MS-ETS1.A Defining and Delimiting Engineering Problems

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

MS-ETS1.B Developing Possible Solutions

A solution needs to be tested and then modified on the basis of the test results.

There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem.

Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors.

Key Words/Vocabulary

Position: The location of an object.

Force: A push or pull on an object in any direction.

Friction: The force causing an object to resist movement or a change in position.

Machine: A tool that makes work easier.

Materials (choose either Option A or B)

Option A: A device that can carry a student across a sand pit outside.

Per whole group:

- ☐ Sand pit
- ☐ Hose or bucket of water
- ☐ Optional: force probe

Per team:

- ☐ 4 feet of wood (scraps, planks, 2 x 4s)
- ☐ 2 yards of rope
- ☐ Hammer
- ☐ Handful of nails

Per student:

- ☐ Examining Ancient Egyptian Hieroglyphs sheet
- ☐ Engineering a Rock Moving Machine sheet

Option B: Small-scale device that can carry a stone across a tub of sand indoors.

Per whole group:

- ☐ Plastic storage bin filled with a layer of sand
- ☐ Heavy object, such as a bag full of rocks
- ☐ Spray bottle filled with water
- ☐ Optional: force probe

Per team:

- ☐ 20 popsicle sticks
- ☐ 1 hot glue gun
- ☐ 1 hot glue stick
- ☐ 1 yard of string

Per student:

- ☐ Examining Ancient Egyptian Hieroglyphs sheet
- ☐ Engineering a Rock Moving Machine sheet

Teacher Prep Notes

Decide whether you want to do Option A or Option B. Note: The ideal team size for Option A (the student-sized device) is three or four students. This activity has to be tested outside in a sand pit. The ideal team size for Option B (small-scale device) is two students.

Notify parents that students will be using a hammer and nails for an engineering activity.

Teach students how to use a hammer and nails safely. If you choose Option B, students need to know how to handle a hot glue gun safely.

Prepare to teach students about force, friction, and the kinds of systems and simple machines people have used throughout history to move heavy objects over long distances. Examples relevant to this activity include slickening a surface and using an inclined plane.

To Do

Determine the Problem or Question to Solve: 15 minutes

1. Before watching the film *Dream Big*, 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:
   a. What are some of the lessons engineers have learned from studying the ancient architecture of Rome and China?
   b. How can we use the information they gained through these studies as we engineer structures for our modern life?
2. Debrief as a whole class after viewing the film. Allow students to verbally reflect on the guiding questions you gave them.
3. Introduce the design challenge. Students will study hieroglyphs recently discovered on the inside of an Egyptian ruin. From these hieroglyphs, engineers think they may have finally identified the mysterious system that Egyptians used to move heavy rocks to build the pyramids. The students' task is to recreate a working model of the system and to test the claim to see if it really does make moving heavy objects easier.

Research and Gather Information:
45 minutes

1. Using the information you have prepared, teach students about force, friction, and simple machines that have been used throughout history to move heavy objects. Engage students in a discussion about how these topics relate to the challenge faced by the ancient Egyptians, who wanted to move large, heavy rocks over the rough and yielding surface of sand.
2. Organize students into teams, if they will be completing Option A, or pairs, if they will be completing Option B.
3. Distribute the worksheet "Engineering a Rock-Moving Machine." Ask students to fill in the answer to the first question based on this discussion.
4. Ask students to look at the Egyptian hieroglyphs image on the "Examining Ancient Egyptian Hieroglyphs" handout and to read the information below it. Ask them to describe the system the Egyptians used to move rocks in as much detail as possible. Tell them to write down their ideas at the bottom of the sheet. Push students to identify the following key components:
   a. Water was poured in front of the sled to reduce friction and therefore the force needed to move the sled.
   b. Multiple people pulled on the rope connected to the device. This shared the pulling force of moving the rock between many people and therefore reduced the force each person had to exert.
   c. The rock/statue was tied to the sled.
   d. The sled had a slight upturn in the front.
5. Important: Remind students that their task is to recreate what they think the hieroglyphs are conveying, not what might be the easiest way to move the sled. For example, since there are no round logs placed beneath the sled to roll it along the desert, the students can't use this method in their own design.
6. Have students determine what materials they will use by looking at the image. Tell them to answer question 2 on their worksheet "Engineering a Rock-Moving Machine" by listing the materials that were present and available to Egyptians. Tell students that they cannot use anything other than these to create their rock-moving device.

Plan a Solution: 20 minutes

Ask students to fill in the “Plan” section of the worksheet “Engineering a Rock-Moving Machine.” Students should write a step-by-step process for how their device will be built. Based on their knowledge of machines, force, and friction, they should describe how their device will reduce the amount of force and work that each person on their team will need to do in pulling a heavy object.

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.

Make It: 30 minutes

Once students have drawn their plan, allow them to begin building their device. As students are building, visit each group, reviewing what they learned about force and motion. Ask students questions about how their system reduces friction and decreases the work needed to be done by each worker. Allow students to make mistakes along the way and to struggle. When they do, ask questions about what they have observed and what they could change to fix the problem. Avoid offering solutions and instead encourage students to test ideas as they build.

Test: 20 minutes

Students will test either Option A or Option B:

Option A: Build a device that can carry a child across the sand pit outside of the school.

Option B: Build a device that is smaller but can carry a stone load across a tub of sand indoors.

1. In either case, students will first test the amount of force required to move their test load across dry sand.
2. Then the teacher will lightly wet the sand with water. If doing this exercise outdoors, use a hose to lightly spray down the sand pit. If doing this on a smaller scale indoors, use a spray bottle to mist water onto the sand.
3. Have the students conduct a secondary test with the same load, this time dragging it across the wet sand to identify if there was a difference in terms of the force required to complete the task.
4. For the third test, heavily wet down the sand so that more than just the top layer is moist. Again, have the students drag their device across the sand and record the force necessary to pull the load.

You can measure the actual amount of force exerted in each case with a force probe held by the students pulling the device. Or, do qualitative assessments as students describe if it “felt easier” to pull. Other good qualitative observations to take are the amount of sand that gathers at the front of the device and the depth the device sinks into the sand.

Evaluate: 10 minutes

Have students assess their device with the questions found on “Engineering a Rock-Moving Machine.” As time permits, hold a class discussion about students’ thoughts.

Taking It Further

Explore other possibilities: Could that liquid in the hieroglyphs have been something other than water? Obtain other liquids that would have been plentiful in the time of the Egyptians and use them to wet the sand and test the force necessary to pull heavy loads. Options include soapy water, salty water, and tea from marshmallow root.

Extend the impact of your device: Students identify additional ancient cultures and mythologies that they can explore, test, and verify.

Learn about this engineering in the real world: Engineers can look at ancient technology to uncover secrets of how to create modern structures. For example, Christine Fiori of Virginia Tech is studying the ancient roads of the Incan culture through the Andes mountains to uncover ways we can sustainably build roads in our modern culture.

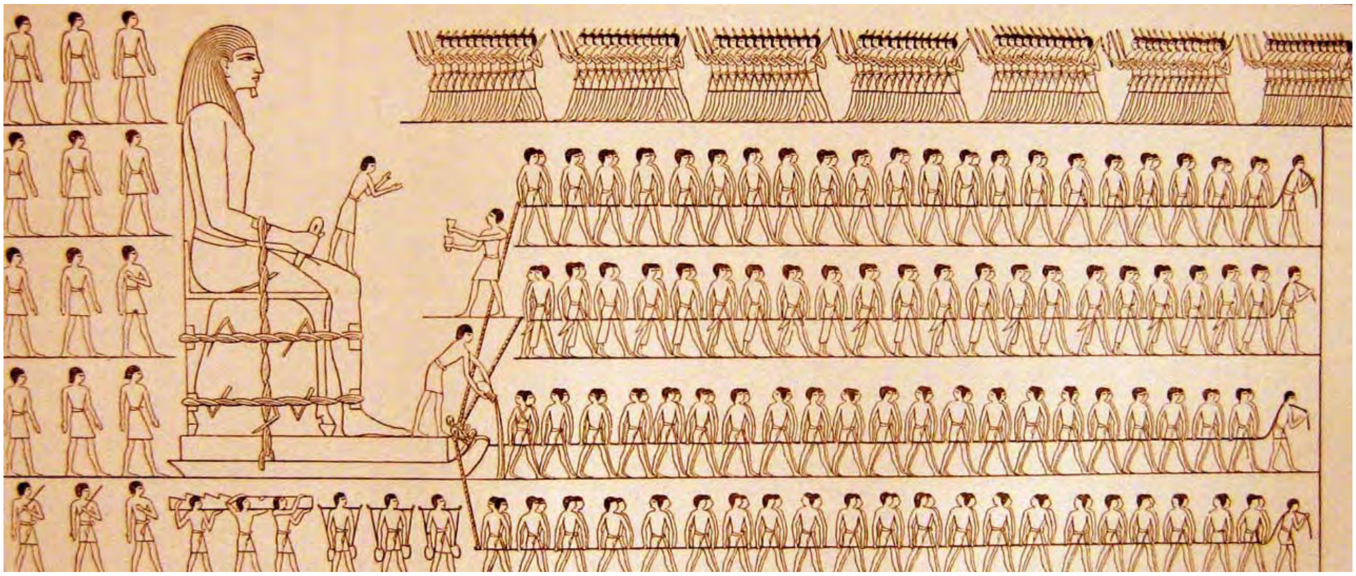
Current road creation involves modifying the landscape by blasting through rock, which often creates landslides. The ancient Inca, however, carefully followed the native landscape and controlled the water flow around it. Because of this, many of their roads still exist today, thousands of years later. Learn about what her team is doing to study these roads and replicate them in today's modern engineering at: mlsoc.vt.edu/articles/students/dr-christine-fiori-leads-expedition

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

EXAMINING ANCIENT EGYPTIAN HIEROGLYPHS

Name: ____

How Were the Pyramids Made?



For years archaeologists and engineers alike have investigated how an ancient culture like the Egyptians could move such large stones miles across the desert floor. The Egyptians built the pyramids over 5,000 years ago, well before the development of advanced machinery or motors. Each stone weighed over 2.5 tons and dragged heavily across the high friction of the desert sand floor. Recently, however, engineers feel they may have discovered the secret to how the Egyptians were able to achieve this incredible feat. An international team of researchers led by the University of Amsterdam investigated the claim that the hieroglyphs found in the tomb of Djehutihotep show the use of water being poured in front of the rock-moving device to reduce the friction of the sand floor. According to the results of the study, the water substantially reduced the amount of force necessary to pull 2.5-ton rocks across sandy terrain.

1. What is the building system present in this text and image?

2. Drawing from the text and the image, describe in as much detail as you can how this system worked and what materials were used:

ENGINEERING A ROCK-MOVING MACHINE

Name: ____

Problem to Be Solved

Recreate a working model of the ancient Egyptian system of moving large stones. Test the model to see if it does indeed make moving heavy objects easier.

Research and Gather Information

1. What do we know about friction and the ways that simple machines can make work easier in areas with heavy friction?

2. Based on the hieroglyphic image, what are our material constraints? What are the materials they used in this image?

Plan

- ☐ The criteria of the engineering and design challenge are:

- ☐ The constraints of the engineering and design challenge are:

- ☐ Draw a picture of what you plan to make.

☐ Write a step-by-step process of how to create your design.

☐ Describe how your device will reduce the amount of force and work needed to be done by each person pulling the heavy object.

Make It!

Evaluate

Did your device meet the constraints of the engineering challenge?

Did you use only the materials present within the hieroglyphic image?

Did your device meet the criteria of the engineering challenge?

Did it make pulling the rock easier than if it was dragged across the sand alone?

Did it safely move the heavy object without it falling off?

What differences did you observe among the dry sand, lightly moistened sand, and soaking wet sand?

What can you conclude from your class's data about this method of moving rocks across the desert floor? Can you confirm that the Egyptians would have had an easier time of moving the large stones? Can you disprove it with your results? Were your results inconclusive? Why?

DREAM BIG VIDEO SERIES

WATCH *LESSONS FROM THE GREAT WALL: REVERSE ENGINEERING*

Will your home or your school still be here in 100 years… or 1,000 years? Today's engineers still marvel at the ancient engineers who built the now 2,000-year-old Great Wall of China, the largest structure on Earth. Go to discovere.org/dreambig/media-assets and visit Educational Webisodes.

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GRADE 8: WATER PURIFICATION DEVICE

Grade level: 8

Lesson length: 3 hours (can be broken into multiple class periods; this time doesn't include collecting water to test)

Students design a portable water purification device that creates clean, drinkable water for people who live in places where clean water is not always available.

In the Film

In the film *Dream Big*, we see ways that engineers help build the world of tomorrow. As seen in the film, the population of Earth continues to grow exponentially and to concentrate in major cities. It is estimated that by the end of the century, 90% of Earth's population will live in a city. With the dense concentration of human inhabitants, we face new challenges to use our limited resources in the most effective ways. Engineers are solving the problem of limited space by creating vertical homes like the tower in Shanghai. Engineers are also working on maintaining the health of the water systems in major cities. With more people, we have more waste. How can we keep our fresh water clean?

NGSS Disciplinary Core Ideas

MS-ESS3.B Natural Hazards

Mapping the history of natural hazards in a region, combined with an understanding of related geologic forces, can help forecast the locations and likelihoods of future events.

MS-ESS3.A Natural Resources

Humans depend on Earth's land, ocean, atmosphere, and biosphere for many different resources. Minerals, fresh water, and biosphere resources are limited, and many are not renewable or replaceable over human lifetimes. These resources are distributed unevenly around the planet as a result of past geologic processes.

NGSS Engineering Practices

MS-ETS1.A Defining and Delimiting an Engineering Problem

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

MS-ETS1.B Developing Possible Solutions

A solution needs to be tested and then modified on the basis of the test results.

There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem.

Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors.

Key Words/Vocabulary

Agricultural runoff: Pollution that enters a system from fertilizer and pesticides dissolving in water during a period of rain.

Disinfection: The removal of dangerous bacteria and pathogens in a water sample.

Fecal coliform: Harmful bacteria found in the digestive system of mammals, including humans, that can contaminate water through runoff.

Filtration: The removal of dirt and particulate in a water sample.

Industrial runoff: Water pollution that enters a system as a result of industrial waste or spills, such as oil spills.

Municipal runoff: Pollution that enters a water system from human waste in the municipal water system.

pH: The amount of H or OH ions in a water sample; how acidic or basic a solution is.

Potable: Safe to drink.

Turbidity: The amount of suspended dirt in a water sample.

Materials

Per class:

- ☐ Standard water quality kit capable of testing for pH, fecal coliform, and turbidity
- ☐ Receptacle for dirty water that needs filtering
- ☐ Receptacles to pour filtered water into to be tested

Per group:

- ☐ 1 L water bottle (other sizes work as well; adjust the amount and size of filtration materials below to fit)
- ☐ 5 coffee filters
- ☐ Empty 20 oz. bottles for collecting water to test and filter
- ☐ 100 mL each of coarse sand, fine sand, gravel, pebbles, and stones
- ☐ 20 g of activated charcoal
- ☐ 10 cotton balls
- ☐ Several sponges
- ☐ Other materials that might be useful in creating a filtration device

Per student:

- ☐ Protective equipment (goggles, gloves)
- ☐ Water Filtration Engineering Sheet

Teacher Prep Notes

Cut off the bottom of the 1 liter bottles with scissors or a razor. Students will be inverting them and pouring dirty water into the top; filtered water will come out of the mouth of the bottle.

Prepare to review or teach students about the water cycle, natural ways that storms contaminate clean water supplies, and the role that the runoff phase plays in transporting pollutants into larger bodies of water. An example could be Brazil, where up to 50% of the surface water is contaminated with raw sewage, which caused concerns about the water conditions at the 2016 Olympic Games.

Prepare to teach about the natural processes of filtration and how aquifers can remove impurities and preserve clean drinking water underground. Prepare to explain how water in rivers is naturally purified from UV light exposure.

Students will also need to learn about ways that municipalities mimic and build on such natural processes to purify drinking water. Real-life examples of this are available from Civil Engineering Magazine online articles (see asce.org/ce-magazine/web-exclusives/, in the environmental and water resources area).

Be ready to review the two major functions of water purification systems:

- Filtration: The removal of dirt and particulate in a water sample.
- Disinfection: The removal of dangerous bacteria and pathogens in a water sample.

Students will also need to learn about the qualities that municipalities test before releasing drinking water (turbidity, salinity, fecal coliform, and pH).

To Do

Determine the Problem or Question to Solve: 15 minutes

1. Before watching the IMAX movie *Dream Big*, 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:
    - As the population of humans continues to increase exponentially and concentrate in cities, what are some ways that engineers are working to make life comfortable and feasible?
    - Can you predict any other challenges that humans will face as we continue to concentrate in cities? What will engineers have to "dream big" to create to solve these problems?
2. Debrief as a whole class after viewing the film. Allow students to verbally reflect on the guiding questions you gave them.
3. Introduce the design challenge. Students will create a water filter to help people living in major cities, or other places where clean water is not readily available, gain potable water from the closest water sources.

Research and Gather Information: 60 minutes

1. Assign students to small groups. As students learn and gather research, tell them to fill in the relevant section of their Water Filtration Engineering Sheet.
2. Review the water cycle, natural ways that storms contaminate clean water supplies, and the role that the runoff phase plays in transporting pollutants into larger bodies of water. Brazil is an example: Up to 50% of their surface water is contaminated with raw sewage, caused concern about the water conditions at the 2016 Olympic Games.
3. Have students watch associated *Dream Big* webisode content: "Drinking Water."
4. Teach students about the natural processes of filtration: how aquifers can remove impurities and preserve clean drinking water underground, and how water in rivers is naturally purified from UV light exposure.
5. Teach students, and have them research, how municipalities mimic and build on such natural processes to purify drinking water. Real-life examples of this are available from Civil Engineering Magazine online articles (asce.org/ce-magazine/web-exclusives/), in the environmental and water resources area.
6. Review the two major functions of water purifications systems:
    - Filtration: The removal of dirt and particulate in a water sample.
    - Disinfection: The removal of dangerous bacteria and pathogens in a water sample.
7. Teach students about the qualities that municipalities test before releasing drinking water (turbidity, salinity, fecal coliform, and pH).
8. Have students brainstorm materials that are capable of filtering dirt out of water and materials that are capable of disinfecting water.

Plan a Solution: 30 minutes

Place the following on a table for groups to consider for use: coffee filters, cotton balls, rocks, pebbles, sand, sponges, activated charcoal, and any other material you think would be useful in a water filter. Show students the inverted 1 liter bottle that they will use to make their water filter and where dirty water will be poured in and clean water will be poured out.

Allow students time to brainstorm with each other what each material might do, how much of each material they could use, and what order they should be placed in the 1 liter bottle. Tell students to write down their plans in the Plan section of their worksheet.

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 class brainstorming the criteria and constraints of this particular engineering challenge.

When they are ready, students should write down on their worksheet a step-by-step process for how their device will be built and what materials they will use. Based upon student knowledge of water purification systems and quality indicators, they should explain how each step of their water filtration device works to provide clean water.

Make It: 30 minutes

Once students have drawn their plan, instruct them to begin building their device. As students are building, visit each group, reviewing what they learned about water quality and purification processes and how their device works to create clean water. Allow students to make mistakes along the way and struggle. When they do, ask questions about what the students observed and what they could change to fix the problem. Avoid offering solutions and instead encourage students to test ideas as they build.

Test: 20 minutes

To test their device, students will bring in a 20 oz. water bottle of locally sourced water (from streams, rivers, ponds, or lakes). Students will then complete pre-assessment of the water source by testing pH levels and testing for turbidity and fecal coliform. After filtering their water source through their filtration device, students will then test again, with the goal of removing as many contaminants as possible. Students should record their test results on the chart provided in the Water Filtration Engineering Sheet.

Evaluate: 15 minutes

Have students assess their device using the Evaluate section of the Water Filtration Engineering Sheet.

As time allows, discuss students' thoughts about the success of their devices and what they would do to improve them.

Taking It Further

Learn about this engineering in the real world: Fresh water availability is one of the greatest issues our planet faces. The United Nations estimates that over 1.8 billion people do not have access to clean water systems. Water in developing countries is often contaminated with human and agricultural waste. Recently, one group of engineers created a life-saving device that allows people to drink from contaminated systems by purifying the water in a "straw." This device is called the LifeStraw. Learn more about this device at lifestraw.com

Research and investigate how the revolutionary LifeStraw works to disinfect and filter water for individuals living in water-threatened areas. How is it similar and different from the devices that students made? What scientific principles are at play in the LifeStraw?

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

Dream Big: Engineering Our World is a film and educational project produced by MacGillivray Freeman Films in partnership with the American Society of Civil Engineers and presented by Bechtel Corporation. The centerpiece of the project is a film for IMAX and other giant screen theaters that takes viewers on a journey of discovery from the world's tallest building to a bridge higher than the clouds and a solar car race across Australia. For a complete suite of *Dream Big* hands-on activities, educational videos, and other materials to support engineering education, visit discovere.org/dreambig. The *Dream Big* Educator Guide was developed by Discovery Place for the American Society of Civil Engineers.

WATER FILTRATION ENGINEERING SHEET

Name: ____

Problem to Be Solved

Create a water filter to help the people of Haiti rid their water of both human-caused pollutants and contamination from storms and floods.

Research and Gather Information

1. What are ways that storms can contaminate fresh water systems?

2. What are ways that cities and industries can contaminate fresh water systems?

3. How do municipal water filtration systems work? How does this relate to what we must create in our water filter?

Plan

- ☐ The criteria of the engineering and design challenge are:

- ☐ The constraints of the engineering and design challenge are:

- ☐ Draw a picture of what you plan to make.

- ☐ Write a step-by-step process of how to create your design.

- ☐ Describe how each step of your water filtration device works to provide clean water.

Make It!

Evaluate

Test	Before Filtration	After Filtration
Turbidity		
Fecal Coliform		
pH		

1. Did your device meet the constraints of the engineering challenge?

2. Did you test the device using water that is similar to water you would find in environments threatened by natural disasters and human runoff?

3. How did the water sample you tested live up to (or not live up to) this constraint?

4. Did your device meet the criteria of the engineering challenge?

5. Did your device filter the water sample effectively? Why or why not?

6. Did your device disinfect the water sample effectively? Why or why not?

DREAM BIG VIDEO SERIES

WATCH *WATER WISHES: ENGINEERING FOR THOSE IN NEED*

What can an engineering student in New Jersey do to help mountain villagers in Peru who lack clean water to drink? Building a safe water system for people halfway across the globe is an example of how Engineers Without Borders and other organizations are helping people build healthier communities. Go to discovere.org/dreambig/media-assets and visit Educational Webisodes.

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NCEES advancing licensure for engineers and surveyors

ASCE American Society of Civil Engineers

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MACGILLIVRAY FREEMAN'S
DREAM BIG
ENGINEERING OUR WORLD

LIFE SCIENCE:

ENDANGERED SPECIES

Grade level: High School Life Science

Lesson length: 225 minutes (plus ongoing evaluation)

> Students identify a species in their region that is endangered and in need of support. They engineer a device or method capable of supporting that species and its future sustainability.

In the Film

In the film *Dream Big*, engineers are often seen solving the problems of today as well as preparing for the problems of tomorrow. A theme throughout many of the challenges engineers face relates to the overpopulation of the human race. As humans continue to break new ground and expand our civilization, citizens, scientists, and engineers have to determine how to balance the needs of the human race with the needs of our environment and the species we share this planet with.

NGSS Disciplinary Core Ideas

HS-LS2.C Ecosystem Dynamics, Functioning, and Resilience

Moreover, anthropogenic changes (induced by human activity) in the environment—including habitat destruction, pollution, introduction of invasive species, overexploitation, and climate change—can disrupt an ecosystem and threaten the survival of some species.

HS-LS4.D Biodiversity and Humans

Biodiversity is increased by the formation of new species (speciation) and decreased by the loss of species (extinction).

NGSS Engineering Practices

HS-ETS1-2 Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

HS-ETS1-3 Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.

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Key Words/Vocabulary

Anthropogenic: Resulting from the influence or activity of human beings on nature.

Materials

Per team:

- ☐ Recycled and repurposed materials of student selection and teacher approval. Push students to develop a feasible budget, even if it is zero dollars, and establish materials and sources for those materials.

Teacher Prep Notes

Make sure you are familiar with the engineering code of ethics: asce.org/code-of-ethics/

Prepare to teach students about:

- ☐ Environmental niches
- ☐ Adaptive biology
- ☐ Environmental stressors that affect species populations
- ☐ Changes that disrupt ecosystems and drive species to extinction

Review the examples you will discuss with students in step 4 of the Research and Gather Information phase.

Give some thought to the criteria students could use in the rubrics they develop to evaluate the success of their device. They should include a quantitative and qualitative evaluation of the impact upon the species and ecosystem, adherence criteria and constraints of the challenge, cost effectiveness, feasibility of replication, and aesthetic quality.

Student projects could be reviewed and utilized over the course of weeks or months. The developed devices could be used and revised by new groups of students on a year-to-year basis and evaluated based upon their effectiveness.

To Do

Determine the Problem or Question to Solve: 10 minutes

1. Before they watch the IMAX movie *Dream Big*, 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:

   a. In the film, what challenges are identified that correlate to population growth?

   b. What are some of the strategies that engineers employ to compensate for the ever-growing population of humans?

   c. What are some of the ways that the safety of society is incorporated into these designs? (Discuss the engineering code of ethics: asce.org/code-of-ethics/)

2. Debrief as a whole class after viewing the film. Allow students to reflect on the guiding questions you gave them.

3. Remind students that every project and structure has a component of engineering. It is the responsibility and challenge of engineers to consider all of the variables at play in each structure that is being built.

4. Introduce the design challenge. As populations continue to increase, the need for more homes, businesses, food, water, fiber, and goods is placing greater demands on our natural surroundings. With expanding development, we alter the habitat that supports nonhuman organisms. Students will acknowledge the impact that humans have on the environment and think critically about how to compensate for the losses of those organisms. Students will identify and select a species that is threatened or on the cusp of extinction in their region. They will determine the root causes (anthropogenic or otherwise) that are contributing to the demise of that species. Students will then engineer a method to help sustain and promote the species.

Research and Gather Information: 120 minutes

1. Teach students about the concept of environment niche and adaptive biology.

2. Teach students about the environmental stressors (natural and manmade) that do not force adaptations and may reduce the population of a species.

3. Teach students about extreme changes (anthropogenic cause: resulting from human activity) that can disrupt an ecosystem and threaten the overall survival of a species.

4. Provide a sample scenario that can be shared with students.

   a. Example 1: Brown-headed Nuthatch nc.audubon.org/conservation/make-little-room-brown-headed-nuthatch

   b. Example 2: Bats asce.org/magazine/20160809-bridge-goes-to-bat-for-bats/

5. Divide students into teams of three. Teams should research species in their region whose ecosystems are being threatened or who are experiencing a decline (resource: fws.gov/endangered/species/index.html); they should then choose a species to work with for this project.

6. Students should consider the “trade-off” scenario: with any changes to an ecosystem there will be unforeseen effects that must be accounted for when possible.

Plan a Solution: 20 minutes

Once teams know which species they will focus on, instruct them to plan a design that would relieve the impact and improve conditions for that species, according to one of these options:

Option 1: Design a structure that mimics the habitat that is being destroyed.

Option 2: Design a structure that physically stops the habitat from being destroyed.

Whichever option students choose, they will also need to create a rubric or an instrument to gauge the success of their device.

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.

Make It: 30 minutes

Upon completion of the plan, tell teams to construct and enable their process or device. The product should reflect their research as well as their plan, and they should consider whether or not the process or device can be altered after a period of observation. Remind students that iteration is a vital part of the engineering process.

Test: 15 minutes

Arrange for students to take their structure into nature, in an area frequented by the species they are trying to help. Instruct students to set up the device and begin testing its effectiveness at maintaining the population of a species per the rubric that they developed. How long this part of the lesson takes will vary depending upon the expectations and rubric designed by the students. The testing process may take weeks or even months to evaluate effectiveness. For example, if students build a bird house specific to the needs of a species, their rubric might note telltale signs such as fecal matter, nests, and sightings of the species in question near or in the birdhouse as proof that it is being used as intended.

Evaluate: 30 minutes

Students have created their own rubric as part of the planning process. This assessment tool should include a quantitative and qualitative evaluation of the impact upon the species and ecosystem, adherence criteria and constraints of the challenge, cost effectiveness, feasibility of replication, and aesthetic quality.

Taking It Further

Use technology (microcontrollers, sensors, and coding) to develop monitoring systems that support the tracking of student devices to ensure successful integration into the environment.

For example: Use an Arduino or Hummingbird Robotics Kit to place, on the exterior of a birdhouse, a small light-emitting diode (LED) that is activated when a bird has stepped on a pressure sensor inside the house. If it's within Wi-Fi range, the device could be coded to create an If This, Then That (IFTTT) communication, notifying students via text or email. Learn more at https://ifttt.com/

Explore how environmental engineers are raising awareness and designing solutions to mitigate the impacts our planet is experiencing from pollution, habitat loss, and the declining availability of fresh water.

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

DREAM BIG VIDEO SERIES

WATCH *WATER WISHES: ENGINEERING FOR THOSE IN NEED*

What can an engineering student in New Jersey do to help mountain villagers in Peru who lack clean water to drink? Building a safe water system for people halfway across the globe is an example of how Engineers Without Borders and other organizations are helping people build healthier communities. Go to discovere.org/dreambig/media-assets and visit Educational Webisodes.

MACGILLIVRAY FREEMAN'S
DREAM BIG
ENGINEERING OUR WORLD

CHEMISTRY:

MAKING AN IMPACT ON HABITAT

Grade level: High school chemistry or physical science

Lesson length: 3.25 hours (can be broken down into multiple class periods)

Industrialization has changed our lives for the better in countless ways, but it has done our planet no favors. Manufacturing has taken a toll on our planet's environmental health. The byproducts of production may be especially harmful to plant and animal life if they are released directly into the environment. Engineers are challenged to create ways to allow for the manufacture of useful products while maintaining, or improving, the health of the environment. Students experience one way engineers are preserving environmental health when they are tasked with creating a way to neutralize the acidic byproduct of a new factory.

In the Film

In the film *Dream Big*, teams of engineers compete to create the best underwater robot. Many teams show up with highly refined robots, custom-fabricated metalwork, and laser measurement devices. The team that wins, however, is a high school group using cheap, inexpensive materials like PVC pipe and tampons. Engineers know that sometimes, the best solutions to problems aren't the most expensive or complex. The best solutions are those that limit the need for nonrenewable resources and take advantage of systems we already have in place. For this reason, chemical engineers experiment with using the chemicals left over from everyday human activities to solve problems like energy production and pollution reduction.

NGSS Disciplinary Core Ideas

HS-PS1-6 Matter and Its Interactions

Refine the design of a chemical system by specifying a change in conditions that would increase the effectiveness at creating product equilibrium.

NGSS Engineering Practices

HS-ETS1.A Defining and Delimiting Engineering Problems

Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them.

Humanity faces major global challenges today, such as the need for supplies of clean water and food or for energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities.

HS-ETS1.B Developing Possible Solutions

When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts.

Both physical models and computers can be used in various ways to aid in the engineering design process. Computers are useful for a variety of purposes, such as running simulations to test different ways of solving a problem or to see which one is most efficient or economical; and in making a persuasive presentation to a client about how a given design will meet his or her needs.

Key Words/Vocabulary

Acid: A compound that forms H+ ions when dissolved in water.

Base: A compound that form OH- ions when dissolved in water.

Effluent: Wastewater, treated or untreated, that flows out of a treatment plant, sewer, or industrial outfall. Generally refers to wastes discharged into surface waters.

pH: The measurement of hydrogen ion concentration within a solution.

Indicator: A chemical substance used to determine the pH of a liquid; usually, a chemical that will turn colors as the concentration of H+ ions varies.

Solution: A mixture where one substance is dissolved within another.

Materials

Per group:

- ☐ 1 chemistry testing plate or set of small test tubes
- ☐ Set of plastic pipettes or eyedroppers
- ☐ pH test strips
- ☐ Graph paper and pencils
- ☐ Alkaline vegetables: avocados, broccoli, celery, cucumber, kale, spinach (blend each with water to create a solution)
- ☐ Ground bivalve shells (seashells or clam/mussel/oyster shells from restaurant waste)
- ☐ Tea leaves
- ☐ Mortar and pestle
- ☐ Blender
- ☐ 0.1M concentration of hydrochloric acid (HCl), or lemon juice if HCl is unavailable
- ☐ Glassware
- ☐ Safety wear

Per student:

- ☐ Engineering a Neutralizer Sheet

Teacher Prep Notes

This engineering challenge requires students to test solutions on a 0.1M molar concentration of hydrochloric acid (HCl). If you do not have HCl on hand, lemon juice serves as a good alternative.

If you are preparing the solutions used in this activity the night before, blend 1 cup of a vegetable type with ½ cup of water. Prepare tea leaves by blending ¼ cup of tea leaves with ¾ cup of water. Strain out large particles of each solution before extracting your 2 mL solution.

Make sure that students understand the nature of acids and bases. They will need to practice balancing acid-base reaction equations.

Prepare to help students understand the difference between strong and weak bases in terms of the amount of H+ atoms they produce when dissolved in water.

Be prepared to teach students about neutralization processes and techniques.

To Do

Determine the Problem or Question to Solve: 15 minutes

1. Before watching the IMAX movie *Dream Big*, 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:
   - **a.** What are some ways that engineers use unconventional or recycled materials in their designs?
   - **b.** In what ways are engineers working to lessen their impact on the environment?
2. Debrief as a whole class after viewing the film. Allow students to verbally reflect on the guiding questions you gave them.
3. Introduce the design challenge. Students are going to do some chemical engineering. To set context for the challenge, explain that the growth of an industrialized society has changed our lives and our planet. People have access to better medicines, protective homes, faster communication, and many other transformative technologies. The manufacturing of these technologies, however, can take a toll on our planet's environmental health. The byproducts of their production may be toxic and harmful to human, plant, and animal life if released directly into the environment. Licensed professional engineers, P.E.s, are charged with preserving the essentials that protect the health, safety, and welfare of the public. Licensure requirements vary by discipline. Chemical engineers work to create ways to solve the problem of industrial effluents. Tell students that today they are tasked with the same challenge: to create an environmentally friendly way to neutralize the acidic byproduct of a factory's production.
   For this activity, they are to imagine that the factory owners know that many vegetables are naturally alkaline. Seashells, which can be an unwanted byproduct of seafood processing, are also alkaline. Could the factory use such products to neutralize the acidic byproduct in an environmentally sustainable way?

Research and Gather Information:

60 minutes

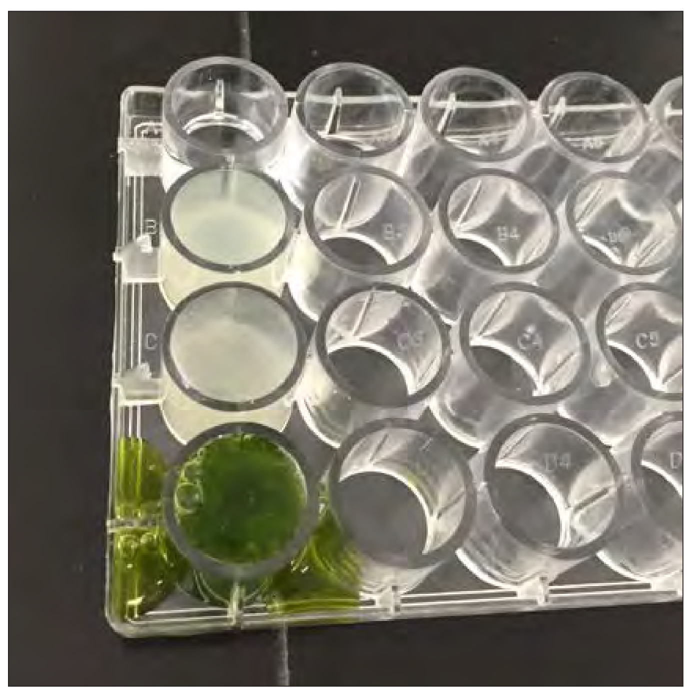
1. Have students research the different causes of toxic discharges into water systems.
2. Look at the Engineering a Neutralizer worksheet with students and point out where to take notes during this research phase of the activity. Teach students about the nature of acids and bases and practice with balancing acid-base reaction equations. Help students understand the difference between strong and weak bases in terms of the amount of H+ ions they produce when dissolved in water.
3. Explain neutralization processes and techniques.
4. Have students investigate the effect of solutions made from food waste on acidic runoff:
   - **a.** Have students fill pH testing wells with 2 mL of 0.1M HCl to represent acidic byproduct. Review how this acid is similar to and different from the acid in mine drainage.
   - **b.** Give students a variety of naturally alkaline foods that are listed in the Materials section. (If you are preparing the solutions the night before, blend 1 cup of each vegetable with ½ cup of water. Tea leaves should be prepared by blending ¼ cup of tea leaves to ¾ cup of water. Be sure to strain out large particles of each solution before extracting your 2 mL solution. If you are having students create their own solutions, have them decide the ratio of liquid to solid they will use and record it on their Engineering a Neutralizer sheet.)
   - **c.** Have students add 2 mL of each alkaline solution to the “acid byproduct” and test the resulting pH. They should complete the table in their worksheet and then discuss results with the class.and what similar things we could use to collect trash from a river.

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 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 and writing them down in the Plan section of the Engineering a Neutralizer worksheet.

Place students in small groups. Using what they have learned, each group of students must create a solution using the natural materials they tested during research that they believe will be capable of neutralizing 25 mL of the acidic byproduct solution. Students must research the chemicals present in each of the materials they chose and write a chemical equation theorizing the acid/base interactions within their solution and the acidic byproduct. Tell students to complete the Plan section of the Engineering a Neutralizer Sheet.



Make It: 30 minutes

When they are ready, students should create their solution. As students are mixing, visit each group, asking questions about what volume of their solution they think will be needed to achieve a neutral pH of 7 in the water system, and the molecular chemistry behind how their solution will work.

Test: 45 minutes

Instruct students to combine the solution they developed with 5 mL of the 0.1M HCl. (Students use the volume of solution they predicted would neutralize the byproduct in the previous step.) Ask them to record the pH range. They should do the same with the following amounts of the acidic solution:

10 mL	15 mL	30 mL
20 mL	25 mL	

At each interval, record the pH on a simple data table. Have students graph the information and create a line of best fit for the data. Using this data and graph, they should predict the volume of neutralizer necessary to bring 1,000 liters of acidic waste to a neutral pH.

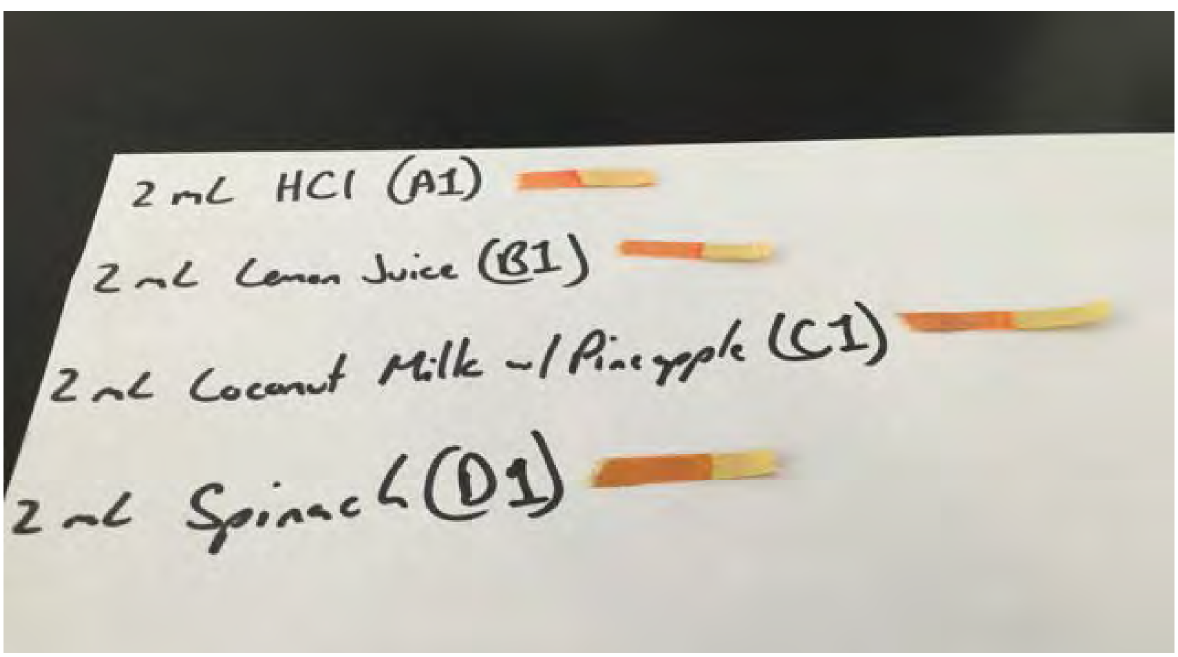
Evaluate: 15 minutes

Have students assess their plan using the rubric found on the Engineering a Neutralizer Sheet.

Engineers must often decide between solutions that may not be perfect. For example, using seashells to neutralize effluent may be very practical for a seaside community with a nearby source. On the other hand, bringing seashells to an inland location may be expensive and require the use of trucks or trains that could contribute to air pollution. How should any leftover solids be disposed of? Discuss the practicalities of the "best" solution in light of your local community.

Licensed professional engineers, P.E.s, are charged with preserving the essentials that protect the health, safety, and welfare of the public. By meeting standards in education, exams, and experience, professional engineers demonstrate that they have the skills and knowledge needed to perform their jobs. As licensed professionals, they must continue to practice in a manner that is both technically competent and ethically sound. Their first responsibility is to protect the public.

How does this plan address a licensed professional engineer's responsibility to protect the public?



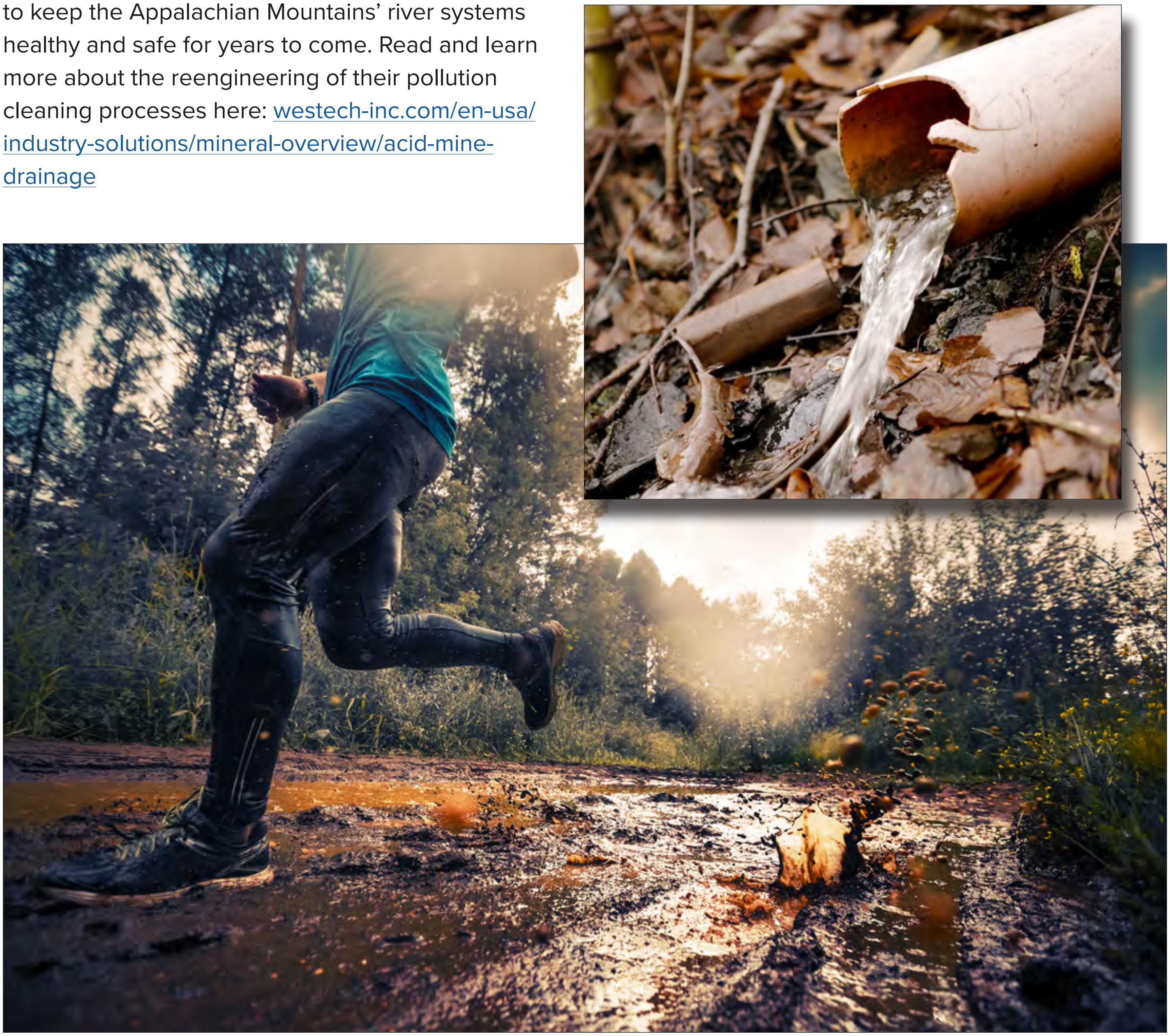
Taking It Further

Learn about this engineering in the real world: Engineers are passionate about creating a better tomorrow. They are the creative forces that drive the development of ever more innovative ways to solve environmental issues that arise from our industrialized lifestyle.

In the United States, engineers are inventing ways to keep the Appalachian Mountains' river systems healthy and safe for years to come. Read and learn more about the reengineering of their pollution cleaning processes here: westech-inc.com/en-usa/industry-solutions/mineral-overview/acid-mine-drainage

The byproduct of Greek yogurt is acidic whey. Learn the challenges of dealing with a growing amount of acidic byproduct: modernfarmer.com/2013/05/whey-too-much-greek-yogurts-dark-side/

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



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ENGINEERING A NEUTRALIZER SHEET

Name: ____

Problem to Be Solved

Create a way to neutralize 25 mL of acidic byproduct from a factory.

Research and Gather Information

1. Fill in the blanks with acid, base, or neutral.

   a. The neutralization of a strong acid with a strong base produces a ____________ solution.

   b. The neutralization of a weak acid with a strong base produces a ____________ solution.

   c. The neutralization of a strong acid with a weak base produces a ____________ solution.

2. Testing natural alkaline solutions: What is the pH of a mixture of 2 mL of acidic byproduct and 2 mL of each of the following solutions?

Material	**pH when added to 2 mL factory discharge**
Solution with ground sea shells	
Tea	
Solution with alkaline vegetable (insert name):	
Solution with alkaline vegetable (insert name):	

Plan

- ☐ The criteria of the engineering and design challenge are:

- ☐ The constraints of the engineering and design challenge are:

- ☐ Write the step-by-step directions of the solution you plan to make. Include the volume of each material and total volume of solution.

- ☐ Explain the chemical processes that will lead to the neutralization of your acidic solution.

Make It!

Evaluate

Use the following rubric to assess your design.

Criteria for this design challenge (Fill in each row with a description of criteria that needed to be met)	Did your design meet the criteria for the challenge?	Why or why not?
Constraints for this design challenge	Did your design follow the constraints?	Why or why not?
Marketability of this design	Is your design marketable?	Why or why not?
What is the environmental impact of your procedure? Can it be scaled up for factory use?		

DREAM BIG VIDEO SERIES

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Engineers not only create the tools that produce virtual environments, they also use the virtual world to study and build the real world. Learn how engineers are changing the worlds we imagine and live in. Go to discovere.org/dreambig/media-assets and visit Educational Webisodes.

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DREAM BIG
ENGINEERING OUR WORLD

PHYSICS:

LED HOLIDAY CARD

Grade level: High School Physics

Lesson length: 150 minutes (can be broken down into multiple class periods)

Students design a greeting card that illuminates at least two LED lights by converting chemical energy in batteries to radiant energy when the card is opened.

In the Film

In the film *Dream Big*, engineers work to create renewable and sustainable energy. Traditionally, we harness the chemical energy found in fossil fuels and use technological devices to convert it to electrical energy. This electrical energy is then easily transferred over long distances and used in devices in our homes and businesses. As our technological capabilities continue to evolve, so too does the creativity of engineers in designing electrical circuits and grids to power our society. In this engineering challenge, we will use our own creativity to design a device that converts chemical energy to radiant energy.

NGSS Disciplinary Core Ideas

HS-PS3-3 Energy

Design, build, and refine a device that works to convert one form of energy into another.

NGSS Engineering Practices

HS-ETS1.A Defining and Delimiting Engineering Problems

Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them.

Humanity faces major global challenges today, such as the need for supplies of clean water and food or for energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities.

HS-ETS1.B Developing Possible Solutions

When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts.

Both physical models and computers can be used in various ways to aid in the engineering design process. Computers are useful for a variety of purposes, such as running simulations to test different ways of solving a problem or to see which one is most efficient or economical; and in making a persuasive presentation to a client about how a given design will meet his or her needs.

Key Words/Vocabulary

Mechanical energy: Energy used in the physical movement of an object.

Chemical energy: Energy found within the chemical bonds of molecules.

Electrical energy: Energy found in the movement of electrons through a medium.

Radiant energy: Energy found in the movement of photons.

Circuit: A closed path through which electrons flow.

Controller: A component of a circuit that regulates the flow of electrons. A switch is an example of a controller.

Actuator: A component of a circuit that uses currents and voltage to perform an action. A lightbulb or buzzer is an actuator.

Materials

Per class:

- ☐ Materials for decorating the greeting card (markers, glitter, ribbon, glue stick, etc.)
- ☐ Color printer (optional)

Per student:

- ☐ 3 two-legged LED lights (color irrelevant)
- ☐ 1 3V coin battery
- ☐ 1 tube of Bare Conductive paint or 1 meter of conductive copper or aluminum tape
- ☐ 1–2 pieces of cardstock
- ☐ Scissors
- ☐ Engineering a Greeting Card worksheet

Teacher Prep Notes

Gather examples of greeting cards that do something when opened, such as playing a song or lighting up. Alternatively, ask students to bring these types of cards in before class. You will need one card for each group of two or three students to examine and take apart.

Prepare to teach students about the directional flow of energy through circuits and the conversion of chemical energy from batteries to electricity and then to radiant energy. Also prepare to teach students about parallel and series circuits and how to identify their effect on volt and current flow through LEDs.

To Do

Determine the Problem or Question to Solve: 15 minutes

1. Before watching the IMAX movie *Dream Big*, 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 question to think about as they watch the film:
   - What are some innovative ways that engineers are creating usable energy for communities?
2. Debrief as a whole class after viewing the film. Allow students to verbally reflect on the guiding question you gave them.
3. Introduce the design challenge. Tell students that they are going to design a greeting card that illuminates at least two LED lights by converting chemical energy to radiant energy when the card is opened.

Research and Gather Information: 45 minutes

1. Organize students into pairs or triads. Give each group a greeting card that lights up or makes music upon opening, and a pair of scissors. To teach students about the common components of a circuit, have students carefully cut open the card so that they can see the components and what triggers the music or lights. Describe each circuit component: the energy source, actuators, and controllers. Make sure students can identify each one in their greeting card.
2. Distribute the “Engineering a Greeting Card” worksheet. Ask students to draw a circuit diagram of their greeting card as the first step under Research and Gather Information.
3. Teach students about the directional flow of energy through circuits and the conversion of chemical energy from batteries to electricity and then to the radiant energy of the LED bulb. Calculate the voltage and amperage drop across a circuit, identifying how changes occur because of the resistance found in activators like LED bulbs. Familiarize students with the appropriate symbols that engineers use when they are drawing schematics as part of the planning phase for a new project.
4. Teach students about parallel and series circuits to identify their effect on volt and current flow through LEDs. Allow students to experiment and determine the optimal circuit design to illuminate at least one LED.

Plan a Solution: 20 minutes

Tell students that they are now ready to each design their own greeting card. Review the Plan section of the "Engineering a Greeting Card" worksheet. Tell students to fill out this section as they decide how they want to make their greeting card. This includes drawing a circuit schematic using the appropriate symbols that represent their plan. The circuit schematic should include the power source, the direction of electron flow, the controller, and the resistor/bulb. Students should calculate the resistance, current, and voltage drop across each LED bulb. Finally, students should describe the controller device that they will use to complete the circuit when the card is opened.

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 and have students write them down in their worksheets.

Make It: 30 minutes

When they are ready, students should create their greeting cards. As students work, walk around asking questions about the directional flow of electrons in the circuit. Encourage students to fluently discuss their card using circuit terminology.

Test: 10 minutes

As students finish creating their card, they should trade with another student who is also done. Students should evaluate each other's cards based on the effectiveness of the switch: Have each student close and open the card under evaluation five times. How many times does it work properly? Students can also evaluate the aesthetics of the card and its layout and marketability (how likely are they to buy this card?).

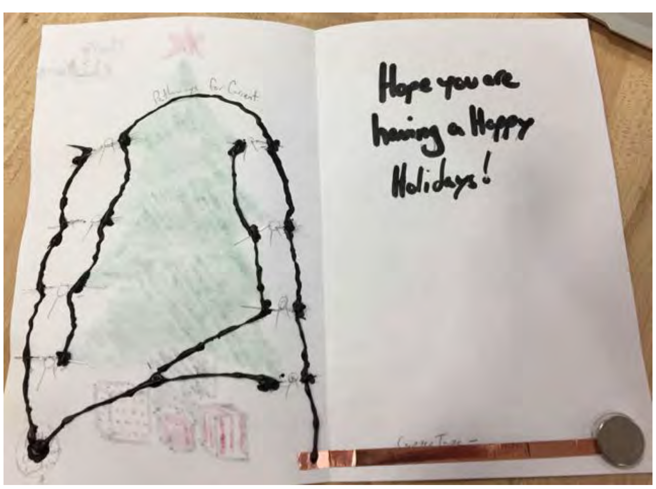
Evaluate: 30 minutes

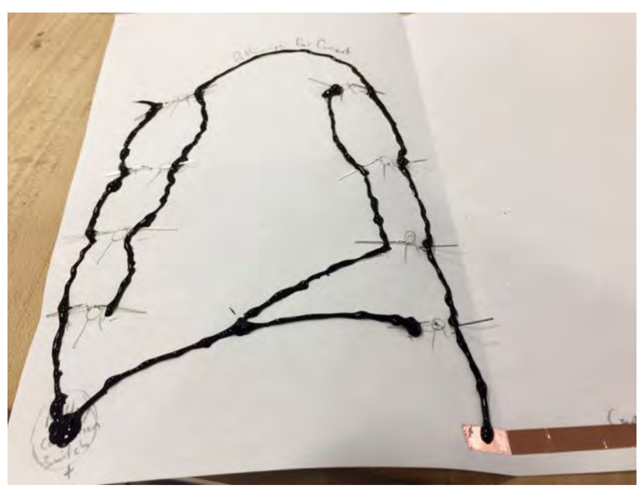
Have students assess their greeting card with the rubric found on the "Engineering a Greeting Card" worksheet.

Create a class data set that includes information such as:

- ☐ Card design trends
- ☐ Number of cards using series vs. parallel circuits
- ☐ Number of LEDs illuminated

Students can then determine the longevity of their card. How many times can it be opened and still function, or how long will the lights stay on if the card is left open? Students should then graph the data to see if there are any trends in circuit design and longevity.





Taking It Further

Use software: Digital design software can be used to create the look of the card that utilizes a circuit in fun, meaningful ways. Recommended software: Inkscape, CorelDraw, GIMP, and so on.

Use hardware: Using microcontrollers, sensors, speakers, and so forth, students can design and build a card that is interactive—that plays music or blinks lights in a specific sequence based upon environmental stimuli.

Learn about this engineering in the real world: Batteries provide an excellent source of energy to smaller circuits by converting chemical potential into electrical energy flow. Batteries, however, have their environmental limitations. They are nonrenewable energy sources, losing their ability to produce electrical current as the chemical potential stabilizes. When they are disposed of improperly in landfills, they release harmful chemicals into the groundwater system. Engineers are finding innovative ways to solve this problem. Previously, renewable energy sources like solar panels would have been too large and expensive to substitute for batteries. Engineers in South Korea are solving this problem as they create small flexible solar panels that can fit into any thickness of device. Follow this link to learn more about this device: engineering.com/ElectronicsDesign/ElectronicsDesignArticles/ArticleID/12683/Flexible-Solar-Cells-with-Flexible-Applications.aspx

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

Dream Big: Engineering Our World is a film and educational project produced by MacGillivray Freeman Films in partnership with the American Society of Civil Engineers and presented by Bechtel Corporation. The centerpiece of the project is a film for IMAX and other giant screen theaters that takes viewers on a journey of discovery from the world's tallest building to a bridge higher than the clouds and a solar car race across Australia. For a complete suite of *Dream Big* hands-on activities, educational videos, and other materials to support engineering education, visit discovere.org/dreambig. The *Dream Big* Educator Guide was developed by Discovery Place for the American Society of Civil Engineers.

ENGINEERING A GREETING CARD

Name: ____

Problem to Be Solved

Design a greeting card that illuminates at least two LED lights by converting chemical energy to radiant energy when the card is opened.

Research and Gather Information

Dissect a greeting card, and draw a circuit diagram of its inner workings below. Label the actuators and energy sources within the circuit. Where is the controller within the card? How does it work?

Plan

- ☐ The criteria of the engineering and design challenge are:

- ☐ The constraints of the engineering and design challenge are:

- ☐ Draw a circuit diagram of the card you intend to make.

- ☐ Write the step-by-step directions for how to assemble the card you plan to make.

- ☐ Describe your controller mechanism and how you intend to make the lights illuminate when the card is opened.

Make It!

Evaluate

Create a rubric to assess your design.

Criteria for this design challenge (fill in each row with a description of criterion that needed to be met)	Did your design meet the criterion for the challenge?	Why or why not?
Constraints for this design challenge	**Did your design follow the constraint?**	**Why or why not?**
Marketability of this design	**What is marketable?**	**Why or why not?**
What is the environmental impact of your device?		
What are the aesthetics of your device?		

DREAM BIG VIDEO SERIES

WATCH *INNOVATIVE ENGINEERS: OUR HIGH-TECH FUTURE*

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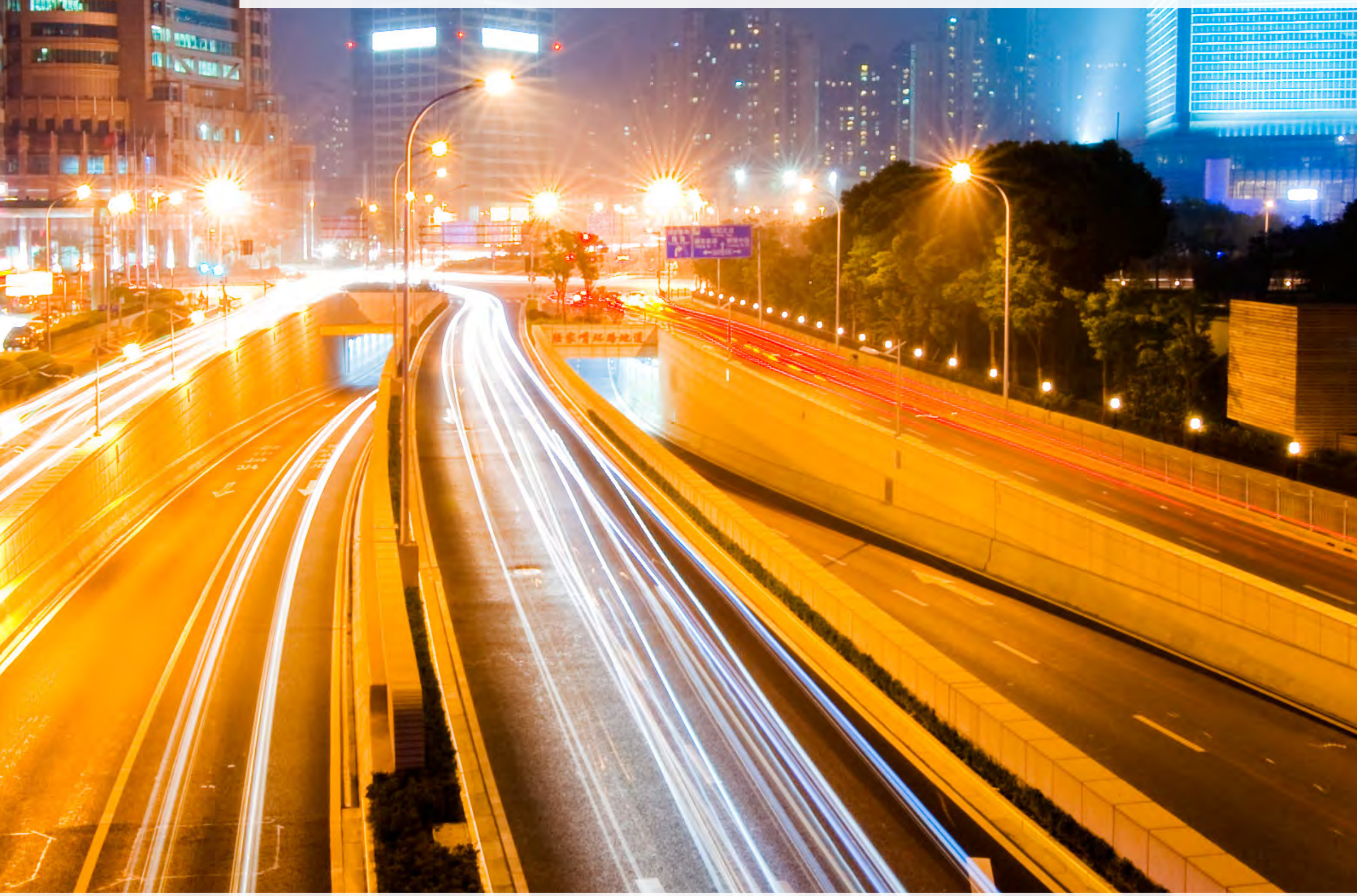

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