ENGINEERING STUDY GUIDE

Engineering! by ArcAttack
Teacher's Resource Manual

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Mission

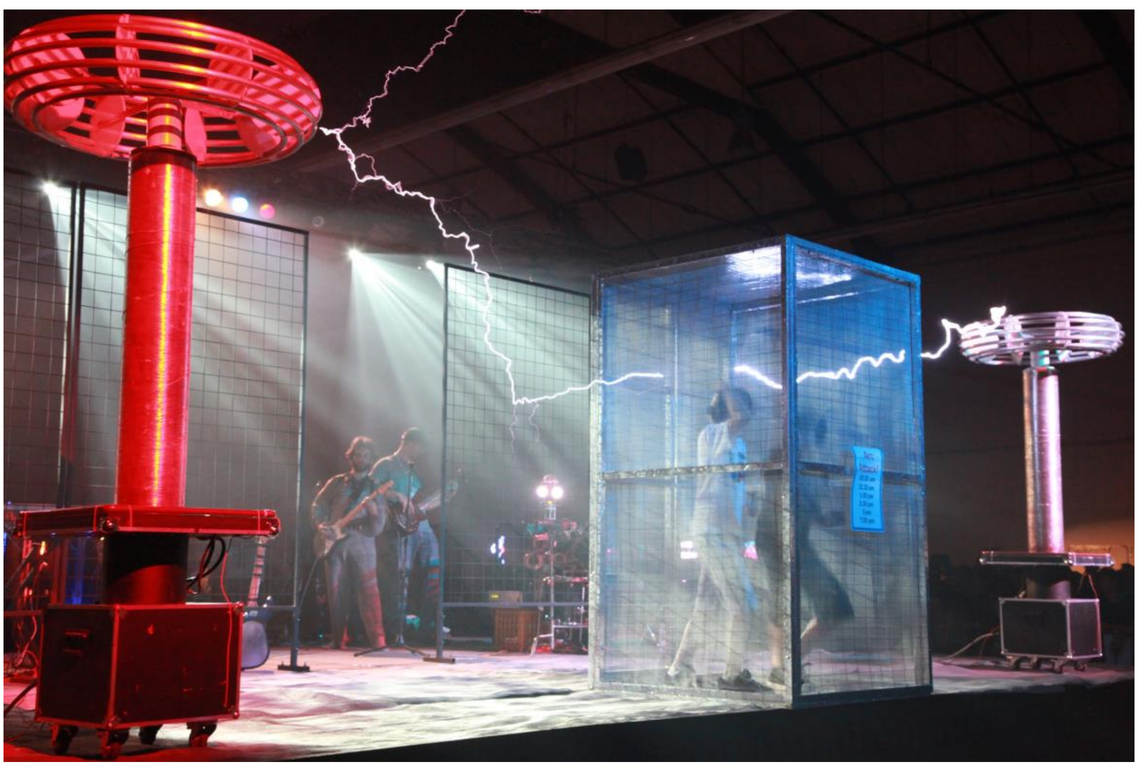
ArcAttack is a performing arts group that originated in Austin, Texas in late 2005. Our goal is to explore new possibilities between the union of scientific and musical concepts and to share this knowledge with the world. After years of performing, we realized that we were doing much more than simply entertaining crowds through musical performance. We discovered that our performance has a natural tendency to stimulate our spectator's' curiosity about science and technology. Using music as a medium of propagating these concepts and ideas, we hope to help others understand the relationship between science, art and music. “Engineering!” is a new addition to our educational series, as part of a continuing effort to expand our capabilities as educators while reflecting the latest standards in science education through our performance.

Introduction to the Teachers' Resource Manual

The Engineering! resource manual is a comprehensive guide to understanding not only the science behind our musical performance, but also lays the foundation for the understanding of the engineering principles that compose modern day technology and promote it's advancement. It addresses the Next Generation Science Standards (NGSS) for engineering design for grades K-2, 3-5, middle school, and high school. However, most of the concepts and activities will be most useful for students in the elementary and middle school grades.

In this manual, we will explore engineering design through simple explanation and hands on experimentation. The world of engineering is vast and can provide an individual with endless avenues to explore and challenges to overcome. We only hope that you enjoy the subject matter in this guide as much as we do, and join us in our lifetime learning process!

The ArcAttack study guide introduces key scientific principles and historical figures in an interactive format as a foundation to understanding concepts students will experience during the live performance. The experiments that follow illustrate principles tied to the core components of the technology we feature in order to provide a framework for the student to experience in a hands-on fashion how these principles have allowed for the creation of that technology. Additionally, it explores natural phenomenon associated with the key components of the ArcAttack presentation and provides resources for further exploration by student and teacher alike.



Next Generation Science Standards (NGSS): Engineering Principles

The Next Generation Science Standards (NGSS) includes sections on engineering design that are meant to play a critical role in the science education of students from kindergarten through high school. In fact, the NGSS standards specifically state that they are hoping to raise engineering design to the same level as scientific inquiry within science education.

While this is an important, if lofty, goal- it can be problematic for teachers as engineering it not generally offered as a separate class or even as an elective at any level of K-12 education. It is therefore up to the science teachers (or, in the case of elementary school, primary teachers) at all grade levels to incorporate engineering information in their classes across all scientific disciplines.

ArcAttack created Engineering! in order to help classroom teachers fulfill the NGSS engineering standards without having to sacrifice precious classroom time that might already be in short supply due to the large array of topics that teachers are expected to cover. In our NGSS-curriculum aligned show, we touch on all of the required engineering design standards while at the same time presenting information key to succeeding in any engineering discipline: the importance of communication, determination, and even failure.

We hope that by providing students with a foundation in engineering design we can not only help teachers in their effort to teach these new standards, but also to inspire students to engage in critical thinking and aspire to engineering careers later in life. After all, many of the world's current problems: climate change, providing clean energy, enduring access to clean water, etc., will be solved by engineers.

The NGSS standards related to engineering design principles are broken up into four general age groups: kindergarten through second grade, third through fifth grade (elementary grade levels), middle school, and high school. These standards are broken down in the table on the following page.

Age Group	Standard	Description
K-2	K-2-ETS1-1	Ask questions, make observations, and gather information about a situation people want to change to define a simple problem that can be solved through the development of a new or improved object or tool.
K-2	K-2-ETS1-2	Develop a simple sketch, drawing, or physical model to illustrate how the shape of an object helps it function as needed to solve a given problem
K-2	K-2-ETS1-3	Analyze data from tests of two objects designed to solve the same problem to compare the strengths and weaknesses of how each performs.
3rd-5th	3-5-ETS1-1	Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.
3rd-5th	3-5-ETS1-2	Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.
3rd-5th	3-5-ETS1-3	Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.
MS	MS-ETS1-1	Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.
MS	MS-ETS1-2	Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.
MS	MS-ETS1-3	Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.
MS	MS-ETS1-4	Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.
HS	HS-ETS1-1	Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.
HS	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	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.
HS	HS-ETS1-4	Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.

A Framework for K-12 Science Education defines engineering as beyond general applied science, and instead describe it as “any engagement in a systematic practice of design to achieve solutions to human problems” (NRC 2012, p. 11-12). It explicitly states that design-based thinking is something that all students will be expected to learn.

The purpose of defining “engineering” more broadly in the *Framework* and NGSS is to emphasize engineering design practices that all citizens should learn. For example, students are expected to be able to define problems—situations that people wish to change—by specifying criteria and constraints for acceptable solutions; generating and evaluating multiple solutions; building and testing prototypes; and optimizing a solution. These practices have not been explicitly included in science standards until now.

Key Engineering Principles used by Arcattack!

ArcAttack uses a number of engineering principles in their work which align with the NGSS curriculum in their shows. During the Engineering! performance, a number of instruments created by ArcAttack go awry, and do not work as expected. Together with the audience, ArcAttack will ask questions, make observations, define the problems, and gather information in order to overcome the struggles with their instruments (K-2-ETS1-1). In doing so, they will also touch on the constraints of their problem relating to time and the available materials that are needed solve it (3-5-ETS1-1, MS-ETS1-1).

In order to better solve the problems that occur during the show, ArcAttack will use sketches, drawings, physical models, and prototypes in order to help isolate variables and solve the cause of their predicament (K-2-ETS1-2, 3-5-ETS1-3, MS-ETS1-4, HS-ETS1-4). Then, with the help of the audience, ArcAttack will conduct and analyze the data from multiple trial in order to compare the strengths and weaknesses of each solution in order to find the solution that best meets the criteria of the problem (K-2-ETS1-3, 3-5-ETS1-2, MS-ETS1-2, MS-ETS1-3).

In addition to meeting all of these educational metrics (which include all of the engineering metrics from K-8), ArcAttack also addresses other principles that are key to understanding engineering. For example, a lesson mentioned multiple times during the show is the importance of finding solutions that do NOT work as a way to better guide them towards finding a solution that does. Failure is a natural part of the engineering process, and not something to be frowned upon. In addition, ArcAttack demonstrates that there can be more than one solution to an engineering problem- that while there are multiple solutions that get you to an answer, it is important to continue working in order to find one that best fits within the given constraints. In addition, they stress the importance of both collaboration and communication, and note that solving problems together leads to more solutions that working alone

Within their performance ArcAttack stresses to children that the material that they are learning in science and math class can be applied to real-world problems. By demonstrating contextual learning and active problem solving, ArcAttack demonstrates the importance of applying both critical thinking as well as creative, out of the box thinking in order to find the best solutions. This focus on 21st century-skills and project-based learning aligns with the most recent cognitive science literature concerning long-term deep retention of educational material.

The Technology of ArcAttack

Tesla Coils

The Singing Tesla coils are perhaps the most exciting component of the Arcattack performance. Although you may have seen images of Tesla Coils producing lightning, like in the image below, the Tesla Coils used by ArcAttack are of a different variety, called solid state Tesla Coils. Unlike traditional Tesla Coils, solid-state Tesla Coils contain transistors that make them capable of producing musical notes. The music that the audience hears is generated by the method in which these coils produce lightning.

The music is created by turning the Tesla Coils on-and-off very quickly. When this is done fast enough, the brain interprets the sound as a continuous note. For example, turning the coils on and off 440 times per second is heard as the musical note “A.”

King Beat and his robotic drums

King beat is a robotic band mate that specializes in playing the drums. His movements are a combination of pre sequenced actions and live control from an operator by means of a wireless signal. When King Beat docks in front of the drum set, his hands move into position to play the snare drum. The rest of the drums are played with a separate automated machine, comprised of a controller and individual mallets that are mounted to each drum. The robot and the accompanying automated drum set are activated by a MIDI signal that is sent from a master sequencer.

Can Crusher

The can-crusher is a giant electromagnet that is named after its most impressive feature. It is comprised of a high voltage power supply, a very large capacitor to store electrical energy, and electromagnetic coils. The machine has two main purposes, or “modes.” In the first mode, the machine can be used to magnetize and launch an aluminum ring up to 20’ in the air. The second mode is it’s “can crushing” mode, in which an aluminum soda can is sheared in half and launched in 2 directions like a cannon. Both of these demonstrate “Lorentz” force, and other properties of electricity and inductance as well. The complexity of the explanation is tailored to the level of the audience. The machine is used both as a standalone demo, as well as a percussive “instrument” in ArcAttack compositions.

Bell Machine

The Bell Machine is a set of 7 aluminum chimes, which are played by “Air rockets”. These rockets are blasted from the bottom of the machine by means of a quick high pressure burst of air. The rockets travel up a 5’ clear tube to eventually hit the chime at the top. This machine demonstrates basic pneumatic systems and the resonant properties of aluminum cylinders.

The String Instrument

This machine is the most basic stringed instrument, consisting of a single string and electromagnetic pickup. It is built with parts available from any hardware and music store, and is played using drum sticks that are used to strike the string, slide on the string, and shorten the string in order to create different percussive effects, pitches and sound effects. It is a demonstration of how sound is created from a vibrating string, and also an example of how extremely functional a simple device can be.

Lightning Guitar

The lightning guitar is a basic MIDI control that was designed specifically to be immune to Tesla coil arcs and interference. The performer wears a faraday suit, and plays the Tesla coil with this controller while being struck by lightning.

Key Scientific Principles

Static Electricity

Have you ever been shocked by the doorknob after you crossed the living room carpet in your socks? Have you ever taken off your sweater and noticed your hair was standing up? You weren't the only one. During the 5th century BCE, Greek philosophers were making observations about the world around them. One observation was how when rubbed with fur, amber (Figure 1) would attract feathers or small pieces of straw. "*ηλεκτρον*" (*elektron*) was the Greek word for amber. In 1600 CE, William Gilbert explored the properties of amber and realized that the attraction of certain materials was actually a force (force – a push or pull). He called this force *electron* (Greek for amber) and came up with a new Latin phrase, *vis electrica,* or "the amber force".

Figure 1: http://upload.wikimedia.org/wikipedia/commons/thumb/a/a7/Gouttes-drops-resine-2.jpg/220px-Gouttes-drops-resine-2.jpg

In order to understand this "amber force" we need to understand the structure of matter. According to quantum mechanics, atoms are composed of three main subatomic particles: the proton, neutron, and electron. The protons (positively charged) and neutrons (no charge) are located in the nucleus of the atom, acting as the core. Protons and neutrons are strongly bound together. The electrons have a negative charge and can be found in electron shells – concentric spherical regions of space around the nucleus – where each shell is characterized by a discrete energy level. Outer shells have higher energy levels than inner shells. It takes a certain discrete amount of energy to cause an electron to change to a higher-level shell and releases that same discrete amount of energy when the electron returns to its original lower-level shell. Electrons are weakly bound to the nucleus and can be removed or added to an atom by everyday occurrences, like rubbing a balloon on your hair. When an atom has the same number of protons and electrons, it is electrically neutral. When an atom has more electrons than protons, then it has an overall negative charge. Similarly, if an atom has more protons than electrons, it has an overall positive charge. Material objects are made up of different types and combination of atoms. For example, table salt (NaCl) is made up of a sodium atom (11 protons and 11 electrons) and a chlorine atom (17 protons and 17 electrons). The sodium atom is *ionically bonded* with the chlorine atom.

So how does an object, like a balloon, become charged? There are several different ways that an object can become charged: by friction, induction, or by conduction. We will be discussing charging by friction and induction.

Charging by Friction

There are many different types of atoms and these atoms can be combined in a variety of ways to form the material objects we encounter every day. Depending on the type of atoms an object is made of, an object can be more or less attracted to an electron. This electrical property is known as *electron affinity*. If an object has a high electron affinity, then it is more attractive to electrons. Different materials have different affinities for electrons. The *triboelectric series* is an ordering of materials by their electron affinity (Figure 2). This property is very important to consider when discussing the method of charging by contact or friction. When you rub the balloon on your hair, or your socked feet across the carpet, you are experiencing friction. During the process, atoms in the balloon are forced to be close to the atoms in your hair. The protons in the atoms of one object start to interact with the electrons on the other object. The rubber of the balloon has a higher electron affinity and will take electrons from the atoms of your hair. When you pull the balloon away from your hair, the balloon will have more electrons and has a negative charge while your hair has lost electrons, and now has a positive charge. You might notice that your hair is attracted to the balloon. This is evidence that *opposite charges attract*. If you rub two balloons on your hair and place the balloons near each other you will notice that *like charges repel* (Figure 3).

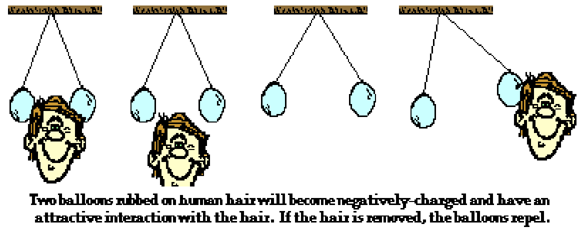


Figure 2: http://www.physicsclassroom.com/class/estatics/U8l2a.cfm

Figure 3: http://www.ecd.com/blog/wp-content/uploads/2009/04/triboelectricseries.jpgcontent/uploads/2009/04/triboelectricseries.jpg

Since charging by friction requires the transfer of electrons, charge is not created from nothing. The charge of an object is created either by losing electrons (positive charge) or gaining electrons (negative charge). The net charge for the system of objects that are being rubbed together is 0 since the same number of electrons that left the now positively charged object have been transferred to the now negatively charged object. Charge cannot be created nor destroyed, it is always conserved; this is known as the *law of conservation of charge*.

Charging by Induction

Charging by induction is another way an object can become charged. However, unlike charging by friction, no contact is necessary when charging an object. In order to understand induction, you must first study conductors, insulators, and polarization. Conductors allow the free movement of electrons within the object, while insulators do not. An object can become polarized when the electrons rearrange such that one side of an object is more negative than the other.

An example of charging by induction can be seen in the figure below. We have two conductive metal spheres supported by an insulating stand. This ensures that no electrons will leave the metal sphere through the stand. When the conducting spheres are placed next to each other, the electrons are free to move about the two spheres. Let's say we bring a negatively charged balloon (you just rubbed it on your hair) towards one of the spheres. Since *like charges repel*, the electrons on the sphere will be repelled by the negative charge of the balloon. Note that the protons do not move toward the negative balloon, but that the side of the metal sphere closest to the balloon has a positive charge due to a lack of electrons. So there is a stronger negative charge in the sphere furthest from the negative balloon. When the spheres are separated, we have two charged objects: one positive and one negative. Again, the net charge in the system is zero – charge is conserved.

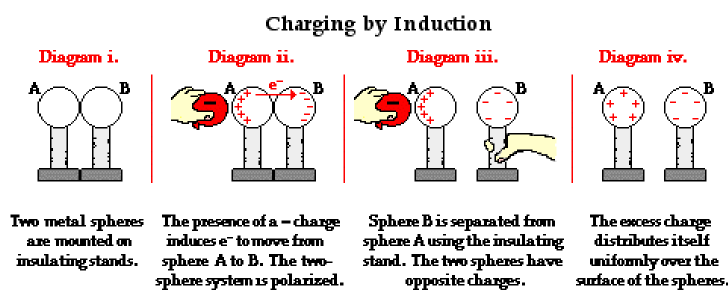


Figure 4: http://www.physicsclassroom.com/class/estatics/U8l2b.cfm

Electric Forces and Fields

Electric Forces

As you have observed, like charges repel and opposite charges attract. But what is causing these charged objects to move towards or away from each other? A force is defined as a push or a pull. The charged objects are experiencing a pull when attracted and a push when repelled from each other. French physicist Charles Coulomb discovered that the force between two charged object depends on the amount of excess charge two objects have and the distance between the two objects. One electron has the charge of -1.602×10^{-19} coulombs. So if

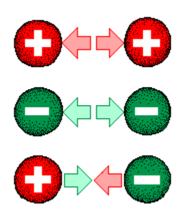
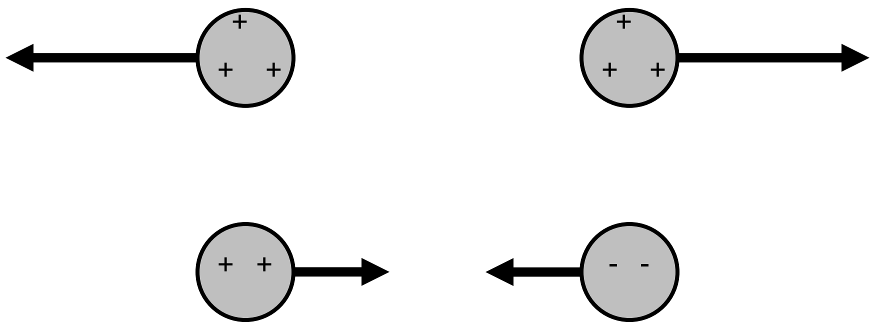


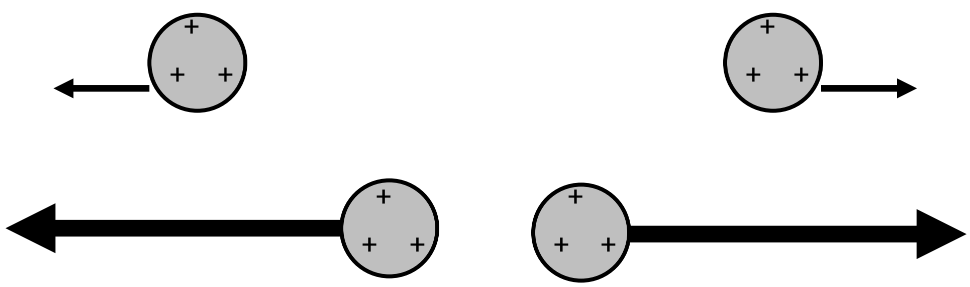
Figure 5: http://www.datasync.com/~rsf1/eas.htm

an object has an excess of 10^{14} electrons, it's overall charge is q = (-1.602×10^{-19} C/electron)(10^{14} electrons) = -1.602×10^{-5} C.

The electric force between two charged objects is proportional to the product of the excess charge on each: $F \propto q_1 q_2$



The electric force between two charged objects is proportional to the inverse of the square of the distance between the objects: $F \propto \frac{1}{R^2}$



When we put the two observations together, we get that $F = k\frac{q_1 q_2}{R^2}$, where k is the electric force constant, $k = 9\times10^{9}\ {}^{N\cdot m^2}\!/_{C^2}$.

What similarities can be drawn between the equation for electric force and Newton's law for gravitational force?

Electric Fields

Have you ever walked by a trashcan and been repulsed by the smell? The dirty trash has a *field* around it that your nose can detect. A field is a three-dimensional description of a region of space. In this case, the field your nose detects is that created by the odorous molecules from the trash. If there are more odorous molecules, the field is stronger, and you can tell! If there aren't very many odorous molecules around the trash, you might not notice the smell.

Electric fields work in a similar way. As we just discussed, an electric force exists between any two charged objects. If a test charge (your nose) is placed within a certain radius of the large charge that's creating the field (trashcan), there will be a force acting on the test charge. The larger the charge of the test or the field-creating charge, the larger the force is between the two. The larger the charge on the field-creating charge, the stronger the electric field. The direction of the electric field is defined as the direction that a positive charge would move in a certain field. If the electric field and the test charge are positive, the electric field is drawn from the field-creating charge. If the direction of the electric field is negative, then the positive test charge is attracted to the field-creating charge and the electric fields lines are drawn into the field-creating charge. Electric field can be quantitatively defined as the amount of force per charge, or $E = {F}/{q} = \frac{{kQq}/{R^2}}{q} = \frac{kQ}{R^2}$ where Q is the charge of the field-creating object and q is the charge of the test object.

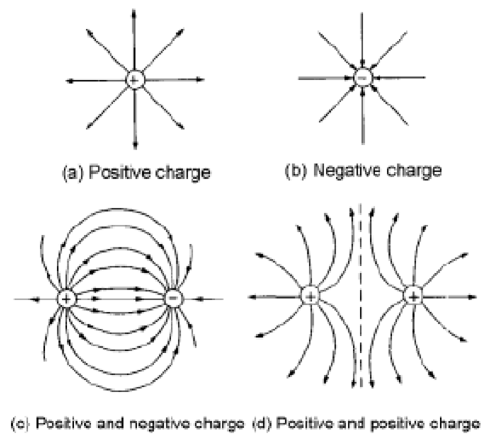


Figure 6: http://www.mea.or.th/internet/understanding_emf_web/emf_eng/webpage_eng/page01_eng.htm

The following chapters include a number of different examples of classroom-based engineering activities that can help teachers continue to focus on the engineering standards after attending the ArcAttack Engineering! Show.

Activities and Demonstrations – K-2

Which Roof is Tops?
From The *C*enter for Engineering Educational Outreach, Tufts University
https://www.teachengineering.org/activities/view/which_roof_is_tops

Summary:
When you walk or drive around your neighborhood, what do the roofs look like? What if you lived in an area with a different climate, how might that affect the style of roofs that you see? Through this introductory engineering activity, students explore the advantages of different roof shapes for different climates or situations. They observe and discuss what happens in a teacher demo when a "snow load" (sifted cups of flour) is placed on three model roof shapes.

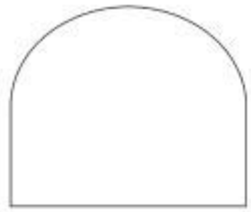
Engineering Connection:
Civil engineers always consider the climate of the area in which they plan to design and build structures. The design and materials chosen for the roof of a building help to maintain the desired temperature within the building and provide a stable structure to protect against the local weather conditions. Engineers use models to test the shapes, materials and functionality of their designs.

Time Required: 40 Minutes
Cost per group: $1
Number of groups: NA
NGSS Standards: K-2-ETS1-3

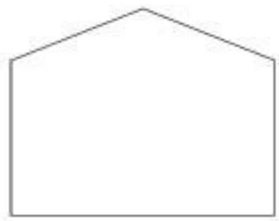
Learning Objectives:

- Materials both natural and human-made have specific characteristics that determine their suitable use.
- Engineering design requires creative thinking and consideration of a variety of ideas to solve practical problems.

Materials List:



Curved Roof



A-Frame Roof

Flat Roof

- 3 shoeboxes or similar containers
- 1 poster board
- 1 newspaper and/or cookie sheet
- ~2 cups flour
- Flour sifter or sieve
- Free worksheet about roof shape: http://content.teachengineering.org/content/wpi_/activities/wpi_which_roof_is_tops/student_worksheet.pdf

Introduction for students:

What shape is the roof on your house? What is the climate where you live? Can you think of reasons why the climate might influence the shape of your roof?

Imagine you live in an area that receives a lot of snow. Architects and engineers who design homes in regions with a lot of snow think about how so much snow adds up on the roofs. If a roof is not strong enough, the weight of the snow (the "snow load") may cause the roof to cave in.

If you were an engineer designing a roof for a snowy climate, what roof shapes would you consider to prevent snow from building up on the roof? What types of materials would you use to build your roof to help prevent snow from sticking to it?

Useful Background Information:

A **model** is a copy of an object that is too big, too small or too complicated, costly or dangerous to study easily. Engineers use models to test and study how well things are built or to test different designs. A "load" to an engineer is any force that pushes or pulls. For example: the weight of snow pushes down on a building, creating a snow load. A wind load pushes on the sides of a building.

Procedure- Before the Activity:

- Gather materials and make copies of the Roof Shape Worksheet. Obtain flour and containers to hold about 2 cups of flour. A flour sieve is helpful to use, if available.
- Gather a collection of photographs of different types of roofs in different climates to show the class.
- Create three model roofs for a class demo. Cut away one end of each box so that students can view the effects of snow loads. Use poster board to make three different roof types, one for each box: curved, A-frame and flat (see Figure 1 or the worksheet). Using a single piece of masking tape, tape each edge of the roof to the open top of the box. Place newspaper and/or a cookie sheet under the testing station to catch any loose flour (to control the mess and collect flour to use again in the next test).

Procedure- With the Students:

1. Show the class pictures of different roof designs. Talk with them about what types of climates these roofs might be found in. What characteristics make a roof good or bad for a given climate? Incorporate the Investigating Questions into the activity.
2. Show the class the example roofs that you created. Explain that the flour represents snow and have them make predictions as to which roof would be best for a snowy climate?
3. Slowly sprinkle "snow" onto the center of the roof as students watch the roof through the open end of the box.
4. Have students make observations on their worksheets as the snow is applied to the roof and builds up to a weighty amount ("the snow load").
5. Repeat the process with each model roof type.
6. Conclude with a class discussion to share and compare observations and conclusions. Refer to the Investigating Questions.

Investigating Questions:

- Predict which types of roofs will cave in to snow the easiest? Why?
- What happened to each model roof when a snow load was applied?
- Does the "snow" pile up or slide off?
- Which roofs sag? What does the sagging mean?
- Which roofs fall down? Do they fall slowly or all at once?
- Which roof design is "tops" for snowy climates?
- In addition to snow loads, what other forces should we plan for?
- Which roof would you want if you lived in a snowy area? A windy area? Rainy?
- What roof styles, shapes and materials are best for which climates and weather conditions?

Invent a Bakscratcher from Everyday Materials!
From The Center for Engineering Educational Outreach, Tufts University
https://www.teachengineering.org/activities/view/invent_a_backscratcher

Summary

Being able to recognize a problem and design a potential solution is the first step in the development of new and useful products. In this activity, students create devices to get "that pesky itch in the center of your back." Once the idea is thought through, students produce design schematics (sketches). They are given a variety of everyday materials and recyclables, from which they prototype their back-scratching devices.

Engineering Connection

When engineers design products, they must make sure that they meet the desired functions, as well as consider other important aspects of the designs for the users. Beyond being functional, in many cases the product must also be easy or comfortable to use, and aesthetically pleasing. Engineers also take into consideration material and labor costs, durability to withstand intended use, and efficient material use in manufacturing.

Time Requirement: 45 minutes

Cost per group: NA
Number of groups: NA
NGSS: K-2-ETS1-1, K-2-ETS1-2, K-2-ETS1-3

Learning Objectives:

- How to use creativity and everyday materials to build something useful.
- How to utilize designs and sketches in creating a product.

Materials List

- tape
- string
- scrap cardboard
- paper towel tubes
- scissors
- glue
- any other materials you wish to use; students may also bring supplies from home

Introduction for students:

Engineers are constantly using their creativity to find solutions to everyday problems. To solve a problem, you must first recognize that the problem exists. For example, have you ever had a pesky itch on your back that you just could not reach? Typically, when you have an itch on your body, your first reaction is to scratch it with your fingernails. However, this itch is an unreachable itch and no one is around to scratch it for you. What do you do? As an engineer, you use your creativity and the materials around you to come up with different solutions and design a backscratcher. What types of materials would you want to use for the backscratcher and why?

Useful Background Information:
Lever: A simple machine that utilizes a ridged bar and a fulcrum (pivot point) to raise or move an object.
Sketch: A rough drawing or plan of an idea.

Procedure: Before the Activity

- Gather materials.
- Build a backscratcher as an example to show the students.
- Have students bring in any backscratchers they might have at home to show.

Procedure: Class Discussion

1. Ask the students: Why is it hard to scratch your back?
2. Discuss why new products are made and innovations take place. (They solve a problem or fill a need.)
3. Have students show example backscratchers they brought in from home.
4. Discuss what a backscratcher is and why it is a useful device or tool.
5. Talk about formulating an idea and sketching a picture before construction.

6. Talk about what makes a good sketch. Why are plans/sketches an important step in the design process?
7. Point out how there is more than one way to make a backscratcher. (Bring up different brand names of the same product.)

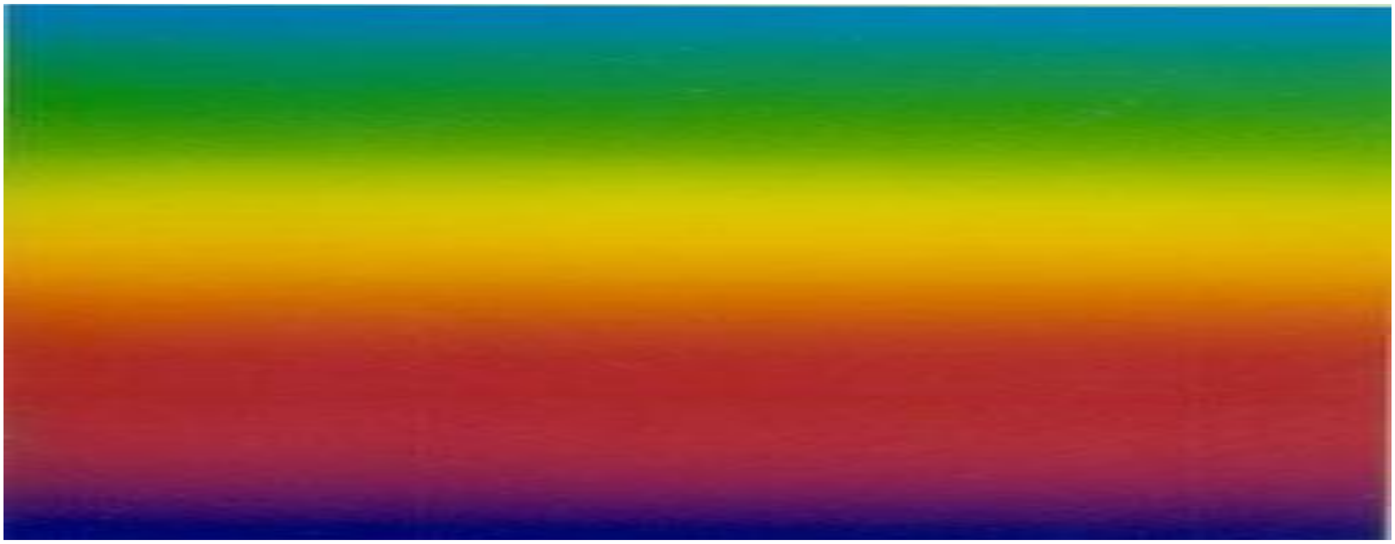
Procedure: With the students

1. Prepare a station with the materials available for students to use.
2. Have students work alone or in pairs.
3. Talk about safety; do not eat the glue, careful with scissors, etc.
4. Introduce the activity to the students and let them examine the materials, brainstorm for ideas and sketch designs. Have the students explain their sketches to you before they start construction. Tell the students that they may use as much or as little of the materials available.
5. Once students have completed their backscratchers, have them lay them out on a table so that everyone in the class can see each design. Encourage them to try out the different backscratchers, but remind them to be respectful of everyone's inventions.
6. After everyone has tested the designs, have the class decide which of the backscratchers is the most useful and explain what features they liked about it.

Investigating Questions:

- What materials were the best to use for this project?
- What would you have done differently?
- What other materials could have worked?
- What is a good design for a backscratcher?

Do Different Colors Absorb heat better?
From The Center for Engineering Educational Outreach, Tufts University
https://www.teachengineering.org/activities/view/colors_absorb_heat_better© 2013 by Regents of the University of Colorado; original © 2004 Worcester Polytechnic Institute



Summary

Students test whether the color of a material affects how much heat it absorbs. They leave ice cubes placed in boxes made of colored paper (one box per color; white, yellow, red and black) in the sun, and predict in which colored box ice cubes melt first. They record the order and time required for the ice cubes to melt.

Engineering Connection

The study of light and its behavior is an important component in the design of many items, everything from optical instruments to roofing materials to solar cells. The performance and characteristics of light guide engineers to come up with different forms of light detection for lenses in cameras, microscopes, CD players and medical devices. Different sources of light carry different quantities of energy. For example, powerful lasers can cut through stone or even metal.

Time Requirement: 60 minutes
Cost per group: $2.00
Number of groups: NA
NGSS: K-2-ETS1-1
Common Core Standards: Math: K.MD.2, 1.MD.4, 2.MD.10

Learning Objectives:

- Certain colors absorb light better than others.
- The sun produces heat and light.
- Why ice cubes melt.

- (optional) The purpose of solar panels.

Materials List:

- colored paper 4 sheets per group (white, yellow, red, black)
- newspaper
- scissors (one per student if you want the them to cut out the boxes [cube templates] from the colored paper)
- clear tape, to make the cube boxes from colored paper
- 4 ice cubes per group
- sunny day or a heat lamp

Introduction for students:

Imagine that it is 100 degrees outside. How do you stay cool? What kinds of clothing do you wear? Any thought to color? (Listen to student ideas.)
What might be the influence of color and its relationship to heat? Can you think of any instances in which the color of something makes a difference in how hot it gets in the sun? (Listen to student ideas. Possibilities: Wearing white vs. black clothing on super hot days. Flat rooftops sealed in black tar vs. white polymer material. Walking barefoot across a black asphalt roadway vs. lighter concrete roadway. Choosing a white car instead of a black car if you live where it is sunny and hot all the time.)
The sun emits energy in the form of electromagnetic waves. We see part of the electromagnetic wave as light and we feel part of it as warmth. Darker colors absorb more sunlight than lighter colors, which is why darker colors get warmer more quickly in the sunlight than lighter colors. The lighter colors reflect more of the sun's radiant energy, so they remain cooler to touch in the sunlight.
Let's do our own testing to find out.

Useful Background Information:

Absorb: to take in; to transform (radiant energy) into a different form usually with a resulting rise in temperature.
Energy: The capacity for doing work; raising weight, for example.
Heat: A form of energy that causes substances to rise in temperature or to go through associated phase changes (as melting, evaporation, or expansion).
Radiant Energy: Energy (as heat waves, light waves, radio waves, x-rays) transmitted in the form of electromagnetic waves.
Reflect: To bounce waves of light, sound, or heat off a surface.
Solar Cell: A photo-electric cell that converts sunlight directly into electrical energy and can be used as a power source.
Solar Energy: Energy derived from sunlight.
Solar panel: A group of solar cells forming a flat surface (as on a spacecraft).

Procedure: Before the Activity

- Make enough ice cubes so that each group can have four. Try to make them the same size for experiment consistency.

- To save time, pre-cut and assemble (using tape) the colored paper into five-sided boxes each big enough to fit an ice cube. Otherwise, have students cut, fold and tape together their own boxes. See the Additional Multimedia Support section for Internet resources on how to make a cube from a piece of paper.
- Gather the rest of the materials.

Procedure: With the students

1. With the class, talk through the Introduction/Motivation section.
2. Once the class is thinking about the influence of color and its relationship to heat, divide the class into small groups.
3. Give each group four sheets of colored paper (white, yellow, red, black) and have them cut and fold their sheets into boxes.
4. Hand out newspaper and have each group spread the newspaper in an exposed, sunny place outside, or under a heat lamp.
5. On the newspaper, place the boxes side by side with the opening facing away from the sun/light so students can see inside.
6. Give each group four ice cubes and instruct them to place one ice cube in the center of each colored box.
7. Let the ice cubes sit in the sun until they have melted. Have students check them every few minutes and record which ice cubes melted first, second, third, and fourth.
8. Direct groups to record their data in the worksheet chart.
9. Have students create a bar graph representing the time it took the ice to melt for each color of paper.
10. Discuss with the class their observations, touching on the different colors and their ability to reflect light and heat. Also, talk about how these color characteristics help to melt the ice.
11. Ask students the Investigating Questions. Discuss some real-world examples in which engineers use their understanding of how different colors reflect light and heat to design products and find solutions. (Example: Asphalt roads and tar roofs are dark surfaces that absorb heat from the sun. Measurements show that white roofs reflect some of the sun's heat back into space and cool temperatures, much as wearing a white shirt on a sunny day can be cooler than wearing a dark shirt. So, designing white roofing materials or paint for roofs has the effect of cooling temperatures within buildings.)

Investigating Questions:

- Why do ice cubes melt?
- How does the sun affect ice?
- What kind of clothes do people wear outside in the winter? In summer?
- On which color did the first ice cube completely melt? Why?
- If an ice cube was placed on a blue piece of paper, how much time do you think it would take to completely melt?
- Which color absorbs heat the quickest in the sun?
- Which color would be the best to help keep ice cubes from melting too quickly in the sun?

Activities and Demonstrations – 3-5 (Elementary School)

All Caught Up
Contributed by: Engineering K-PhD Program, Pratt School of Engineering, Duke University
https://www.teachengineering.org/activities/view/duk_bycatchunit_musc_act

Summary

Commercial fishing nets often trap "unprofitable" animals in the process of catching target species. In this activity, students experience the difficulty that fishermen experience while trying to isolate a target species when a variety of sea animals are found in the area of interest. Then the class discusses the large magnitude of this problem. Students practice data acquisition and analysis skills by collecting data and processing it to deduce trends on target species distribution. They conclude by discussing how bycatch impacts their lives and whether or not it is an important environmental issue that needs attention. As an extension, students use their creativity and innovative skills to design nets or other methods, theoretically and/or through hands-on prototyping, that fisherman could use to help avoid bycatch.

Engineering Connection

Through the activity extension, students imagine and design technological solutions for addressing the problem of bycatch by making design changes to the nets they use in the activity.

Time Requirement: 30 minutes
Cost per group: $2.00
Number of groups: NA
NGSS: 3-5-ETS1-1

Learning Objectives:

- Students will be able to explain the basics of bycatching and what species are most affected by it.
- Students will question the importance of environmental activism with regard to bycatching, relating it to their daily lives.

Materials List:

Each group needs:

- larger bucket/container
- smaller container
- blindfold
- "fishing net" (provide an assortment, such as cups, mesh bags, sandwich bags or aquarium fishing nets)
- an assortment of many marbles and other balls of different colors and sizes, placed in a bowl to prevent them from rolling around; cheaper materials can be used, such as rocks; while numbers/colors/types of balls (fish) are flexible, here is an example assortment: 5 large red rubber balls (like the type for playing jacks), 10 glass marbles of color A, 10 glass marbles of color B, 3 golf balls, 4 pairs of dice, 10 very small pebbles (much smaller than the marbles)
- water
- paper and pencils, for recording data

Introduction for students:

The issue of bycatching has many different points-of-view. Three of the main perspectives are: fishermen who are trying to make a living, bycatched dolphins and turtles that innocently lose their lives as a casualty of the economic market, and the average consumer who wants to be able to buy seafood at an affordable price.

Today you will get the chance to experience a simulation of what it is like to be a commercial fisherman and experience some of the problems related to bycatch.

Procedure: Before the Activity

- Fill each group's larger bucket or container about three-quarters full with water.
- Add a good variety of different marbles or balls to the water in each container.
- Pick one of the marble types to be the "target fish." The rest are potential bycatch species. As an example, from the example ball list in the Materials List, the five large rubber balls would be a good target species because they are medium-sized relative to the other balls, leving the remainder of the other balls well sized to represent larger and smaller "species," with the potential to become bycatch, depending on the "fishing net" used.

Procedure: With the students

Divide the class into groups of four students each. Direct each student in every team to complete the following procedure:

1. Choose a type of fishing net to use.

2. Have your group members add the remaining marbles and balls to the water.
3. Have your teammates blindfold you.
4. Attempt to fish for the "target fish." Use the net to make two sweeps (make sure everyone is consistent), emptying your net into the group's smaller container.
5. Remove the blindfold.
6. Make a table to record your data: Initial number of total balls in the bucket and Number of balls removed during fishing. Within the number of balls removed, tally the exact number of each type of ball removed (for example, 5 small red balls, 2 large purple balls). After each student in the class completes this activity, each group of four will have four tables of numbers.
7. Then, each group combines its members' data in order to calculate different percentages, which might include: 1) percentage of "target fish" in the initial full bucket (number of total "target fish" divided by number of total fish) versus the percentage of "target fish" that comprised the total number of fished balls (number of target fish obtained in the net divided by the total number of balls obtained fishing) or 2) percentage of "target fish" caught (number of "target fish" caught divided by the total number of "target fish") versus the percentage of other fish that were caught.
8. Lead a class discussion to analyze results, as described in the Assessment section. Ask the Investigating Questions.
9. Conduct the lesson extension to have students design (and perhaps prototype and test) innovative fishing nets as solutions to bycatching, as described in the Assessment and Lesson Extension sections.

Activity Extensions:

- For older students, incorporate a design element to the activity by having groups design innovative fishing nets that could be used to help eliminate bycatching. Use the example of dolphin bycatching in tuna fishing nets, or turtle bycatching in fishing nets. Start by having teams brainstorm ideas and sketch concepts for net designs that avoid bycatching large balls while still catching smaller balls (as designated in the activity). Take it further by providing materials from which they can create and test prototype nets.
- For students of all ages, especially younger ones, conduct the following exercise to help them experience firsthand the difficulty of escaping from entanglement. Have each student loop a rubber band around his or her thumb and fourth finger. Then, have them try to remove the rubber band from their fingers without using their other free hand. See http://www.vims.edu/bridge for more information on this activity.

Investigating Questions:

- Do you think bycatching affects your life? Do you think it is an important issue?
- Did you find it easy or hard to just catch the "target species"? Why or why not?
- Which types of gathering devices worked the best, and why?
- What types of results did you get, in reference to your calculations? Were you surprised by your results? Did your teammates get similar or different results? Why?
- Can you think of ways of designing a net that could be more effective? Are there any other materials you wish you could have tried? What are they and why do you think they would work better?
- Are there any other methods you think would be successful in reducing bycatch besides modifications in fishing gear design?

Cars: Engineering for Efficiency

Contributed by: Integrated Teaching and Learning Program, College of Engineering, University of Colorado Boulder
https://www.teachengineering.org/activities/view/cub_motion_activity1

Summary

Students learn how the aerodynamics and rolling resistance of a car affect its energy efficiency through designing and constructing model cars out of simple materials. As the little cars are raced down a tilted track (powered by gravity) and propelled off a ramp, students come to understand the need to maximize the energy efficiency of their cars. The most energy-efficient cars roll down the track the fastest and the most aerodynamic cars jump the farthest. Students also work with variables and plot how a car's speed changes with the track angle.

Engineering Connection

The energy use and pollution associated with transportation is one of the largest issues facing society today. By building energy-efficient cars, engineers can lower the negative impacts that cars have on the environment and ultimately help improve our lives. The energy efficiency of a car is affected by a variety of factors, including size, aerodynamics, weight, and the rolling resistance of the wheels. Engineers must know all about these factors to design better cars.

Time Requirement: 150 minutes (three 50 minute class periods)
Cost per group: $2.00
Number of groups: NA
NGSS: 3-5-ETS1-1, 3-5-ETS1-2
Common Core Standards: Math: 4.NBT.5, 5.G.2

Learning Objectives:

- Describe the characteristics that affect a car's energy efficiency.
- Explain how rolling resistance affects a car's energy efficiency.
- Describe how a car's shape and size are related to aerodynamics.
- Explain the steps of the engineering design process.
- Explain the difference between an independent and dependent variable.
- Plot the results of a simple experiment on a graph.

Materials List:

Each group needs:

- 5 Popsicle® / hobby sticks
- masking tape, ~24 inches
- 4 Lifesavers® mint candies (Tip: Use the mint-flavored candies because they do not get as sticky as the fruit-flavored ones.)
- 3 drinking straws (small enough diameter to fit inside the mint candy holes)
- 3 index cards
- Car Design Worksheet, one per student

To share with the entire class:

- scissors
- play money (Monopoly® money works well)
- rain gutter section(s), ~7 ft in length
- duct tape (or other heavy duty tape)
- cardboard ramp
- electric fan
- projector, for showing the attached PowerPoint presentations
- stopwatch (if racing only one car at a time)

Introduction for students:

How far can a car travel on one gallon of gas? (Answer: It depends on the car, but usually between 6 and 70 miles.) Do you think all cars are the same? (Answer: No) How about a semi-truck? (Answer: Definitely not.) What makes the difference in a vehicle's energy efficiency? A car's energy efficiency depends on many things, including its weight, its rolling resistance, and its aerodynamics. A car that is energy efficient can travel farther on the same amount of gas, which saves the driver money. Creating more energy-efficient cars also decreases air pollution and helps decrease greenhouse gas emissions due to automobile emissions. Also, gasoline is made from oil, a fossil fuel. Oil is a non-renewable energy source, which means that when it is used up, no more is available. For these reasons, engineers are continually figuring out ways to make cars more energy efficient by decreasing their air resistance, rolling resistance, and weight.
The *aerodynamics* of a car is dependent on how much air the car has to move out of the way as it travels along a road. Engineers often design cars to resemble aerodynamic animals and shapes in nature. Can you think of any aerodynamic animals? (Possible answers: Fish, birds, sharks.) These animals move through the air (or water) easily and use little energy because they are sleek in their shapes, having no sharp corners or flat surfaces facing the wind. This causes the air to flow smoothly (efficiently) over

them. A sleek car moves more easily through the air than a semi-truck does, which means the car is more energy efficient.

The amount of energy a car uses can also be affected by the resistance of a car's tires on the road surface. You need to be able to find the balance between the amount of resistance, or friction, needed to keep the vehicle on the road and the ability to move efficiently without it flying off the road or being "stuck" to the road. Engineers design tires that increase a car's energy efficiency by rolling smoothly while making sure they are "sticky" enough to stay safely on the road, especially through corners and on wet surfaces. A great example of this would be a NASCAR race. Have any of you watched racing on television? The tires they use are expertly engineered so that the cars can reach high speeds while staying on the track during the tight corners.

Finally, a car's weight affects its energy efficiency. Is it harder to push a loaded grocery cart or an empty one? (Answer: Loaded) How about if you had to push the grocery cart uphill? Would you rather do it empty or full? (Answer: Empty) A car's weight determines how much energy it takes to accelerate, or speed up, the car, and it also affects how much energy it takes to move the car up a hill. Heavier cars are less energy efficient than lighter ones. Engineers use newly created, innovative materials whenever possible to reduce the weight of cars, as well as find ways to build them smaller so fewer materials are needed, which in turn reduces the weight of the car.

All of these factors contribute to a car's energy efficiency, with some of them being more important at high speeds and others being more important at low speeds.

All of these factors are considered *variables*, or something that you can change in an experiment or test. Engineers perform experiments on the many different variables to design cars for different purposes. When engineers perform experiments, they test only one variable at a time, while making sure that all of the other potential variables are kept unchanged. A variable that is kept from changing during an experiment is called a *control*. At the end of this activity, we will conduct several experiments to see how changing the angle of the track affects the speed of a car. In this case, the angle of the track is called the *independent variable* because we intentionally change it to gauge its affect on our vehicles. The speed of the car is called the *dependent variable* because it will be affected by the changes we make to the angle of the track. Once we have chosen our variables, we need to be very careful to control all other factors so that we get really accurate results. Let's get started!

Useful Background Information:

aerodynamics: The ability of an object to cut through air (or water) efficiently
control: A variable that you are careful to keep the same during an experiment.
dependent variable: A variable that changes in value when you change an independent variable. Usually this is the variable about which you collect data during an experiment.
energy efficiency: Being able to do more with less energy.
independent variable: A variable you intentionally change in an experiment. Usually, the intent of the experiment is to see how a change in this variable affects the dependent variable.
rolling resistance: The force of friction acting on a rolling object by the ground to slow it down.
variable: Something that can be changed in an experiment.

Procedure: Before the Activity

- Decide which of two ways to set up the activity: To run the activity as a series of two cars competing against each other (that is, two separate cars being raced at once), set up two rain gutter race tracks at approximately a 30-degree angle from the ground (see Figure 1). Tape the two gutters together to ensure the tracks are even. To run the activity with only one car racing at a time, use a single track and a stopwatch to record individual race times.
- Gather materials and make copies of the Car Design Worksheet.
- On Days 1 and 3, have the attached PowerPoint presentations ready to show.
- Set up race brackets, depending on number of student groups.

Procedure: With the students

Day 1 (or first hour)

1. Show the Day 1 PowerPoint presentation, as part of the Introduction/Motivation.
2. Divide the class into groups of two or three students each.
3. Hand out the worksheets.
4. Give $700 of play money to each group.
5. Have students follow the steps in the worksheet (look at constraints, brainstorm ideas, draw a design, determine cost, re-design if over budget).
6. Once groups have completed detailed designs that are within budget, have them purchase materials. Encourage them to reserve some funds to make later modifications (improvements) to their original designs.
7. Have groups begin assembling their model cars.

Day 2 (or second hour)

1. Briefly remind students of the activity goals.
2. Have groups work on completing the assembly of their model cars.
3. Have students test cars and make changes to improve the designs.
4. Once all students have completed their model cars and made improvements, collect all of the cars at the front of the classroom.
5. Race cars against each other using double elimination to find the most energy efficient car (that is, cars are raced twice; after each race, the winner moves on to the next round; if a car is deemed the "slowest" car in more than two races, it is eliminated from the trials). If a single track is being used, record times and eliminated the slowest cars after two runs down the track. Have students record on their worksheets the fastest time for each car.
6. As a class, discuss why the winning car was the most energy efficient by examining its aerodynamics, rolling resistance, and size.
7. If time allows, place a ramp about 6 inches away from the bottom of the rain gutters, as shown in Figure 2. If available, place a fan flat on the ground blowing air upwards. Have students run their model cars down the gutters and jump them off the ramp. Mark where each car lands.
8. Discuss why specific cars jumped well and others did not.

Day 3 (or third hour)

9. Using the Day 3 PowerPoint Presentation, introduce the topic of variables.
10. Select the fastest car from the previous day's races to use to collect data.
11. Race the cars at the track angles specified in the worksheet, and have students record the times.

12. Have students practice graphing by having volunteers graph each data point on a graph drawn (or projected) on the board.
13. Discuss the shape of the graph with the students.
14. Have students predict the speed of the car at an angle that is less than 10 degrees and at an angle greater than 60 degrees. Record predictions.
15. Test students' predictions by moving the track to the specified angle and timing the car.

Investigating Questions:

- What characteristics do the fast cars have in common?
- What is the most important characteristic that made the cars go fast?
- What effect does changing the angle of the track have on the car speed?

Activities and Demonstrations – 6-8 (Middle School)

<u>*Bend that Bar*</u>

Contributed by: Integrated Teaching and Learning Program, College of Engineering, University of Colorado Boulder https://www.teachengineering.org/activities/view/cub_airplanes_lesson03_activity1 © 2004 by Regents of the University of Colorado

Summary

Students learn about material properties, and that engineers must consider many different materials properties when designing. This activity focuses on strength-to-weight ratios and how sometimes the strongest material is not always the best material.

Engineering Connection

Finding the best engineering solution for a given design challenge requires a delicate balance between many factors such as weight, strength, cost, performance, safety and ethics. For example, the strongest design might be too expensive, or the safest design might be too heavy. An engineer's final design is a compromise between all considered criteria. The strength-to-weight ratio is an important balance engineers must find when designing airplanes because we want airplanes to be very strong, but also as light as possible.

Time Requirement: 50 minutes
Cost per group: $10.00
Number of groups: NA
NGSS: MS-ETS1-3
Common Core Standards: Math 6.RP.1, 6.SP.4, 6.NS.2, 6.NS.

Learning Objectives:

- Explain the significance of a material's strength-to-weight ratio.
- Compare and contrast how useful a material is for a project based on its strength, weight and other properties.
- Measure and record mass, height and distance of a bending bar.

Materials List:

Each group needs:

- Bend That Bar Worksheets, one per person
- (optional) spring scale (or groups take turns if fewer are available)
- 1 bar 15"-18" (38-46 cm) in length and 1/8"-1/4" (3-6 mm) in diameter of each of the following: steel, aluminum and wood, and if possible, plastic, brass and copper; the metal rods and wooden dowel can be found at most hardware and hobby stores
- 1 Sharpie® or marker/pen to write on the bars
- yard/meter stick
- (optional) calculator
- bathroom or top-loading scale to weigh individual bars

Introduction for students:

Engineers must carefully select the materials they will use to build different parts of airplanes.The body and wings may be made from a metal such as aluminum. The seats and storage bins may be made from some type of plastic. Every material in an airplane must have some level of strength to perform its task. The wings must hold the weight of the entire plane, while the seats need only support a single person. No matter what the purpose, every object in an airplane must be made from the lightest materials possible and yet be strong enough so that it will not break apart during normal use and, of course, flight. In today's activity, you will see how different materials have very different physical properties and how engineers must chose which material has the best properties for each part of a bigger design project, like creating an airplane.

Procedure: Before the Activity

Note: This activity may be conducted in English or metric units (1 inch = 2.5 cm; 1 cm = .4 inch), but since scales usually measure in grams, it may be easiest to do this activity entirely in metric units.

- Cut each bar into the desired lengths if they are not already in the specified lengths.
- Make sure the scales are available when you need them and have been recently calibrated.

- Make copies of the [Bend That Bar Worksheet](), one per student.

Procedure: With the students

1. Review the correct use of the scales so that students get accurate results. It is helpful to demonstrate the experiment using one bar so students understand the process better.
2. Have students measure the weight of each bar and record on the worksheet. Measure the length of each bar, and make a mark 10 inches (about 25 cm) from one end and 1 inch (2.5 cm) from the same end.
3. Have one student hold a bar against the top of a table or chair so that 10 inches (25 cm) sticks out from the table or chair. They need to hold it fairly tightly.
4. Have another student hold the yard/meter stick vertically next to the bar so that the yard/meter stick rests on the ground. This is so students can measure how far the bar bends. Assign one student the job of reading the measurement, kneeling to be at about the same height as the bar to see it more easily. For best results, place the yard/meter stick at the very tip of the bar.
5. Have students record the initial height of the bar. Make sure to measure the height at the top of the bar each time.
6. Have the fourth student hang the scale 1 inch from the end of the bar on the mark made previously. If 1/8" (6 mm) bars are being used, expect the weight of the scale to be sufficient to noticeably bend the bar. If the wooden bar does not bend more than 1 inch, have students pull on the scale with 1 to 5 pounds so that the wooden bar bends more than 1-1 ½" (2.5 to 3.8 cm), but does not break
7. Have students record the new height of the top of the bar.
8. Have students repeat #6 and #7 with the remaining bars.
9. Have students complete the remainder of the worksheet questions.
10. Discuss the worksheet answers as a class. Have students give examples of their values for how far each bar bent. Discuss what they observed about the weight and strength of each bar. Expact that students observe that aluminum and steel have similar strengths. The aluminum bar, however, is much lighter. Discuss how a high strength-to-weight ratio is desirable for building airplane parts. Aluminum has a higher strength-to-weight ratio than steel because it has similar strength but it is much lighter than steel. Strength-to-weight ratios are important to consider when designing airplanes because aircraft must be as light and strong as possible.

Activity Extensions:

If you have thin bars you may choose to have students pull each bar until it bends permanently or breaks. (Note: have students be very careful if they break the bars! Ragged ends are very sharp.) The point where it bends permanently is called the *yield point*. Have students measure the force needed to break each bar and divide this number by the weight for a new strength-to-weight ratio. This is more accurate than the above procedure because a material may be very stiff but break under less total force than a material that is more elastic. However, this is still not exactly the strength-to-weight ratio used by engineers because it is dependant on the length and thickness of the bar. The strength-to-weight ratios used by engineers use equations to make sure the same material gives the same measurement no matter the size of the material being tested.
Have students convert their results between metric and English units.

Activity Scaling

- For younger students, this activity may be more effective as a demonstration because of the complicated procedure. Have students in the class volunteer for jobs as the teacher demonstrates the activity. Discuss the results as a class.
- For older students, require them to make bar graphs with the strength-to-weight ratio on the vertical axis and the different materials on the horizontal axis. This gives students a graphical representation of their results.

Building an Arm and a Leg

Contributed by: K-12 Outreach Office, Worcester Polytechnic Institute
https://www.teachengineering.org/activities/view/hydraulic_joy

Summary

As an introduction to bioengineering, student teams are given the engineering challenge to design and build prototype artificial limbs using a simple syringe system and limited resources. As part of a NASA lunar mission scenario, they determine which substance, water (liquid) or air (gas), makes the appendages more efficient.

Engineering Connection

Bioengineering technologies explore the production of mechanical devices, products, biological substances and organisms that are created to improve health and/or contribute improvements to our daily lives.

Time Requirement: 180 minutes
Cost per group: $5.00
Number of groups: NA
NGSS: MS-ETS1-3
Common Core Standards: Math 6.NS.3, 6.RP.3.b, 8.G.9

Learning Objectives:

- Describe how movements of bones are dependent upon the interaction of pairs of muscles.
- Identify the major bones and muscles of the arm and leg.
- Explain that a force (push or pull) is needed for movement.
- Explain that movement is a complex process involving more than one body system.
- List all body systems involved in movement.
- Describe how the location of muscle attachment is important to the movement of the bone.
- List and describe the working of different joints.

Materials List:

Each group needs:

- 14-10 ml oral syringes
- 7-30 cm length pieces of ¼-inch aquarium tubing
- 20 Popsicle sticks
- 5 rubber bands
- 1 meter of duct tape
- string
- water

Introduction for students:

Your engineering challenge: NASA is setting up a workstation on the moon. You are part of a team that has just landed on the moon. One of your team members has an artificial arm and leg and has lost functionality of his limbs. It is up to your team to design and build one of the replacements. The only materials at your disposal are string, duct tape, Popsicle sticks, water and aquarium tubing and these materials must be shipped from the main shuttle located above the moon to the station where your team is located.

Useful Background Information:

articulate: To connect with a joint.
bone: Rigid connective tissue that makes up the skeleton of vertebrates.
compression: The process of pressing items together.
contract: To draw or squeeze together so as to make or become smaller or shorter and broader.
force: To break open or through.
gas: A phase of matter in which the molecules are widely separated, move around freely, and move at high speeds.
ligament: A tough band of tissue that holds bones together or keeps an organ in place in the body.
liquid: A phase of matter that is free to conform to a shape of a vessel, but has a fixed volume and has a greater density than a gas.
muscle: A body tissue consisting of long cells that can contract and produce motion.
Newton: A unit of force that is of such size that under its influence a body whose mass is one kilogram would experience an acceleration of one meter per second per second.
relax: To make or become loose or less tense.
solid: A phase of matter characterized by resistance to deformation and changes of volume.
system: A group of objects or units combined to form a whole and to move or work together.

tendon: A tough cord or band of dense white connective tissue that links a muscle to some other part.

Procedure: With the Students

1. Direct each group to design a robotic arm or leg that simulates the body movement of that part. Inform students about the available resources.
2. Require groups to create sketches with all parts labeled. For example: Popsicle sticks representing bones and the bone labeled (humerus). Please refer to the design sketch rubric.
3. Have teams indicate how many syringes, Popsicle sticks, rubber bands and length of duct tape and/or string are needed. Have them fill out materials request forms and submit them in order to obtain the materials.
4. Direct groups to build device prototypes.
5. Test and evaluate the design based on the provided rubric.
6. Have each group share its design with the class and demonstrate how it works in relation to movements and parts of the body. Remember to use appropriate terminology.

How to Create a Hydraulic System

1. Put together two syringe sub-systems. Define a sub-system as a piece of tubing with a syringe attached at each end. See Figure 1.

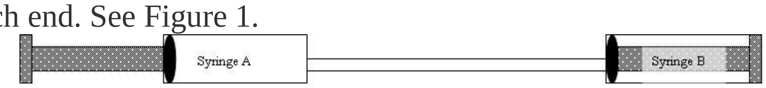


Figure 1. A syringe sub-system.

2. Fill one sub-system with water. Do this by removing both plungers from the syringes.
3. Now place the open end of the syringe side A under a water faucet while holding syringe B at a lower elevation. Fill the sub-system with water until it overflows. Turn water off.
4. Holding both syringes A and B at an equal elevation, place plunger A into syringe A and push plunger SLOWLY all the way down. Water will enter syringe B, filling it completely.
5. Finally, place plunger B into syringe B. Make sure that the plunger is in contact with water and not air. If necessary, top off syringe B with water.
6. This is a hydraulic sub-system because it contains a liquid. The other sub-system is filled with air (gas) and it is called a pneumatic sub-system.

Amusement Park Rides: Up and Down in Design

From Making the Connection, Women in Engineering Programs and Advocates Network (WEPAN) https://www.teachengineering.org/activities/view/wpi_amusement_park_ride © 2013 by Regents of the University of Colorado; original © 2001 WEPAN/Worcester Polytechnic Institute

Summary:
Students design, build and test model roller coasters using foam tubing. The design process integrates energy concepts as they test and evaluate designs that address the task as an engineer would. The goal is for students to understand the basics of engineering design associated with kinetic and potential energy to build an optimal roller coaster. The marble starts with potential energy that is converted to kinetic energy as it moves along the track. The diameter of the loops that the marble traverses without falling out depends on the kinetic energy obtained by the marble.

Engineering Connection

Mechanical and civil engineers are involved in the design of roller coasters. Engineers must understand how the basic physics concepts of energy apply to a successful roller coaster. They must understand how to make it fast and fun, without compromising structural integrity, which is critical for ride safety.

Time Requirement: 2 hours (2 50 minute class sessions)
Cost per group: $3.00
Number of groups: NA
NGSS: MS-ETS1-1, MS-ETS1-4

Learning Objectives:

- Model, test, evaluate and modify a design.
- Invent a product to meet a need.
- Use science, math and engineering principles to design and optimize a product.

Materials List

- 5-7 6-foot lengths of foam pipe insulation tubing, cut in half lengthwise per group
- 2 rolls masking tape
- 2 boxes round toothpicks (~20 per group)
- 16 mm marbles (5 per group)

Each group needs:

- container to catch marbles
- flexible tape measure
- scissors and ruler
- 2 different-colored stickers: one marked "P," the other "K"

Introduction for students:

The city of Wahoo wants to build a new roller coaster ride on their town common as part of the celebration of their 300th year. For consistency with the round number, they want a design to be as "loopy" as possible while keeping cost to a minimum. They are looking for engineering designs that optimize the ratio (inches of loop diameter/material costs) and are aesthetically pleasing (look good!). Every section of a roller coaster has different characteristics. Some portions have very light turns while others have more gentle curves and turns. Each scenario has its limits for whether or not it will work.

Roller coasters at amusement parks utilize potential energy and kinetic energy. Typically, a roller coaster car is pulled up by a motor, gaining its initial potential energy. Once at the peak point, no motors are connected to the car in any way. The car begins its winding and looping descent along a track that has been designed to safely transfer the potential energy into kinetic energy while making it a thrilling ride.
If the car is going through a loop-de-loop, and does not have enough kinetic energy, it will not stay on the track as it reaches the peak of the loop. Kinetic energy is measured as $KE=(mV^2)/2$), where m is the

mass of the object and V is the velocity. Potential energy is measured as PE =mgh, where m is the mass, g is the gravitational force, and h is the distance above the reference point where the mass starts. Ideally, all the potential energy is converted to kinetic energy. This never holds true, as some of the energy is lost to friction. Because of the loss of energy, the peak of the loops must be lower than the initial starting point of the car. See Worksheet 3 for a reference diagram.

Useful Background Information:

gravitational force: Force exerted between the Earth and an object that attracts the object toward the Earth.
kinetic energy: Energy associated with motion of an object.
potential energy: Energy an object has because of its relative location.

Procedure: With the students

Part 1: Design and Preliminary Testing

1. Show Worksheet 1: Reference Diagram as an overhead transparency or make copies and pass ithem out as a handout to all students. Discuss the worksheet.
2. Pass out Worksheet 2: Building Guidelines to all students. Review the task and design criteria.
3. Divide the class into groups of three students each.
4. Give each group one marble, a container to catch the marble, one foam piece, one toothpick, and a one-foot piece of masking tape.
5. Have each team design and test a preliminary prototype.
6. As they test, each group should be planning their final design and the amount of materials that will be needed. Have them sketch their ideas on paper and fill in quantities of materials on Worksheet 3: Cost and Evaluation Sheet. After 20 minutes, have students return the materials from the preliminary prototypes and obtain the materials listed in Worksheet 3 from the "store." If this is done at two separate times, the materials can be ready for students when they arrive for the second meeting.

Part II: Final Design and Testing

1. Permit additional materials to be purchased during the first phase of design and testing, about 30 minutes. Once materials have been obtained from the store, they may not be returned or exchanged.
2. Allow 10 minutes to finalize designs. Give each group one "P" sticker and one "K" sticker. Remind groups to use the stickers to mark the places on their roller coasters that have the greatest kinetic and potential energy.
3. When time is up, have groups step back from their roller coasters. Test each roller coaster individually by having a team member release the marble to go through it. Remember, each roller coaster must be able to stand alone and the marble must travel completely from start to finish. Permit two tries per coaster, though more testing can be done if time allows.
4. Identify an "aesthetic rating." Have each group look at all of the roller coasters and come up with an aesthetic ratting (such as 1-6 if six groups, with 1 being the best). Based on the group responses, the leader announces the ratings.
5. Have groups measure the diameter of each loop in the roller coaster and total the cost of purchased materials in Worksheet 3.
6. Have students compute the loop diameter to cost ratio, then add the aesthetic ranking.

7. After all the groups have completed the tests, come to a consensus as a class about the results. Lead a discussion on observations about effective and non-effective solutions. Was there a stronger design/construction that seemed to work? How did potential and kinetic energy play a role? Along with justifying the best design, did your group consider structural integrity? Is the ride safe?

Investigating Questions:

- Where is the potential energy greatest in your system? (Answer: It is greatest at the highest location).
- Why do most roller coasters have corkscrew turns instead of loop-de-loops? (Answer: It takes a lot of kinetic energy to make it all the way around a loop-de-loop. Corkscrew turns [twisty downhill turns] simply use the potential energy to gain speed through the turn).
- How must the track be designed to keep the car in corkscrew turns? (Answer: The track must be at an angle, tilting forward, instead of level to the ground).