TOOLS & TECHNIQUES

OMSI™

Everyday Encounters with Science

TOOLS & TECHNIQUES

Contents

Acknowledgements

This book would not be possible if it weren't for the generous support of JPMorgan Chase and Co., the Boeing Corporation, and the National Girls Collaborative Project. This project was also supported by the entire team at the Oregon Museum of Science and Industry (OMSI) especially the Grants and Development departments for securing funding and the Marketing department for transforming a folder of documents into a book. Much of the material presented here is based on previous work by members of the Research and Development team and Museum Educators.

JPMorgan Chase & Co.

Boeing

Project Lead:
David Perry, M.Ed.

Editor:
Marilyn Johnson, Ph.D.

Lead Writers:
Susan Barrett
Lindsey Vincent

Writers:
Kirsten Goldman
Heather Blair
Andrea Klingle

Advisors:
Ryan Collay, MS STEM Outreach Oregon State University
Cary Sneider, Ph.D., Portland State University
Dave Vernier, Vernier Software and Technology

Activity Testers:
Joseph Brown, M.A.
Jenny Gardner
Tony Irlbeck
Patrick Mangan, M.Ed.
Craig Reed
Natalie Reynolds
Ian Sterry

Illustrations:
Berin B

Design:
Martin Douglass

Proofreading
Cyndi Rhoads

Introduction

This handbook contains several activities designed to facilitate active participation in the engineering design process. While they were tested and modified at the Oregon Museum of Science and Industry (OMSI), their origins are as diverse as the roles engineers play in society. The goal of this book is not to prescribe a set curriculum but to provide resources for integrating the engineering design process into your existing classroom activities. The activities we chose are some of our favorites, chosen to serve as examples of what an engineering activity may look like, or how an existing activity can be adapted to engage learners in "Engineering Design." Chances are you're already doing activities which could be considered engineering. Hopefully this book will help you recognize these opportunities and be more intentional with how you use them.

The timing of this book is to address the need for resources in response to the February 2009 adoption of Oregon State Science Standards which include Engineering Design as a science process standard for the first time. The intent of these standards is for teachers to integrate the scientific content with process skills, such as scientific inquiry or engineering design. In this format, engineering is a rich context for other subjects.

Engineering instruction, and Science, Technology, Engineering and Math (STEM) education in general, has a role beyond engineering workforce development. All students entering the current and future workforce will need what are known as 21st century skills. These are the basics of problem solving and technological literacy which members of the modern workforce will need. The process skills of engineering are essential to being competitive for future jobs.

The inclusion of engineering into the science standards comes amidst a nationwide trend towards engineering education. During the launch of the Educate to Innovate campaign, the President of the United States recognized that the way towards job creation and a healthy economy is for students to engage in science and engineering activities in and out of schools. He stated the need to "encourage kids to become makers of things and not just consumers of things." This reflects a growing Maker Movement around the world, as people find spaces in their garages and workshops to tinker and do-it-themselves (New York Hall of Science, 2010). Of these intrepid inventors and amateur engineers, President Obama said they would be the source of solutions to our greatest problems. Our hope is to help create that same sentiment in your classroom.

The Engineering Design Process

Engineering Design (ED) is not a set of stand-alone activities to add to your curriculum. Similar to scientific inquiry, ED is a process. The aim of the Oregon State Science Standards is to integrate this process strand with the Big Ideas in the content strands. For example, while studying weather and climate for a particular region, an activity may support both Earth science content standards and ED process standards by asking students to identify the needs of earthquake victims, design a shelter which can withstand aftershocks, evaluate their solution, and refine it.

This approach is not about increasing the amount of instruction time or content we must provide to students. Instead, it is a style of activity to include in your units. When integrated effectively, the design process can make classroom activities more engaging and relevant, while increasing students' problem solving skills.

So what is the Engineering Design process? In the world of professional engineers, the answer depends on context. Similar to the Scientific Inquiry Process, there is no universally agreed upon, concise definition, and the process is not necessarily linear. Instead, Engineering Design is more accurately described as a system of processes for solving problems. Different types of engineers use different processes, as do different corporations. Different state and national organizations also have different definitions. The definition of the process also gets more layered as students move through the grades. However, there are some agreed upon necessary components. For ease of use, we have distilled some specific process skills out of the various definitions. They are:

- Define the problem
- Develop a solution
- Evaluate solutions
- Present your solution to an audience

OMSI's popular Engineer It! Exhibit is based on these dimensions of engineering distilled down to "Think It," "Build It," "Test It." A more in-depth description of these processes follows.

Define the Problem

Benjamin Franklin's phrase 'Necessity is the mother of invention' is a perfect example of how the engineering process begins. Someone somewhere recognizes a need. This could mean a better way to bring water to fields in rural Africa, or a smaller personal electronic device for listening to music on the bus. The problem may be identified by someone else, but the engineers are the people who dive in and find the solutions. Often, the problem may not be fully articulated, and the engineers must work to get to the true root of the problem.

In the classroom, you may provide your students with the problems or needs they are to address. Especially early in the curriculum, this is an excellent way to provide context and give real examples of the types of things engineers work on. A design challenge is a common tool used to drive innovation. In a design challenge, a very specific need is posed, usually with some specific criteria for success. The X-prize is a modern example, encouraging teams of engineers to design a production capable 100mpg car or a better way to clean oil spills. Similar challenges were laid forth hundreds of years ago, such as the Longitude Act of 1714 in the United Kingdom. At the time, ships were not able to determine their longitude with accuracy, causing the loss of many lives in naval disasters. The story of John Harrison's
work towards a successful solution is a compelling engineering tale, told in Dava Sobel's *Longitude* (1996).

With guidance, students will be able to identify and define a need on their own. This more open format is closer to what an inventor does, and while it may come naturally to some of your students, others may struggle initially. Without some experience in what these types of problems look like, it is hard to recognize and articulate them. It is also intimidating to try to think of problems nobody has addressed yet. Assure students that many problems are old, and that engineers are constantly looking for new ways to solve them. Extra guidance will be critical as they work to identify problems encountered in their everyday life . When problems are defined by the students themselves, they are more relevant to the students.

Often, the problem you set forth (or they develop on their own) is the hook you can use to draw your students in. Spending time creating compelling needs that are both believable and relevant to your students will help engage a wide range of students. In later sections, we'll talk more about using drama while integrating engineering design into your curriculum; that begins with the need your students are addressing.

There are two sub processes which are a part of defining the problem, Identifying Constraints and Identifying Criteria. In the Oregon State Science Standards, these specific skills begin to appear in the 7th grade.

Identifying Criteria

Identifying criteria is the process of determining your measures of success. Using bridge design as a classic example, one rather obvious criterion is that the bridge must cross a river. A bridge halfway across a river would be unsuccessful, and likely be the last project an engineering firm is offered.

There are many other criteria for the success of bridges, however. The bridge needs to hold a certain amount of weight; it needs to withstand wind and earthquakes; vehicles and/or pedestrians need to be able to make it across—usually in both directions and often with multiple lanes; the bridge may need to lift to accommodate tall boats passing beneath. Activity From Here to There is an example of this type of design challenge the students design a multi-use bridge for objects representing bikes, cars, and trains. They quickly learn that what works for one user will not work for others.

During early activities, you will likely define the criteria for success, as in the example above. However, students in upper elementary and middle school will quickly be able to grasp the concept and create lists of their own criteria. Younger students may be more readily able to articulate what a successful design would look like, or need to have. Discussions about criteria are an excellent opportunity to talk about how engineers and designers must remain mindful of users when developing solutions. Pedestrians may be less likely to use a multi-use path if they perceive it as dangerous or surrounded by the noise of traffic on all sides.

Most importantly, remind your students that the criteria of their engineering project are not necessarily the criteria you use for grading. The fear of failing to achieve their criteria deters students from taking risks and pushing the limits of their creativity. A team of students which clearly understands and applies the relevant science concepts as they work through the design process deserves grades which reflect their effort, regardless of the success of their design.

Identifying Constraints

Often criteria can get confused with constraints. While criteria define the characteristics of a successful design, constraints set the limitations an engineer must work within. The most common constraints are time and money. However, there may be limitations on size (minimum or maximum), the materials one can use, location, or any other requirement.

At first glance, it might seem like increasing constraints would make an activity more challenging. While you can use constraints to make simple activities more complex, in some cases it can help provide some much needed guidance. Especially early in their engineering work, your students may become overwhelmed with too many options if you provide a vast array of materials and tools. Being intentional with the materials you provide can help students decide on a design quickly, and may encourage creative uses of materials.

Another way to increase the challenge of an activity is to change the constraints during the process. Shortening the amount of time to finish, or allowing additional materials not provided initially are examples of constraint changes. While your students may complain about the fairness of changing rules, this simulates the reality of unexpected twists in the process.

Near the end of this book, we have provided an optional extension for intergrating budgeting into the design process. Using a budget is an excellent way to give your students experience working within constraints. We have also included a chapter titled Workshop-in-a-Box, which deals with the use of materials and tools.

Developing a solution

Developing a solution is the fun part included in nearly all ED activities. During this stage, students are actively working on solutions to the identified problems. This stage of the process is often the most exciting, frustrating, and rewarding. It often includes the hands-on building of models, prototypes, or other physical objects, but it also includes all the planning and design required for the construction.

There are two general approaches to this stage. Some students may prefer to think through their design in a very organized format. Others may prefer to 'just do it' by grabbing materials and trying things out. Both styles have their strengths and weaknesses. As a facilitator, encouraging your students to learn the strengths and weaknesses of each is a very valuable lesson.

A team of students who thinks through their design fully before trying anything is typically displaying a better understanding of the ED process and any related scientific content. Often, teams will have discussions about criteria and constraints before touching any building materials while they sketch out solutions. One way to encourage students to plan out their design is by introducing constraints, such as the budget extension in appendix A. The downside of this approach is that teams may spend too much time working out their design, and end up without enough time for testing and refining.

The other approach embraces the idea of 'failing early.' Here, students may grab a handful of materials and begin tinkering. This often produces some interesting ideas, and leads to lots of refining of ideas. Activities with wide-open criteria and constraints encourage this type of experimenting. On the negative side, students who tinker may do so independently of their team, creating several different solutions within a single team. This may also use more raw materials, as students try and fail more often.

Testing and Refining

As with many parts of the process, testing and refining of solutions is heavily integrated with the development phase. There are typically many 'back to the drawing board' moments during the process, and designs are constantly being tweaked to improve performance.

In modern engineering, much of the initial testing is done through computer modeling. Through computer modeled simulations, structures can be placed under massive loads or encounter extreme weather to see how they react. With these simulations, an engineer can drive a concept car around a 3D race track to test performance, or run miles in a new pair of tennis shoes before the actual car or shoe is ever produced. However, many engineers still end up creating prototypes of their designs prior to full scale build. The final version of a product is almost never the same as the prototype.

The key to testing is data. Encourage your students to look for ways to consistently quantify their results by asking, "How could you measure that?" This phase is the closest tie to the scientific inquiry process, and is also an excellent opportunity to integrate mathematics into your lessons. Many sensors are available for collecting data, and several smartphone applications can turn your student's mobile devices into precision instruments that go way beyond text messaging.

As your students are collecting data, encourage them to keep a log of the small and large changes they make to their design. In appendix C you'll find an example data table and change log. Revisions to their designs should be made one at a time, so they can easily see the influence their changes have on the performance of their design. This is equivalent to changing only one variable at a time in a scientific investigation. It also allows students to 'rewind' their design if the revisions have a negative or even neutral effect.

Evaluating Solutions

A critical part of technological literacy is the ability to understand and make decisions about the technology we use. In this part of the process, engineers must assess their solution to determine the strengths and weaknesses. They may need to compare several versions of a design and choose one to put forward as the 'best.'

This is typically a game of trade-offs. No design is perfect. As a result, engineers, or their clients, must be able to look at the positive and negative aspects of a design to choose a solution.

This part of the process refers back to the criteria determined initially. If a design does not meet the defined criteria for success, the engineers have more work to do. If a design does meet criteria, engineers must look at any negative impacts to maximize success. The impacts of a design may be financial, on the environment, on a community, or even the entire planet. If the impacts are perceived as too negative, the engineers may take a design through several more rounds of development for Optimization.

Again, data is central to this process. Evaluations of a design are often based on analyzing data collected during the testing and refining phases. Being able to interpret the data they gather is arguably more important than their ability to collect it. This ability is tied closely to how data is presented.

Communicating Results

A key part of evaluating a design is how the design is presented. There are many ways to incorporate this into your curriculum: from papers, to bar graphs, to presentations. Use different methods if you wish, but emphasize clarity and accuracy.

Facilitating Learning

In a climate where test scores and grades are so critical to how students measure their success, one of the most critical parts of an engineering curriculum is encouraging your students to be comfortable with 'failure.' Their idea for a solution may not work, but often the knowledge of what doesn't work is just as valuable as an instant success. There are many stories of inventors working tirelessly with disastrous or imperfect results, and then finally finding the best solution. There are also plenty of stories of inventors who never achieved the solution they were looking for. Often, generations later, another engineer would solve the problem by looking at the work done by these struggling predecessors.

But how does this translate into the classroom? First, create an environment where students are encouraged to develop their ideas, no matter how outrageous they may sound. This does not mean taking each crazy idea to full prototype, but try to avoid pointing out any obvious flaws in those crazy ideas. Encourage them to think through the idea more fully, to draw sketches or do more research. Hopefully they will discover flaws on their own, but if not, let them try. Spectacular failures are often great teachable moments.

However, in a results-oriented environment such as school, not finding the solution can make some students anxious. Assure them you will be grading on the process they go through and not the results. A major part of that process is examining results and making recommendations. Taking this into account, the only way a student could fail would be when they give up and don't make any attempts to modify their design.

As your students work to solve the problems in front of them, they will often work independently in their groups. As a facilitator, your role is to help them articulate what they're working on. Check in with groups regularly to ask them to describe what they're working on. Not only does this give you a chance to assess their progress, it also gets them to self-assess their solution. Finally, asking your students to regularly describe their process will provide practice for when they need to communicate their final recommendations.

Engaging Diverse Audiences

Engineering as a profession has long had a PR problem. A common perception has been that engineers work by themselves, building bridges. Maybe the lucky engineers get to build the cars that drive over the bridges. However, engineers work in countless fields solving the problems we encounter every day. And they don't build bridges. Their work is done in the years leading up to the construction: designing, testing, evaluating, planning, and selling the idea for the bridge to their stakeholders.

Demonstrating how the work of engineers is relevant to our everyday lives is critical. Luckily, it is easy to make this case to our students. Take a moment to ask them what pieces of technology they value. Remind them that technology is all of the tools and techniques humans have created to make our lives easier. Discuss how people came up with these solutions, and all the challenges they needed to overcome. What can be trickier but just as important is conveying that in many cases engineering is an altruistic pursuit. This is a difficult case to make when talking about the latest iPod or sports car, but not when looking at the broader impacts engineers make in society. Ask your students what the most important problems are in the world today and you will find plenty of ideas for engineering curriculum. The problems are the hook that will draw your students in, and make them eager to take part in coming up with solutions. By keeping the focus on the problems they see and how engineering has affected their lives, your curriculum will be more engaging because it is student driven.

Strive for accuracy when integrating the engineering design process into your curricula. When possible, have your students address real problems in their homes, schools, communities, or even the world. Look at other solutions people have already proposed and judge it's validity. Invite engineers into the classroom to talk about what they do, and the projects they are working on. If possible, take a tour of a site and speak with engineers on site about what is going on. Local organizations of engineers or engineering departments at universities are a great place to make contacts.

Promoting Gender Equity

Interest in STEM subjects amongst girls has not risen over the past couple decades, despite increasing advancement and reliance on these fields. Women make up only 20.4% of engineering majors in universities (National Science Board 2008) and 11.1% of practicing engineers in the field (Bureau of Labor Statistics 2007). But, this isn't just a problem for the field of engineering. The skills embedded in STEM subjects are essential in most future careers.

Market research conducted by the National Academy of Engineering (NAE 2008) concluded that to make the field more attractive to young people in general, and girls in particular, engineering advocates need to reinforce how engineers benefit society and enjoy meaningful careers. For example, engineers should be portrayed as creative people who work collaboratively to "improve people's lives in meaningful ways" rather than reinforcing the image of the lone engineer who works independently to design and build things. Research also shows that for girls to be successful in engineering, they need: 1) strong personal experiences and role models in the field (Halpern et al. 2007; Liston et al. 2007); 2) opportunities to increase their self-confidence in STEM (ScienceDaily 2008; 3) exposure to examples of how engineering relates to their lives (Fadigan and Hammrich 2004; Liston, Peterson, and Ragan 2007), and; 4) support from parents and educators (NAE 2008; ScienceDaily 2008).

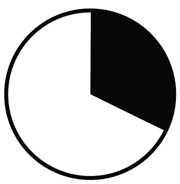
Jitterbugs

Students design, construct, reconsider and modify a "jitterbug" toy.

SCIENCE TOPICS	PROCESS SKILLS	GRADE LEVELS
Forms of Energy	• Identify Criteria and Constraints • Develop Solutions • Test, Evaluate, Refine • Communicate Results	3-8

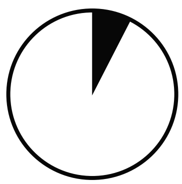
TIME REQUIRED

Advance Preparation



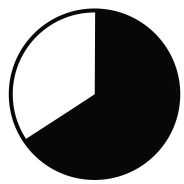
20 minutes

Set Up



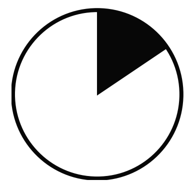
5 minutes

Activity



40 minutes

Clean Up



10 minutes

SUPPLIES

Each group of students will need:

- ❏ *Motor, 1.5-3V with wire leads (available at many electronics stores, or check the resources section)*
- ❏ *1 AA battery*
- ❏ *1 Hot glue stick, approx 3" (bottle corks also work)*
- ❏ *1 Fat "broccoli-style" rubber band (size #81) Note: for students with latex allergies, you can use a AA battery holder, also available from electronics stores.*
- ❏ *1 washable marker (at least)*
- ❏ *4-6 Rubber bands or 12" of masking tape (masking tape may be easiest, but rubber bands are reusable)*

- ❏ *Paper to draw on, 1 sheet of butcher paper or poster board plus any sheets of letter or tabloid size copy paper for individual take homes*
- ❏ *Copy of Jitterbugs project sheet paper for individual take homes*
- ❏ *Copy of Jitterbugs project sheet*

Suggested Prototyping Supplies (per class)

- ❏ *Toilet paper tubes*
- ❏ *Small boxes*
- ❏ *Popsicle sticks*
- ❏ *Straws*
- ❏ *Coffee stirrers*
- ❏ *Yogurt tubs*
- ❏ *Plastic cups*
- ❏ *Empty plastic soda bottles*
- ❏ *Egg cartons*
- ❏ *Paper cups*
- ❏ *Pipe cleaners (cut into assorted lengths)*
- ❏ *Paper clips*
- ❏ *Scissors*

Safety Precaution: This activity may contain small parts. Pipe cleaners and other wire materials may be sharp. Elastic bands can store lots of energy

ADVANCE PREPARATION

- ❏ *Copy Jitterbugs project worksheet for each student*
- ❏ *Gather supplies*
- ❏ *Test motors and batteries to ensure they are working*
- ❏ *Before doing the activity with the class, practice the activity procedure below.*

SET UP

- ❏ *Have several areas in the classroom that will serve as "prototyping areas" for jitterbugs. In this area:*
  - ❍ *Layout several sheets of poster board or butcher paper.*
  - ❍ *Provide extra markers*
- ❏ *In a central location, set out assorted prototyping supplies for jitterbug designs*

INTRODUCING THE ACTIVITY

Let students speculate before offering answers to any questions. The answers at the right are provided primarily for the teacher's benefit.

Ask the students the following questions in **bold.**
Possible student answers are shown in italics.

How many of you have toys at home that move?
Ask students to describe what their or their siblings' toys do, how they move. This is a great way to give kinesthetic learners a chance to move. If working with older students, you may also ask how many of them use the vibrate feature of their cell phones.

What makes these devices work?
Several parts work together to make cell phones vibrate or toys to bounce around, but the elements to focus on are a source of electricity, such as a battery, and a motor. They may also mention gears or other mechanical parts, buttons, switches and other sensors, computers and any number of other devices. A circuit diagram is included on the Jitterbugs worksheet for reference.

Who designs these objects?
Teams of engineers work in toy or cell phone design, including electronics, software, and mechanical specialists. Other designers look at how they will be used and how appealing they are to their audience.

This activity is intended to be fun and creative. Allow students to be whimsical and draw connections to their favorite toys. Guide them into thinking about the process of how they were made.

CLASSROOM ACTIVITY

1. After introducing the activity tell they students that they will be working as a team to design a 'jitterbug' toy.

2. Begin by handing out the Jitterbugs project sheet, motor, battery, and fat rubber band.

3. Let them experiment with these materials while describing the basics of a circuit and how the wire acts as a switch (see diagram and explanation below).
   Hand out the glue sticks or corks and demonstrate how placing it on the motor's spindle will make the motor jump around. Let them experiment with different placements. Note: placing the glue stick on the motor can be difficult. Poking small pilot holes in the glue sticks at different places will make it easier for younger students to adjust their jitterbugs

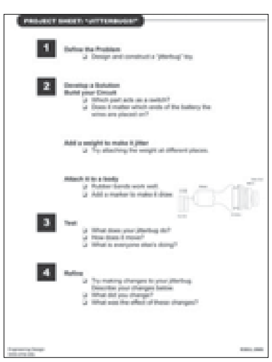
4. Show them the materials they have available and ask them to design a jitterbug which holds a marker onto the paper to draw as it jitters about.

5. Ask students to have their jitterbugs draw on the poster board or butcher paper. They can also draw on smaller sheets of paper to take home.

6. Encourage them to make changes to their design to see how it affects their design.

7. After an appropriate time for experimentation, ask students to gather together and have each team present their jitterbug. See the Class Discussion section following.

8. Instruct students to help clean up by disassembling the jitterbugs and sorting the materials for future reuse.



CLASS DISCUSSION

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

What materials did you use?
Did any materials work better than others? What were some of the challenges of different materials?

How did working in a team affect the outcome of your jitterbug?
Input from their team members probably affected the choice of materials, how the jitterbug looked, and how it ended up moving. Some students might have assumed unofficial roles in their groups.

Which designs were most successful? Least successful?
Ask the students to define why one was more successful than another. Unless you required specific criteria such as 'largest circle', the reasons may vary. If you had the students collect data, ask them for evidence when making claims. With less successful models, ask the teams who created them what they would change on their model to improve the design.

What other kinds of data could we collect about these jitterbugs?
Brainstorm a list of ideas and then ask how they would be valuable while designing a toy such as a jitterbug.

Focus on the process the teams went through as they created their designs.

EXPLANATION

In-depth background information for teachers and interested students.

People who design toys and other devices we use every day are engineers. Typically, no single person designs a product, but a whole team of people work together on different parts. A toy design company may have a designer, a marketing expert, a software programmer, an electronics engineer, and several people with specialized skills for making prototypes.

Students construct circuits in this activity. A circuit is the path along which electricity flows through an electrical system. A circuit forms a loop with components along the way. Along the path, an electric circuit consists of at least three parts:

1) a source of energy, like a battery
2) connecting wires
3) electrical components such as a switch (a device that completes or breaks an electric circuit), a light bulb; a motor (a machine that uses electricity to produce movement); a resistor (to determine the amount of electricity that flows through the circuit); or a capacitor (an electrical component that stores electric charge).

In the Jitterbug circuit, the battery provides power to an electric motor. Connecting or disconnecting the wires from the motor will act as a switch. The wires must be connected ("switched on") for the motor to work.

Electric motors are a useful tool in the classroom. They consist of a coiled copper wire suspended in a magnetic field. As an electric current is passed through the wire, it creates a second magnetic field for the wire. The two magnetic fields push and pull on each other, causing the shaft of the motor to rotate and the motor to spin. Inversely, if the motor is turned by another force, such as your students' hand, the magnetic field moving past the wire induces, or creates an electric current. This is the primary concept behind energy generation. These small electric motors can be used as motors or as generators.

The glue stick acts as an offset weight on the motor, causing a vibration. There are several mechanical ways to create vibrations, but this is a common method used in small electronics such as cell phones. Vibrations have several parameters to be measured, including the amplitude (or size of the vibration) and frequency (or speed of the vibration). Engineers can adjust these by changing the amount of weight, how it is offset, or the power of the electric motor.

OPTIONAL EXTENSIONS

A. Extreme Jitterbug
Advanced students can create more complex circuits using more than one battery or motor. By using the second motor as a generator, they could also develop a hand crank to create enough electricity for the jitterbug to bounce around. A solar powered jitterbug is another option.

B. Jitterbug Sumo
If your students crave competition, you could create some type of game. One option is having a sumo style arena. Rules may include:

- ❍ *Two jitterbugs start each match at the center markings*
- ❍ *The first jitterbug to exit the ring or fall over and stop*
- ❍ *drawing loses*

The winner of 2 matches out of 3 advances to the next round.

C. Jitter Bugs
Younger students may enjoy exploring the idea of their creations being similar to insects, and want to decorate their bugs.

- ❍ *Have them look at pictures of real bugs.*
- ❍ *Ask them to explain what type of bug they created, and what type of habitat it might live in.*

Explanation:
This is a great way to introduce the idea of biomimicry, engineers looking to nature for ideas on how to solve problems.

CROSS-CURRICULAR CONNECTIONS

VISUAL ARTS	Try framing some of the ‘artwork’ created by the jitter-bugs. How do students decide which piece of the paper should be framed, or which side is up? Is this art? Can robots make art? Look at paintings by artists such as Joan Miro or Jackson Pollock. Why were these artists important?
BUSINESS	Have your students create and sell jitterbug greeting cards and wrapping paper to friends and family.
LANGUAGE ARTS	Ask your students to create marketing materials for their toy or artwork. How would they describe it to potential investors? How would they tell their target audience about it?
MUSIC	Try to create jitterbugs which create music instead of drawings, then have a jitterbug symphony.
MATH	Use the data log (handout in appendix C) and a ruler to record measurements such as diameter of the circle the jitterbug creates or number of dots per inch. Ask students to increase or decrease this by modifying their design. Stop watch to measure how long it jitters before falling over. Ask them to make modifications to increase the time.

PROJECT SHEET: "JITTERBUGS!"

1

Define the Problem

- ❏ *Design and construct a "jitterbug" toy.*

2

Develop a Solution

Build your Circuit

- ❏ *Which part acts as a switch?*
- ❏ *Does it matter which end of the battery the wires are placed on?*

Add a weight to make it jitter

- ❏ *Try attaching the weight at different places.*

Attach it to a body

- ❏ *Rubber bands work well.*
- ❏ *Add a marker to make it draw.*

3

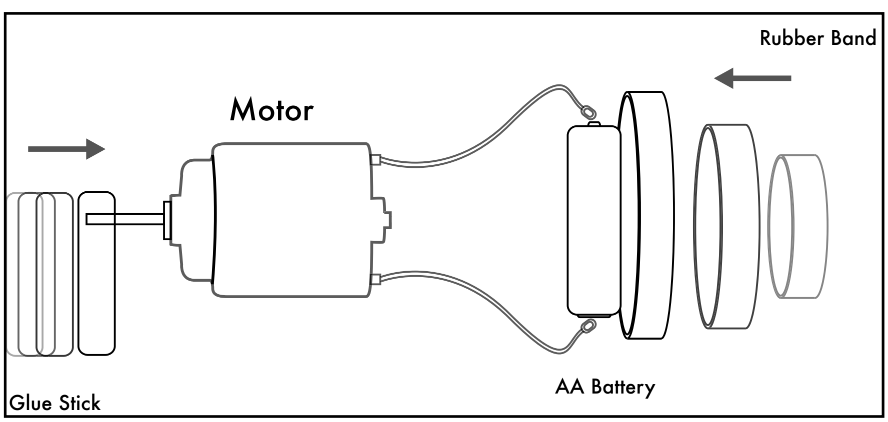
Test

- ❏ *What does your jitterbug do?*
- ❏ *How does it move?*
- ❏ *What is everyone else's doing?*

4

Refine

- ❏ *Try making changes to your jitterbug. Describe your changes below.*
- ❏ *What did you change?*
- ❏ *What was the effect of these changes?*



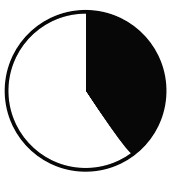
Car Rail Challenge

Students will design and construct a balanced weight system that will allow a toy car to roll down a narrow rail without falling off.

SCIENCE TOPICS	PROCESS SKILLS	GRADE LEVELS
Force/Vectors Weight Balance Gravity	• Defining Problems • Developing Solutions • Evaluating Solutions • Communication • Teamwork	2-9

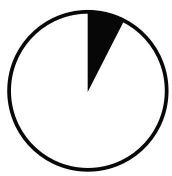
TIME REQUIRED

Advance Preparation



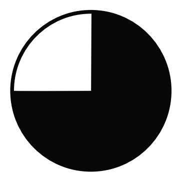
25 minutes

Set Up



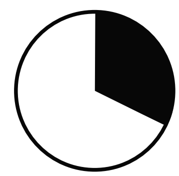
5 minutes

Activity



45 minutes

Clean Up



20 minutes

SUPPLIES

Each student or pair of students will need:

- ❏ *1 toy car such as a Matchbox or a Hotwheels Car Rail Setup*
- ❏ *1 hoola hoop cut in half to make a semi-circle*
- ❏ *2 Ring stand*
- ❏ *4 C-clamps, about $2^{1/2}$”*
- ❏ *Hacksaw or similar saw for cutting the hula hoop*

Materials to photocopy

- ❏ *Student project worksheet, 1per student*

Suggested supplies for the class to have access to for car rail designs:

- ❏ *toilet paper tubes*
- ❏ *beads*
- ❏ *popsicle sticks*
- ❏ *straws*

- ❑ *an assortment of nuts and bolts*
- ❑ *yarn*
- ❑ *hard pastas (macaroni)*
- ❑ *pipe cleaners (cut into assorted lengths)*
- ❑ *paper clips*
- ❑ *twisty ties*
- ❑ *wire*
- ❑ *scissors*
- ❑ *masking tape*

ADVANCE PREPARATION

- ❑ *Copy of project sheet, one per student*
- ❑ *Gather toy cars, 1 for each pair of students*
- ❑ *Gather car rail design supplies (suggested supplies listed above). It is suggested to have 1 supply station for every 4 groups of students.*
- ❑ *Cut 1 hula hoop in half using a hacksaw. Wear safety glasses and use C-clamps to hold it in place while cutting.*
- ❑ *Set up Car Rail Stations. Attach one end of the hula hoop to a ring stand with a C-clamp and set it on the floor. Attach the other end of the hula hoop to a desk or counter with another C-clamp (See Diagrams).*

SET UP

- ❑ *Have two areas in the classroom that will serve as "testing areas" for the toy cars. Set up one car rail in each of these areas.*

INTRODUCING THE ACTIVITY

Let students speculate before offering answers to any questions. The answers at the right are provided primarily for the teacher's benefit

Using a yard stick, demonstrate the concept of balance.
Ask the students to brainstorm their own definitions of balance.

What makes an object balanced?
When it stops tilting. When the weight is equal on both sides.

How can you find the "balance point" of an object?
The center of gravity. The center of the object. Point where the mass is evenly distributed.

Pass out rulers to each student and have them try to find the balance point of the ruler. Ask them to come up with rules to follow to find the balance point of an object.

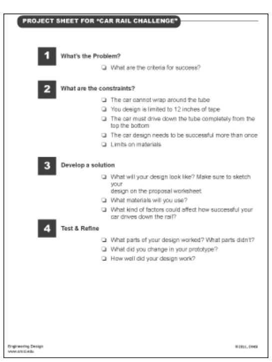
Demonstrate how to find the balance point of the ruler by slowly moving your fingers from the ends of the ruler to the center.

What kinds of factors may affect balance?
Gravity. Weight. Force. Resistance.

CLASSROOM ACTIVITY

Divide the students into pairs or teams. Explain that their task is to design an amusement park ride that can successfully "drive" down a narrow rail without falling off. They have materials to develop a prototype of their design. You may want to suggest they consider factors such as balance, weight and friction during their design process.

- ❑ *Inform the class of basic supplies*
- ❑ *Demonstrate the car rail setup*
- ❑ *Go over activity rules such as:*
  - ❍ *1 toy car per a pair*
  - ❍ *The design cannot wrap fully around the tube, the teacher must be able to take it on and off without changing the design significantly. A successful model must drive down the entire tube.*
  - ❍ *Cars must drive the entire length of the tube*
  - ❍ *Teams are limited to 12 inches of tape (optional)*
  - ❍ *Draw every design you try. Write down what worked and what didn't.*


PROJECT SHEET FOR "CAR RAIL CHALLENGE"

1 What's the Problem?
- ❑ What are the criteria for success?

2 What are the constraints?
- ❑ The car cannot wrap around the tube
- ❑ You design is limited to 12 inches of tape
- ❑ The car must drive down the tube completely from the top the bottom
- ❑ The car design needs to be successful more than once
- ❑ Limits on materials

3 Develop a solution
- ❑ What will your design look like? Make sure to sketch your design on the proposal worksheet
- ❑ What materials will you use?
- ❑ What kind of factors could affect how successful your car drives down the rail?

4 Test & Refine
- ❑ What parts of your design worked? What parts didn't?
- ❑ What did you change in your prototype?
- ❑ How well did your design work?

CLASS DISCUSSION

What other kinds of situations in the real world could this design challenge be used?
Transportation, driving in mountain regions, construction, car design etc.

Were there any common features you noticed between car rail designs that were successful?
Weight distribution, they were balanced, they were simple in design etc.

Were there any designs that worked really well?

What was the hardest part of solving this problem?
Students may say that the limits on their materials or the amount of time they had to build were a challenge

EXPLANATION

In-depth background information for teachers and interested students.

When designing structures such as bridges, airplanes and buildings, engineers have to keep in mind how the structure stays in balance and what makes them fall out of balance. Another word for balance is equilibrium. Equilibrium is a very important concept for engineers to consider because it is necessary to design safe structures. Equilibrium is important for everyday safety. If something is out of equilibrium, then it could fall over.

Center of gravity is a term used by many engineers, especially those involved with the design and construction of airplanes and other modes of transportation. The center of gravity of an object is the point around which the mass of an object is equally distributed.

In the example of the Car Rail, the center of gravity of the car begins above the hula hoop, and the car immediately flips over to the ground. By designing something that lowers the center of gravity below the hula hoop, the vehicle is able to stay on. The lower an object's center of gravity, the more stable it is.

OPTIONAL EXTENSIONS

A. Working on a Budget
This activity works very well with the budget extension in Appendix A.

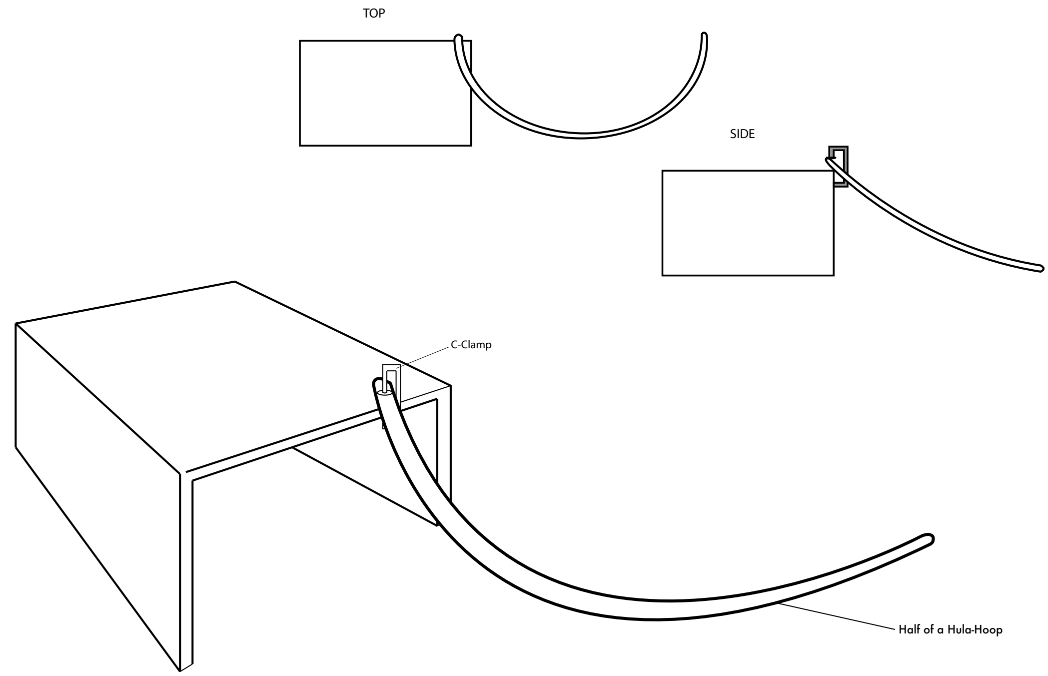
B. Center of Gravity
"All objects have a center of gravity including ourselves! Where is your center of gravity?"

"Your body has a center of gravity. It is located just behind your belly button. In order for you to stand upright, your center of gravity must be supported. To demonstrate this try standing against a wall with your right shoulder and right foot placed firmly against the wall. Now try lifting your left foot. What happens? Why?"

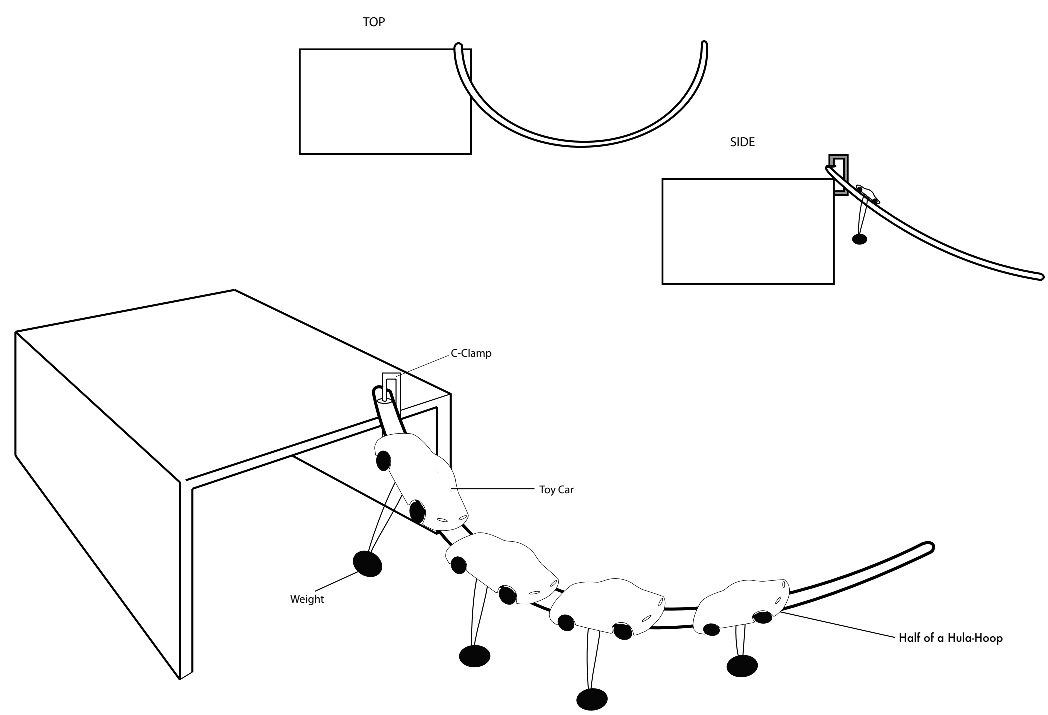
CROSS-CURRICULAR CONNECTIONS

Physics	For 7th and 8th grade: Introduce the concept of vectors and types of vectors such as velocity vectors. Vectors are composed of two main components: magnitude and direction. Have the students determine the types of vectors and direction of the vectors involved with the car rail challenge.
Math	Grades 2–5: Work with the students to measure the amount of masking tape used and the distances traveled. Grades 6 – 8: Introduce the concept of proportions. Have the students determined the weight of the objects attached to either side of their car? What is the proportion of one side to the other? Compare successful cars with unsuccessful cars.

Car Rail



Car Rail



PROJECT SHEET FOR "CAR RAIL CHALLENGE"

1 **What's the Problem?**

- ❏ *What are the criteria for success?*

2 **What are the constraints?**

- ❏ *The car cannot wrap around the tube*
- ❏ *The design is limited to 12 inches of tape*
- ❏ *The car must drive down the tube completely from the top to the bottom*
- ❏ *The car design needs to be successful more than once*
- ❏ *Limits on materials*

3 **Develop a solution**

- ❏ *What will your design look like? Make sure to sketch your design on the proposal worksheet.*
- ❏ *What materials will you use?*
- ❏ *What kind of factors could affect how successful your car drives down the rail?*

4 **Test and Refine**

- ❏ *What parts of your design worked? What parts didn't?*
- ❏ *What did you change in your prototype?*
- ❏ *How well did your design work?*

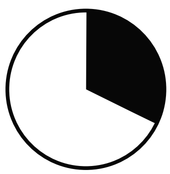
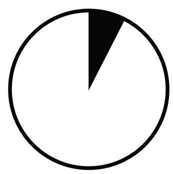
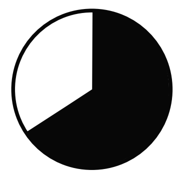
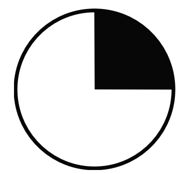
TOOLS & TECHNIQUES

From Here to There

Students design a multi-use trail to get pedestrians, bicyclists, and rail cars where they need to go.

SCIENCE TOPICS	PROCESS SKILLS	GRADE LEVELS
Forms of Energy Forces and Motion	• Define Problem • Identify Criteria and Constraints • Develop Solutions • Test, Evaluate, Refine • Communicate Results	3-8

TIME REQUIRED

Advance Preparation	Set Up	Activity	Clean Up
			
20 minutes	5 minutes	40 minutes	15 minutes

SUPPLIES

For each group of students:

- ❏ *Tennis Ball or other large heavy ball*
- ❏ *2 marbles or 2 other small heavy balls*
- ❏ *2 ping pong or 2 other small light balls*
  - ❍ *Prototyping supplies such as:*
  - ❍ *Paper towel tubes*
  - ❍ *Masking tape*
  - ❍ *Yogurt cups (optional: cut out bottom)*
- ❏ *Aluminum foil*
  - ❍ *Sturdy boxes*

Per each individual student:

- ❏ *Copy From Here to There project sheet*
- ❏ *Copy Sketch Pad sheet from Appendix C*

ADVANCE PREPARATION

- ❏ *Gather for each group of students:*
  - ❍ *Set of test balls*
- ❏ *Before doing the activity with the class, practice the activity procedure below.*

SET UP

- ❏ *Assemble materials*
- ❏ *Divide the class into teams of 3-5 students*

INTRODUCING THE ACTIVITY

The goal of this activity is to get students to identify the criteria and constraints involved in an engineering challenge. Invite the class to a "Design Meeting" and tell them they are civil engineers being asked to design a pathway for people to get from point A to point B. The path should be 'multi-use', meaning it will be used by people, bicyclists, and a light rail commuter train. Ask where issues like this occur in the world, and why a task like this is important.

Tell the students they will be developing a prototype, or model of a multi-use path. For their prototype of the path, different types of balls will represent the users: a tennis ball for the train, a marble for the bicyclists, and a ping pong ball for the pedestrians. Ask the students to list some things the path would need in order to be successful for each user. This list may include:

- ❍ *A separate path for each user to keep them from bumping into each other*
- ❍ *It should work over and over for all three balls*
- ❍ *The balls should move without help*
- ❍ *The design shouldn't use too many resources*

Help the students refine this list until you've agreed upon the criteria for the challenge. If the students miss an important criteria, tell them the city planners have their own set of criteria the engineers must take into account. Having each ball succeed 3 times is a good example of this. This is a good opportunity to tailor the level of challenge to your students. More strict criteria will make the activity more challenging.

Show students how to set up point A and B. Explain that these points cannot be moved or changed. This can be any two points in your classroom, or on student desks. A basic setup would have point A a couple feet from B and a foot higher. This is an opportunity to tailor the level of challenge by increasing or decreasing the distance between points or the difference between their heights.

Break the class up into the engineering groups you have chosen, and make it clear that they will need to use all of their team members' skills and creativity to come up with a solution. One at a time, give each group their challenge worksheet and send them to their designated design area.

CLASSROOM ACTIVITY

Students should work in groups of 3-5. Each group follows the directions below.

1) Introduce the activity.
2) Make sure a list of agreed upon criteria is on the board or other easily viewed location.
3) Show the students what Point A and Pont B look like, explaining that these points cannot move.
4) Before handing out the test balls, protyping materials and worksheet, explain to students that once they get these materials, they need to spend at least 1-2 minutes quietly looking at the supplies and thinking of designs.
5) Pass out the materials to the groups.
6) Give students 5 minutes to discuss and sketch design ideas with their group; still no building at this point.
7) Allow them to build for about 10 minutes before the first round of testing. Students need to discuss whether their pathway was successful or not, given the criteria and modify as needed. If the pathway was successful, how many times does it need to prove so in order to meet criteria?
8) Instruct groups to test their prototypes. Then discuss whether their pathway was successful or not, given the criteria. If the pathway was successful, ask groups to consider how many times it should be tested to prove the design met criteria.

9) Ask groups to propose modifications.

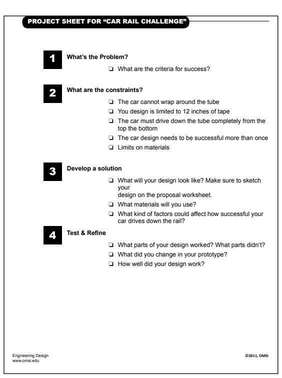
10) Give an additional 5-10 minute build period for modifications and further testing. Repeat as necessary to meet criteria, and/or allotted activity time.

11) Give the students a 5 minute warning before asking them to stop working.

12) Allow enough time at the end for each group to describe their design to the class and run one or more tests (usually about 5 minutes per group). To complete the presentations in one class period, you may need to sub-divide the class for presentations.

Instruct groups to clean up by disassembling the designs and sorting the materials for future reuse.

14) Follow up the activity with a discussion of the engineering processes the groups used.



PROJECT SHEET FOR "CAR RAIL CHALLENGE"

1 What's the Problem?

- ❑ What are the criteria for success?

2 What are the constraints?

- ❑ The car cannot wrap around the tube
- ❑ You design is limited to 12 inches of tape
- ❑ The car must drive down the tube completely from the top the bottom
- ❑ The car design needs to be successful more than once
- ❑ Limits on materials

3 Develop a solution

- ❑ What will your design look like? Make sure to sketch your design on the proposal worksheet.
- ❑ What materials will you use?
- ❑ What kind of factors could affect how successful your car drives down the rail?

4 Test & Refine

- ❑ What parts of your design worked? What parts didn't?
- ❑ What did you change in your prototype?
- ❑ How well did your design work?

Engineering Design
www.omsi.edu
©2011, OMSI

CLASS DISCUSSION

What are the different needs in a path for different types of transportation (train, car, bike, pedestrian)?
Facilitate a discussion about how engineers must account for various needs when designing solutions to problems. Note any times when different needs conflict with each other. Ask about possible solutions.

What was the most challenging part of solving this problem?
Students may say that the limits on their materials or the amount of time they had to build were a challenge

Engineers often have to work within very challenging constraints on budget and time. Ask how they would work differently next time to give themselves more time or use their materials more efficiently
Students may say it was difficult to get the balls to repeat the process three times in a row.

Most problems need a permanent solution which can be repeated over and over. This is a concept called reliability. Ask the students why solutions should be reliable and how engineers can increase the reliability of their designs.

EXPLANATION

In-depth background information for teachers and interested students.

Criteria and constraints both need to be considered in engineering design. Criteria are the wants; constraints are the needs. For example, criteria for aqueducts may include moving water from one place to another efficiently, in additionto looking attractive in order to blend in with a community aesthetic. Criteria are the standards by which the design is judged. Constraints add limits. There may be certain laws in place concerning where the aqueducts can be placed, how they look, what materials can be used, etc. There are also cost constraints to consider.

By creating a prototype of a design, the item or solution can be tested and altered as needed before investing in the actual construction. Prototyping creates the information needed for construction, such as materials, quantity, size, etc.—all the specifics.

OPTIONAL EXTENSIONS

A. Budget
See the Budget extension in Appendix A. This introduces an additional constraint and will encourage the students to spend more time on design before constructing their prototype.

B. Roles
See the Roles extension in Appendix B. Along with some of the more typical roles of project manager, designer, and production try assigning roles based on the three user groups of the path. These students would be responsible for advocating for the needs of their particular group.

CROSS-CURRICULAR CONNECTIONS

CIVICS	Conduct a mock debate and vote Assign students two advocacy groups and give them time to research and prepare arguments for or against the path receiving extra funds to include cars.
MATH	Students can measure the distance traveled by each of their balls and the speed and/or velocity at which each traveled (speed=distance/time; velocity=distance/time). They can then graph the results.
LANGUAGE ARTS	Have students create a brochure, presentation or video that clearly advocates for their design and why it should be chosen from the many project “bids” by various design firms.

PROJECT SHEET: FROM HERE TO THERE

1 **What's the Problem?**

- ❏ *What are the criteria for success?*

2 **What are the constraints?**

- ❏ *Each ball may only be pushed once.*
- ❏ *Each ball must make it from A to B, three times in a row.*
- ❏ *If any ball falls to the ground, you need to start over again from the beginning.*
- ❏ *The start/finish blocks need to remain in their marked positions. They can't be moved or knocked over.*
- ❏ *What are the limits on materials?*

3 **Develop a Solution**

- ❏ *What will your design look like? Draw your design on the sketch pad worksheet.*
- ❏ *What materials will you use?*

4 **Test and Refine**

- ❏ *What parts of your design worked? What parts didn't?*
- ❏ *What did you change in your prototype?*
- ❏ *How well did your design work?*

TOOLS & TECHNIQUES

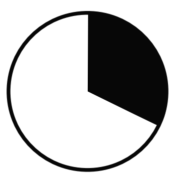
Slow it Down

Students use a variety of materials to slow the passage of a bouncy ball down an inclined plane to model how civil engineers design roadways on steep slopes.

SCIENCE TOPICS	PROCESS SKILLS	GRADE LEVELS
Forms of Energy Forces and Motion	• Define Problem • Identify Criteria and Constraints • Develop Solutions • Test, Evaluate, Refine • Communicate Results	3-8

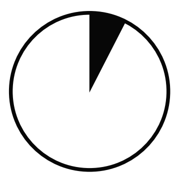
TIME REQUIRED

Advance Preparation



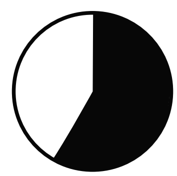
20 minutes

Set Up



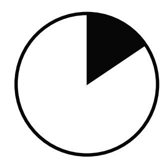
5 minutes

Activity



35 minutes

Clean Up



10 minutes

SUPPLIES

For each group of students:

- ❏ *Piece of pegboard, ~1’x2’*
- ❏ *2 blocks, ~3” long x 2” wide x 1” high*
- ❏ *1 bouncy ball*
- ❏ *Prototyping Supplies: ~20 golf tees, ~20 popsicle/craft sticks, ~20 rubber bands, ~25 straws (cut in half), ~25 pipe cleaners (cut in half)*
- ❏ *Stopwatch (optional)*

Other supplies:

- ❏ *At least one stopwatch for the class*
- ❏ *Yard stick*

SAFETY PRECAUTION: Elastic bands and bouncy balls can store large amounts of energy, turning themselves or other materials into projectiles.

ADVANCE PREPARATION

- ❑ *Copy procedure sheet, one per group.*
- ❑ *Copy Test Report, Appendix C, one per group.*
- ❑ *Gather Supplies.*
- ❑ *Cut straws and pipe cleaners in half.*
- ❑ *Before doing the activity with the class, practice the activity procedure below.*

SET UP

- ❑ *Prepare the classroom so that each team will have a workspace with a flat table (or the floor) for testing.*

INTRODUCING THE ACTIVITY

Let students speculate before offering answers to any questions. The answers at the right are provided primarily for the teacher's benefit.

Note that this is just one example of a context for this activity. Another option may include a chute for fragile materials in a factory, or an amusement park ride.

Ask the students the following questions in **bold.**
Possible student answers are shown in italics.

Has anyone ever driven in a car (or ridden their bike, or hiked) up or down a mountain before? What did you notice about these paths?
Allow students to tell some short stories about their experiences. The goal is to determine the types of roads and/or paths which engineers design to traverse steep slopes. The back and forth, zigzag pattern is known as a switchback.

Why do you think steep paths are designed this way?
Facilitate a discussion about some of the benefits of zigzags, switchbacks, or paths with added texture for going down steep inclines. The primary reason for these paths is to decrease the amount of slope, which makes climbing easier and prevents users from going too fast downwards, and prevents erosion. See the section following for more in-depth background information.

Our Engineering Firm has been asked to design a roadway for this slope, something that works better than going straight up and down the slope. How would we do that?
Let the group brainstorm ideas. Listen for opportunities to point out the criteria and constraints they will be working with, as well as how they'll be measuring their success with the stopwatch. Note that they may suggest lowering the inclined plane to decrease the slope. Tell them this is not an option, because it would mean tearing down the whole mountain. They may also want a good reason for creating the path, such as an excellent view for visitors, a weather or other scientific station, or a site for a radio/water tower (see Wire Towers activity).

Younger or inexperienced students may need some hints on how to use the materials to create pathways. Avoid showing them specific ways to build walls or pathways. Instead, encourage them to think about other things they've seen which are designed to slow objects down.

CLASSROOM ACTIVITY

1) Introduce the activity.
2) Have each group set up their ramp by propping one end of the pegboard onto the blocks. If necessary, use a ruler to measure the height to ensure consistency. Approximately 4.5 inches is appropriate for a 2 foot long pegboard, but feel free to experiment with other slopes.
3) Pass out the materials to the groups and have them spend 1 minute silently looking at the supplies and thinking of the designs. No building at this point.
4) Give students 5 minutes to discuss and sketch design ideas with their group; still no building at this point.
5) Allow them to build for about 10 minutes before the first round of testing.
6) Have students test their prototypes, being consistent with the number of tries each team gets, how and where they release the ball, and when you start and stop the stopwatch.

7) Give an additional 5-10 minute build period to see if the students can improve on their designs, to make the paths slower. Repeat as necessary to fill your allotted activity time.
8) Give the students a 5 minute warning before asking them to stop working.
9) Allow enough time at the end for each group to describe their design to the class and run several tests (about 5 minutes per group). Ask the groups to disassemble their design and clean up.
10) Follow up the activity with a discussion of the engineering process the groups used.

CLASS DISCUSSION

During testing, ask each group of students to describe their design. Use some of the suggested questions below.

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

Did you have enough materials?
Students may point out that they ran out of one or two specific materials. Ask how they overcame the shortage.

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

After all the teams have tested their designs, ask them to clean up their materials. During clean up or right after, have a discussion with your class about the process.

What were some of the most successful designs? What made them successful?
Answers will vary depending on your class's designs.

EXPLANATION

In-depth background information for teachers and interested students.

Often, engineers work to make things faster. However, there are also times when they wish to design a system that works slower or makes things easier. In this activity, students are experimenting with the slope of an inclined plane. The plane remains fixed at a particular slope, similar to the slope of a mountainside. Using a model, they are able to design a different pathway for the ball to take along the plane, which will change the slope it is traveling.

Slope is a measure of the ratio of rise, or change in height, divided by the run, or distance traveled. A larger slope means a steeper incline. A slope of zero means there is no change in height. An inclined plane can have different slopes, depending on how you travel across it. Going directly from top to bottom will have the steepest slope. However, traveling diagonally will decrease it and moving directly across will reduce it to zero.

People who design roadways are typically known as Civil Engineers. Nearly all roadways have some degree of slope, and engineers must pay careful attention. A roadway with a slope that is too steep will be impassable to many vehicles, and extremely dangerous for others. By creating switchback patterns they decrease the slope of a roadway, making it easier to climb and safer to descend. However, Civil Engineers must balance cost and safety, designing their paths to be effective with the least amount of resources. Users will complain if the roadways are too long and winding, slowing them down far more than necessary.

OPTIONAL EXTENSIONS

A. Measurement
Ask the students to measure the length of the path the ball takes on its way down the slope. Use strings and rulers. By dividing the distance by the amount of time, students can determine the average velocity of the ball on their design.

B. Multi-use
Similar to the From Here to There Activity, you can add the criteria that several different types of balls must be able to travel down their designed path. Balls of the same size will be easy; balls of different sizes will be more challenging.

C. Field Trip
Take a trip to a local hiking or biking trail on a mountain. Study the layout of the trail and try to find evidence of erosion. Look at some of the ways that trail designers and maintainers try to prevent or minimize trail erosion, and develop a plan for limiting erosion on their model.

CROSS-CURRICULAR CONNECTIONS

SUBJECT	Activity
Math	Use the pegboard to simulate a coordinate graph and have students create a map of their pathway. They can determine the slope of each pathway on the board as well. Advanced students can determine what the slope is when the board is then placed at an angle. Graph a comparison of the times teams achieved to the length of their path.
Language Arts	Have your students write a trail guide for their path or directions on how to drive the road. Where should they turn? What would users see and hear?
History	Choose a nearby state park with a switchback trail. Find when it was established and what the land was used for before it was a park.

PROJECT SHEET: SLOW IT DOWN

1 **What's the Problem?**

- ❏ *What are the criteria for success?*

2 **What are the constraints?**

- ❏ *What are the limits on materials?*

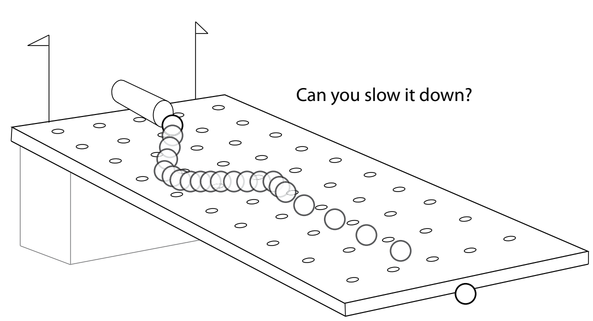
3 **Develop a solution**

- ❏ *Assemble your hill by placing one end of the pegboard onto the blocks, the other end should be resting on the table.*
- ❏ *Use a ruler to make sure the end resting on the blocks is _______ tall.*
- ❏ *Examine the materials and share your ideas with your team.*
- ❏ *Sketch your design.*

4 **Test and Refine**

- ❏ *For each round of testing, record your results on the data report.*
- ❏ *What parts of your design worked? What parts didn't?*
- ❏ *What did you change in your prototype?*
- ❏ *How well will your design work?*

SSSSSLOW IT DOWNNNN



TOOLS & TECHNIQUES

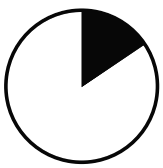
Wire Towers

Students build wire structures and analyze their efficiency

SCIENCE TOPICS	PROCESS SKILLS	GRADE LEVELS
Forces and Motion	• Define Problem • Identify Criteria and Constraints • Develop Solutions • Test, Evaluate, Refine • Communicate Results	**3-8**

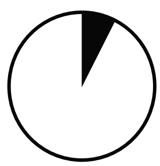
TIME REQUIRED

Advance Preparation



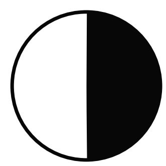
10 minutes

Set Up



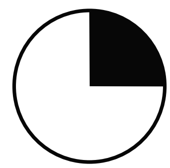
5 minutes

Activity



30 minutes

Clean Up



15 minutes

SUPPLIES

- ❑ *Copper wire, 14 gauge solid core, 12’ lengths (at least 5 per team). Note: Younger students may have difficulty manipulating 14 gauge wire. Try using 18 gauge or pipe cleaners with smaller nuts.*
- ❑ *Wire cutters for teacher use.*
- ❑ *Safety goggles for teacher use.*
- ❑ *2” nut (1 per team).*
- ❑ *Yard/meter stick (1 per team).*

If you choose an Optional Extension below, be sure to consider the supplies you will need.

ADVANCE PREPARATION

- ❑ *Copy Master A, one per team.*
- ❑ *Collect some pictures of different types of towers, such as cell phone, radio antenna, or water tower, or assign this as homework prior to class.*
- ❑ *Wearing safety goggles, cut copper wire into 12 inch (33cm) lengths.*
- ❑ *Gather supplies for each group:*
  - ❍ *One nut*
  - ❍ *5 wire lengths*
- ❑ *Before doing the activity with the class, practice the activity procedure below.*

SET UP

- ❑ *Assemble materials.*
- ❑ *Divide the class into teams of 2-3 students.*

INTRODUCING THE ACTIVITY

The goal of this activity is to get students thinking about how their designs can be evaluated. The students build towers using a heavy weight and bendable wires. Several contexts can be used, such as designing a water tower for a town or constructing a communications tower on Mars.

Start by asking the students what types of towers they have seen before. Ask why towers are used. Ask why a high tower is important. Explain that they will be engineering their own towers, but that height isn't everything in this challenge.

Ask them to list some of the challenges engineers would have when building towers. The list will probably include things such as:

- ❍ *Environmental hazards such as earthquakes or winds.*
- ❍ *Limited materials, budget, time, etc.*

Introduce the materials students will be using. Explain the goal—to get the nut as high as possible while using the materials at hand most efficiently. The nut can represent anything you choose, such as a water tank or electronics package. Explain that you will be measuring their structures from the table to the highest point of the nut, and that they should keep track of the number of wires they use.

Safety Precaution: The ends of the wire pieces can be pokey. Instruct students to use them carefully. Have students wear safety glasses if possible.

CLASSROOM ACTIVITY

Students should work in groups of 2-3. Each group follows the directions below.

1) Introduce the activity.
2) Pass out the materials to the groups and have them spend at least 1 minute silently looking at the supplies and thinking of the designs. No building at this point.
3) Give students 5 minutes to discuss and sketch design ideas with their group; still no building at this point.
4) Allow them to build for about 10 minutes before the first round of testing and measuring.
5) Give an additional 5-10 minute build period to see if they can make their design even higher, sturdier or with less materials.
6) Give the students a 5 minute warning before asking them to stop working.
7) Allow enough time at the end for each group to describe their design to the class and run one or more tests (about 5 minutes per group). Students groups may need to present to only one other group in order to finish during the period.
8) Instruct groups to disassemble their design and clean up.
9) Follow up the activity with a discussion of the engineering process they used.

CLASS DISCUSSION

Ask the students to identify some of the criteria and constraints involved with this problem. How might the constraints on materials be different in different contexts? Would you use the same materials in a tropical environment as on a cold or arid environment? What would change if you were building a tower on Mars?

Let's look at some of the most efficient designs. What are some of the design ideas that seemed to work well? What are some things that didn't work out as well?

Get the students to describe which design ideas used the wires most effectively.

If we wanted to make the most efficient tower using these design ideas, what might it look like? The goal here is to get the students to identify the best solutions to implement.

EXPLANATION

In-depth background information for teachers and interested students.

Engineers often must design structures for height, but they always have to design structures for efficiency. Often, the engineering firm which demonstrates the most efficient use of resources will receive the contract to implement their design.

Different types of towers require height for different reasons. A water tower needs be taller than the highest building it supplies water to. A pump brings water to the tank at the top of the tower from a reservoir or well. It then uses gravity to deliver the water to the homes and buildings it supplies. This is a far more efficient use of electricity than pumping water directly to consumers. Taller towers also create more water pressure. A 100ft (30m) tower will produce 43.5 psi (300kPa) of pressure, which is enough for most applications, such as flushing a toilet or running a shower in an upstairs bathroom.

Water towers are particularly challenging to design because of the large amount of mass resulting from the water tank at the top. Most water towers are one to two hundred feet tall. Often, local topography is used to provide additional height. Look for local water towers on the tallest hills. Some tall buildings also have their own dedicated water towers on the roof. In Midwestern towns without hills, the water tower may be the iconic feature of the local landscape.

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

Radio and cell phone towers also require height, but this is because of the need for long lines of sight for their electromagnetic signals. The taller the tower, the farther they can broadcast. Height does not just translate into longer distances, but also minimizes blockage by hills and valleys. Telecommunications companies use vast networks of these towers to achieve the greatest coverage possible. Again, efficiency in the layout of this network is critical.

These types of towers typically have small electronics packages arrayed on the outside of the tower. These arrays are much less massive than water tanks, making it easier to construct them taller. However, the greater height also brings an increased danger from aircraft and particularly wind. Of course all structures must contend with many other risks, such as earthquakes or extreme weather.

OPTIONAL EXTENSIONS

A. Budget
This activity already has an element of budgeting built into it. However, it does lend itself well to a bidding scenario. In this extension, allow your students to play with the materials for a short time before accepting bids, or allow them to develop prototypes using pipe-cleaners and smaller nuts. Afterwards, ask them to submit a bid for how many wires they will require to reach a minimum height of 10in (30cm). See the Budget extension in Appendix A for more information.

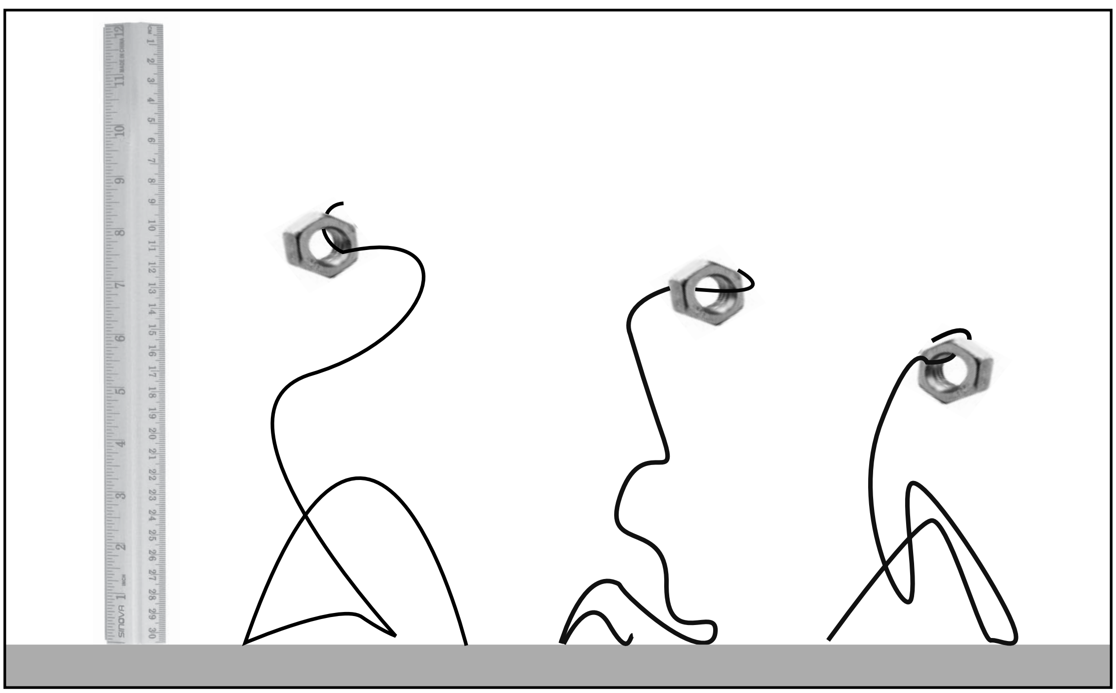
B. Network design
Present students with a map of a town or region and ask them to determine the best placement of towers to achieve the maximum coverage. You can assign different levels of coverage to different types of towers. Provide a budget and let them choose the types and placements of towers.

C. Presentation
Ask student teams to describe their overall best design to the funding board of a town. The town is concerned by how much the tower will cost and how safe it is, and also how it will look when constructed. There are many examples of decorated or disguised towers from around the world for inspiration.

CROSS-CURRICULAR CONNECTIONS

VISUAL ARTS	Describe the tower as a public art piece. Show pictures of other large scale sculptures in public places. Ask students to write artist statements about their sculpture.
MATHEMATICS	Graph the results of the student designs. Use these representations to predict how high they could build the tower given 20 wires, or 30 wires.

Wire Towers



PROCEDURE FOR WIRE TOWERS

1 **What's the Problem?**

What are the criteria for success?

2 **What are the constraints?**

What are the limits on materials?

3 **Develop a solution**

What will your design look like?

What materials will you use?

4 **Test and Refine**

What parts of your design worked? What parts didn't?

What did you change in your prototype?

How well will your design work?

TOOLS & TECHNIQUES

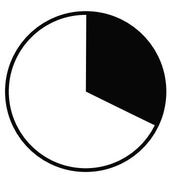
Go With The Flow

Students build aqueducts to move water from point A to point B

SCIENCE TOPICS	PROCESS SKILLS	GRADE LEVELS
Forces and Motion Forms of Energy	• Define Problem • Indentify Criteria and Constraints • Develop Solutions • Test, Evaluate, Refine • Communicate Results	3-8

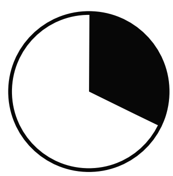
TIME REQUIRED

Advance Preparation



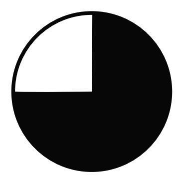
20 minutes

Set Up



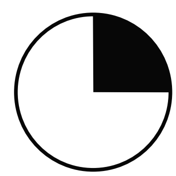
20 minutes

Activity



45 minutes

Clean Up



15 minutes

SUPPLIES

- ❑ *Paper towel tubes: 5-10 per group. (optional: PVC tubing cut in half lengthwise will have a higher initial cost, but will save materials costs over time.)*
- ❑ *Toilet paper tubes: 5-10 per group.*
- ❑ *1 Pitcher with measurements marked; or clean, empty milk jugs that students have pre-marked with units of measure.*
- ❑ *Permanent marker to label jugs.*
- ❑ *Source of water.*
- ❑ *Masking tape.*
- ❑ *Yogurt cups (optional: cut out bottom).*
- ❑ *Aluminum foil.*
- ❑ *Wax paper.*

- ❑ *Sturdy boxes (for aqueduct height and support).*
- ❑ *Outdoor space to do the activity; alternatively, a tarp or kiddie pool to catch water leaks and spills.*

ADVANCE PREPARATION

- ❑ *About 2 weeks in advance, ask students to save and bring in paper towel and toilet paper tubes; and clean empty milk jugs (unless you plan to use pitchers).*
- ❑ *If you will be using plastic milk jugs as water containers, have students learn measurement by creating a measurement grid on the jug with a permanent marker.*
- ❑ *Copy Go With The Flow project worksheet for each student.*
- ❑ *Gather supplies.*
- ❑ *Before doing the activity with the class, practice the activity procedure below.*

SET UP

- ❑ *Have several areas outside that will serve as "Design Testing areas" for the experiment. (It might be optimal to conduct this activity early or late in the year when it is warm). In this area:*
  - ❍ *Lay out a large tarp for groups to work on or set up "kiddie" pools around the room for groups to work in.*
  - ❍ *Multiple pitchers of water.*
  - ❍ *Assorted prototyping supplies for designs.*

INTRODUCING THE ACTIVITY

Ask the students the following questions in **bold**. Possible student answers are shown in italics.

Let students speculate before offering answers to any questions. The answers at the right are provided primarily for the teacher's benefit.

Everyday we see things all around us that are the result of engineering. Some of these things, like computers, help us do really complex things. However, engineering inventions can also help us with simple things. We use products of engineering everyday to help with our most basic needs.

Can you think of examples?
Cars, bikes, phones, bridges, calculators, forks, knives, spoons, trains, lightrail (MAX), coffee machine, refrigerator, toothbrush, soap dispenser, elevator, escalator, etc.

What do you need everyday to stay alive?
Food, water, energy, plants, animals, air, candy, etc.

One of these basic needs is water. Humans, plants, and animals need water to survive. Moving water to our homes and farms is critical.

How do you get water when you're home? Where does that water come from?
Pumps, pipes, faucets, lakes, deep wells, sewers, showerhead, hose, lake, rain, snow, etc.

Moving water is a project engineers have worked on throughout history. Today, we are going to do an engineering challenge that involves moving water from one place to another, just as engineers have throughout history. Explain the challenge for the day. This may include a topography map, a pre-constructed terrain, or a simple "Point A" to "Point B" design. Introduce students to the supplies.

Try not to spill water! Any water that leaks out of your design means less water for the people, crops and livestock.
Explain how successful engineering projects minimize waste while using the least amount of resources.

Safety Precaution: To avoid falling, no running when there could be water on the floor.

CLASSROOM ACTIVITY

1) Introduce the activity.
2) Demonstrate that the basic "aqueduct" can be made from half of a paper towel tube lined with a layer of foil for waterproofing. Toilet paper tubes can also be used, but they are not as versatile due to their length. These "aqueducts" can be supported with cans, boxes or other paper towel tubes.

3) Demonstrate to the class how to test the aqueduct design. Pour a measured amount of water slowly into the top of the duct. Make sure there is a reservoir at the bottom to collect the water. Measure the water and see what percentage of the water successfully makes the journey. This activity could be as simple as creating a downhill path for younger students.
4) Pass out the materials to the groups and have them spend at least 1 minute silently looking at the supplies and thinking of designs. No building at this point.
5) Give students 5 minutes to discuss and sketch design ideas with their group; still no building at this point.
6) Allow them to build for about 10 minutes before the first round of testing and measuring.
7) Give an additional 5-10 minute build period to see if they can enhance their design to collect even more water and/or use fewer materials. Repeat as necessary to fill your allotted activity time.
8) Give the students a 5 minute warning before asking them to stop working. Allow enough time at the end for each group to describe their design to the whole class and run several tests, usually about 5 minutes per group. Ask the groups to disassemble their design and clean up.
9) Allow enough time at the end for each group to describe their design to the class and run one or more tests, usually about 5 minutes per group. You may have to sub-divide the class into smaller groups for presentation to accommodate the class length.
10) Instruct the groups to disassemble their design and clean up.
11) Follow up the activity with a discussion of the engineering process they used.

CLASS DISCUSSION

After cleaning up their prototypes, give the groups some time to reflect on their process and complete their activity sheets. Bring them together for a larger discussion.

What was something you tried that was hard?
Connecting the aqueduct pieces, getting water to travel uphill, waterproofing, etc.

What was something you wanted to do and couldn't?
Have the water move faster or slower, direct water to more than one end point, make the water go "uphill", etc.

Are there any materials you think would work better?
Hoses, bendy straws, twist ties, suction cups, chop sticks, shower curtain, duct tape, etc.

What was something you tried that didn't work the way you thought it would?
Using the paper towel rolls without lining them, supporting the ducts with chop sticks, making the aqueducts turn without losing water, etc.

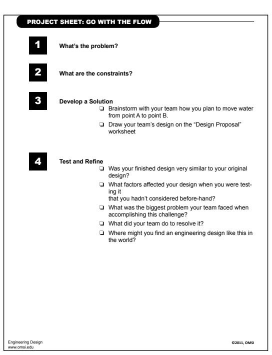
What was something interesting that you discovered from this activity?
That people have been doing this for so many years, it's difficult to change directions, tubes would work better than an open system, etc.

EXPLANATION

In-depth background information for teachers and interested students.

An aqueduct is a water supply system used to move water from one source to another location. Springs, wells, dams, and rivers are common sources of water for aqueducts. Water moves through an open channel or in enclosed pipes. Aqueducts are designed to take advantage of gravity, the force that pulls everything downhill towards the center of the Earth. Aqueducts slope gradually from the source of the water to its destination. When the topography of a location doesn't allow for a slope downward, pumps are used to push the water up to a point at which the water can then flow back downward.

Flow rate measures the amount of fluid that flows within a given time period. There are a number of factors which can affect the flow rate. Topography determines how steep the slope will be, and how many times water will need to be pumped up. Water flows more quickly the straighter the path and the steeper the slope. The width of the channel or pipe and the material used also affects the flow rate. Materials used for aqueducts should be non-porous to ensure that no water is lost due to leaks or absorption. Aqueducts that carry drinking water need to be free of lead or any other material that would make the water harmful to drink. Smooth materials offer less friction allowing water to move more quickly. Even temperature affects flow rate. Liquids expand when warmed, creating more pressure, causing the flow rate to increase. As water cools, it becomes less dense, decreasing pressure, thus decreasing the flow rate. The viscosity (the ability of a liquid to resist flowing) of water decreases with temperature. This is similar to warmed honey flowing faster than cold honey.


PROJECT SHEET: GO WITH THE FLOW

1 What's the problem?

2 What are the constraints?

3 Develop a Solution
- ❑ Brainstorm with your team how you plan to move water from point A to point B.
- ❑ Draw your team's design on the "Design Proposal" worksheet

4 Test and Refine
- ❑ Was your finished design very similar to your original design?
- ❑ What factors affected your design when you were test-ing it that you hadn't considered before-hand?
- ❑ What was the biggest problem your team faced when accomplishing this challenge?
- ❑ What did your team do to resolve it?
- ❑ Where might you find an engineering design like this in the world?

Engineering Design
www.omsi.edu
©2011, OMSI

OPTIONAL EXTENSIONS

A. Water Transport with Obstacles

Many times, water cannot be transported easily in a direct line due to obstacles. These obstacles include mountains, valleys, roads and buildings. Obstacles can easily be integrated into the design challenge:

- ❏ *Pre-make an "environment" with cans and boxes to transport the water through and over. For instance, a "road" can be laid out. Students have the option to build a bridge over the road, or to blast a tunnel under the road (which could be expensive and dangerous). If the students are old enough, they could make environments for other groups, or make environments based off of topographical maps (see extension follow).*
- ❏ *A building or large mountain right in the middle of the preferred path can lead to some creative designs. Students would have to curve their design around the "mountain" or use something like a siphon system to get the water over the "mountain."*

B. Multiple Destinations

After completing the challenge once, try it again with multiple destinations.

C. Uneven Distribution

Once the students have figured out how to get water to multiple destinations, have them distribute the water unevenly, with more going to one destination (i.e., a farm) and less going to a second and/or third destination (i.e., single family residence).

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

D. Floods and Capacity

Even the best water transport system has limited capacity. Too much water and the system floods. This might not be a problem for an aqueduct, but it poses significant risks for something like a sewer system.

- ❏ *The flooding potential of the sewage is why engineers built the Big Pipe Project in Portland. Students can build their own "Big Pipe Projects" to deal with floods.*
- ❏ *To test capacity, pour water into the system at increasing rates until the system cannot hold more water. There is also a potential math/physics connection here with calculating the capacity and the rate of flow.*

CROSS-CURRICULAR CONNECTIONS

History	Study the ancient Romans and their aqueducts. Show pictures that include the 5 basic parts of an aqueduct. What type of government was in place in the Roman Empire? How did this affect the construction of aqueducts? Did everyone benefit from the aqueducts equally?
Art	How might you make the aqueducts look better without compromising the structure? Could they be blended into the terrain? How? Why might this be important?
Ecology	How might these structures affect the habitats and lives of animals in area?
Geography	Topographical Map: Draw a topographical map of your terrain. This can work whether or not the student designed the terrain they are working on.
Physics (Flow rate)	Have students determine the difference in the rate of flow of the water when it is traveling through different apparatuses. Does the size or shape change the rate of flow?
Physics	Have students use different materials to flow through one segment of their completed aqueducts (honey, syrup, hand soap, rubbing alcohol, a batter made of flour and water). How does the change in viscosity change the speed/flow rate?
Global Studies	Can you think of areas where there isn't much water? How do engineers make these locales habitable?
Math	Have students measure flow rate and calculate ratios, percentages and fractions for water successfully transported or separated.

PROJECT SHEET: GO WITH THE FLOW

1 **What's the problem?**

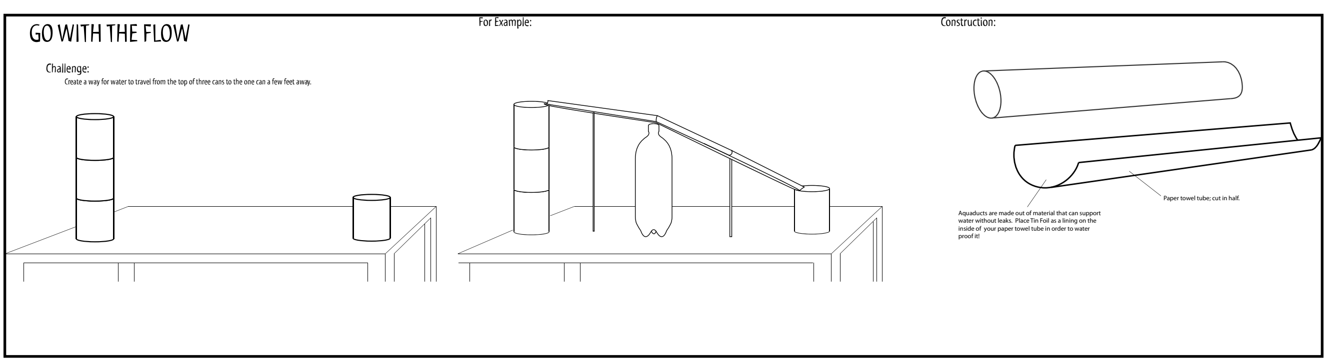
2 **What are the constraints?**

3 **Develop a Solution**

- ❏ *Brainstorm with your team how you plan to move water from point A to point B.*
- ❏ *Draw your team's design on the "Design Proposal" worksheet.*

4 **Test and Refine**

- ❏ *Was your finished design very similar to your original design?*
- ❏ *What factors affected your design when you were testing it that you hadn't considered before-hand?*
- ❏ *What was the biggest problem your team faced when accomplishing this challenge?*
- ❏ *What did your team do to resolve it?*
- ❏ *Where might you find an engineering design like this in the world?*
- ❏ *How fast were you able to pour water down your aqueduct?*



TOOLS & TECHNIQUES

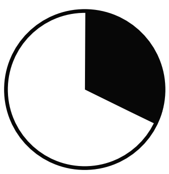
Float On!

Students will learn about seed dispersal and then design and test a seed structure that will utilize wind dispersal.

SCIENCE TOPICS	PROCESS SKILLS	GRADE LEVELS
Forces and Motion Gravity Forms of Energy	• Define Problem • Identify Criteria and Constraints • Develop solutions • Test, Evaluate Refine • Communicate Results	3-8

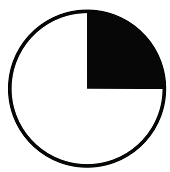
TIME REQUIRED

Advance Preparation



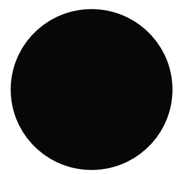
20 minutes

Set Up



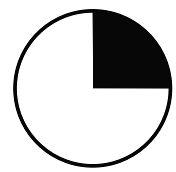
15 minutes

Activity



60 minutes

Clean Up



15 minutes

This activity can be done in as little as an hour, but can be extended well beyond this time through extensions. The activity can be integrated into an extended and comprehensive unit about plants, biodiversity or ecology.

SUPPLIES

Seed station supplies.
For each station have an assortment of seeds. Here is a list of seeds that are easy to obtain.

- ❏ *Grass*
- ❏ *Dandelion*
- ❏ *Coconut*
- ❏ *Fruit (strawberry, mango, tomato)*
- ❏ *Maple seed*
- ❏ *Pine cones*

- ❏ *2-3 dissecting microscopes (optional)*
- ❏ *10 magnifying glasses (optional)*

Seed Design Supplies.
Per student or pair of students:

- ❍ *$8^{1/2}$ X 11 sheets of paper*
- ❍ *Tape*
- ❍ *Scissors*
- ❍ *1 bean (soy bean, lima bean, black bean etc).*
- ❍ *2-3 meter sticks*
- ❍ *1-2 box fans*

ADVANCE PREPARATION

- ❏ *Copy Float On! Project worksheet*
- ❏ *Copy Test report student worksheet*
- ❏ *Copy Sketchbook student worksheet*
- ❏ *Gather supplies for seed stations*
- ❏ *Gather prototyping materials for each student*
- ❏ *Optional: Print Plant Adaptations for Flight poster for reference: http://www.uga.edu/srel/kidsdoscience/sci-method-copters/plant-seed-poster.pdf.*

SET UP

- ❏ *Set up seed stations:*
  - ❍ *Have 1 station for every 4-5 students.*
  - ❍ *At each station have an assortment of seeds displayed.*
  - ❍ *Have a few dissecting scopes and magnifying glasses available for use (optional).*
- ❏ *Set up 2 box fans in the classroom*
  - ❍ *Mark off with tape on the floor: 50cm, 100cm, 150cm etc.*
- ❏ *In the front of the classroom, have the supplies for seed design set out.*

INTRODUCING THE ACTIVITY

Begin your lesson by asking the students the following:

What does "to disperse" mean?
To go away, to move away, to leave.

Why does a seed need to disperse?
So that it doesn't compete with other plants.

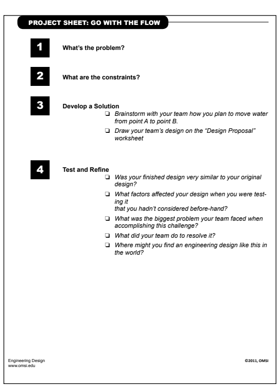
What would happen to the plant species if the seeds did not disperse?
They may not grow new plants or reproduce. The plants would die off.

What are some ways seeds are dispersed?
By animals, by wind, by water.

Is a coconut a seed? How is it dispersed?
Yes. By the ocean/water.

CLASSROOM ACTIVITY

1) Introduce the activity.
2) Have students break into groups and go to one of the seed stations. For each seed, have the students:
   - ❍ *Describe its features.*
   - ❍ *Sketch a diagram of the seed.*
   - ❍ *Speculate on how the seed is transported and explain what observations were used to make this conclusion.*
3) Tell students they will now be designing a seed dispersal mechanism of their own, based on wind. Discuss some examples of seeds that use wind.
4) Pass out the materials to the groups and have them spend at least 1 minute silently looking at the supplies and thinking of designs. No building at this point.
5) Give students 5 minutes to discuss and sketch design ideas with their group; still no building at this point.
6) Allow them to build for about 10 minutes before the first round of testing and measuring.


PROJECT SHEET: GO WITH THE FLOW

1 What's the problem?

2 What are the constraints?

3 Develop a Solution
- ❑ *Brainstorm with your team how you plan to move water from point A to point B.*
- ❑ *Draw your team's design on the "Design Proposal" worksheet*

4 Test and Refine
- ❑ *Was your finished design very similar to your original design?*
- ❑ *What factors affected your design when you were testing it that you hadn't considered before-hand?*
- ❑ *What was the biggest problem your team faced when accomplishing this challenge?*
- ❑ *What did your team do to resolve it?*
- ❑ *Where might you find an engineering design like this in the world?*

Engineering Design
www.omsi.edu
©2011, OMSI

7) During testing, have them record the results of three tests on their test report.
8) Give an additional 5-10 minute build period to see if they can enhance their design to float farther. Repeat as necessary to fill your allotted activity time.
9) Give the students a 5 minute warning before asking them to stop working. Allow enough time at the end for each group to describe their design to the whole class and run several tests, usually about 5 minutes per group. Ask the groups to disassemble their design and clean up.
10) Follow up the activity with a discussion of the process the groups went through.

Do you see any similarities between the designs that dispersed the farthest?

Which seeds from the class traveled the farthest?

What were the features of the seeds that traveled farthest?

Did the structures of the seeds that traveled the farthest appear similar to structures found in nature?

Consider your own seed. What could you change that might make your seed travel farther?

How was this experiment similar to what might occur in nature?

How was this experiment different from what occurs in nature?

What other variables in the natural environment will affect how far a seed travels from the parent plant?

Can you think of other materials you might use to enhance your designs?

EXPLANATION

In-depth background information for teachers and interested students.

Plants need methods of spreading their seeds. If they didn't have ways to do this, their seeds would just fall down and cluster right near the original parent plant. Seeds move around in different ways. Some attach themselves to hiker's shoes or clothing, some hitch a ride on the fur of animals, or are ingested then excreted by animals, some float in water, and others float on air currents. Observing how seeds have adapted in various ways to disperse through the air has inspired aviation design. Taking cues from nature to inform engineering is called **biomimicry**. Some seeds have physical properties similar to helicopters, parachutes, or gliders. By observing how seeds with these characteristics make use of air travel, we can better understand how engineered flight machines, such as planes, helicopters, gliders and parachutes work and canbe improved.

In helicopter seeds, such as maple seeds, the mass is concentrated in the seed, and the wings or propellers branch out pretty far from this center of gravity. The seeds are heavier on one side than the other causing the seed to spin in the air. As the seed spins, there is greater **lift** as the speed of air over its wings increases. The tapered ends of the seed wings reduce **drag**.

Laminar flow is the smooth flow of air. It reduces drag and requires an aerodynamic, streamlined surface. If laminar flow is interrupted, loss of lift occurs, and more drag is created. Lift is created when air is diverted downwards. More technically speaking, lift is a force created when a moving flow of gas is turned.

Parachute seeds, such as milkweed and dandelions, have arched crowns like umbrellas or parachutes, and they float on the air accordingly. Parachutes help seeds, and people, float by pushing air molecules out of the way. As objects fall, they have to push through air molecules. The bigger an area, the more air molecules that need to be moved, causing an object to slow down as it encounters air resistence (drag). This is why parachutes work – they create a larger surface area, plus their shape makes it difficult for the air molecules to move aside.

The long gliding ability of the Zanonia seed inspired the creation of the first glider which lead to further observations and experimentation by aviation enthusiasts such as the Wright Brothers, informing their design for motor-powered aircraft. The wings on each side of a glider help

produce the lift needed to keep the seed (or aircraft) in the air. Moving faster creates more lift. Moving faster also creates more drag.
Falling objects on Earth experience two forces, one that pulls and one that pushes. Gravity is a force that pulls things towards the center of the Earth. Drag is a term used to describe the force of the upward push of air resistance. When the forces are equal, an object has reached its terminal velocity, and will fall at a constant rate. All objects fall at the same rate when there is no air resistance. Without this force, weight would have no bearing on how fast an object falls. On Earth, the acceleration of an object falling near Earth's surface, free from air resistance, is approximately 9.8 meters (or 32.18 feet) per second. Every second, acceleration increases, going from 9.8 meters in the first second to 19.16 meters the next second, and so on. Results are different in outer space, depending on the force of gravity.

However, most objects encounter some form of air resistance. Objects reach terminal velocity when the drag force equals the force of gravity. At low speeds, the drag force is less than the gravity force, so falling objects accelerate. As they accelerate, drag increases, until this force equals the weight of the falling object. Acceleration only occurs when forces are unbalanced. Unbalanced forces cause a change in speed and/or direction. It is important to note that acceleration does not mean just moving faster. Acceleration only happens when there is a change in velocity—the rate at which an object changes its position. Acceleration depends on force and mass; mass being the amount of material an object has. All objects on Earth experience a certain amount of force per mass, due to the gravitational field on Earth. This only comes into play when there is air resistance. The acceleration of an object is directly proportional to the net force on the object and indirectly proportional to the mass of the object. Terminal velocity is dependent on the ratio of weight to drag.

OPTIONAL EXTENSIONS

A. Weight
Have the students record both the distance their seeds travel and the weight of the seed structure as well. Compare the weight of seed structures that were successful with structures that were less successful. Does the size of the seed structure matter?

B. New Materials
Allow the students to repeat the experiment again but let them use any materials they want.

C. Seed Collections
Have the students create seed collections from seeds they find at home and around school. They should also keep note of the plant the seed came from, the habitat it was found in, and the time of year.

CROSS-CURRICULAR CONNECTIONS

Math	Students can plot and analyze the data they collect. For example, students can plot distance versus the weight of the seeds. Do you find any correlations between weight and distance?
Art	Have the students create models of their seed structures and make up a plant that is paired with that seed. They could also make poster displays about their plants and draw how their seed disperses.
Writing	Students can conduct research projects to investigate how airplanes work and describe the forces involved in flight.

PROJECT SHEET FLOAT ON

1 What's the Problem?

- ❏ *What are the criteria for success?*

2 What are the constraints?

- ❏ *Limited materials*
- ❏ *Weight*
- ❏ *The seed structure can only be tested and modified twice before the final trials.*
- ❏ *The seed cannot fall out during the trial runs.*

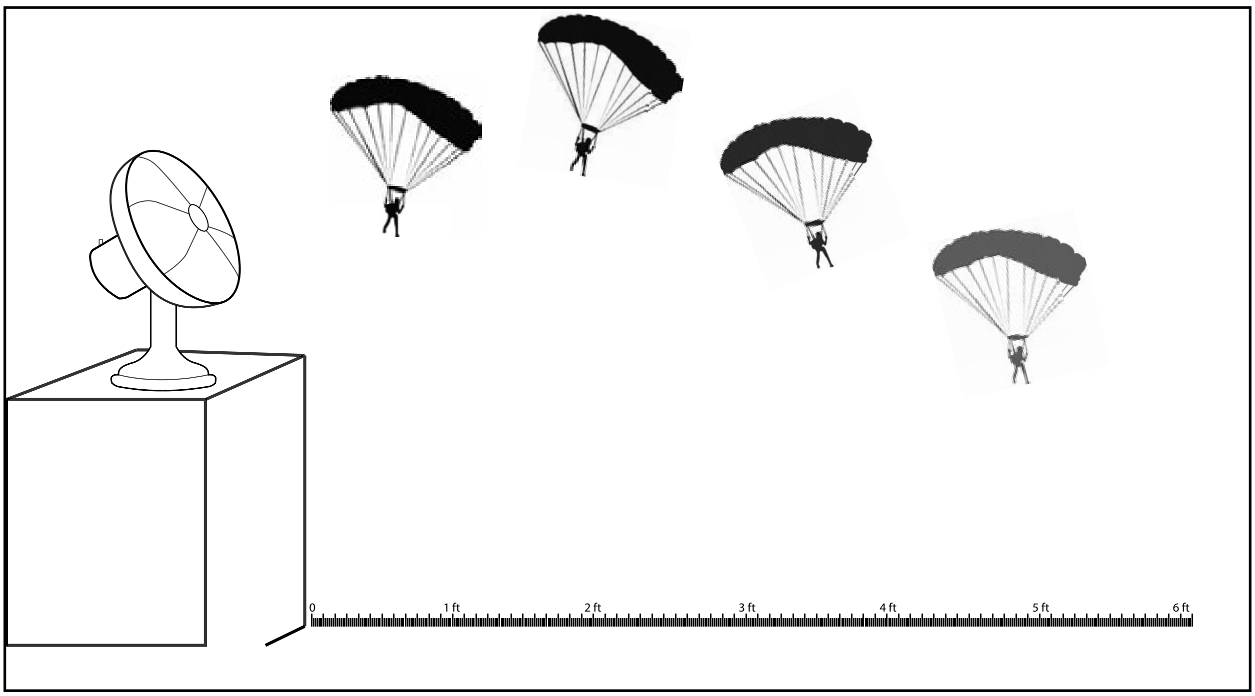
3 Develop a solution

- ❏ *What will your design look like? Draw your design on the "sketch pad" worksheet. Make sure to sketch your final design and note any changes between the two.*
- ❏ *Do you need to use all of the paper provided?*
- ❏ *How are you going to attach the seed?*

4 Test and Refine

- ❏ *How do you find the average distance for your three trials?*
- ❏ *How well did your design work?*
- ❏ *What changes (if any) did you make to your seed design?*
- ❏ *Why did you make these changes?*

Float On



Introducing *ENGINEER IT!* Activities

Let the student speculate before offering answers to any questions. The answers in italics are provided primarily for the teacher's benefit.

What is an engineer?

Students may offer many partial or complete ideas, such as:

- *engineers drive trains*
- *engineers build things*
- *engineers draw things to build*
- *engineers make things work*

What do engineers make?

Students may suggest many possibilities such as buildings, cars, appliances, bridges, planes, etc.

The American Heritage dictionary definition of engineering is "the application of scientific and mathematical principles to practical ends, such as, the design, construction, and operation of efficient and economical structures, equipment, and systems."

Work as a class, in groups, or individually to rewrite the definition of engineering to make it understandable for another class or for younger children. Encourage discussion of terms such as "practical" and "economical." Have students write their definition on index cards, in their notebook, or on the board.

An example student definition of engineering is:
"To use science and math to design, build, and use something useful that works well and doesn't cost too much time and money to make."

Have you ever been an engineer? When?

Students may talk about building with Lego® blocks, designing a doll house, drawing a bridge, making a play structure from cardboard boxes, testing paper airplanes, etc.

Follow this discussion with any of the *ENGINEER IT!* classroom or museum field trip activities.

Draggin' Boats

Students design and build dragon boats using milk cartons. The boats may be tested at the "Boat Hulls" water tank of the *Engineer It!* exhibit.

Grade Levels	Science Topics	Key Science Skills
K–6 (7–8 with optional extensions)	Buoyancy Design technology Scientific inquiry Velocity Mass Variables	Observing Predicting Interpreting data Making models Measuring Hypothesizing Controlling variables

Time Required

Advance Preparation	30–60 minutes (rinsing milk cartons)
Set Up	5 minutes
Activity	30–50 minutes
Clean-up	5 minutes

What you'll need

- School lunch milk cartons
- Bleach
- Paper clips or ornament hangers
- Scissors
- Waterproof heavy tape (duct, gaffer's, etc.)
- Pipe cleaners
- Wallpaper water tray (long narrow plastic tub for wetting wallpaper available in paint and décor departments or at home builders supply stores)
- Drinking straw
- String
- Small metal weight (nuts & bolts, old keys, etc.)
- Screwdriver or other pointed instrument

Optional Extensions

- Decorations: permanent markers, yarn, googley eyes, paper, Popsicle sticks, sequins, felt, etc. for dragon's head and flags.
- Waterproof glue
- Stopwatch or watch with a second hand

- Meter stick or yardstick

Do this first!

Prepare the milk cartons

1. Have students collect school lunch milk cartons in advance (3 per student or student group).
2. Make a dilute bleach solution by adding one capful (about one tablespoon) of bleach to a gallon of water in a large mixing bowl.
3. Rinse school lunch milk cartons under running water.
4. Dip milk cartons in the bleach solution.
5. Rinse milk cartons under running water to remove the bleach.
6. Allow to air dry.

Prepare the classroom testing tank

1. Use a Phillips head screwdriver or other pointed instrument to punch a centered hole in one end of the plastic wallpaper tub near the upper lip (above the water line).

   CAUTION: Hold the tub over wood or the ground to absorb the impact of the screwdriver.
2. Cut a drinking straw to about 1 1/2 inches. Insert the straw into the hole in the plastic tub. The straw will prevent the hole's rough edges from slowing the string when testing. Tape the straw in place if necessary to keep it from sliding.
3. Cut a piece of string a little longer than the length of the wallpaper water tray. Thread the string through the straw
4. Attach a weight to the end of the string outside the tub. You may use a large nut/bolt, old keys, or other metal objects of a similar weight.
5. Tie a fixed loop at the other end of the string. This will attach to the hook on the front of the boat.

Paper clip hooks

Paper clip hooks that attach the boat to the string for testing may be made in advance. See Student Procedure: "Create a Dragon Boat, Step 3."

Student handouts

Copy one worksheet per student from Handout Master section.

Getting Ready

1. Place supplies (student worksheets, three milk cartons, a long strip of tape, and four pipe cleaners) at each group or individual workstation.
2. Place the classroom testing tank on a table. The weight on the string should hang freely over the table's edge.
3. Add water to the tank until the water is within two inches of the top.

Why do this?

Overview of Dragon Boats

Legend says that many centuries ago, on the fifth day of the fifth lunar month, Chu Yuan, a very wise and respected government official, drowned in the Mi Luo River. When the local people discovered that Chu Yuan had drowned, they went out in boats to search for him. When they could not find him, the people threw rice into the river so the fish would eat the rice instead of Chu Yuan. This happened many centuries ago, but each year people in China, Taiwan, and other countries around the world remember Chu Yuan and celebrate Chinese culture by having dragon boat races and eating "Tsung Tze" (sticky rice cakes wrapped in leaves and tied with colorful strings). Today, people around the world race Dragon Boats.

What is a dragon boat?

Dragon boats are boats that look like dragons. They are made of three parts: a head, a body, and a tail. The dragon head is in the front of the boat. The body is in the middle of the boat. The tail is at the end of the boat. The paddlers sit in the body of the boat. Dragon boats may have between 10 and 22 paddlers. During the race, the drummer, near the head of the boat, beats a drum so the paddlers will row together to the drummer's rhythm. Near the tail of the boat is a helmsman (see vocabulary in "Explanation" section). He or she uses a rudder (see vocabulary) to help steer the dragon boat. Near the head of the dragon boat is a flag catcher. The flag catcher usually leans over the head of the dragon boat to grab the flag at the end of the race. The first team to complete the course and catch the flag wins the race.

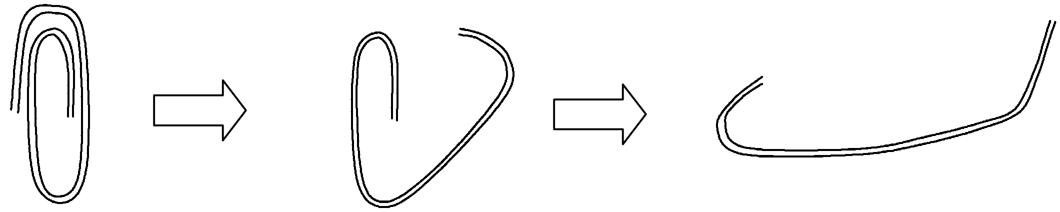
What to do

Create a Dragon Boat

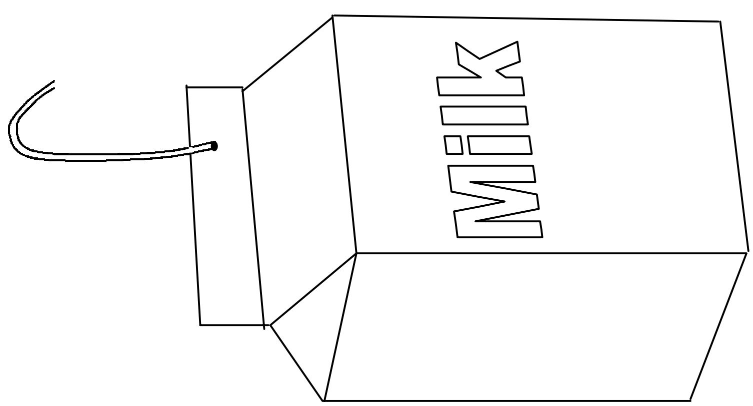
1. Draw a picture of your dragon boat design on your worksheet.

2. Build your dragon boat.
   - You may use up to three milk cartons per boat.
   - Make a head, a body and a tail for your dragon boat.
   - You may cut the milk cartons.
   - Be sure to leave room for the paddlers.
   - Use pieces of heavy tape to connect the pieces of your boat.
   - The boat must be waterproof.

3. Make a hook for your boat by bending a paper clip or ornament hanger.



4. A hook needs to be attached to the front of the boat. The hook should be taped to the top half of the boat so that it will be above the waterline when the boat is placed in the water. The string for testing your boat will attach here.



Test your boat in your classroom

1. Be careful not to spill water onto the floor.
2. Pull the string from the water tank. Attach the looped end to the hook on your boat.
3. Put your boat in the water and let go.
4. Record the time it took for your boat to travel the length of the tank.
5. Record your observations.

Test your boat at the *Engineer It!* Exhibit

1. Pull the string from the water tank. Attach it to the hook.
2. Put your boat in the water and let go!
3. Record the time it took your boat to travel across the water tank.

What's happening?

Have students record and compare different designs and their results.

Let's say you are going to design and make a dragon boat. What design elements do you think are important?
(For example, boat hull shape, weight, craftsmanship; see Explanation section.)

Which design elements do you think are important for a *fast* boat?

Does the shape of a boat's hull affect how it goes through the water? How?

What are different ways to design a Dragon Boat using milk cartons?
Have students come up with as many different designs as they can and make predictions about which design characteristics will be most important. Students may write, draw or tell their plans.

Have students (individually or as a class) describe possible design elements. Include these elements in a chart. Rate which elements will have the most impact on speed (e.g., a boat with a flat hull will go fastest).

How did the results vary with the design of the boat?

What design element(s) seemed to make the boat go fast?

What design element(s) seemed to slow the boat down?

Did you make any changes while making your boat? What happened?

If you could change the design of your boat, what would you do?

How would this change affect the boat's performance? What is your hypothesis?

More stuff to do!

A. Calculate the average velocity of the boats. One student releases the boat while the other measures the time (see Cross Curricular Integration: Math).
Velocity = Distance Covered ÷Time

B. Depending on boat size, dragon boats have crews of 12 or 24 people. Mark the waterline for your empty boat with a permanent marking pen. Add objects (marbles, erasers, or clay) to the boat for a "crew." Mark the waterline. Now retest your boat. How does the added weight change your results?

C. Investigate whether boats will float at different levels in saltwater and fresh water. To make saltwater, add a tablespoon of salt to every cup of water. Stir until dissolved. Using a permanent marking pen, mark the waterline for your boat in a container of fresh water. Now place the boat in the container of saltwater and mark the waterline. What do you observe?

Explanation

Boat terms

Bow	The front of the boat.
Helmsman	The person who is steering the boat.
Hull	The main structural body of the boat. The part that keeps the water out of the boat.
Rudder	A flat surface attached behind or underneath the stern, used to control the direction the boat is traveling.
Stern	The back part of the boat.

The shape of a boat's hull can affect the speed at which the boat travels. The streamlined shape of Dragon Boats helps them go through the water quickly. Dragon Boat racing is popular around the world. There are two types of dragon boats: Chinese and Taiwanese. Chinese dragon boats have larger heads than Taiwanese boats.

Milk carton boats that have flat hulls tend to skim over the top of the water, moving faster than boats with bow-shaped hulls. Elements that produce drag (either in the bow or the stern) tend to make boats slow down. "Fixed rudders" (the pointy ridge of a closed carton) tend to provide stability only when enough mass weighs down the boat in the water. Keep in mind that results may vary.

Scientific Inquiry

This activity allows students to practice their scientific inquiry process skills. In classroom scientific inquiry, students are scientists. They are observing, discovering, asking questions, testing, and drawing conclusions about their boats.

"Draggin' Boats" allows students to explore a boat's design elements using the materials provided. They will use their background knowledge to create a dragon boat that they think will perform well in the testing tank. After building and testing their boats, they may have new ideas about how to improve their boats. At this point, a more formal scientific inquiry may take place.

The following table describes a simplified version of the steps of scientific inquiry, along with examples of each step from the “Draggin’ Boats” activity.

Scientific Inquiry	Student action
Use background knowledge and observations to form a testable question: What are you changing and what are you measuring?	Student uses knowledge of boats and first design experience to ask: “If I make my boat longer, will it go faster?” (The length is changing, time is measured.)
Design an experiment to answer the question	Student plans to build a boat with the same original design, but make it longer than her first one. She may make a third boat even longer.
Collect data, using tables, graphs, pictures, etc., to represent the data	Student makes a table to record her data from the three boats. She times the three boats in the testing tank. She may repeat each trial and average her results.
Use collected data to answer the original question	Student summarizes results and uses data to answer her question.
Suggest further experiments or testable questions	If the results are unexpected (length didn’t seem to affect speed), she may suggest another testable question, such as “Will a boat with a flat hull go faster than one with a curved hull?”

How does it all fit in?

MATH Test the speed of your boat several times and calculate its average speed.   Calculate a class average (see Optional Extension A).

Hypothesize and predict which of the design elements will affect the speed the most. Test and record the data. Make a chart that includes your predictions and the results. Explain your results.

CULTURAL STUDIES Read a story about how dragon boat races began, from *Red eggs and dragon boats: celebrating Chinese festivals*, by Carol Stepanchuk.

ART Glue yarn, googley-eyes, pipe cleaners, etc., to the front of the cartons and create dragon heads for the boats.

Study several examples of Chinese writing/art. Copy a Chinese character (or create your own symbol) for your boat. Put this character on a flag for your boat or draw it on your boat with permanent ink.

Create paper dragons, Chinese lanterns, or multi-colored braided bracelets. See *Working with Paper* and *Red eggs and dragon boats: celebrating Chinese festivals.*

LANGUAGE ARTS Research the cultural history of dragon boat races. Imagine that this is part of your heritage. How would you describe the meaning of dragon boats to future generations?

Describe the structural and cultural differences / similarities between the Chinese and Taiwanese dragon boats.

As a class, prepare and eat *"Tsung Tze"* (sticky rice cakes). See *Red eggs and dragon boats: celebrating Chinese festivals.*

MUSIC Make drums to beat a rhythm for rowing a dragon boat.

DESIGN TECH Study other types of boats. Try designing, building, and testing ocean liners, barges, or catamarans. How do they compare with the dragon boats?

References

Moiz, Azra. *Cultures of the World—Taiwan*. New York: Marshall Cavendish Corporation, 1995.
General information about Taiwan on a range of topics including geography, economy, art, festivals. Many colorful photos of people and what life is like in Taiwan.

Rotner, Shelley. *Boats Afloat.* New York: Orchard Books, 1998.
Large colorful photographs and simple text present many different types of boats and their uses. Children are shown using boats in a safe manner. The engaging photos may appeal to many ages (pre-K to adult).

Portland-Kaohsiung Sister City Association, Portland, OR

Graham, Ian. *Boats, ships, submarines, and other floating machines*. New York: Kingfisher Books, 1993.
Text, illustrations, and diagrams examine different kinds of boats and how they work. Includes simple experiments and activities.

Stepanchuk, Carol. *Red eggs and dragon boats: celebrating Chinese festivals*. Berkeley, Calif.: Pacific View Press, c1994.
This is a book about the celebration of Chinese festivals. Most of the Chinese festivals are based on the lunar calendar. It includes festivals such as the Chinese lunar New Year, Clear Brightness festival, Full-month red egg and ginger party, Dragon Boat festival and Moon festival.

Working with Paper. New York: Franklin Watts, 1971.
Pictures and simple instructions for paper projects, including a dragon, and Chinese lanterns.

Goldstein, Peggy. *Lo'ng is a Dragon*. Berkeley, CA: Pacific View Press, 1991.
Black-and-red drawings show how Chinese characters have changed over time, from pictures to ancient characters to modern characters. Guides to pronunciation and how to draw the characters are included.

Williams, C. A. S. (Charles Alfred Speed). *Encyclopedia of Chinese symbolism and art motives*. Intro. By Kazimitsu W. Kato. New York: Julian Press, 1960 [i.e. 1961].
An alphabetical compendium of legends and beliefs as reflected in the manners and customs of the Chinese throughout history. A re-issue of the work originally titled *Outlines of Chinese symbolism and art motives* published [1931] revised 1932." Includes bibliographies.

Handout

Draw a picture of your boat. Label the parts.

Test your boat in the water tank and record observations.

Describe what happened.

Observations

Was your boat fast or slow?
Did it go straight or curve?
Did it sink or float?

Would a change make your boat go faster or better? Try changing your boat and retesting (draw new boat and record observations on back).

Supplies Worksheet

Instructions: Copy this worksheet and calculate the supplies you already have and what you still need. Then copy your completed worksheet to give to a teacher aid or a parent helper to gather the supplies designated in the right-hand "Supplies Needed" column.

No. of students: ________ No. of groups: ________

Supplies	Amount Needed	Supplies on Hand	Supplies Needed
Clean milk cartons	1–3/group		
Paper clips or ornament hangers	1/group		
Scissors	1/student		
Heavy tape (duct, gaffer's, etc.)	Up to 2 ft./boat		
Decorations: pipe cleaners, permanent markers, yarn, googley eyes, paper, popsicle sticks, sequins, felt, etc., for dragon's head and flags.	4 pipe cleaners/group		
Glue			

Shaking It!

Students build a room in a shoebox and test it on an earthquake simulator.

Grade Levels	Science Topics	Key Science Skills
K–8	Earth science Earthquakes Earthquake safety	Investigating Making models Observing Predicting

Time Required

Advance Preparation	15 minutes
Setup	5 minutes
Activity	30 minutes
Testing	Recommended throughout the day, 2 minutes per student
Cleanup	5 minutes

What you'll need

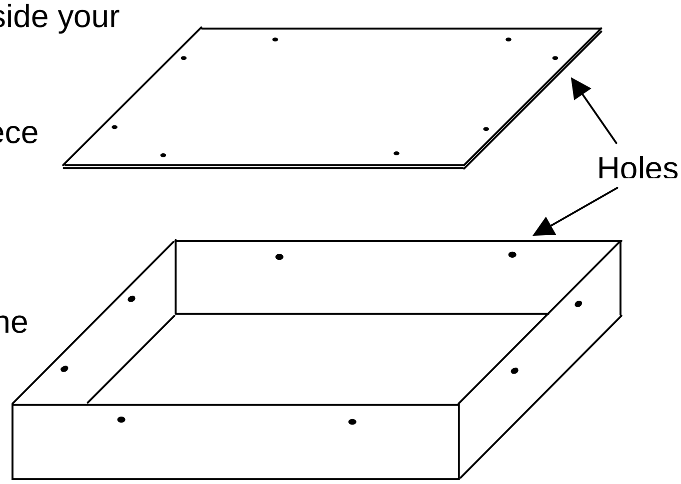
- Copy paper box and lid
- Rubber bands
- String
- Single hole puncher
- Brads
- Optional: 1 1/2 ”-2” rubber bouncing balls
- Optional: beads
- Shoe boxes
- Small jewelry boxes
- Cardstock/manila folders/index cards
- Scissors
- Markers (to decorate)
- Assorted small “recyclables” to make furniture and knick knacks–beads, pipe cleaners, marker tops, plastic film canisters, etc.

Do this first!

Make the Earthquake Testing Site (ETS)

1. Cut a flat piece of cardboard out of the copy paper box. Make it about 1"x1" smaller than your box lid. It will fit inside your box lid when the ETS is complete.

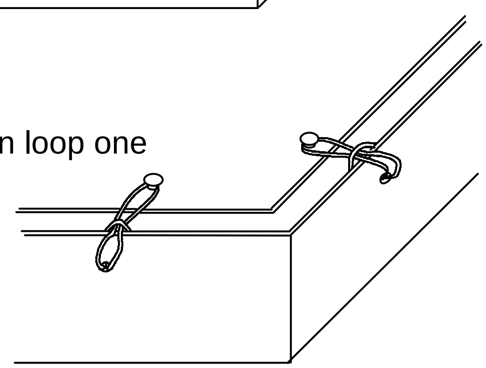
2. Punch a total of 8 holes in the flat piece of cardboard—two holes per side about 1/2 inch from the edge.



3. Insert brads into these 8 holes in the cardboard. Open prongs to secure the brads in place.

4. In the box lid, punch holes 1/2 inch from the bottom (open end of lid) to correspond to the holes in the flat cardboard.

5. Thread rubber bands through the box lid holes, then loop one end of the rubber band through the other end to secure.



6. Secure the other end of the rubber bands around the corresponding brads on the flat cardboard piece inside the box lid. This piece should now be suspended above the box lid.

7. Punch holes in the middle of two adjacent sides of both the box lid and cardboard.

8. Through these holes, thread 1-11/2 feet of string. Tie one end of each string to the inner flat cardboard and let the other end hang free. Students will pull these strings to create the "earthquake."

9. OPTIONAL: Tie a bead to the outside ends of the string for a handle.

Getting Ready

1. Clean off workspace.
2. Set out supplies for each student or student group.
3. Set up the Earthquake Testing Site (ETS) in an accessible area so that students may test their rooms throughout the day.

Why do this?

Ask students: Have you ever been in an earthquake? How did it feel?

Ask students: How can people prepare their houses for an earthquake?

Students may suggest putting breakables in cabinets, locking cabinets, etc.

What to do

Design and build your room

1. Choose a type of room to design and construct. You may choose any room, such as a bedroom, kitchen, classroom, library, etc.
2. You will use the supplies in your classroom to build your room. First decide what you want in your room and design your room.
3. Build your room in a shoe box putting in furniture, decorations, and supplies. Remember to think about which things can be attached and which things cannot. For example, can you glue books to a bookshelf?

Test your room on the ETS

1. Carefully carry your room to the Earthquake Testing Site (ETS). Place your room in the ETS. You may have to set up the furniture at this time.
2. Hold the ETS as steady as you can. Have two other students pull the ETS strings to simulate an earthquake for 30 seconds.
3. Write down what happens.

Redesign your room

1. Redesign your room to see if you can design an earthquake-resistant room.
2. Build your room according to your new design.
3. Test your room to see if it is more earthquake-resistant than your first model.
4. Record your observations.

Send your creative solutions to webmaster@omsi.edu (or serc@omsi.edu). Please be sure to put the words "Shaking It" in the subject area of your E-mail message. Some responses will be posted on the *Engineer It!* Web site.

More stuff to do!

A. Change the design of the ETS to more closely model a specific type of earthquake. You may change the number and location of shaker strings or rubber bands. Have students predict the effect of the changes, then test the same structure on the various Earthquake Testing Sites and compare results.

B. Try the *Engineer It!* activity on building a communications tower to test on the ETS. Coming to OMSI's *Engineer It!* Website (http://www.omsi.edu/) in June 2000.

How does it all fit in?

LANGUAGE ARTS

Write a descriptive story about your memory of an earthquake or how you imagine it might be. Include sights, sounds, smells, and feelings.

Journal about telephone usage. How would your life be changed without a phone for a week?

Read earthquake legends from around the world, then write your own earthquake legend.

Vocabulary and spelling of earthquake-related words (see Glossary of Earthquake Terms in the Handout Masters section).

MATH

How much water do you need for cleaning, cooking, and drinking? Calculate the amount per family per day, per class per week.

LIFE SCIENCE

How are plants and animals impacted by earthquakes?

SOCIAL STUDIES

Study the "Ring of Fire," a geographical area containing the majority of the world's volcanic and seismic activity.

Student reports on history of significant earthquakes, such as the ones in San Francisco, New Madrid, Japan, Greece, Mexico, etc.

HEALTH AND

Earthquake-proof your classroom. Tour your school and make

SAFETY suggestions for earthquake-proofing your school.

INTERNET RESEARCH Use the following sites to begin your earthquake research.

http://www.fema.gov
FEMA (Federal Emergency Management Agency)

http://www.fema.gov/kids/
FEMA for Kids

http://vulcan.wr.usgs.gov/
Cascade Volcano Observatory

http://www.neic.cr.usgs.gov/
National Earthquake Information Center

What's happening?

An earthquake is a result of a sudden slip on a **fault** plane. This action releases energy in the form of waves that travel through the surrounding earth. The shaking we feel during an earthquake is actually the waves traveling through rock. Earthquakes can occur when **tectonic plates** grind and scrape against each other or when **magma** moves within a volcano. There have even been man-made earthquakes!

There are two basic types of earthquakes. **Strike-slip earthquakes** occur on vertical fault planes as the rock on one side of the fault slides horizontally past rock on the other side of the fault. The San Andreas fault in California produces strike-slip earthquakes. **Dip-slip earthquakes** occur on faults that are at an angle to the earth's surface. Movement of the rock during these earthquakes is up and down.

There are two scales to measure earthquakes by. The **Modified Mercalli Intensity Scale** has no mathematical basis and is an arbitrary ranking based on observed effects. These effects include certain key responses such as people awakening, movement of furniture, damage to chimneys, and total destruction. The more commonly used **Richter Scale** is a mathematical scale based on the amplitude of seismic waves recorded by **seismograph**s.

The largest earthquakes in the contiguous United States include:

1. New Madrid, Missouri – 1812 – magnitude 7.9
2. Fort Tejon, California – 1857 – magnitude 7.9
3. Owens Valley, California – 1872 – magnitude 7.8
4. Imperial Valley, California – 1892 – magnitude 7.8

5. New Madrid, Missouri – 1811 – magnitude 7.7
6. San Francisco, California – 1906 – magnitude 7.7
7. Pleasant Valley, Nevada – 1915 – magnitude 7.7
8. New Madrid, Missouri – 1812 – magnitude 7.6
9. Landers, California – 1992 – magnitude 7.6
10. Kern County, California – 1952 – magnitude 7.5

The largest earthquake ever recorded was a magnitude 9.5 earthquake that struck Chile in 1960.

Earthquake Safety Tips

Before an earthquake:

1. Check for hazards in your home
   - ✓ Bolt bookcases and other heavy objects to a wall
   - ✓ Place large or heavy objects on lower shelves
   - ✓ Hang heavy items, such as pictures or mirrors, away from beds, couches, or any "high traffic" areas
   - ✓ Brace overhead light fixtures
   - ✓ Secure the water heater by strapping it to the wall studs and bolting it to the floor

2. Identify safe places in each room
   - ✓ Under sturdy furniture such as a heavy desk or table
   - ✓ Against an inside wall
   - ✓ Away from glass (windows, mirrors, etc.)

3. Have disaster supplies on hand
   - ✓ Flashlight and extra batteries
   - ✓ Portable battery-operated radio and extra batteries
   - ✓ First aid kit and manual
   - ✓ Emergency food and water—remember to allot one gallon of water per person per day
   - ✓ Non-electric can opener
   - ✓ Essential medicines
   - ✓ Cash
   - ✓ Sturdy shoes
   - ✓ Fire extinguisher
   - ✓ Crescent and pipe wrenches to turn off gas and water, if needed
   - ✓ Extra pet food

4. Develop an emergency communication plan
   - ✓ In case family members are separated during an earthquake, develop a plan for reuniting after the disaster.
   - ✓ Ask an out-of-state relative or friend to serve as the "family contact." After a disaster, it's often easier to call long distance. Make sure everyone in the family knows the name, address, and phone number of the contact person.

Kids’ Activity Survival Kit

Adapted from the FEMA for Kids web site
http://www.fema.gov/kids/

Students may want to put together their own survival kit. Items can be stored in a duffel bag or backpack near the family’s emergency supplies. Items in the Kids’ Activity Survival Kit can include:

- ✓ A few favorite books
- ✓ Crayons, pencils, pens, and paper
- ✓ 2 favorite toys such as a doll or action figure
- ✓ A deck of cards
- ✓ A puzzle
- ✓ Small people figures and play vehicles, such as MicroMachines, Hot Wheels, Beanie Babies, etc.
- ✓ Favorite stuffed animal or puppet
- ✓ Favorite pillow or blanket
- ✓ Pictures of family and pet
- ✓ A “keep safe” box with a few treasures that make you feel special

Glossary of Earthquake Terms

Aftershock	an earthquake that follows a large earthquake and has an epicenter at or near the initial earthquake. An aftershock does not have to be smaller than the initial earthquake. Aftershocks do decrease in frequency and magnitude over time.
Dip-slip earthquakes	a type of earthquake in which one block of rock slides horizontally past another block of rock.
Epicenter	the point on the Earth's surface directly above the hypocenter.
Fault	a thin zone of crushed rock between two blocks of rock. A fault can be any length, from centimeters to thousands of kilometers.
Hypocenter	the point where the earthquake rupture begins, usually deep within a fault. This is also known as the focus.
Magma	naturally occurring molten rock. Magma is commonly found in volcanoes.
Modified Mercalli Intensity Scale	an earthquake intensity scale. It is not based on mathematics but on observed occurrences.
Richter Scale	a numerical, mathematical scale of earthquake magnitude.
Seismograph	an instrument that records earthquake waves.
Seismogram	a record of earthquake waves made by a seismograph.
Strike-slip earthquake	a type of earthquake where one block of rock slides up or down relative to another block of rock.
Tectonic plates	large segments of the outer layer of the Earth that move relative to one another.

Supplies Worksheet

Instructions: Copy this worksheet and calculate the supplies you already have and what you still need. Then copy your completed worksheet to give to a teacher aid or a parent helper to gather the supplies designated in the right-hand "Supplies Needed" column.

No. of students: ________ No. of groups: ________

Supplies	**Amount Needed Per Group**	**Supplies On Hand**	**Supplies Needed**
Copy paper box and lid	1/class		
Rubber bands	8/class		
String	1-5 ft./class		
Single hole puncher	1/class		
Brads	8/class		
Shoe boxes	1/group		
Cardstock/manila folders/index cards	81/2 x 11"/group		
Scissors	1/group		
Markers (to decorate)	Several/group		
Assorted small "recyclables" to make furniture and knick knacks—beads, pipe cleaners, marker tops, plastic film canisters, etc.	Several/group		

Wingin' It

Students learn about the Bernoulli effect by building an airfoil (airplane wing) and making it fly.

Grade Levels	Science Topics	Key Science Skills
5–8	Aerodynamics of lift Bernoulli effect Force Velocity Pressure	Formulating models Observing Inferring Questioning Controlling variables Hypothesizing Making models

Time Required

Advance Preparation	10 minutes
Set Up	5 minutes
Activity	25–35 minutes with introduction and discussion
Clean-up	2 minutes

What you'll need

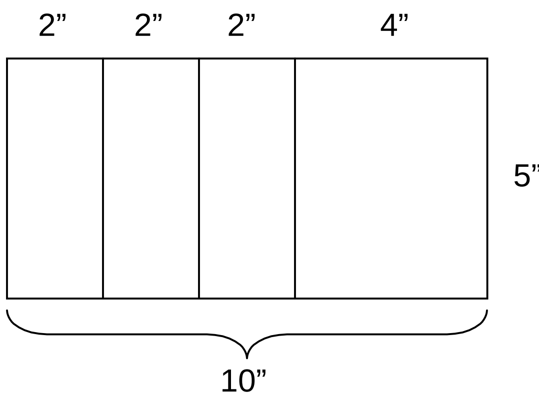
- Regular weight copy paper
- 5" x 10" corrugated cardboard
- Ruler
- Bamboo skewers (shish kebab sticks, available in grocery stores) or knitting needles
- Clear tape
- Scissors
- Pencil
- Small electric fan
- Cardboard, cardstock, manila file folder or heavy weight paper 4"x6" or larger
- Pencil-top erasers

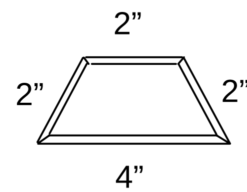
Do this first!

Assemble the base

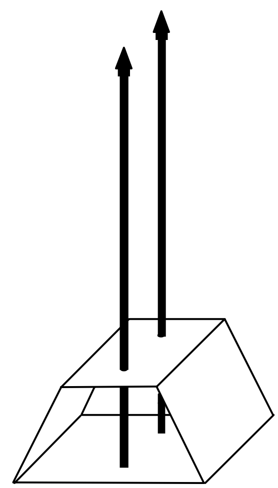
Build two bases for the class to use as wing testers.

1. With a 5”x10” piece of corrugated cardboard, make a fold at 2”, 4”, and 6” from the end.
2. Fold the cardboard into a box-like structure with open ends shaped like a trapezoid with the widest edge on the bottom.
3. Tape the structure together into this shape.





4. Repeat steps 1 – 3 to make a second base.



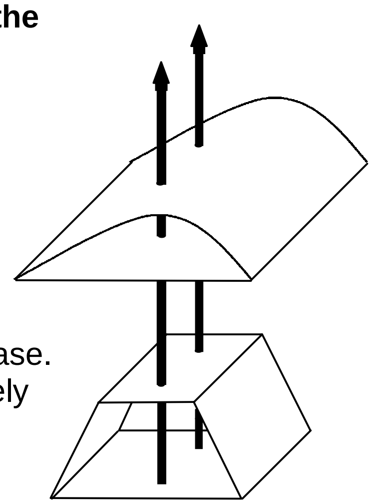
Insert the rods

1. Make two dots 3 in. apart in the center of the top side of the cardboard base.
2. Poke the rods (skewers or needles) through the top of the base at the dots. Make sure that the rods are straight with the ends secured in the bottom of the base to keep them stationary.

CAUTION: Place pencil end erasers on the sharp ends of the skewers or knitting needles for safety.

Make a sample paper wing

1. Photocopy one “wing worksheet” for each student or student group, and extras for optional extensions.
2. Follow directions under “Student Procedure,” steps 1–3 to make your sample wing.
3. Place the wing over the skewers onto your assembled base. The holes should be large enough that the wing falls freely to the base over the rods.



Getting Ready

1. Tape the trapezoidal base with the rods to the table.

2. Set up the fan. Test and adjust using the sample base and wing. Position the fan so that the wind blows over the top of the wing, and the wing rises up the rods. Start with the fan approximately 12 in. away from the base and adjust the distance as needed. Depending on the size and capacity of your fan, you may need to adjust its height, angle, or distance from the base.

CAUTION: Always replace eraser tops on skewer ends immediately after airfoil is placed on base to avoid eye injuries with active students.

Why do this?

Ask Students: How do planes fly?
Students may suggest that the motor pulls it up, the air lifts it up, propellers push it up, or air pressure forces it up.

In reality, there are many factors, which contribute to the airplane lifting into the sky. The Bernoulli effect is one of those factors.

Is an airplane wing like a bird's wing? How is it similar or different?

Students may suggest that an airplane wing is different than a bird's wing because it is not made of feathers, or because it doesn't go up and down. They may suggest it's the same as a bird's wing because it sticks out sideways from the body.

Show the students a sample wing for the activity. This type of wing is called an "airfoil."

Hand out the Wing Worksheet and ask students *not* to fold it yet.

Make some observations about the placement of the dotted "fold" line on the Wing Worksheet.

Students will notice that it is not in the middle. It does not divide the wing into equal halves.

Make observations about the wing you have made.

Students will notice that it is curved on top and pointed on one side.

Demonstrate how to gently fold the wing along the fold line without making a heavy crease. Demonstrate how to tape the edges of the wing neatly together to form the wing. (See "Make a paper wing" Student Procedure, steps 1–2.)

Consider a red ant starting at the dashed line and walking along the top (the long arched surface) of the wing. Now suppose a black ant starts in the same place at the same time and travels along the bottom (short flat surface) of the wing. Which ant will travel farther? If the two ants meet at the same time at the end of the wing, which ant will have to go faster?

The red ant traveling along the top of the wing will have to go faster since it will have to travel farther in the same amount of time. The red ant travels a greater distance because the top surface of the wing is longer.

Normally ants do not walk across airplane wings, but air and wind does pass across the wing.

What is air/wind made of?

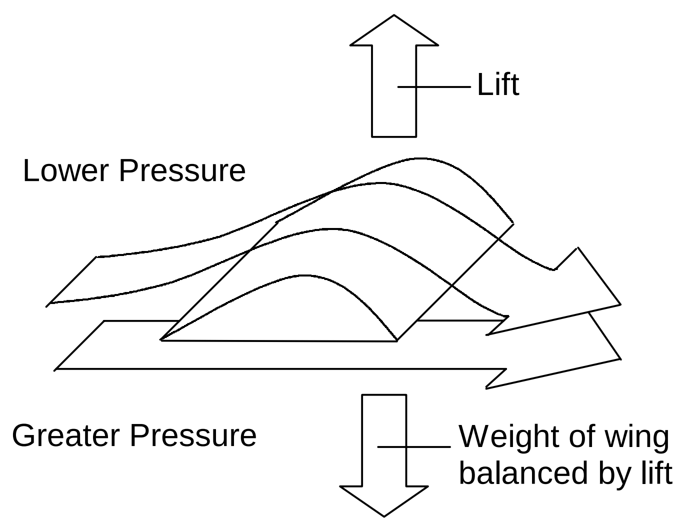
Students may suggest any of the following, all of which are correct: gas, oxygen, nitrogen, carbon dioxide, molecules, atoms.

Remind students that we can't always see molecules of a gas (like the air they're breathing right now!). Sometimes we can see gases, such as the steam (gaseous water molecules) from a teapot. If air is made of molecules, imagine wind (moving air) passing over our airplane wing.

Do the air molecules blowing over the top wing have to travel farther than the air molecules blowing along the bottom of the wing?

Answer: Yes. Air molecules travel farther over the long top of the wing, just as the ant has to walk farther. Since the air molecules on the top surface of the wing have to go farther in the same amount of time, they are moving faster than the air molecules on the lower wing surface. When the molecules move faster over a greater distance, they are more spread out (less dense).

When molecules move, they put pressure on whatever they strike. The more molecules that strike the object, the more pressure or force there is on the object. Because there are more air molecules per inch along the bottom of the wing, the pressure of the molecules hitting the bottom of the wing is greater than the pressure from the less dense layer of molecules on the top surface of the wing. This pressure difference causes the wing to be pushed or lifted upward.

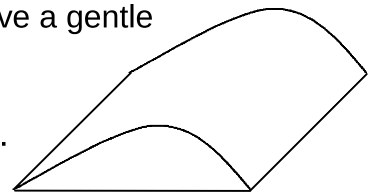


What to do

You will take turns testing your wings on the wing tester.

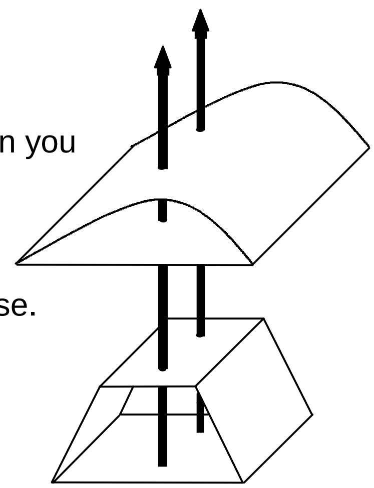
Part A: Make a paper wing

1. Make a light fold at the dashed line so that the printed surface faces out. Do not crease heavily. Note: the fold divides the paper into two *unequal* parts—a longer section and a shorter section.
2. Bring the corners of the paper together, causing the longer side to arch. Tape the edges of the paper together. The wing should have a gentle curve on the upper surface.
3. With the pencil, poke holes through the paper at the circles on both the upper and lower sides of the wing. Make a hole large enough for the yellow part of the pencil to pass through.

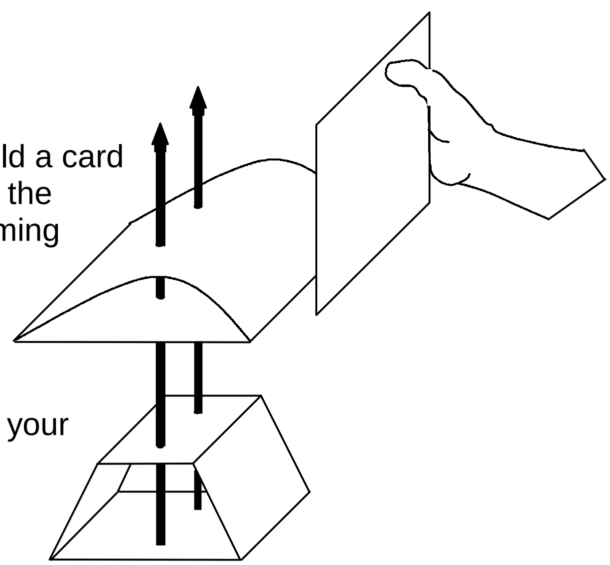


Part B: Test the paper wing

1. Draw your paper wing. What do you predict will happen when you test your wing in the wind of the fan?
2. Line up the holes in the wing with the rods in the cardboard base.
3. Slide the wing all the way down the rods to the cardboard base. The wing should be curved on the top and flat on the bottom. You may choose to experiment with different positions.



4. Trial 1:
   - Turn on the fan.
   - Observe the wing for 15–90 seconds. Record your observations.
   - Turn off the fan.
5. Optional Trial 2:
   - Turn on the fan.
   - When the wing is halfway up the rods, hold a card in front of the wing to block the wind from the upper surface of the wing. If the lift is coming from lower pressure on top of the wing, blocking the wind will cause the wing to slide down to the base.
   - Try to block the wind in different ways. Observe for 15–90 seconds. Write down your observations.



- Turn off the fan.

Stuff to talk about

What may have caused unexpected results (e.g., misaligned holes, someone moved the fan). These are called sources of error and can affect your experimental results. If we repeated the experiment, how would we fix these problems or "control the variables?"

In the 1700s a European scientist called Daniel Bernoulli developed an idea called the Bernoulli principle. The principle can explain why air moves through a prairie dog's burrow, why smoke goes up a chimney, and how airplanes can fly. We call this the Bernoulli effect.

More stuff to do!

A. Have students perform additional trials, placing the wing at different angles by making holes at other points in the wing. Encourage students to hypothesize, test, observe, make changes, retest, and draw conclusions. For example, students might put the rods through a different pair of holes on the upper surface of the wing, but in the same holes on the lower surface. This should adjust the angle of the wing. If the angle of the wing is too steep, the difference in air pressure above and below the wing will not be enough for lift.

B. Have students repeat the experiment with different weights of paper. Try light construction paper, tracing paper, etc.

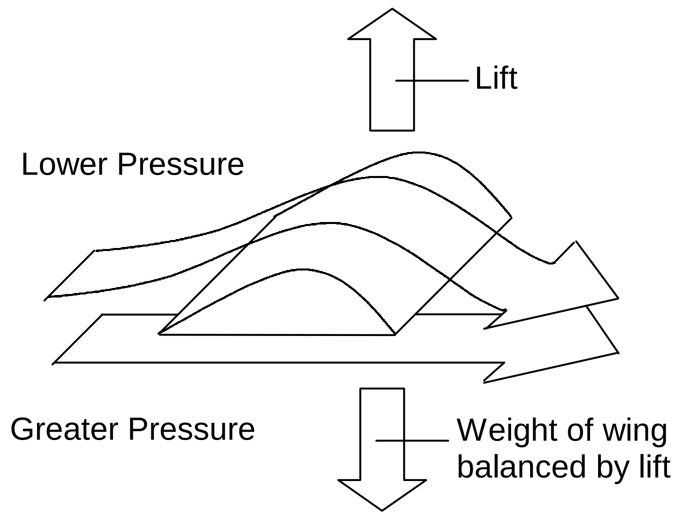
C. Students may use the inquiry process to investigate different airfoil shapes, e.g., a box shape, a tube shape, a flat leading edge.

What's happening?

There are many aerodynamic factors that make airplanes fly. In particular, the shape of the wings helps create the force necessary to lift the airplane into the air. Airplane wings are specially designed to provide the upward force called lift.

A cross-section of an airplane wing has a shape that is called an airfoil. The upper surface of an airplane wing is curved downward, and the lower surface is usually flat. As the wing moves through the air, the special shape of the wing changes the path of the air flowing around it, which affects the air pressure surrounding the wing. The air passing over the upper curvature of the wing moves faster than the air passing along the lower flat surface. The downward pressure of the faster-moving air above the wing is less than the upward pressure of the air below the wing, so the wing is pushed up. This upward force resulting from a difference in air pressure is called lift.

Daniel Bernoulli developed the physical principle that describes these phenomena in 1783. He discovered that increasing the velocity of a gas (or liquid) would lower its pressure. Thus, most airplane wings are designed to take advantage of air pressure differences.



How it all fits in

MATH

Mark off the rods in half-inches. Record the height to which each wing rises. Calculate the mean, mode, and median of the results of the class. Graph results.

Mean: The sum of a list of numbers, divided by the total number of numbers in the list.
Median: "Middle value" of a list.
Mode: Most common (frequent) value.

Other Options: Have each student group collect data on multiple trials of each experiment. Each group will then calculate mean, median, and mode for their trials. How do these numbers differ from group to group or from the whole-class values? Discuss possible reasons for a wide range of numbers, such as the use of different bases or differing fan positions (different "variables" and "sources of error").

ZOOLOGY

Research and report on the structure of the wings of birds. How does the size and shape of the wing affect the bird's flying habits? For example, compare an eagle, albatross, chicken, robin, duck, penguin, and emu. What is the wing shape? What is the overall body size and shape? What is the wingspan? Do they flap or soar? How long can they soar?

PHYSICS	Research and report on the discoveries of Daniel Bernoulli.
HISTORY	Research and report on the Wright brothers' first flight.
LANGUAGE ARTS	Study the Greek myth of Daedalus and Icarus.
ART	Look at the scientific and artistic designs of Leonardo da Vinci, then create da Vinci-like designs. Design and color an airfoil.
CULTURAL/ SOCIAL STUDIES	Investigate aircraft from other nations. How do the designs differ? Can you tell which aircraft originate from the same design? Can you tell which aircraft were manufactured by the same company? Investigate the impact that rapid air travel has had on our society.

Wing Worksheet

Upper Curved Surface

Lower Flat Surface

Supplies Worksheet

Instructions: Copy this worksheet and calculate the supplies you already have and what you still need. Then copy your completed worksheet to give to a teacher aid or a parent helper to gather the supplies designated in the right-hand "Supplies Needed" column.

No. of students: ________ No. of groups: ________

Supplies	**Amount Needed**	**Supplies on Hand**	**Supplies Needed**
Regular weight copy paper for wing	1-3/student		
Corrugated cardboard for trapezoid base 5" x 10"	2/class		
Ruler	1/class		
Bamboo skewers or knitting needles	4/class		
Clear tape	small amount		
Scissors, paper cutter, or x-acto knife	1/class		
Sharpened pencil	1/student		
Small electric fan	1-2/class		
Cardboard, cardstock, or heavy weight paper 4"x6" or larger	2/class		
Eraser ends	4/class		

Note: This activity is a preliminary draft of one of several classroom activities, which are being developed to complement OMSI's *Engineer-It!* exhibit. Comments and suggestions about this activity are welcome. Please send them to <*stephanie.anderson@omsi.edu*>.

APPENDICES

The two most common constraints engineers work within are time and money. Engineers and designers are constantly striving to deliver their product on time and under budget, whether it's a vast skyscraper or the latest videogame. Introducing these concepts to your students provides rich opportunities for cross curricular connections to math concepts and deeper engagement with the engineering design process.

The phrases 'time is money' or 'buying time' represent the idea that these two constraints are related. For example, the longer a project takes, the more expensive it tends to be. Conversely, if a project is behind schedule, smart investment of funds can help it catch up. Budgeting typically refers to money, but we also budget our time when we create a schedule or timeline for a project. Both activities are valuable additions to Engineering Design curriculum.

Money

Engineers never work with unlimited funds or access to any materials they choose. Giving your students a monetary budget to work within is an excellent way to make activities more challenging and realistic. Often when students must decide in advance which materials they want to purchase, they will invest more time in pre-planning their design. There are several different ways to integrate this into your curriculum.

- **Give each group something to represent cash**, such as play money or multi-colored tokens such as poker chips. Alternatively, use an accounting system for a greater challenge. This is more representational of real world engineering, but requires more effort to track. Provide students with a balance sheet and purchase orders or checks. Examples of these can be found later in this section.
- **Create a 'store'** where groups can purchase the materials they need to execute their design. A sheet with various price tags to match with materials is on page 87 The store may also be a list of materials and their prices. An example of this is on page 89 You may provide the option to sell back unused materials at a full or reduced rate.
- **Offer 'Recycled' materials** such as bent paperclips or cut toilet paper tubes at the store. The incentive to re-use these materials may be a reduced cost, or perhaps the cost is increased but there is some other incentive for using them. Many businesses use recycled goods to improve their public image.
- **Offer non-material items in the store**. Allow your students to hire a consultant by paying for advice from you or another 'expert.' You can also include fees for such things as construction permits, safety inspections, taxes, utilities, etc.
- **Change prices, materials available, or budget**. Prices fluctuate in the real world, sometimes from day to day. You can adjust the prices of items based on the supply and demand in your classroom. You may also run out of an item, or introduce new items as a 'breakthrough in materials engineering'. Additionally, you can challenge your students with a mid-project budget cut—an all too familiar part of the real workplace..

- **Use a bidding system to determine a team's budget**. Often, an engineering contract goes to the firm who makes the case that they can successfully achieve a set of criteria for the least amount of money. After introducing a challenge, give teams a chance to plan their solution and submit a budget. Determine some type of incentive for the team who submits the lowest successful bid.

Time

- **At the simplest level, giving your students a deadline.** For completion is using time as a constraint. This will occur in nearly every activity so you can keep your classroom on track. A great way to start exploring this topic is to be reflective asking questions during post activity discussions—about how much time students used to accomplish their task, and how that affected their final product. As students become more familiar with the design process, try some of the ideas below to further explore this constraint. These extensions will increase the challenge level of activities and provide new ways to assess your students' learning. With all of these activities, be sure to debrief the experience during post activity discussion.
- **Use a variety of deadlines**. The process students go through, and the products they produce, will vary greatly from 'quickfire' challenges of 20 minutes or less to longer, multiday or even semester long projects. You may find that some students excel at one type or the other. In general, longer projects will be more beneficial at the end of your curriculum, as students become more familiar with the different stages of the engineering design process.
- **Change deadlines midway through a project**. This often happens in engineering, where a deadline is extended (or even worse, shortened) due to some external factor. For example, during the Gulf oil spill of 2010, prototype designs for emergency capping mechanisms needed to be accelerated to minimize ecological and economic damage. A similar impact can occur when the criteria for success are changed without granting the project additional time. Suddenly, students will need to scramble to adjust their designs. These modifications, imposed by the teacher, are designed to simulate real world situations. However, mid-stream modifications can exasperate students who are not confident in their own abilities, so it is suggested that you employ these types of modifications judiciously. While they do simulate the challenges engineers have to deal with, they will also simulate the frustrations the engineers feel as a result.
- **Provide an opportunity** for students to plan a project timeline. This is an extremely useful skill that will benefit them in nearly any career, as well as their academics. This process can be broken into several steps:
    - *Have students list all the tasks that will need to occur to successfully meet the criteria*
    - *Identify the logical order for tasks, and critical benchmark tasks that will derail the project if not completed in a timely fashion.*
    - *Estimate how long each task will take to complete*
    - *Work backwards from the final, overall deadline and build a Gantt Chart. Many examples and tutorials can be found on the internet.*

- *Alternatively, work forward from the current time, determining deadline based on their timeline. They will have different deadlines, which they may or may not meet based on their estimates. As students work on the project, have them check in on the timeline regularly to gauge their progress. If you are using the Roles extension (page 91) this is an excellent role for the project manager.*

Company Name: ___________
Project: ___________

Project Balance Sheet

Starting Balance: _________
Date: _________

Check No.	Date:	To:	Amount:	Balance:

Purchase Forms

Reciept

Date: ______
To:________

For:________
____

Amount:
$ [ ]

Company Name: Check #No. ____

PROJECT ______________ PURCHASE

Supply Company Name:

Items Ordered:	Quantity:	Cost:
Signature ______________	Total:	

Reciept

Date: ______
To:________

For:________
____

Amount:
$ [ ]

Company Name: Check #No. ____

PROJECT ______________ PURCHASE

Supply Company Name:

Items Ordered:	Quantity:	Cost:
Signature ______________	Total:	

Reciept

Date: ______
To:________

For:________
____

Amount:
$ [ ]

Company Name: Check #No. ____

PROJECT ______________ PURCHASE

Supply Company Name:

Items Ordered:	Quantity:	Cost:
Signature ______________	Total:	

Reciept

Date: ______
To:________

For:________
____

Amount:
$ [ ]

Company Name: Check #No. ____

PROJECT ______________ PURCHASE

Supply Company Name:

Items Ordered:	Quantity:	Cost:
Signature ______________	Total:	

FREE

$100

$200

$300

$500

$750

$1,000

$2,000

$2,500

$5,000

$7,500

$10,000

$12,500

$15,000

$20,000

$30,000

$40,000

$50,000

$75,000

$100,000

$250,000

$500,000

Company Name: ______________

Project: ______________

Date: ____________

Materials List

Subcontractor	Item	Price

A common misconception is that engineering is a solitary process, carried out by individuals working in isolation. Furthermore, engineers are often portrayed as lacking basic social skills. However, engineering is almost entirely team-based. While specific individuals may work on small deliverables, their efforts contribute to larger team-based projects. Group work is a necessary part of the process for engineers, and will contribute to social learning for your students.

Students may gravitate to particular roles when they work in groups. One member may assume a leadership role in the group, while another may be content to take on the majority of the construction. While this is an accurate representation of how engineering teams operate in the workplace, it is important to give students the opportunity to rotate through a variety of roles over time in order to build a broader understanding of engineering teams. Ensuring that each student is taking part in the process, in a way that is personally challenging and rewarding, is not always easy.

In particular, it is important to encourage a wide range of individuals to take on leadership roles. As you get to know your students, identify those who naturally assume the role of group leader and those who are content to sit back and follow. Try shifting them out of their comfort zone by placing them in groups with others of similar disposition. A group comprised entirely of students with leadership tendencies may struggle initially as they learn the fine art of following and how to work in a support role. The students less inclined to leadership roles may find it's easier to have their voices heard and will often step up to the challenge.

There are several explicit strategies you can mix and match to make working in groups a positive experience and a valuable addition to your curriculum.

1. ***The whole group works together on each part.*** In this format, the educator actively encourages the groups to avoid taking on roles. Instead, each element of the process must be done by consensus.

   Pros: each student gets to try different parts of the process; no complaints about wanting a different role; requires little planning by educator or groups of students; can provide you insight into areas where students need more experience or subjects that studebts are particularly interested in.

   Cons: requires regular check-ins by the educator; feels less authentic; students have less ownership over specific parts of their work; less room for individual approaches.

2. ***Student selected roles.*** Here, the students can decide within their groups what parts of the process they'd like to work on.

   Pros: allows students to focus on their interests and strengths; provides excellent experience with team-based work and group dynamics.

Cons: may create conflicts about who's in specific roles; some roles may be undesirable; students may not gain as much experience in the roles they do not select; may require extra time for the students to work out.

3. ***Assigned Roles.*** There are many variations to thisapproach, from just selecting the team captain to specifically selecting each team member and the roles they will assume.

Pros: allows for a rotation system, giving students the opportunity to work in different roles; assigning teams based on known personalities may lessen conflicts.

Cons: less student control; may require more prep by the educator; may create disappointment in assigned role.

Most importantly, remember to include group dynamics as part of your discussions following the activity and in your assessments of how the students performed during the activity. Some sample questions you may wish to include:

- How was your team successful?
- What challenges did your team face?
- How did your group divide the work between members?
- What was it like acting as the (insert role)?

The groups could also conduct a group or self-evaluation that you collect after the activity to gain insight on what worked and didn't work for the students (see example page 94).

Roles Based Extension

One interesting twist you can add to a roles based activity is to place specific rules on how the team members can work and interact with each other. This highly structured format is a great way to demonstrate the challenges of team-based work and the importance of clear communication between team members, but can be frustrating and require extra preparation by the educator.

This works best with a simple activity. The example below was written for an activity where groups designed, built, and tested a ramp to launch a marble as far as possible. The roles can be modified, as can their specific supplies and rules, based on the activity you wish to integrate it with.

Four roles:

Designer, Manufacturer, Field Tester, Manager

There can be more than one person in each role. Set up your classroom so that there is a design area, manufacturing area, and a testing area. After an initial team meeting, members of each role should stay within their area, except for the manager.

Designer
Supplies: Notebook, Pencils, Ruler.
Can: Draw designs in notebooks, talk to manager.
Cannot: Talk to anyone except the manager and other designers, leave design area.

Manufacturer
Supplies: Scissors, Tape, Protractor, Construction Paper, Ruler.
Can: Follow the design given to construct the ramp, talk to manager.
Cannot: Talk to anyone except the manager and other manufacturers, test the ramp with marbles, leave the manufacturing area.

Field Tester
Supplies: Paper, Pencil, Ball, Ruler.
Can: Roll marbles down the ramp, record results, talk to manager.
Cannot: Talk to anyone except the manager and other testers, help with designing or building, leave the testing area.

Project Manager
Supplies: None.
Can: Transport supplies around, communicate messages between members.
Cannot: Use their hands to actively design, test or build.

Other Possible Roles:

Researcher
Supplies: Internet search engine.
Can: Talk to the manager or designer.
Cannot: Use their hands to actively design, talk to anyone else, leave the design area.

Presenter
Supplies: Posterboard, Markers, Ruler.
Can: Talk to the manager, talk to the designer and tester once each.
Cannot: Help with designing or building.

If you are using the Budget extension Appendix A create another area for the store.

Finance Director
Supplies: Paper, Pencil, Calculator.
Can: Purchase supplies, track budget and timeline, talk to the manager.
Cannot: talk to anyone except the manager, help with designing or building, leave the store area.
Place an X in the box that most accurately answers the following question:

While working with my group, I

	Often	Sometimes	Seldom	Never
Contributed my ideas				
Listened to and respected the ideas of others				
Positively encouraged others in my group				
Compromised and cooperated				
Followed directions				
Helped solve problems				
Focused and concentrated on my task				
Took risks				
Did my share of the work				

How was your team successful?

What challenges did your team face?

How did your group divide the work between members?

What role did you take on, and what was it like acting in that role?

Design Proposal

Company Name:______________________ **Date:**____________

Project:_____________________________

Describe your Problem:

____

____

Criteria for Success:

____

____

Materials and Tools needed:

____

____

Draw a picture of your proposed design:

Company Name: ____________
Project: ____________

Sketch Pad

One Square = ______
Date: ______

Drawn by:____________

Company Name________
Project __________

Date:______

Test Report

DESIGN 1	Trial 1:	Trial 2:	Trial 3:

Data Analysis

DESIGN 2	Trial 1:	Trial 2:	Trial 3:

Data Analysis

DESIGN 3	Trial 1:	Trial 2:	Trial 3:

Data Analysis

This curriculum is considered "No Hassle" because it does not require the specialized equipment you might find in a wood or metal shop. Use this section as a shopping list to gather supplies for your classroom. All materials can be found at supermarkets, office supply stores, craft stores, or hardware stores.

Tools

The proper use of tools is an important skill, one which many students never have the opportunity to learn or practice. Putting real tools in their hands is valuable and can be done safely as long as you follow some basic rules and teach them to respect the tools they use.

Always wear safety glasses.

Use the right tool, the right way. Don't use a screwdriver to pry something, or a pair of scissors to drill a hole. Most injuries in a workshop are from failure to follow safety instructions. Tools are safe when used as intended, and will last longer.

The most important safety rule is always **cut away from yourself and others**. Before making any cut, make sure that the sharp side of the blade is not pointing at anyone or anything important. This prevents cuts if the blade slips.

A sharp knife is a safe knife seems like a counterintuitive rule, but dull blades are far more dangerous. A dull tool takes far more effort to cut with and is more unpredictable. This creates dangerous possibility of slipping knives.

Recommendations. There are some pieces of equipment that are used in virtually all activities. Designate an easy-to-access area of your classroom to store these materials. You may choose to have students collect these items and bring them in for use in your classroom.

- **Scissors**
- **Diagonal (wire) cutters**
- **Needle nose pliers**
- **Screwdrivers—standard and torx**
- **Allen wrenches**
- **Adjustable wrenches**
- **Clamps-various types:** C clamps are good for attaching things to a desk.

MEASUREMENT

To make this curriculum "No Hassle," the activities have been designed so that precise measurements (either in standard or metric) are often not necessary for success. Slow it Down will work just as well if the ramp is 5 inches high instead of 4.5 inches.

However, for some activities and extensions, students are required to use accurately measured amounts. This is an important part of the engineering design process, as it is often the only way to determine success. You should have sets of measuring tools (either in metric or standard) for students to use in these situations.

Recommended Measuring Tools

- **Rulers**: stainless steel are the most durable but more expensive.
- **Yard/meter sticks**
- **Tape Measures- fiberglass long rule:** useful for measuring long distances for activities such as a paper airplane contest.
- T**ape Measures-spring loaded:** great for most measurements; can also be used as drive mechanism (see Resources section).
- **Scale- electronic, accurate to 1/100ths of an ounce**
- **Scale-push/pull spring scale**
- **Thermometers**
- **Stopwatches**

Electronic measuring tools

A wide variety of options exist. See the Resources section for more information.

- LEGO Mindstorms robotics kits have a variety of sensors. If you have access to them, you can measure light, sound, distance, rotation and more.
- Vernier Software and Technology creates a wide variety of sensors for classroom use, as well as software and curriculum.
- Smart phones can run applications that act as a stopwatch, a level, or even a seismometer. Show your students they can be used for far more than texting!

If you are in the U.S., it is not important which measurement system you use: standard or metric. However, it is recommended that you be consistent. Students will develop better measurement habits and estimation skills when they are using a familiar system. Depending on the level of your students, you may wish to integrate Engineering Design activities into your conversion lessons.

SUPPLIES

When we think of engineering activities for the classroom, it's hard not to think of a huge mess. Piles of craft sticks and puddles of glue, or balls of tape and newspaper are not only messy, but also wasteful and expensive. There are some things you can do to avoid these problems.

- **Reduce, Reuse, Recycle:** And make sure it's in that order. Encourage your students to use fewer materials. This can be done by providing a limited amount to start with, or by using a budgeting system to encourage frugal use of materials. Try to eliminate materials or processes that cannot be easily reused for future activities. Collect materials such as soda bottles or paper towel tubes for reuse. If a material cannot be reused, make sure it is recyclable at the end of the activity.
- **Avoid Tape and Glue:** These are the two usual suspects of waste. Every teacher has seen students use miles of tape to hold something together when a few inches would have worked. Or, seen miles of tape when a few elastic bands would have worked even better. Tape can almost never be reused and can rarely be recycled. And the expense quickly adds up. Glue can also create waste, because it often prevents the glued materials from being reused or recycled. It is also expensive, messy, and can be replaced in most applications by clever use of elastic bands
- **Use Constraints:** In the classroom, students will be constrained by the materials you provide them as well as how they are provided. Giving students full access to materials allows them to focus on their design, and may encourage more testing and modifications. However, it will also usually lead to students using more materials. By placing limits on the materials your students can use, you can prevent wasteful behavior. As an added side effect, students often think through their plan more carefully when they have limited resources to work with. Not only does this help achieve your learning outcomes, it also saves you money, mess, and waste.

This is a list of required or recommended items for all of the activities in this book, as well as some things that are handy for prototyping with multiple activities. Stock up on these materials so you can do any activity on a whim!

Items available at a supermarket
(e.g., Fred Meyer, Kmart, Wal-Mart, Target)

- Balls: ping pong, tennis, waffle, super bounce, etc.
- Marbles—various sizes
- Plastic cups—various sizes
- Straws
- Balloons
- Paper cups—4oz
- Sealing plastic bags, (e.g., Ziploc) snack, sandwich, pint, or quart size
- Spoons
- Play money or poker chips
- Plastic golf tees
- Towels and sponges
- Plastic wrap
- Wax paper
- Aluminum foil

Items available at office supply or craft store
(e.g., Office Depot, Michael's)

- Tape—clear, duct, electrical, masking: each is useful, but can be wasteful. Place limits on use.
- Washable Markers
- Paper clips
- Elastic bands—#10
- Tongue depressors or craft sticks
- Small hot glue sticks
- Pipe cleaners
- Fans

Items available at hardware or home improvement store
(e.g., The Home Depot, Lowe's, Ace, TrueValue, RadioShack)

- Tape—clear, duct, electrical, masking: each is useful, but can be wasteful. Place limits on use.
- Nails, screws, bolts
- Wooden blocks or scraps of wood
- Pegboard—~1' x 2' sheets
- Foam Insulation
- 50' 14 gauge solid core copper wire
- 2" Nuts
- Batteries—AA, 9v
- Electric motors—1.5-3v

An excellent way to secure some materials inexpensively and give your students experience working with tools is to run a 'take apart' activity. Ask for donations of old electronic devices. Not only will your students get to see the inner workings of these devices, but the bits and pieces they discover can be repurposed. Unscrewed *(Sobey 2011) is a new book giving several examples of these types of activities. Look in the Bibliography for more info*

Items available for scrounging
(Sometimes all it takes is asking)

- Biodegradable packing peanuts
- Phonebooks: Make great blocks for propping things up; tear out the paper for paper airplanes
- Egg cartons
- Yogurt tubs
- Plastic bottles
- Cafeteria Trays: useful for carrying and distributing equipment
- Cardboard: all sizes and types can be useful
- Paper Towel and toilet paper tubes
- Corks—natural

OMSI Exhibits and Demos

Teachers are always welcome to preview OMSI before bringing a group of students. Please check at least two weeks in advance of visit to confirm availability.

Engineer It!

Lots of engineering exhibits, including Bridge Builder, Shake Tables, Wind Tunnels, and Water Tables. This museum assembled a great list of resources tied to OMSI's travelling version of Engineer It!

http://www.midamericamuseum.org/ei_resources.html

Science Playground

Pre-K area featuring Construction and Simple Machines activities.

http://www.omsi.edu/science-playground

Technology and Physics Labs

Resources on the history of inventions and engineering, as well as demonstrations and activities about the following:

- Circuits and electricity
- How stuff works (smoke detectors, toilets, LCDs, etc).
- Design Challenges
- LEGO Robotics Reserved Labs

OMSI Vernier Technology Lab

http://www.omsi.edu/tech/

Online and classroom activities and links to other resources.

Nanoscale Informal Science Network

OMSI and several other museums received a grant from the National Science Foundation to develop programs, activities, and exhibits about science and engineering at the sub 100 nanometer scale. Nanotechnology is just getting started today, but will be a major part of the engineering your students will be doing when they enter the workforce.

http://www.nisenet.org/catalog/programs

Software

World of Goo

Fun and intuitive engineering game where players build towers, truss bridges, and more. There is a fee to download.

http://2dboy.com/games.php

West Point Bridge Designer
http://bridgecontest.usma.edu/download.htm
A FREE bridge simulator created by the Army Corps of Engineers.

The Soda Constructor
http://www.sodaplay.com/
Allows users to draw shapes and animate them.

Google Sketchup
http://sketchup.google.com/
A FREE 3D drafting tool. The 3D warehouse has loads of community created models, and there's plenty of tutorials on the Web.

LEGO Digital Designer
http://ldd.lego.com/
A FREE tool for designing Lego models in 3D, then creating build instructions or ordering the parts.

Create a Graph
Excellent online graphing tool.
http://nces.ed.gov/nceskids/createagraph/default.aspx

Scratch Programming Language
http://info.scratch.mit.edu/Educators
Scratch is a programming language that makes it easy for students to create interactive stories, animations, games, music, and art -- and share those creations on the web. This link for educators has many resources, including some focusing on design-based learning.

Curriculum and Inspiration

Engineering is Elementary
The Museum of Science in Boston developed one of the leading Engineering Curricula in the nation. 20 units connect engineering process activities to science topics, while storybooks provide context and offer cross-curricular connections to language arts and cultural studies.
http://www.mos.org/eie/

Kids Invent!
Provides innovation-based learning kits for students ages 7-15.
http://www.kidsinvent.com/

Toys From Trash

The website of a man who builds toys for kids out of discarded materials. Here find good small projects that teach construction and may inspire ideas on reusing the things you have laying about your classroom.
http://www.arvindguptatoys.com/toys.html

LEGO and LEGO Mindstorms

LEGO may be the ultimate engineer's toy, and the Mindstorms platform is an excellent tool for teaching robotics at several different levels.
http://www.lego.com/education/
Has a searchable database of activity ideas.

http://www.nxtasy.org/
A LEGO Mindstorms blog with lots of cool ideas

Center for Engineering Educational Outreach at Tufts University

http://ceeo.tufts.edu/
Heavily focused on LEGO Mindstorms.

Changing the Conversation online messaging toolkit

http://www.engineeringmessages.org/
Resources created to provide a better understanding of what engineering is.

Everyday Examples in Engineering (E3s)

http://www.engageengineering.org/?page=40
While the goal of this project is to engage undergraduates in engineering schools, there are a number of engineering lessons plans.

Tape Measure Racers

http://www.workbenchmagazine.com/main/wb293-races01.html
Brief information about the history of tape measure racing, and a six second video of a race.

http://www.youtube.com/watch?v=hBtJkgWlSok
This video is just over four minutes and shows how people modified their tape measures to make them race faster.

http://www.legoeducation.us/store/detail.aspx?ID=1488
Lego offers special resources for enhancing tape measures for racing, such as a starter kit and related DVD.

Organizations and Programs

Engineer Girl

Provides profiles of women engineers, fun facts, contests, and interactive features.
www.engineergirl.org

Oregon Pre-engineering and Applied Sciences Initiative

http://opas.ous.edu/
Promotes students entering the field of engineering in Oregon, workshops and resources.

For Inspiration and Recognition of Science and Technology (FIRST)

FIRST is the sponsoring organization of the FIRST LEGO League Tournaments.
http://www.usfirst.org/

Oregon Robotics Tournament and Outreach Program (ORTOP)

Local support for FIRST teams including registration, scholarships, and free coach mentor training.
http://www.ortop.org/

Pacific Northwest FIRST

Organizes the local competitions for High School FIRST Robotics teams.
http://www.pnwfirst.org/

Brightworks

http://sfbrightworks.org/
Not local, but doing some really interesting things with kids and power tools.

Tinkering

http://www.tinkeringschool.com/
One of the founders of Brightworks also started the Tinkering School, an exploratory curriculum to help kids learn to build things.

Cyberchase

A PBS kid's show about engineering They have a guide for parents and teachers.
http://www.pbs.org/parents/cyberchase/

Design Squad

A PBS show for teens loaded with cool projects. They have an excellent section for parents and educators.
http://pbskids.org/designsquad/

The X-Prize Foundation
The foundation strives to bring about breakthroughs in engineering and science to solve major global issues by creating and managing high profile, high incentive awards. A current example is a $1.4 million prize to a team that develops a highly efficient oil spill clean-up system.
http://www.xprize.org/

Young Makers
http://www.youngmakers.org/
Information and inspiration for starting a Young Makers program.
The Young Makers Program organizes opportunities for kids to imagine and create projects for Maker Faire each year in collaboration with adult mentors.

Equipment and Supplies

SCRAP (School and Community Reuse Action Project) is a Portland non-profit that inspires creative reuse and environmentally sustainable behavior by providing education programs and affordable materials to the community.
http://scrapaction.org/

Schoolhouse Supplies
Free store in Portland providing teachers with the supplies they need
http://www.schoolhousesupplies.org/

American Science and Surplus
Lots of bizarre stuff alongside some good deals on basic equipment and supplies.
http://www.sciplus.com/

Mr McGroovy's Box Rivets
A unique construction material designed for creating the ultimate cardboard box fort.
http://www.mrmcgroovys.com/

Vernier Software and Technology
Creates solutions for classroom measurement, including sensors, data collection devices, software, and Lab based curriculum guides.
http://www.vernier.com/

Books, Authors and Artists

Dr. Ed Sobey is the author of more than 20 books about technology, innovation, and education. He provides professional development workshops around the world.
http://www.invention-center.com/

MAKE Magazine
Quarterly DIY book of fun.
http://makezine.com/
http://makeprojects.com/
An almost endless list of DIY projects to inspire makers of all ages.

Theo Jansen, kinetic sculpture artist
http://www.strandbeest.com
View his new life form, then watch the TED video to learn how he creates them.
http://www.ted.com/talks/theo_jansen_creates_new_creatures.html

Arthur Ganson, kinetic sculpture artist
http://www.arthurganson.com/
View his moving sculptures, then watch the TED video about what inspired him.
http://www.ted.com/talks/arthur_ganson_makes_moving_sculpture.html

Cabaret Mechanical Theatre
http://www.cabaret.co.uk/
Resources and inspiration for making mechanical structures.

YouTube has many videos, here's some favorites:

Honda Cog
http://www.youtube.com/watch?v=Kh4zWeUDW-E
This amazing video is sure to make students wonder how to make a tire roll uphill.

Ok Go: This too shall pass
http://www.youtube.com/watch?v=qybUFnY7Y8w
Not just an ordinary music video, this one will leave students imagining what they can create.

GLOSSARY

Biomimicry: The study and imitation of nature's best systems in order to design sustainable solutions to human problems. The core idea of biomimicry is that nature has already solved many of the issues humans are now dealing with, so it provides a great model to study.

Blueprint: A technical drawing or detailed plan. The term comes from the 19th century technique that involved a chemical process of reproducing original drawings where the open spaces (negative space) turned blue, and the drawn lines (positive space) turned white. Modern engineers and architects often use Computer Assisted Drawing (CAD) to design their plans.

Circuit: A closed path through which an electric current flows.

Constraint: A restriction or limitation. A design constraint limits what options may be used. They often include considerations such as budget, materials, laws, safety considerations, environmental impact, etc.

Criteria: A standard or rule by which judgments and decisions can be made. For homework, teachers have criteria that determine a student's grade. Engineers follow design criteria (set of rules) in creating their product.

Deduction: A type of logic. Deductive reasoning is a conclusion drawn from testing a theory. This process starts with a theory, and narrows it to a hypothesis which can then be tested. Observations are noted, leading to affirming or negating the initial theory.

Designers: A person who plans the properties, form, or look of something before it is created.

Gantt chart: A bar chart that illustrates a project's schedule. It is named after Henry Gantt, who developed this in the early 20th century. Gantt charts display the status of an activity in a quick glance.

Induction: A type of logic. Inductive reasoning is a conclusion based on experience or experimental evidence. This process starts with making observations, then noting any patterns, leading to formulation of a hypothesis, followed by creation of a theory.

Logic: The principles which guide reasoning. Logic can be inductive or deductive.

Motor: A machine that supplies power for another device.

Optimization: This is the process of continually improving a design or system to increase its overall effectiveness, while still staying within constraints.

Proof of Concept: A rough prototype meant to test if an idea or design is feasible.

Prototypes: The initial attempts to create something new. They are simplified models of the true design, intended to test out specific elements without the cost of a full scale development.

Scope: The extent or range of an activity, operation, view, or effectiveness. In project management, scope has two distinctions: product scope (the features that will be part of the product) and project scope (the work that needs to be accomplished to complete the project).

Slope: A surface in which one end or side is higher than another. In mathematical terms, the slope is the measurement of the altitude change (rise) divided by the horizontal distance (run) between any two points on a line.

Switch: This is a device that can make or break the electric flow in a circuit.

Switchback: A sharp bend in a road or trail. These are built often as a series of sharp turns arranged in a zigzag pattern when there is a steep slope. This allows for travel to be done in segments of moderate steepness.

BIBLIOGRAPHY

AAUW. 2010. Why so few? Women in Science, Technology, Engineering, and Mathematics. http://www.aauw.org/learn/research/whysofew.cfm (accessed July 13, 2010).

Ault, P. and R. Kruger. 2001. Engineer it! Evaluation report. Report, OMSI.

Bandura, A. 1986. Social foundations of thought and action: A social cognitive theory. Englewood Cliffs, NJ: Prentice Hall.

Bhattacharjee, Y. 2006. A passion for teaching leads to engineering change in schools. Science 311: 1237–1238. http://www.sciencemag.org/cgi/reprint/311/5765/1237.pdf (accessed June 10, 2009).

Bureau of Labor Statistics. 2009. Women in the labor force: A databook. http://www.bls.gov/cps/wlf-databook-2009.pdf (accessed November 10, 2010).

Fadigan, K. A. and P. L. Hammrich. 2004. A longitudinal study of the educational and career trajectories of female participants of an urban informal science education program. Journal of Research in Science Teaching 41 (8): 835–860.

Halpern, D. F., C. P. Benbow, D. C. Geary, R. C. Gur, J. Shibley Hyde, and M. A. Gernsbacher. 2007. Sex, math and scientific achievement: Why do men dominate the fields of science, engineering and mathematics? Scientific American Mind. December 2007/January 2008: 44–51.

Honey, M., and Siegel, E. 2011. Encouraging the hand mind connection in the classroom. Education Week, 30 (19), 25, 32.

Lent, R. W., S. Brown, and G. Hackett. 1994. Toward a unifying social cognitive theory of career and academic interest, choice, and performance. Journal of Vocational Behavior 45: 79–122.

Liston, C., K. Peterson, and V. Ragan. 2007. Guide to promising practices in informal information technology education for girls. NCWIT Girl Scouts of the USA. http://www.ncwit.org/pdf/Practices_Guide_FINAL.pdf (accessed August 11, 2008).

Marra, R. M., K. Peterson, and B. Britsch. 2008. Collaboration as a means to building capacity: Results and future directions of the National Girls Collaborative Project. Journal of Women and Minorities in Science and Engineering 14: 119–140.

Mattessich, Paul. 2005. Collaboration: What makes it work. Wilder Research Center.

Morgan, C., J. D. Isaac, and C. Sansone. 2001. The role of interest in understanding the career choices of female and male college students. Sex Roles 44: 295–320.

National Academy of Engineering (NAE). 2002. Raising public awareness of engineering. L. A. Davis and R. D. Gibbin (eds).. Washington, DC: National Academy Press. http://books.nap.edu/catalog/10573.html (accessed September 15, 2009).

National Academy of Engineering (NAE). 2004. The Engineer of 2020: Visions of engineering in the new century. Washington, DC: National Academy Press. http://newton.nap.edu/books/0309091624/html/48.html (accessed Sept 15, 2009).

National Academy of Engineering (NAE). 2008. Changing the conversation: Messages for improving public understanding of engineering. Washington, DC: National Academy Press.

National Girls Collaborative Project. 2009. Webcast, February 2009. http://www.psctlt.org/ngcp/events/events.cfm?eventid=112

National Science Board (NSB). 2008. Science and engineering Indicators. http://www.nsf.gov.

National Science Foundation, Directorate of Engineering. 2005. Extraordinary women engineers: Final report. EEC-0438810. http://www.nsf.gov/attachments/104206/public/Final_Case.doc (accessed November 21, 2006).

National Science Foundation. 2006. Women, minorities and persons with disabilities in science and engineering. Division of Science Resource Statistics. Arlington, VA: Author. http://www.nsf.gov/statistics/wmpd/sex.htm (accessed June 12, 2009).

NRC (National Research Council National Committee on Science Education Standards and Assessment). 1996. National science education standards. National Academies Press: Washington, D.C.

NRC. 2009. Learning science in informal environments: People, places, and pursuits. National Academies Press: Washington, D.C.

Oregon Department of Education. 2009. Oregon science K–HS science standards. http://www.ode.state.or.us/teachlearn/subjects/science/curriculum/2009feb-adopted-k-h-science-standards.pdf (accessed June 10, 2009).

President's Council of Advisors on Science and Technology. (2010, September). Report to the President: Prepare and Inspire: K-12 Education in Science, Technology, Engineering, and Math (STEM) for America's Future. Office of Science and Technology Policy. Available at: www.whitehouse.gov/administration/eop/ostp/pcast/docsreports

PPDR (People, Places and Design Research). 2005. Technoquest (Innovation Station) exhibit: A summative evaluation report. Northampton, Massachusetts. Report, OMSI.

Sobel, D. 1995. Longitude. New York: Walker and Company.

Sobey, E. 2011. Unscrewed: salvage and reuse motors, gears, switches, and more from your old electronics. Chicago: Chicago Review Press.

University of Wisconsin–Milwaukee. 2008. Tracking the reasons many girls avoid science and math. ScienceDaily. http://www.sciencedaily.com¬/releases/2008/09/080905153807.htm (accessed June 26, 2009).

Weisgram, E. S. 2006. Girls and science careers: the role of altruistic values and attitudes about scientific tasks. Journal of Applied Developmental Psychology 27: 326–348.