Design and Discovery

Facilitator Guide

Curriculum

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Curriculum

Overview

Design and Discovery is a curriculum that can be implemented in a variety of settings, depending on the format of your program. *Design and Discovery* introduces students ages 11-15 to engineering through design. The curriculum is organized into six sections which are further divided into 18 sessions. Each session is 2.5 hours and includes two to four 20 – 90 minute hands-on activities.

Each activity includes a facilitator instruction page and a student handout with directions for students. Many activities also include a student reading. Some sessions include a Home Improvement activity, which should be completed at home with input from family members. Key Concepts provide supporting information for the facilitator on new concepts introduced in sessions 1-12.

Understanding the Design Process

In the first two sessions, students are introduced to the designed world through a shared experience and then practice the 10-step design process that is revisited throughout the curriculum.

Session 1: Jump Into Design
Students re-think and re-engineer everyday objects. These hands-on activities reinforce a 10-step design process that is used many times throughout the *Design and Discovery* curriculum.

Session 2: The Designed World
Students learn that design opportunities are everywhere. This session builds the ability to analyze existing objects for improvements and helps students identify good problems to solve with design and engineering.

Engineering Fundamentals

These four sessions provide background in materials, electrical, and mechanical engineering principles that students may want to incorporate in their designs.

Session 3: Materials for Design Students learn about four different classes of materials and test them to understand their properties. They apply selection criteria to determine the best materials for different applications, while learning to consider cost and environmental impact when choosing materials.

Design and Discovery Curriculum Overview (continued)

Session 4: Getting a Charge From Electricity
Circuits are the building blocks of all electrical appliances. In this session, students explore simple, series, and parallel circuitry with bulbs, batteries, wires, and breadboards. They then build on these concepts by learning about short circuits, fuses, and then wiring an LED number display to light up their favorite numbers.

Session 5: Making Machines
Students explore the mechanics of simple machines, and then apply what they learn to make a mechanical toy of their own design.

Session 6: One Problem, Many Solutions
Wake up students' observation skills by having them analyze the form and function of a digital clock radio. Students compare clock radios to see how the functions are implemented in different designs.

Thinking Creatively

In these three sessions, students identify interesting and personally meaningful problems and develop ideas for solutions.

Session 7: The 3 R's Of Problem Identification
The 3 R's Of Problem Identification invites students to revisit, refine, and research design opportunities for a project of their own. Using a variety of techniques, students narrow down their list of design opportunities.

Session 8: A Brief Focus on Your Design Problem
Preparing a design brief helps students to focus their understanding about a problem and propose a solution.

Session 9: A Solution Taking Shape
Students delve deeper into their proposed design solution as they research patents for similar ideas and consider the necessary parts to get from "think" to "thing."

Making, Modeling, and Materializing

Throughout these three hands-on working sessions, students turn their thinking into things and begin several cycles of building trials and testing their ideas.

Session 10: Bicycle Breakdown: Systems, Components, and Parts
Some ideas have complex solutions that need to be divided into manageable parts. Students use bicycles to think about systems and components in a product they might design and engineer.

Design and Discovery Curriculum Overview (continued)

Session 11: Design Requirements and Drawings
Design requirements help designers focus on the user and fine-tune design details. Drawings help to further the process of moving from “think” to “thing.”

Session 12: Planning for Models and Tests
Students make their project ideas tangible—going from what’s in their mind to things in their hand. Students reflect on changes to their ideas and then plan what to construct—a model of systems, components, or the product itself.

Session 13: Making It! Models, Trials, and Tests
Let the construction begin! Pieces, parts, and connections become trials and models of a system, a component, or the product itself.

Prototyping

In these three sessions, students refine their projects into working prototypes.

Session 14: Prototype Practicalities
Projects are taken to the next level as students plan how to develop their working prototypes. They consider the product specifications, materials, and budget.

Session 15: Develop It!
This work session gives students time to construct their prototypes. Like all other stages in the design process, students may need to make several prototypes as they conduct trials and tests of the product.

Session 16: Test It!
Conducting user testing allows students to try out their products, get feedback, evaluate the feedback, and plan their revisions.

Final Presentations

Design and Discovery culminates with students sharing their projects. In the final two sessions, students plan for and participate in an event to showcase their projects and get feedback.

Session 17: Fairly There
Students begin to prepare for a culminating celebratory event to share their projects and their engineering and design expertise—either a showcase or a mini-engineering fair. Preparation involves planning the event and designing a display.

Session 18: Dress Rehearsal
Get ready for the big event! Practice makes perfect, as they say. Students practice their presentations and receive feedback from their peers. Following the event, they reflect on their *Design and Discovery* experience.

Design and Discovery

Understanding the Design Process

A 10-step Design Process is introduced and practiced in this session. The design process used for students' project development is the same one that guides the work of professional engineers and designers. In *Session 1: Jump Into Design*, students learn how to look at the world from a designed perspective by examining and redesigning everyday objects. In *Session 2: The Designed World*, students develop skills by thinking creatively about designed things they use. They also learn to identify problems that lead to opportunities for new design solutions.

Session 1

Jump Into Design

Understanding the Design Process

In This Session:

A) Build a Better Paper Clip (60 minutes)
- Student Handout
- Student Reading

B) The Design Process (45 Minutes)
- Student Handout
- Student Reading

C) Toothpaste Cap Innovations (45 Minutes)
- Student Handout

Jump Into Design orients students to a design process that guides the work of engineers and designers. Three hands-on activities build understanding of the role of engineering and design in producing effective solutions to real-world problems.

In *1A: Build a Better Paper Clip* students carefully examine the form and function of standard paper clips. Given a set of wires and tools, they are challenged to design a new paper clip that meets predetermined requirements. This design challenge provides a firsthand connection with a 10-step design process that is introduced in a group activity, *1B: The Design Process*. The design process forms the foundation for work on students' own projects, and each step is revisited in greater depth in subsequent sessions. In the final hands-on design activity in this session, *1C: Toothpaste Cap Innovations*, students examine a designed solution to the problem of conventional screw-top toothpaste caps as they walk through the steps of the design process.

Supplies

- For each student: straight pins, safety pins, and a variety of different types of paper clips of varying sizes
- 20 feet (4 meters) each of 4 different types of wire cut into lengths of 1 foot (30 cm) for designing paper clips
- Several pairs of wire cutters and needle-nose pliers
- Stack of scratch paper to test solutions
- Additional materials for embellishment, such as beads, buttons, glue, etc.
- Toothpaste cap samples: screw top and flip-top cap
- Flip chart and markers, white board and markers, or computer to display discussion points
- Safety goggles

Jump Into Design

Key Concepts: Session 1

Throughout Session 1, students are introduced to the concept of design and engineering as a *formal process* through a series of hands-on activities. They begin with redesigning a simple object—the paper clip—in order to develop a common reference point as they begin their experience with **the design process**. Another product example follows and is used to practice and reinforce understanding. These experiences with the design process build the important foundation for the rest of the activities in *Design and Discovery* as the design process forms the basis of the curriculum.

Key Concepts

The Design Process: A systematic problem-solving strategy, with criteria and constraints, used to develop many possible solutions to solve a problem or satisfy human needs and wants and to winnow (narrow) down the possible solutions to one final choice.

The design process is a recognized set of generally defined steps designers and engineers use based on a problem-solving strategy that leads to product development. It begins with the identification of a problem through a series of exploratory and data-gathering stages, to the creation of a solution. Though the process is introduced as a series of sequential steps, it is important to understand that the process is not truly linear—it is much more like a design *cycle* since many of the steps are intended to be revisited as more information is gathered. Because this forms the core of this curriculum, adults working with students must be comfortable with the process and how it plays out in the subsequent activities.

If you recall "the scientific method" you were introduced to in science classes, you will recognize the similarity of a sequenced set of steps, used as reference by professional scientists. There are natural and logical steps that facilitate the desired outcome. However, the scientific method and the design process are fundamentally different. While scientists propose a "solution" up front (the hypothesis) and then test it through experimentation to see if it is correct, designers identify the problem, define it as a design challenge, then brainstorm, research, gather data, and test to identify *what the correct solution should be*. The "solution" is arrived at later as a result of the process of data gathering and experimentation. Both represent the formal process used by each profession from each field, though inquiry and experimentation are at the heart of both.

Students are introduced to the design process in *1B Handout: The Design Process*. Become familiar with the steps.

1. **Identify a design opportunity.**
   The design process begins with identifying a need. Notice that opportunities to design a new product or redesign an existing one are everywhere. They often come from a

Key Concepts Session 1 (continued)

problem that has been experienced personally. The goal is to identify many design opportunities and narrow them down later.

2. **Research the design opportunity.**
   Gather a lot of information about the nature of the problem in order to help narrow down your choices. Find out if other people experience the same problem and research any existing products or solutions that may currently be used to solve the problem. Choose a design opportunity to address. Write a problem statement.

3. **Brainstorm possible solutions to the problem.**
   Try to come up with as many ideas as you can for solving the problem or addressing the design opportunity. Brainstorming may involve the use of SCAMPER and other techniques. Then, narrow down your solutions and choose one to three to pursue further.

4. **Draft a design brief.**
   Write a design brief to help outline the problem. A design brief includes a problem statement, a description of the user needs, a proposed solution, and often a sketch of the idea or solution. This is a working document that can be changed.

5. **Research and refine your solution.**
   Do a literature review and talk to experts in related fields and users to find similar solutions and other approaches to the problem. Analyze your solution for feasibility, safety, and practicality.

6. **Prepare design requirements and conceptual drawings.**
   Define the criteria the solution must meet (design requirements) and sketch conceptual drawings.

7. **Build models and component parts.**
   Analyze the project design for its systems, components, and parts. Consider appropriate materials and methods for constructing a model. Now build a model of the entire design and/or its systems.

8. **Build a solution prototype.**
   Develop detailed project specifications, consider material properties required, choose materials, and create a working prototype.

9. **Test, evaluate, and revise your solution.**
   Evaluate the prototype for function, feasibility, safety, aesthetics, and other criteria. Consider how it could be improved. Modify your prototype or create another and test it.

10. **Communicate the solution.**
    Present your design solution to an audience. Gather feedback and revise and redesign your product as necessary.

More About the Design Process

Garratt, James. *Design and Technology*. New York: Cambridge University Press, 1993.

Petroski, Henry. *Invention by Design; How Engineers Get From Thought to Thing*. Cambridge: MA: Harvard University Press, 1998.

Petroski, Henry. *To Engineer Is Human: The Role of Failure in Successful Design*. Reprint, New York: Vintage Books, 1992.

Technology Student, www.technologystudent.com*
This site supports the UK's Design Technology course. The information covers a wide range of topics, including the design process, electronics, and gear systems.

Session 1, Activity A

Build a Better Paper Clip

Goal

Experience the design process by re-engineering an everyday object.

Outcome

Design and engineer a new paper clip that meets requirements.

Description

After careful observations of how different kinds of paper clips function and perform, participants design a new paper clip that meets several requirements including a unique look. They construct them using a selection of materials and prepare drawings of the various designs. Each designer presents a new paper clip model.

Supplies

- For each student: straight pins, safety pins, and a variety of different types of paper clips of varying sizes
- 20 feet (4 meters) each of 3 or 4 different types of wire cut into lengths of 1 foot (30 cm) for designing paper clips
- Several pairs of wire cutters and needle-nose pliers
- Stack of scratch paper to test solutions
- Additional materials for embellishment, such as beads, buttons, superglue, etc.
- Safety goggles

Safety Guidelines

Safety goggles should be worn during this activity when either you or the student is cutting wire.

Note About Wire

Wire needs to be flexible but have sufficient springiness to retain its shape after some bending. Recommended: Steel or copper wire, 14 or 18 gauge. Floral stem wire (18 gauge steel) is available in craft stores and floral shops.

Preparation

1. Read *1A Reading: The Perfect Paper Clip.*
2. Optional: Invite mentors to the first activity. Review the mentor section in Implementation for more information on mentors.

1A: Build a Better Paper Clip (continued)

Procedures
Introduction

1. Introduce students to their design notebooks. Remind students that the notebook is a place to record ideas, inspirations, discoveries, sketches, and notes. They will begin using the design notebook in this first activity to record their thoughts and ideas. Some general guidelines include:
   - Leave a few pages blank at the beginning to create a table of contents.
   - Date and sign each page.
   - Number each page.
   - Never remove pages.
   - Do not erase.

2. Mentors could be brought in and assigned to students during this activity. They offer the ability to provide guidance and prompt discussion while the students are designing their paper clip.

3. At the start of this activity, identify the problem by introducing students to the Design Challenge: The owners of P&C Office Supplies are seeking new designs for paper clips. The company has come across hard times and believes a new paper clip design could revive its once-thriving business. It is up to you to save their company. Use your imagination and creativity to invent a new paper clip design. After researching their paper clip sales pattern, the owners have come up with requirements for the design. Please refer to them before you begin. (Refer to the handout with the design requirements, and allow time for students to read it thoroughly.)

4. Describe the materials and tools for the design challenge. Discuss the different types of wire the students will be using and what is meant by wire gauge—the size of the wire's diameter. The higher the gauge number, the smaller the diameter and the thinner the wire. Pay special attention to the needle-nose pliers and wire cutters. Some students may not have experience with these tools. Take time to show students the correct way to hold and use the tools. Review the requirements with students before they begin brainstorming solutions to the design challenge.

5. Before students begin designing a new paper clip, they should explore the existing designs you have provided and make observations in their design notebooks. Remind them that all these fasteners represent different solutions to the same problem—holding papers together.

1A: Build a Better Paper Clip (continued)

Exploration

1. Encourage students to experiment carefully with all the examples provided, exploring the ability of various materials to hold paper.

2. Remind students to make sketches and take notes about their observations of different materials and paper clip designs in their design notebooks.

3. Move among the students and discuss their observations about the materials and the extent to which different materials bend and spring back, retaining the ability to "hold" materials (evidence of Hooke's Law).

Design

1. Monitor progress to allow at least 25 minutes for designing, engineering, and testing a new paper clip prototype.

2. Remind the students to draw quick sketches in their design notebooks of their ideas and note test results.

Supplementary Information
Paper Clip History
The radio show, "Voices of Innovation" (www.voicesofinnovation.org*), provides listeners with two-minute sound portraits of engineering wonders and the people who developed them. These sound clips can be downloaded and played for students.

The following clips talk about the invention of the paper clip:

- www.voicesofinnovation.org/archives/Sept_02/P17_9_24_02.asp*

The Early Office Museum (www.officemuseum.com/paper_clips.htm*) provides a brief written history of the paper clip and a gallery showing early paper clip designs.

Paper Clips and Hooke's Law

Robert Hooke, a contemporary of Sir Isaac Newton, was an early advocate of the microscope. He examined things like the points of needles and edges of razor blades, noting the qualities of objects and thus making suggestions for improvements in their performance. He also identified what has come to be called Hooke's Law: *Ut tensio sic vis* (Latin) which means, "As the extension so the force." Each object stretches in proportion to the force applied to it. The more we stretch something, the more resistance it offers in response. In engineering, this law is

1A: Build a Better Paper Clip (continued)

applied to airplane wings, bridges, skyscrapers, and paper clips.

Read more about paper clips and Hookes Law: Petroski, Henry. *The Evolution of Useful Things: How Everyday Artifacts—From Forks and Pins to Paper Clips and Zippers—Came to be as They Are.* Chapter 4: From Pins to Paper Clips. New York: Vintage Books, 1992.

Wrap Up

Each student presents a brief explanation and demonstration of his or her paper clip design. Have students read *1A Reading: The Perfect Paper Clip*, an excerpt from *Invention by Design* by Henry Petroski. This can be done as a group, reading sections out loud, time permitting. Otherwise, students can take it home to read.

Follow With

In the next activity, *1B: The Design Process*, students become familiar with the design process which they will use throughout the sessions.

Build a Better Paper Clip

Handout: Session 1, Activity A

Exploration of Existing Paper Clips

Explore the paper clips and pins (two types of fasteners) that you have in front of you. Pins were used to fasten paper together before the invention of the paper clip. Pay close attention to your hands and fingers as you use each one to fasten together pieces of paper. What do you notice?

You might notice the action needed to separate the paper clip loops so it slips onto the papers, or the way your fingers direct the clip onto the papers. Each of these actions is unconscious, and the ease with which the object is used indicates a successful design.

Explore the properties of the shape and the materials of each paper clip design. Observe the operation of each design, make notes about each, and apply what you learn to designing a unique, new paper clip. What is common about the way each shape works to do the job? What properties in the material allow each to do the job of fastening paper together?

Investigation of Materials and Tools

Investigate the materials and tools provided to you. Notice the different types of wire. The wire's diameter is measured in order to determine its gauge. The higher the gauge number, the smaller the diameter and the thinner the wire. The needle-nose pliers may be used to bend the wire into specific shapes.

Design Challenge

The owners of P&C Office Supplies are seeking new designs for paper clips. The company has come across hard times and believes a new paper clip design could revive its once thriving business. It is up to you to save their company. Use your imagination and creativity to invent a new paper clip design. After researching their paper clip sales pattern, the owners have come up with requirements for the design. Please refer to them before you begin.

Try out all your ideas and make drawings of your designs. Choose one design to engineer and test. Be prepared to present your model.

Requirements

- Your paper clip will be unique. It cannot look like any paper clip you have ever seen before, but it may have features of other clips.
- It can be no bigger than 2 inches by 2 inches (5 cm x 5 cm).
- It must hold 10 pieces of paper together.
- You may use other materials to enhance your design, but your main material must be wire.

- It must not have sharp ends.
- You should use your design notebook to draw your various designs.

You may use this square to test for the paper clip size requirement.

The Perfect Paper Clip

Reading: Session 1, Activity A

Why in the world would you study a paper clip as you learn about engineering and design? Henry Petroski, a professor of civil engineering, has written many interesting books about design and engineering in everyday things. In his book, *Invention by Design*, he devotes a whole chapter to paper clips. He notes that the paper clip, although one of the simplest of objects, can provide many lessons about the nature of engineering.

We take paper clips for granted—it seems as if they've always been around. In fact, they've been in use only since the time of the Industrial Revolution. Before that, paper was held together with straight pins. However, the straight pin was difficult to thread through more than a few sheets of paper because it left holes in the paper, and it bulked up piles of paper.

With the developments of the Industrial Revolution, however, volumes of paper increased as technology enabled business to expand nationally and internationally. The paper clip had a clear advantage over the straight pin in holding together a group of papers, and eliminated pricked fingers! The increase in technology associated with the Industrial Revolution also allowed paper clips to be produced in quantities that kept the cost per clip low.

Early versions of the paper clip had problems that later versions sought to remedy. The paper clip we know and love today, with its (almost) perfect design, did not start out that way. Earlier models got tangled together, slipped off too easily, had too much "springiness" or not enough...

As Henry Petroski notes, the paper clip we are familiar with works because:

"... its loops can be spread apart just enough to get it around some papers, and when released, can spring back to grab the papers and hold them. This springing action, more than its shape per se, is what makes the paper clip work. Springiness, and its limits, are also critical for paper clips to be made in the first place."

The most successful paper clip yet designed is the Gem* clip. The shape of the Gem clip was introduced in England in the late 19th century by a company known as Gem, Limited. The classic Gem has certain proportions that seem to be "just right."

Petroski quotes an architecture critic who had the Gem in mind when he wrote:

"Could there possibly be anything better than a paper clip to do the job that a paper clip does? The common paper clip is light, inexpensive, strong, easy to use, and quite good-looking. There is a neatness of line to it that could not violate the ethos of any purist. One could not really improve on the paper clip, and the innumerable attempts to try—such awkward, larger plastic clips in various colors, or paper clips with square instead of rounded ends—only underscore the quality of the real things."

1A Reading: The Perfect Paper Clip (continued)

The Gem became to paper clips what Kleenex* is to facial tissue because of a patent issued to William Middlebrook, of Waterbury, Connecticut, in 1899. The unique aspect of Middlebrook's patent was that, although there were many inventors patenting all sorts of sizes and shapes of paper clips, Middlebrook was patenting the machine that would form the paper clip economically.

Petroski writes:

"The complexity of Middlebrook's machine is clear from his patent drawings, and it is apparent that he was engaged in serious mechanical engineering…The principles upon which the machine works, bending wire around pegs, are well suited to the Gem design and it to them. In short, Middlebrook's machine and the Gem were made for each other."

So the combination of a well-designed paper clip and a well-designed machine led to the success of the Gem clip today.

The architecture critic aside, many believe that even the Gem could use improvement: It goes on only one way; it doesn't just slip on; it doesn't always stay on; it tears the papers; it doesn't hold many papers well.

This is what makes engineering and inventing so challenging. All design involves conflicting objectives and thus compromise. The best designs will always be those that come up with the best compromise.

Of course, inventors will always look for ways to improve upon an object. They will continue to look for ways to make a better paper clip. Newer clips, for instance, may be plastic coated, or shaped like Gems, yet their proportions never seem to be quite right. One improvement to the paper clip has been the introduction of a turned-up lip on the end of the inner loop. This allows the paper clip to slide onto the papers without actually opening the clip. As mentioned above, design involves tradeoffs. This "improvement" adds to the bulk of bundled papers.

One key point to remember is that the laws of nature always bind invention, design, engineering, and manufacturing. Change in one area of design may lead to design weakness in another.

To inventors, the quest for the perfect paper clip remains elusive. Perhaps the simple paper clip isn't so simple a device after all!

Adapted from:

Petroski, Henry. *Invention by Design: How Engineers Get from Thought to Thing.* Cambridge, MA: Harvard University Press, 1996.

Session 1, Activity B

The Design Process

Goal
Become familiar with the design process.

Outcome
The experience with designing paper clips is formalized into a design process that guides students throughout their design and engineering projects.

Description
A small group discussion of the paper clip design activity collects the students' experiences with the design process they experienced directly. The discussion moves to connecting their experience to a general design process outlined on *1B Handout: The Design Process*. A short reading that clarifies the relationship among design, engineering, and scientific research wraps up the activity.

Supplies
Flip chart and markers, white board and markers, or computer to display discussion points.

Preparation
Set up flip chart and markers, white board and markers, or computer to display discussion points.

Procedures
Brief Discussion

1. Ask students to reflect on their experience with designing a new paper clip. You might prompt them to think about:
    - What gave them their ideas?
    - What stages or steps did they go through as their ideas took shape?
    - What helped them move their idea into a prototype?

2. Ask students to share their experience with their designs. Have each person share. Make quick notes on flip chart paper or white board. Call attention to areas of common experiences.

Design Process Review

1. Look at the *1B Handout: The Design Process*, and have students take turns reading each step out loud.

1B: The Design Process (continued)

2. Discuss any connections between the students' experience and the design process as you go through each step.

3. Emphasize that the design process consists of several steps that are revisited throughout the stages of designing a product. The process may go through cycles as ideas are refined and information is gathered. Reinforce the idea that mistakes and failures are part of the process and can help develop a better solution to a problem.

4. Introduce the idea that students will be using this process to identify a need that could be met by redesigning, modifying, or improving an existing product or designing a new product.

Wrap Up
Ask participants to look around the room and discuss:

- What things in the room were designed?
- Which ones were engineered?
- Why do people design things?
- What frustrations do you have with products you use?
- How would you improve those products?

Follow With
The *1C: Toothpaste Cap Innovations* activity walks students through the design process using a designed solution to the problems of conventional screw-top toothpaste caps.

The Design Process

Handout: Session 1, Activity B

Getting From "Think" to "Thing"

You will be using a design process to guide the development of your project from an idea to the design of a prototype. The steps of the design process are iterative, or cyclical. That means that throughout the stages of designing a product, you will revisit many of these steps as you refine your ideas.

1. **Identify a design opportunity.**
   The design process begins with identifying a need. Notice that opportunities to design a new product or redesign an existing one are everywhere. They often come from a problem that has been experienced personally. The goal is to identify many design opportunities and narrow them down later.

2. **Research the design opportunity.**
   Gather a lot of information about the nature of the problem in order to help narrow down your choices. Find out if other people experience the same problem and research any existing products or solutions that may currently be used to solve the problem. Choose a design opportunity to address. Write a problem statement.

3. **Brainstorm possible solutions to the problem.**
   Try to come up with as many ideas as you can for solving the problem or addressing the design opportunity. Brainstorming may involve the use of SCAMPER and other techniques. Then, narrow down your solutions and choose one to three to pursue further.

4. **Draft a design brief.**
   Write a design brief to help outline the problem. A design brief includes a problem statement, a description of the user needs, a proposed solution, and often a sketch of the idea or solution. This is a working document that can be changed.

5. **Research and refine your solution.**
   Do a literature review and talk to experts in related fields and users to find similar solutions and other approaches to the problem. Analyze your solution for feasibility, safety, and practicality.

6. **Prepare design requirements and conceptual drawings.**
   Define the criteria the solution must meet (design requirements) and sketch conceptual drawings.

7. **Build models and component parts.**
   Analyze the project design for its systems, components, and parts. Consider

1B Handout: The Design Process (continued)

appropriate materials and methods for constructing a model. Now build a model of the entire design and/or its systems.

8. **Build a solution prototype.**
   Develop detailed project specifications, consider material properties required, choose materials, and create a working prototype.

9. **Test, evaluate, and revise your solution.**
   Evaluate the prototype for function, feasibility, safety, aesthetics, and other criteria. Consider how it could be improved. Modify your prototype or create another and test it.

10. **Communicate the solution.**
    Present your design solution to an audience. Gather feedback and revise and redesign your product as necessary.

Form Follows Function—What Does That Mean?

Reading: Session 1, Activity B

"The scientist seeks to understand what is; the engineer seeks to create what never was."
—attributed to Theodore Von Karman, engineer (1881-1963)

Every thing is supposed to function—it's supposed to do something, to work. Engineering is about function: Does the product work? Does it meet specifications? Can it be manufactured efficiently? All of this involves solving problems. We are going to be problem solvers and create things that function; we will think like engineers.

We will also learn the skills of good industrial designers. The *form* of an object (how it is designed and constructed) should *follow* the task it is to perform. In other words, you must know exactly what you want something to do before you can design and build it. How effectively something *functions* is often related to its *form*, or the quality of its design. Designers are concerned with qualities such as ease of use, efficient operation, and appealing aesthetics. We will pay attention to form in our project development. Though we will not focus on packaging design or marketing aesthetics, we will talk about the subtle but powerful influences of the "visual attraction" and "tactile appeal" of a product. Our goals are to meet an identified need with an idea that could work.

Science, Engineering, and Design: Where Do They Intersect?
While both engineers and scientists experiment and research problems, they differ in the kind of problems they work on. Engineers tend to work on problems that are of immediate concern to many people's daily lives. Scientific problems often build on basic understanding and may not have an immediate application in daily life.

The work of designers and engineers overlaps as well. Both seek to develop solutions to specific and immediate problems and needs. While design is involved in the entire process, engineering is the more specific process of making the idea meet specifications and function. One is useless without the other.

The First Step to a Good Design Is a Good Description of the Real Problem
The ability to really see a need, and then be able to describe that need, is at the heart of successful product development. It requires a heightened awareness of the way people use things, and an ability to observe one's surroundings. Watching for difficulties people experience in doing a task, or how a particular product is used in an unintended way, takes practice and skill. Our job will be to learn to watch for opportunities for improving a tool or product.

Session 1, Activity C

Toothpaste Cap Innovations

Goal
A thorough review of the design process.

Outcome
Experience with each step of the design process.

Description
This activity takes students through each step of the design process by focusing on the problem of toothpaste screw caps. This is started in a whole-group think-and-discuss format. Students may then work with a partner to complete remaining steps.

Supplies
- Toothpaste tubes with flip-top cap (1-2 for each group)
- Toothpaste tubes with screw cap (1-2 for each group)
- Other examples of toothpaste containers (1-2 for each group)

Preparation
None

Procedures
The Process

1. Walk through the design process using the toothpaste screw cap as the identified problem. Use the questions on the handout to guide discussion. Work with the whole group on steps 1 to 3.

2. Have students work with a partner on steps 4 to 10.

3. Below is a sample of how the handout could be filled out. This activity can either be open-ended, where the students come up with their own designs for a toothpaste cap, or it can focus on the development of the flip-top cap as a design solution. The sample "answers," which reflect the development of the flip-top cap, can be used to prompt students during the activity.

1C: Toothpaste Cap Innovations (continued)

Sample Responses

1. **Identify a design opportunity.**
   What is the problem or need? Describe in detail.

   The toothpaste screw cap poses many problems for people. When taken off, the cap may be easily dropped into the sink drain, on the dirty floor, or even into the toilet. The cap is usually placed on the sink and often leaves toothpaste on surfaces. Furthermore, toothpaste usually gets onto the exterior of the cap. If the cap has grooves in it, it is difficult to clean, which means that the next person to use the toothpaste will end up with toothpaste on her hands.

2. **Research the design opportunity.**
   What is important to know about the nature of this problem? Who are the "users" in this case? How could you find out more about the "users" and their behavior?

   In this case, the users are those who use toothpaste—everyone. However, a younger person might have different complaints about the cap than an older person. User information could be gathered by observing family members' use of toothpaste, surveying, and interviewing people. A trip to the local pharmacy to see what else is on the market might be helpful, too.

3. **Brainstorm possible solutions to the problem.**
   What solutions can you come up with? Take five minutes to brainstorm as many ideas as you can for solving this problem.

   A flip-top cap, a pump, all-in-one toothbrush and toothpaste.

Steps 4 to 10 can be done in small groups or pairs. Students can complete the steps using the flip-top cap example or any of the other examples brainstormed together.

4. **Draft a design brief.**
   Clearly define the current situation or need in a "problem statement," and describe a proposed solution. This is just the first part of the design brief.

   The current most-popular toothpaste cap is a screw cap. This cap poses many problems for the users, including: the cap falling off and getting lost or dirty, the cap leaving toothpaste on the sink and on the outside of the cap. A flip-top cap could solve this solution. This cap would remain on the toothpaste tube so that it could not be lost or dropped. It would not be separately placed on the sink and would therefore not make the sink top dirty.

1C: Toothpaste Cap Innovations (continued)

5. **Research and refine your solution.**
   What questions would be needed to gather the right data? Have other people tried to solve this problem? Are some materials more appropriate than others? If so, what are they? What about manufacturing costs associated with your idea? How would you analyze solution for feasibility, safety, and implications of the idea?

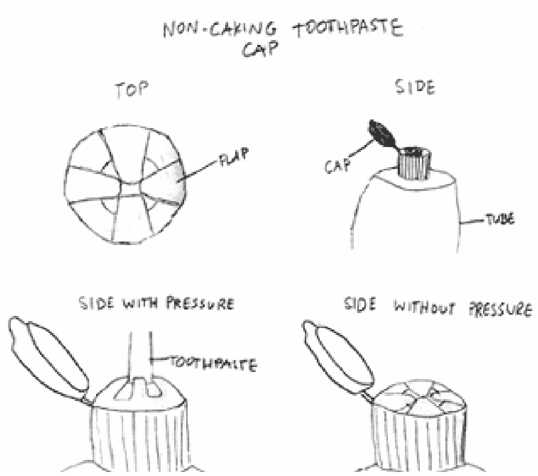
   I would need to do some research to see what types of toothpaste caps are out there. I might do a patent search, look online, go to the library, and browse the toothpaste aisle of the pharmacy. I would think that plastic would need to be used—something lightweight, cheap (it's disposable), and nontoxic. I think this product could be manufactured cheaply since many can be made at one time.

   I think it is feasible to make this product since it is similar to what is already on the market. In terms of safety, the cap would have to be able to screw on tightly so that it would not present a choking hazard to young children. It would have to open and close easily.

6. **Prepare design requirements and conceptual drawings.**
   Outline design requirements—general ways the product will meet the need of the users—and draw a quick sketch of your best ideas here.

   The cap would need to:

   - *Fit on a standard toothpaste tube*
   - Have an attached flip-top cap
   - *Screw on to the tube*
   - *Create an even flow of toothpaste*
   - *Be made of a lightweight, cheap, nontoxic material*
   - *Be leakproof*



1C: Toothpaste Cap Innovations (continued)

7. **Build models and component parts.**
Does your solution have parts or components? What could you use to build a quick model of your best solution?

A model could be built out of Styrofoam. The flip-top cap could be cut out of the Styrofoam and attached with a piece of rubber. The nozzle might be a separate component.

8. **Build the prototype.**
What are the specifications for the product? What materials would you need to build a prototype?

The specifications for the flip-top cap are:
- *Plastic top with 3/8 in. (1 cm) opening*
- *Dispensing nozzle*
- *Outer tube: 1 7/16 in. (3.5 cm) diameter*

9. **Test, evaluate, and revise your solution.**
How would you test your prototypes? What criteria would be useful to evaluate the solution? How would you know if your solution was going to solve the problem? How can I improve my solution based on feedback from my testing?

I would establish criteria, such as: It is easy to use, it stays clean, it stays sealed, and the toothpaste flows easily. I would conduct user-testing focus groups and observe how people used the product.

10. **Communicate the solution.**
How would I present my design solution to an audience? How would I gather feedback from the audience?

I would present my solution through a presentation to peers and community members or I would enter a local science and engineering fair. I would create a feedback form that I would hand out to my audience so I could capture their comments and questions and incorporate them into the next phase of revisions to my design solution.

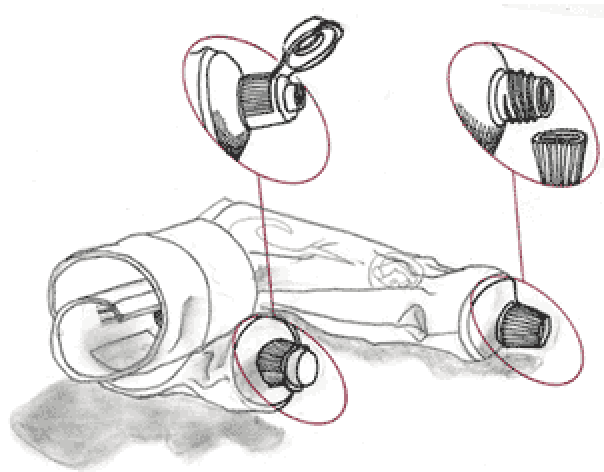
Wrap Up
Have teams describe their solutions or results of specific steps.

Follow With
In Session 2, *The Designed World*, participants learn how to look for design opportunities everywhere.

Toothpaste Cap Innovations

Handout: Session 1, Activity C

In this exercise you will have the opportunity to better understand the design process by applying it to a toothpaste cap. Currently, the most common toothpaste cap is the screw cap. However, many people are dissatisfied with this cap and would like an alternative. What else is on the market? What ideas can you come up with? The first question is done for you. As a group, you'll do the next three together. The remaining questions you will do on your own.



1. **Identify a design opportunity.**
   The toothpaste screw cap poses many problems for people. When taken off, the cap may be easily dropped into the sink drain, on the dirty floor, or even into the toilet. The cap is often placed on the sink and often leaves toothpaste on surfaces. Furthermore, toothpaste usually gets onto the exterior of the cap. If the cap has grooves in it, it is difficult to clean, which means that the next person to use the toothpaste will end up with it on her hands.

2. **Research the design opportunity.**
   What is important to know about the nature of this problem? Who are the "users" in this case? How could you find out more about the "users" and their behavior?

3. **Brainstorm possible solutions to the problem.**
   What solutions can you come up with? Take five minutes to brainstorm as many ideas as you can for solving this problem.

1C Handout: Toothpaste Cap Innovations (continued)

4. **Draft a design brief.**
   Clearly define the current situation or need in a "problem statement," and describe a proposed solution. This is just the beginning of the design brief.

5. **Research and refine your solution.**
   What questions would be needed to gather the right data? Have other people tried to solve this problem? Are some materials more appropriate than others? What are those materials? What about manufacturing costs associated with your idea? How would you analyze solution for feasibility, safety, and implications of the idea?

6. **Prepare design requirements and conceptual drawings.**
   Outline design requirements—general ways the product will meet the need of the users— and draw a quick sketch of your best ideas here.

7. **Build models and component parts.**
   Does your solution have parts or components? What could you use to build a quick model of your best solution?

8. **Build the prototype.**
   What are the specifications for the product? What materials would you need to build a prototype?

9. **Test, evaluate, and revise your solution.**
   How would you test your prototypes? What criteria would be useful to evaluate the solution? How would you know if your solution was going to solve the problem?

10. **Communicate the solution.**
    How would I present my design solution to an audience? How would I gather feedback from the audience?

Session 2

The Designed World

Understanding the Design Process

In This Session:

A) Design Opportunities Are Everywhere (50 minutes)
- Student Handout

B) Mapping Out a Problem (25 Minutes)
- Student Handout

C) Design Improvements (30 Minutes)
- Student Handout

D) SCAMPER and Backpack (45 Minutes)
- Student Handout

Home Improvement
- Student Handout

This session builds appreciation for the designed world around us and prepares students for finding a design and engineering project. Students learn to identify problems that lead to opportunities for new design solutions. They also develop skills by thinking creatively about designed things they use. The first activity, *2A: Design Opportunities Are Everywhere*, involves students taking a short field trip or walking tour to practice recognizing problems and needs around them. The activity ends with students developing a list of design opportunities that interest them and could be used as the first step of their project development. The next activity, *2B: Mapping Out a Problem*, introduces Activity Mapping, a technique used to help students identify problems and design opportunities.

In *Activity 2C: Design Improvements*, students learn about and practice a seven-part creative technique for improving existing designs known as SCAMPER. The next activity, *2D: SCAMPER and Backpack*, reinforces generative thinking using the SCAMPER technique with another object, a backpack.

A Home Improvement activity, *Improvement of Everyday Things*, has students make distinctions between functional and superficial improvements with objects in their homes.

Supplies

- Water bottles in multiple styles
- For each pair of students: 1 backpack (have students bring their own)
- Additional backpacks with other designs
- Clipboards (optional, but handy for taking notes during walking tour)
- Chart paper for posters and markers

The Designed World

Key Concepts: Session 2

In Session 2, students are introduced to three brainstorming techniques. Although many strategies exist to encourage creativity, this session focuses on **Activity Mapping**, **SCAMPER**, and **Brainwriting**. These techniques help students think creatively about designed objects. Another important aspect of this session is a short field trip or walking tour. Students use this field trip as an opportunity to practice recognizing design problems. The final goals of this session include introducing students to the idea of design opportunities and the development of a list of design opportunities that interest them.

Key Concepts
Problem Identification and Activity Mapping

The Activity Mapping technique allows for keen observation into processes needed to accomplish a certain activity. Describing four process stages in detail helps determine if any design opportunities might exist. In addition to the "packing for a trip" example introduced in 2B: Mapping Out a Problem, another example of the four phases of Activity Mapping for "brushing your teeth" is shown below.

		Four primary user goals summarize what people are trying to accomplish when engaging in daily oral care.
Prepare ↓	Get Paste Locate Brush Wet Brush Load Brush Cap Paste	**Prepare** Preparation involves all the tool preparation steps that need to be done before users actually brush their teeth.
Mouth Cleaning ↓	Brush Upper Lower Interior Exterior Tongue	**Mouth Cleaning** Mouth cleaning begins when the cleaning surfaces of the toothbrush are applied to the inside of the mouth. This is the active part of the brushing, where all efforts are physically focused on the removal of food debris, night films, mouth freshening, and gum maintenance.
Cleanup ↓	Spit Rinse Mouth Rinse Hands Wipe Mouth Dry Hands Store Brush Store Paste	**Cleanup** Cleanup has three elements: tool maintenance, tool storage, and personal rinsing. Tool maintenance is focused primarily on getting brushes, sinks, and toothpaste rinsed and ready for next use. Tool storage involves keeping a bathroom tidy and getting the brush, paste, cups, etc. to a safe place where they are less likely to be contaminated. Personal rinsing refers to removal of saliva and paste from the mouth and hands. Rinsing is followed by towel drying.
Assessment	Mouth Feels Clean Looks Good Tastes Good	**Assessment** Assessment allows users to determine whether they've accomplished their personal goals with respect to mouth cleaning. Methods include visual inspection in the bathroom mirror, tactile inspection with the tongue, and self-perception of a minty mouth and fresh breath.

Key Concepts Session 2 (continued)

Students can look back on the processes involved with any activity (in this case, brushing your teeth) and see if any design opportunities can be identified. Students could be asked these questions to help them isolate a design challenge.

What products are involved in each process?
Are there problems with any of these products?
What existing product could be improved or modified?
What new product could be designed?

SCAMPER
The SCAMPER technique is a brainstorming method that builds one idea into several ideas by asking questions about the actions represented by the SCAMPER acronym. Alex Osborn, an early teacher of creativity, first introduced the idea of using questions to spur idea creation in his book Applied Imagination. This technique was later adapted by Bob Eberle and is now used often as a method for new idea generation. Students are introduced to the SCAMPER technique by examining an everyday item—water bottles.

Substitute
Combine
Adapt
Minimize/**M**agnify
Put to other uses
Eliminate/**E**laborate
Reverse/**R**earrange

Some questions to ask students as they use this technique and some examples to illustrate the concepts are shown below:

Substitute: What can be used instead? What can you use instead of the materials, objects, places, or methods now used? Meatless burgers and disposable cameras are examples of products that illustrate substitution.

Combine: Which parts or ideas can you blend together? What could be added? How can I combine uses with something else? Can you combine materials? Scented markers and clock radios are examples of combinations.

Adapt: What else is like this? What can be copied or imitated? How can it be adjusted to fit another purpose? What else is like this? What has worked before? What would you copy? Running shoes and hiking boots are examples of adaptations.

Minimize: Can it be smaller, lighter, less frequent, or divided? How can it be made smaller or shorter? How can it take less time? Mini-staplers and pocket-sized cell phones demonstrate how objects can be minimized.

Magnify: Can it be stronger, larger, higher, exaggerated, or more frequent? What happens if I exaggerate a component? How can it be made larger or stronger?

Key Concepts Session 2 (continued)

What can be duplicated? Repeated? Big-screen televisions and oversized floor pillows illustrate products that have been magnified.

Put to Other Uses: Can it be used in a way other than how it was intended to be used? Who else might be able to us it? What other market can it be used in? What else can it be used for other than its original purpose? Old tires used as swings and drinking cups used as pen and pencil holders illustrate the idea of "put to other uses."

Eliminate: What can you take away or remove? What parts aren't really necessary? Cordless telephones and wireless keyboards are examples of eliminating something.

Rearrange: Can parts be exchanged or the pattern changed? Can any components be interchanged? Can it be laid out differently? Ergonomic keyboards and recumbent bicycles are examples of products that have been rearranged.

Brainwriting

The brainwriting technique encourages students to produce ideas by silently recording the ideas in their design notebooks. This technique gives every student a voice in generating ideas. This is especially true for students who don't naturally speak out during "talking out loud" brainstorming sessions. The goal of this technique is to encourage more idea creation through the eventual sharing of students' written ideas.

Once ideas have been generated individually, they can be shared in a variety of ways. For example, students could write three of their ideas on a piece of paper (leaving room between the ideas) and pass the papers around the classroom. The other students could note suggestions, provide feedback, or ask questions relating to each of the three ideas. Students may now refine their ideas or list new ones based on the feedback and suggestions provided by others.

More About Brainstorming

Eberle, Bob. *Scamper: Games for Imagination Development*. Waco, TX: Prufrock Press, 1996. This book provides a description of SCAMPER and also activities that can be used with students to practice the technique.

Eberle, Bob. *Scamper On*. Waco, TX: Prufrock Press, 1997. This book provides more guided activities encouraging students to think in creative ways.

IDEO. *IDEO Method Cards: 51 Ways to Inspire Design*. San Francisco: William Stout Architectural Books, 2003.
www.ideo.com/methodcards/MethodDeck/index.html*
IDEO, a design firm, publishes cards illustrating methods they use to inspire innovative ideas. Sharing these methods with students will provide additional ways to look creatively at design solutions.

Key Concepts Session 2 (continued)

Michalko, Michael. *Cracking Creativity: The Secrets of Creative Genius*. Berkeley, CA: Ten Speed Press, 1998.
This book provides creative thinking strategies, stories, and exercises to use with students.

Michalko, Michael. *Thinkpak: A Brainstorming Card Deck*. Berkeley, CA: Ten Speed Press, 1994.
Thinkpak is a deck of cards focusing on the SCAMPER technique. The cards may be used to develop new and innovative ideas through the practice of the SCAMPER technique.

Osborn, Alex. *Applied Imagination*. New York: Scribners, 1953.
This book discusses the idea of brainstorming and the study of creativity. Published in 1953, this book influenced the development of creative thinking techniques and idea generation.

Session 2, Activity A

Design Opportunities are Everywhere

Goal
Learn to identify problems, needs, and opportunities for design improvements.

Outcome
Students generate a list of problems that they see as opportunities for design solutions.

Description
This activity helps students begin identifying problems that they could use for their own design project. Through a short field trip or walking tour, students expand their awareness into many possible opportunities for designed solutions. This outing can be as simple as a walk within the facility where you meet or a walk across the street to a park. A field trip to any convenient public place such as a department store or a mall will work well.

This activity should involve mentors and other experts as resources for students to interview about problems or needs. Students collect their observations and information and begin creating a list of possible opportunities for designing new solutions. Students will revisit and refine this list of problems and begin to work on solutions in Sessions 7 and 8.

Supplies
Clipboards (optional, but handy for taking notes during walking tour)

Preparation

1. Identify the location and make any arrangements for a walking tour of public places. As an alternative: make arrangements for a panel of guest speakers (mentors) to bring problems or needs from their lives.

2. Make arrangements for mentors to join you during or after the walking tour.

3. Review the *Field Trips* section in *Implementation Strategies*

Procedures
Asking Questions

1. Introduce the field trip task using the handout.

2. Lead a warm-up discussion about students' experiences with problems or product needs:

2A: Design Opportunities are Everywhere (continued)

- What problems are you aware of?
- Think about something in the physical world that frustrated you recently. What do you find frustrating?
- Have you ever broken your arm or been in a wheelchair? If so, what was most difficult about this experience?
- Is anyone left-handed? What do you find most challenging as a left-handed person?
- What things, services, or processes that you use regularly could be improved?

3. Point out that these same questions could be asked of anyone—friends, parents, mentors.

4. Ask students to think of other questions to ask.

Walking Tour

1. Orient students to the field trip, the location, logistics, and responsible behavior.

2. During the field trip be sure to stop, observe, and identify problems. This should be reinforced with the entire group. Students should jot down notes as they see problems that interest them.

3. After the field trip, students complete a "brainwriting" exercise to generate problems that interest them. Have students share a couple of their ideas with the rest of the group. Encourage students to share any ideas that were triggered as they listened to each other. For example, "That's a great idea. Have you thought about…?" The sharing of ideas may trigger other ideas.

4. Encourage students to take the list home and talk to family and friends to add to their list of design opportunities. This list will be added to throughout Design and Discovery.

5. In the future, have students practice looking at the world differently by taking time before an activity to ask them specifically about a designed object. It could be something as simple as a chair, pencil sharpener, or notebook. Ask them what needs are being met by the design. Have them conjecture why it was designed the way it was. This brief practice of looking at designed objects may help students find other design opportunities to add to their list.

Wrap Up

End with a brief discussion about how design is all around us. Remind students to keep looking at the world as a designed environment. Have them think about what they use and interact with every day as being intentionally designed.

2A: Design Opportunities are Everywhere (continued)

Follow With

Activity 2B: *Mapping Out a Problem* introduces students to a problem identification technique called Activity Mapping.

Design Opportunities Are Everywhere

Handout: Session 2, Activity A

Problem identification: What makes a good problem to solve?
Many important engineering and design ideas start with a problem or need. You have the capacity to solve important problems and make amazing things happen. Good ideas are inside you. Good problems often start with things you know about or have some personal connection to. Perhaps it's something that bothers you and you think about how it could be different. Maybe you have a relative or friend who struggles with something. Sometimes a problem to solve just comes from an idea of yours that sounds like a fun or easier way to do something.

In this activity, you will practice identifying design opportunities. Some of these opportunities may be problems, while others may be needs or simple improvements.

Who knows about problems? What kinds of problems are there?

- Health problems: Doctors and nurses would know, researchers too. Safety problems: Emergency room staff would know, firemen and police would know.

- Problems of a specific group: The elderly, the very young, people in wheelchairs, left-handed people, short people, deaf people. Try to understand through experience what it would be like to be in their shoes. Research the associations or organizations of these groups.

- Inconvenient problems: What bugs you? Always losing your keys?

Make a list, in your design notebook, of the people or organizations you could call for more information about problems or things that don't work well enough.

Where can you find problems to solve?
The answer is: everywhere. With attention and focus on designed things you see and use wherever you go, you will see all kinds of problems just waiting for your ideas and creativity. You will be taking a trip today to observe a public place (a mall, a park, or a store). Look for problems to solve. Watch how people use things in that place. Look for problems to solve. Study a few objects and items in that place. Look for problems to solve. Take notes in your design notebook.

What problems would you like to solve?
They can be big problems or small problems. You decide. Creativity takes practice and patience. And it takes a few good strategies. One strategy is called "brainwriting." Brainwriting is different from brainstorming because you don't talk. You write your ideas on paper, quietly.

Write down "problems" or "design opportunities" you are aware of (these may be from the field trip). Include things that exist that could use improvement. Write this list in your design notebook.

2A Handout: Design Opportunities are Everywhere (continued)

Save this list. Revisit it as you work through the other *Design and Discovery* sessions. Add new design opportunities as you think of them.

Session 2, Activity B
Mapping Out a Problem

Goal
Introduce and practice Activity Mapping, a creative technique for identifying design opportunities.

Outcome
Learn and practice the Activity Mapping technique.

Description
This activity introduces a brainstorming technique, Activity Mapping, where students analyze an activity, think about the steps in this activity, and identify problems and design opportunities.

Supplies
None needed

Procedures
ZIBA Design Activity Mapping

1. Activity Mapping is used as a way to identify processes, the products used in the processes, and problems that arise in the processes. Use the Activity Mapping example below to model strategies for identifying design opportunities. Examine the processes and products involved with packing for a trip and consider if opportunities for improvement exist. This technique is used by ZIBA Design, www.ziba.com*, an international design firm that has designed products for many global companies, including FedEx, Microsoft, Intel, Fujitsu, Black & Decker, Sony, Pioneer North America, Dial, and Clorox. Students practice using Activity Mapping as a group by exploring the processes used in brushing teeth.

2. Explain that Activity Mapping has four primary user goals that summarize what people are trying to accomplish when engaging in an activity.

Activity Mapping

1) Pre-activity: Describes what is done before the activity

↓

2) Activity: Explains what is involved in the activity

↓

3) Post-activity: Includes what is involved after the activity

↓

4) Assessment: Involves how one knows if the activity has been successful

2B: Mapping Out a Problem (continued)

3. Using chart paper, ask students what is involved for each phase of "packing for a trip." In the example below, "prepare" is the pre-activity, "packing" is the activity, and "unpacking" is the post-activity. The Activity Mapping should look something like this:

		Four primary user goals summarize what people are trying to accomplish when engaging in packing for a trip.
Prepare ↓	Check weather Make a list of items Wash clothes Locate needed items Buy any needed items	**Prepare** Preparation involves gathering all the information and items needed to pack your luggage completely.
Packing ↓	Fold and lay out clothes Put items in luggage Check list Secure luggage	**Packing** Packing means making sure all items will fit inside your luggage or bags securely, ensuring there is a place for everything.
Unpacking ↓	Put clothes in drawers or hang up Put toiletries in bathroom Place shoes in closet Store luggage	**Unpacking** Unpacking has two main elements: removing and storing items, and storing luggage. All clothes, toiletries, shoes, and miscellaneous items should be stored in appropriate locations—closet, dresser, and bathroom. Luggage storage involves putting any suitcases or bags out of the way.
Assessment	Packed for the right weather Had enough clothes Did not need to buy any additional items	**Assessment** Assessment allows users to determine whether they've packed correctly for the weather and the circumstances. Methods include taking an inventory of items not used and any items that were forgotten.

4. Ask students what products are involved in each process. Ask them to consider if there are any problems with any of these products, any suggestions they have for improving a product or inventing a new product. What could make life easier for people when they pack for a trip? Explain that this is one way to identify problems and begin to consider solutions.

5. Students can apply this tool to identifying other problems and ultimately coming up with solutions.

Error Analysis

Error Analysis (used by the IDEO* design team) is another technique for identifying problems or design opportunities. With this method, students list all the things that can go wrong when using a product. For example, some of the possible things that could go wrong when using a

2B: Mapping Out a Problem (continued)

backpack include: a stuck zipper, easily torn material, or poorly adjusting shoulder straps. Any of these features could be identified as a design opportunity and researched further to come up with a solution to the problem.

Wrap Up
Remind students of the 10-step design process introduced in *Activity 1B.* Discuss how the Activity Mapping technique addresses the first step in the process—identify a design opportunity. By using the Activity Mapping technique, problems can be identified by analyzing something they have experienced personally. One of these identified design opportunities could be one they pursue for their independent project.

Follow With
Activity 2C: *Design Improvements* introduces students to SCAMPER, a brainstorming technique that helps them generate ideas for improving existing designs.

Mapping Out A Problem

Handout: Session 2, Activity B

Problem Identification and Activity Mapping
As a group, you'll do a practice Activity Mapping on packing for a trip. This is a useful tool for identifying problems. Activity Mapping has four primary user goals that summarize what people are trying to accomplish when engaging in an activity.

Activity Mapping

1) Pre-activity: Describes what is done before the activity

↓

2) Activity: Explains what is involved in the activity

↓

3) Post-activity: Includes what is involved after the activity

↓

4) Assessment: Involves how one knows if the activity has been successful

Answer the following questions in your design notebook.

What products are involved in each process?
Are there any problems with any of these products?
What suggestions do you have for improving a product, or inventing a new product?
What could make life easier for people when they pack for a trip?

This process is one way to identify problems and begin to consider solutions.

Now, do your own Activity Mapping, in your design notebook, for a common activity you experience—for example, making a sandwich, washing the dog, or cleaning your room. This process may help you identify a problem or design opportunity. If you identify a problem, add it to the list you began in *2A Handout: Design Opportunities Are Everywhere.*

Session 2, Activity C

Design Improvements

Goal
Introduce and practice SCAMPER, a creative technique for improving existing designs.

Outcome
Learn and practice the SCAMPER process.

Description
Students learn about and use SCAMPER, a systematic technique for generating ideas about improving existing designs. This technique can be used to develop possible solutions to design problems, such as ones found during the walking field trip or Activity Mapping process. To get students started, they study a variety of water bottles and use SCAMPER to generate ideas about water bottle improvements.

Substitute
Combine
Adapt
Minimize/**M**agnify
Put to other uses
Eliminate/**E**laborate
Reverse/**R**earrange

Supplies

- Water bottles in multiple styles (ask students to bring in examples)
- Clipboards (optional, but handy for taking notes during walking tour)
- Chart paper for posters and markers

Preparation

1. Read through the SCAMPER technique for expanding thinking about improvements.
2. Practice using SCAMPER to come up with an improvement yourself!

   Note: The SCAMPER technique may be used on a variety of items. You may substitute something else for water bottles in this activity or use additional items as extra practice.

2C: Design Improvements (continued)

Other possible items include: headphones, shoes, wrenches, hand drills, watches, telephones, umbrellas, and coats.

Procedures

1. Distribute water bottles among groups of students.
2. Present each step of the SCAMPER process using water bottles as an example. Use the student handout to go through each step.
3. Assign a different letter of SCAMPER to seven groups and have them create and display posters of the SCAMPER technique using the letters and keywords from the handout.
4. Provide time for groups to study different types of water bottles. Have participants come up with additional water bottle improvements using their assigned SCAMPER step and add it to their poster—include sketches of their ideas.
5. Share posters and ideas with the whole class.
6. Together, compare two different water bottle designs and determine which step of SCAMPER was applied.

Wrap Up
Discuss any other strategies for generating new ideas and approaches to existing solutions.

Follow With
Activity 2D: SCAMPER and Backpack applies the SCAMPER technique to another item, a backpack.

Design Improvements

Handout: Session 2, Activity C

Ready to SCAMPER? SCAMPER is a technique that gets you to think about improving an existing design. It is an acronym that helps you remember seven different ways to think up new improvements. It is useful for being creative in a systematic way. It generates ideas you might not have on your own. Try it!

S Substitute one thing for another.

C Combine with other materials, things, or functions.

A Adapt: Can it be used for something else?

M Minimize/Magnify: Make it larger or smaller.

P Put to other uses: Can you put it to another use? In this case, use it for another vegetable? If you make it larger, would it work for some other food?

E Eliminate/Elaborate: Remove some part or material, or make one section more detailed or refined.

R Reverse/Rearrange: Flip-flop some section of the item, move parts around.

Here are some improvements that can and have been made to water bottles. Can you think of any more improvements by using the SCAMPER technique?

2C: Design Improvements (continued)

SCAMPER	Questions to Ask	Water bottle Improvement	Benefit
Substitute	What could be used instead? What kind of alternate material can I use?	Different bottle material	Plastic bottle is unbreakable, unlike glass
Combine	What could be added? How can I combine purposes?	Add straw into top	Straw allows access to bottom of water bottle without lifting and tilting bottle
Adapt	How can it be adjusted to fit another purpose? What else is like this?	Use squirt top for watering plants	Directed stream gets water to the plant roots
Magnify	What happens if I exaggerate a component? How can it be made larger or stronger?	Larger bottle	More water for better hydration
Minimize	How can it be made smaller or shorter?	Smaller bottom of bottle	Can store in car's cup holders easily
Put to other uses	Who else might be able to use it? What else can it be used for other than its original purpose?	Turn upside down	Hand washing station
Eliminate	What can be removed or taken away from it?	Eliminate the handle	More volume for water storage
Elaborate	What can be expanded or developed more?	Larger base	Lower center of gravity helps keep water bottle from tipping
Rearrange	Can I interchange any components? How can the layout or pattern be changed?	Move handle from side to top	Better ergonomics for hauling large amounts of water
Reverse	What can be turned around or placed in an opposite direction?	Water spout at bottom	Easier to dispense water into cups

Session 2, Activity D

SCAMPER and Backpack

Goal
Apply the SCAMPER technique to the components of a backpack.

Outcome
Improve a backpack design using SCAMPER.

Description
Students look at the different components of a backpack and apply the SCAMPER technique to each component. They are introduced to sketching by enhancing an existing drawing with their improvements.

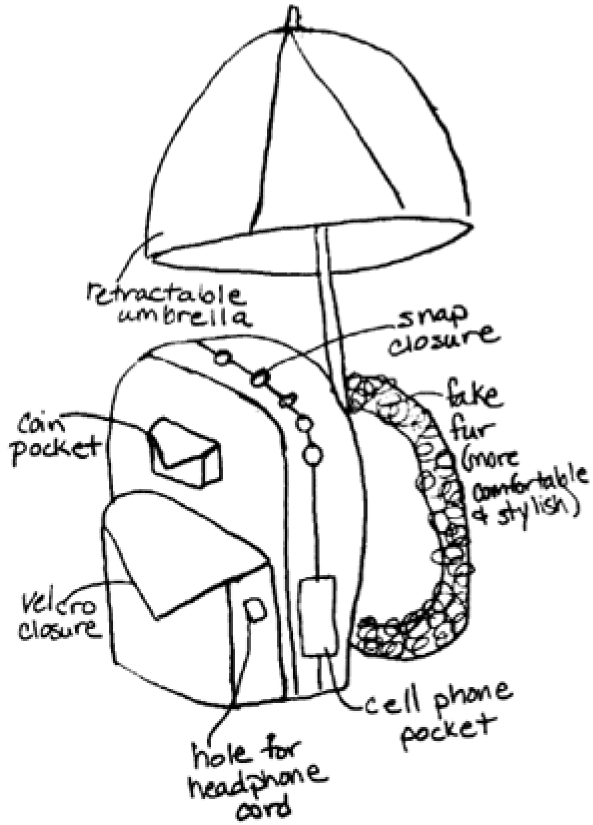
Supplies

- For each pair of students: 1 backpack (Have students bring in their own and then make comparisons with others.)
- Additional backpacks with other designs

Procedures

1. Distribute backpacks to students.
2. Ask the students to compare the backpack to the drawing on the handout.
3. Call attention to different components of the backpack. Notice how a product can be broken down into parts:
    - Large pocket
    - Small outside pocket
    - Shoulder straps
    - Zippers
4. Explain the task: Use SCAMPER to improve one part or all.
5. Walk through the first two letters of SCAMPER as a group, and then continue the process in teams.
6. As they work through the process, encourage students to sketch and make notes about possible improvements in their design notebooks.
7. Have them draw improvements in their notebooks or on the handout that shows a drawing of a backpack.

2D: SCAMPER and Backpack (continued)



8. Share improvement ideas for each SCAMPER letter and discuss:

- What component was improved or used differently?
- What idea comes to mind first?
- How many ways do you think this product could be changed?

Wrap Up
Introduce the Home Improvement activity, *Improvement of Everyday Things.*

Follow With
Session 3, *Materials for Design*, is the first of three sessions that provides engineering fundamentals needed for project development.

SCAMPER and Backpack

Handout: Session 2, Activity D

The Backpack, Improve It!

Apply SCAMPER to each of the backpack parts. Sketch and make notes about your improvement ideas. Make your drawings in your design notebook.

Improvement of Everyday Things

Home Improvement: Session 2

Goal
Know the difference between a superficial improvement and a functional improvement.

Description
Students study household objects with similar functions. They distinguish functional improvements from superficial improvements. A functional improvement is something that improves the performance of the product. A superficial improvement, such as a color change, does not affect the performance.

Directions Before Going Home

1. Review the list of objects on the Home Improvement handout.

2. Discuss and add to the list as a group. Agree on three to five items that students will bring in.

    - What else could be included here? (Remember, we are trying to find familiar, everyday items that can be found anywhere.)

    - Remind students that the task is to identify objects with functional improvements.

Next Day

1. Share the three things that best represent functional improvement.

2. Follow-up discussion could address the following questions:

    - What is more common, functional or superficial improvement?

    - What examples can you think of that we couldn't bring in, but could talk about?
      Example: different cars, stoves, lamps, chairs, etc.

    - Did anyone find a superficial improvement that reduced the object's function? (Form that messes up function.)

Improvement of Everyday Things

Handout: Session 2, Home Improvement

Where Do You See Improvement?
The following list represents common items found in most household kitchens, garages, or junk drawers. These items have been specifically designed to serve one need. In some cases, the variety of these items represents improvements in functionality; in others, the variety merely represents aesthetic appeal. Functionality is an engineer's job, and it is important to recognize the difference between "appeal" factor and meaningful improvement in functionality.

Bring three things from this list of items that best represent functional improvement:

- Cheese grater
- Cherry pitter
- Nail cutter
- Cup lids for hot liquids
- Candle holder
- Stapler
- Napkin ring
- Can opener
- Tooth floss container
- Eraser
- Key ring
- Lemon peeler
- Can opener
- Potato peeler
- Umbrella
- Toothpick dispenser

Be prepared to explain the functional improvement.

Design and Discovery

Engineering Fundamentals

In these sessions, students are introduced to basic engineering concepts that they can later apply to their design projects. In *Session 3: Materials for Design*, students learn about material classes, properties, and cost considerations when selecting materials. In *Session 4: Getting a Charge from Electricity*, students explore electrical circuits as they learn to wire simple, series, and parallel circuits. *Session 5: Making Machines*, introduces the principles of simple machines and gives students an opportunity to apply these principles to mechanical toy designs. *In Session 6: One Problem, Many Solutions*, the difference between form and function is introduced as students compare alarm clocks.

Session 3

Materials for Design

Engineering Fundamentals

In This Session:

A) Properties of Materials (60 minutes)
- Student Handout
- Student Reading

B) Materials Applications (45 Minutes)
- Student Handout
- Student Reading

C) Materials Choice (45 Minutes)
- Student Handout
- Student Reading

Home Improvement
- Student Handout

In this session, students learn about the principles behind materials selection. Like materials engineers, they learn to differentiate and select materials based on their properties. In *3A: Properties of Materials*, students test samples of metals, ceramics, polymers, and composites to compare their properties. They test for density, ductility, strength, fatigue, electrical and thermal conductivity, and optical properties. In *3B: Materials Application*, students apply their knowledge of material properties to solve real-world problems faced by materials engineers. When materials engineers select which materials to use, they also consider the cost of materials. In *3C: Materials Choice*, students gain an understanding of the economics of material selection through a cost analysis of a beverage container made of different materials. They then think innovatively about how to design a beverage container that can be put to another use.

A Home Improvement activity, *Materials Scavenger Hunt*, has students looking at objects and analyzing what materials were used to make them.

Supplies

Note: The supplies listed are suggestions. Alternate supplies may be substituted to demonstrate and test material properties.

For Demonstration

- 1 brick, 1 block of wood, and 1 block of Styrofoam*, all the same size, recommended: 2 inches x 4 inches x 8 inches (5 cm x 10 cm x 20 cm)
- Optional: balance scale
- 2 chocolate bars with caramel filling (1 frozen, 1 at room temperature)
- 3 12-oz. (355 mL) or 16-oz. (473 mL) beverage containers: 1 plastic, 1 aluminum, and 1 glass

For Each Small Group

- 1 wooden craft stick, 1 plastic cable tie, 1 paper clip
- 8 inch x 1 inch (20 cm x 2.5 cm) strips of heavy-duty aluminum foil, heavy-duty plastic bags, and paper
- 2 buckets: 1 large and 1 small, such as 10 quart (9 liters) and 5 quart (4.7 liters)

Session 3, Materials for Design (continued)

- 5 lbs. (2.2 kg) of sand, rice, or beans (as weights). Batteries work too. Or, balance scale if available
- 2 2-inch (5 cm) C-clamps
- Candle, matches
- "D" size battery, wire, bulb (also used in Session 4)
- Flashlight (also used in Session 4)
- Piece of ceramic tile (4 inch x 4 inch) (10 cm x 10 cm)
- Samples of a transparent material (such as a plastic bag), a translucent material (such as a hazy plastic cup), and an opaque material (such as a colored plastic bucket)

Note: The property tests in *3A: Properties of Materials*, can be done as stations, and therefore the following supplies may be purchased for one station: buckets, sand, rice, or beans, C-clamps, battery, wire, bulb, flashlight, ceramic tile, candle, matches, sample transparent, translucent, and opaque materials.

Materials for Design

Key Concepts: Session 3

Session 3 is about **materials**. In order to select suitable materials for use in a product, it is important to know the differences among the classes of materials and their related properties. Students need to build familiarity with material classes, material properties, how materials are selected and used, how cost is considered, and the environmental impact of materials.

Key Concepts

Materials are so important to engineering and design that there is a whole field of engineering devoted to materials. Materials engineers envision, design, prototype, and test new or modified materials for products. They provide expertise on materials selection and properties for a given product. Some materials engineers develop materials processing methods and even create new materials.

Materials Classes

Materials are grouped into categories or classes based on their chemical composition. Material selection is determined by the capabilities and qualities of materials, or their properties. The chart below shows four classes of materials, their definitions, types of materials within the class, properties, and examples of usage.

Materials Class	Definition	Examples	Properties	Applications
Metals	Metals are combinations of "metallic elements," such as iron, gold, or lead. These elements, when combined, usually have electrons that are nonlocalized and as a result have certain physical properties. Alloys are metals like steel that combine more than one element.	Steel, aluminum, iron, gold, lead, copper, platinum, brass	Strong, dense, ductile, electrical and heat conductors, opaque	Electrical wiring, structures (buildings, bridges), automobiles (body, springs), airplanes (engine, fuselage, landing gear assembly), trains (rails, engine components, body, wheels), shape memory materials, magnets
Ceramics	Ceramic materials are inorganic materials with non-metallic properties usually processed at high temperature at some time during their manufacture.	porcelain, glass, cement	Lower density than metals, strong, low ductility (brittle), low thermal conductivity, corrosion resistant	Dinnerware, figurines, vases, art, bathtubs, sinks, electrical and thermal insulating devices, water and sewage pipes, floor and wall tile, dental fillings, abrasives, glass windows, television tubes
Polymers	A polymer contains many chemically bonded parts or units that are bonded together to form a solid. Plastics, for example, are a large group of organic, man-made compounds based upon a polymer of carbon and hydrogen.	Plastics (synthetic, nylon, liquid crystals, adhesives), rubber	Low density, poor conductors of electricity and heat, different optical properties	Fabrics, car parts, packaging materials, bags, packing materials (Styrofoam*), fasteners (Velcro*), glue, containers, telephone headsets, rubber bands

Composites - Synthetic - Natural (biocomposite)	Composites are two or more distinct substances that are combined to produce a new material with properties not present in either individual material. Biocomposites are composites found in nature.	Fiberglass (glass and a polymer), plywood (layers of wood and glue), concrete (cement and pebbles) Wood, cotton, silk	Properties depend on amount and distribution of each type of material. Collective set of properties are more desirable and possible than with any individual material.	Golf clubs, tennis rackets, bicycle frames, tires, cars, aerospace materials, paint, wooden craft stick, paper

Materials Properties

The definitions for eight material properties are below.

Property	Definition
Density	How heavy objects are that occupy the same volume
Ductility	How easily a material stretches when force is applied
Strength	How much weight a material can hold without failing or breaking
Fatigue	How easily a material withstands repeated stresses
Electrical Conductivity	Whether or not electricity passes through the material
Thermal Conductivity	How easily heat passes through the material
Optical Properties	How easily light passes through (transparent, translucent, opaque)
Corrosion	If the material degrades easily because of the physical environment

Material Cost

Materials are usually sold by weight or by size. Material costs are therefore given as cost per unit weight or cost per unit volume. Many materials are initially made in bulk (such as cast metal ingots). They are usually shaped into standard stock items (for example, a sheet or tube) before being bought by a manufacturer. As a result, the cost of a material to a manufacturer is often higher than the cost of the raw material. Also, as a general rule, the more a material is "improved," for example by alloying, the more expensive it becomes.

Material costs are not fixed, but are strongly affected by the marketplace and international trading, and by changes in the stability of the supply of the raw materials—which can be disrupted by wars and global politics. Some materials, such as steel, have had a very stable price for many years. Others, like aluminum, have varied by as much as a factor of 3 in the last decade. The cost of newer materials steadily decreases as their usage increases. The most accurate information on material price can be obtained by contacting material suppliers. Note that the price will depend on the form the material is supplied in (as a raw material, or formed into a sheet or tube), and that bulk discounts can be significant.

Key Concepts Session 3 (continued)

Material Recycling

Aluminum Recycling: Aluminum is easily and frequently recycled. It is sorted at a sorting plant using magnets that separate steel and aluminum. Aluminum is a chemical element that cannot be found in the earth in its pure form. Therefore, extraction becomes quite a complex and energy-intensive process that takes aluminum oxide from bauxite and then removes the oxygen in a smelting process to produce aluminum. The recycling of aluminum is relatively easy, and saves up to 95 percent of the energy required to refine it after original extraction. This significantly increases the need for keeping refined aluminum within the material stream rather than letting it become waste, thereby placing a premium on its recycling.

Glass Recycling: Glass is a highly effective recycled material and a very stable, nontoxic material when disposed of. Glass recycling is heavily dependent on the appropriate color separation of the material. In addition to color considerations, glass recycling must remove other impurities that are common, such as porcelain, ceramics, cork, and paper from labels, which all cause problems in the subsequent manufacturing process.

Paper Recycling: The recycling of paper and cardboard is the most easily attained and most effective. The quantity of paper recycled has increased. The quality of paper recycling depends on the process used. Paper cannot be recycled forever. Each process reduces the fiber length, thus reducing the ability of the fibers to stick together without the use of additional adhesives.

Plastics Recycling: The primary problem with plastics recycling is cross-contamination of resins. If one type of plastic is recycled with another, it can significantly degrade the quality of the end product. Therefore, a careful process of sorting is required to ensure this does not occur. There are different methods used to sort plastics. Once the material has been sorted, it can be remanufactured using a number of different techniques including extrusion, blow molding, and injection molding, and reused in many different applications. Certain packaging functions do not allow the use of recycled materials, particularly packaging of foodstuff.

The Plastic Coding System
The use of coding facilitates sorting for plastic recycling. It ensures that plastic containers and materials of various resin types can be identified so that they can be properly collected, sorted, and recycled. Plastics are numbered 1-7 based on their material composition.

Type of Plastic	Common Uses
1 = PET or PETE – Polyethylene terephthalate	Soft drink bottles, some fruit juices, alcohol beverage bottles
2 = HDPE – High-density polyethylene	Clear HDPE—milk jugs, distilled water, large vinegar bottles, grocery bags Colored HDPE—liquid laundry and dish detergent, fabric softener, motor oil, antifreeze, bleach and lotion

3 = V or PVC – Vinyl/polyvinyl chloride	Vegetable oil bottles, mouthwash, salad dressings
4 = LDPE – Low-density polyethylene	Bags for dry cleaning, bread, produce and trash, and for food storage containers
5 = PP – Polypropylene	Battery cases, dairy tubs, cereal box liners
6 = PS – Polystyrene	Yogurt cups, clear carryout containers, vitamin bottles, fast food, spoons, knives and forks, hot cups, meat and produce trays, egg cartons, clamshell carryout food containers
7 = Other types of plastics	Squeezable ketchup bottles, most chip snack bags, juice boxes (individual servings)

More About Materials
American Plastics Council, www.americanplasticscouncil.org*
This site provides everything that you ever wanted to know about plastics.

Materials World Modules, www.materialsworldmodules.org*
These modules provide more in-depth activities for students and can be ordered from Northwestern University.

Design inSite, www.designinsite.dk*
This Danish Web site is a designer's guide to manufacturing. It provides information about materials, materials properties, and material use in products.

Demi Guide to Sustainability, www.demi.org.uk*
This guide explores design for sustainability, environmental issues of design, and how to design materials and products with sustainability in mind.

Inquiring Minds, www.tvo.org/iqm/site_contents.html*
This site provides clear explanations and pictures that make learning about plastics easy. The site also includes short videos, for example, "How Velcro Works."

Session 3, Activity A

Properties of Materials

Goal
Understand four classes of materials and be able to differentiate materials based on their properties.

Outcome
Students know the differences between materials and can conduct tests to compare properties of materials.

Description
Students test samples of metals, ceramics, polymers, and composites to compare their properties. They test for density, ductility, strength, fatigue, electrical and thermal conductivity, and optical properties.

Supplies
For Demonstration

- 1 clay brick, 1 block of wood, and 1 block of Styrofoam*, all the same size (recommended: 2 inches x 4 inches x 8 inches) (5 cm x 10 cm x 20 cm)
- Optional: balance scale
- 2 chocolate bars with caramel filling (1 frozen, 1 at room temperature)

For Each Small Group

- 1 wooden craft stick, 1 plastic cable tie, 1 paper clip
- 8 inch x 1 inch (20 cm x 2.5 cm) strips of heavy-duty aluminum foil, heavy-duty plastic bags, and paper
- 2 buckets: 1 large and 1 small, such as 10 quart
- 5 lbs. (2.2 kg) of sand, rice, or beans (as weights). Batteries work too. Or, balance scale if available
- 2 2-inch (5 cm) C-clamps
- Candle, matches
- "D" size battery, wire, bulb (also used in Session 4)
- Flashlight (also used in Session 4)
- Piece of ceramic tile (4 inch x 4 inch) (10 cm x 10 cm)
- Piece of ceramic tile (4 inch x 4 inch) (10 cm x 10 cm)
- Samples of a transparent material (such as a plastic bag), a translucent material (such as a hazy plastic cup), and an opaque material (such as a colored plastic bucket). Other materials may be substituted.

3A: Properties of Materials (continued)

Note: The property tests can be done as stations, and therefore the following supplies may be purchased for one station: buckets, sand, rice, or beans, C-clamps, battery, wire, bulb, flashlight, ceramic tile, candle, matches, sample transparent, translucent, and opaque materials.

Safety Issues
Be sure to have students use safety precautions when testing materials. During the thermal conductivity test, students use candles to heat materials. Demonstrate how to hold each material between 1 and 2 inches (2-4 cm) from the flame.

Preparation

1. Familiarize yourself with the four classes of materials addressed in this session: metals, ceramics, polymers, and composites.

2. Conduct the properties tests yourself.

3. Distribute supplies to each pair or group, or set up testing stations. Decide if students will do all the tests first and then discuss the results or if a discussion will take place after each test.

Procedures
Debrief Home Improvement

1. Ask students to share their objects from the Home Improvement in Session 2.

2. Using the objects, discuss functional versus superficial improvements.

Materials Around Us

1. Ask students what types of materials they see in objects around them. Tell them to list all the materials.

2. Now, have students look at their lists and group together the materials that they think are similar.

3. Ask students how many different types of materials there are. Discuss their categorizations and then explain the five different classes of materials used by materials engineers. *There are five main types of materials: metals, ceramics, polymers, composites, and semiconductors (not addressed in this session).* Give an overview of each material with examples. Read *3A Reading: What Are Things Made Of?*

4. Have students recategorize their lists based on these classes.

3A: Properties of Materials (continued)

Why Do Materials Matter?

1. Use an example in the room, such as a chair. Ask what materials the object is made of. Together, list each part of the object and the material it is made of.

2. For each part of the object, ask why that particular material was selected. For example, why does a chair have metal legs and a plastic seat? *The legs need to be made of a strong material to hold a lot of weight; therefore, they are metal. The chair should be fairly light so that it is easy to move around. It should also not wear with use; therefore, plastic is used.*

3. In pairs or small groups, have students describe a few objects, identify the materials used in the object, and hypothesize as to why those particular materials were selected.

4. Explain that students are going to learn more about the differences between materials by testing them. The qualities of materials (such as strength, weight, etc.) are called *material properties*.

5. Materials engineers are familiar with material properties. When they choose materials, they base their selection on the required properties (strength, stiffness, etc.).

Testing Material Properties

1. To understand material properties, have students compare materials by conducting the tests listed below. These tests can be done in pairs or small groups. Stations can also be set up and students can rotate through the stations. Have students record their test results.

2. Be sure to explain that understanding material properties will help students when planning what materials to use for their projects. They will be able to select materials that make the most sense for their required use.

3. It is important to point out that properties of materials may differ within the same class of materials, depending on the type of material, the thickness, and the size of the material. Therefore, the tests results are not conclusive for each material class. The point is for students to understand how to differentiate materials based on their properties and to learn how to test materials' properties. Students can apply these tests when determining what materials to use for their design projects.

4. After each test, have students consider examples of objects where that property characteristic is important.

Density Test
Question: Which materials are denser?

Materials: 1 clay brick, 1 block of wood, and 1 block of Styrofoam (The materials should all be the same size. Other materials that are the same size, but different densities may be substituted.) Balance scale (if available)

1. Explain: Discuss what density is. Density is a measure of the mass of material per unit of volume. Simply put, if mass is a measure of how much "stuff" there is in an object (or how much matter an object has), then density is a measure of how tightly that "stuff" is packed together. The formula to determine density is:

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

2. Demonstrate: Show an example of how to use the formula. Use objects that are the same size (length, width, and height): a brick, a block of wood, and a block of Styrofoam. Call up three students to measure the length, width, and height of each object. Record the volume (L x W x H). (Measurement should be the same for all these objects.) Now, using a balance scale (if you have one), weigh each object and record its mass. Then use the formula to determine the density of each object. Without a scale, lift the objects and rate them from heaviest to lightest, 1, 2, and 3, and determine the volume using these numbers.

3. Rate materials: high, medium, or low density.
   Results: The brick (ceramic) has the highest density, followed by wood (composite). Styrofoam (polymer) has the lowest density.*

4. Discuss design issues: Think of examples of other objects where high density is important *(paperweight, building material)*. Think of examples of objects where low density is important *(baseball bat, tennis racket, backpack)*. You may want to discuss new composite materials that are used in sports equipment to make them lighter in weight.

Ductility Test
Question: How easily does the material stretch when force is applied?

Materials: For optional demonstration: 2 chocolate bars with caramel filling (1 frozen, 1 at room temperature). For testing: 1 wooden craft stick, 1 plastic cable tie, 1 metal paper clip

1. Demonstration (optional): To demonstrate the concept of ductility, break chocolate bars one at a time. What happens? Does it bend or crack first?
   Results: The unfrozen bar will stretch and bend before breaking (ductile), while the frozen one will not stretch but rather break immediately (brittle).

3A: Properties of Materials (continued)

2. Test: Bend the wooden craft stick, a plastic cable tie, and a paper clip. What happens? Which one is most ductile? Ask what would happen if a piece of ceramic tile were part of the test.

3. Rate materials: most ductile to the least ductile.
Results: The plastic cable tie (polymer) will bend easily and return to its original form and is therefore the most ductile. The metal paper clip will bend and almost return to its original form and is therefore ductile. The wooden stick (composite) will bend but not break immediately, however, it will not return to its original form and is therefore less ductile. A piece of ceramic tile would break when bent and is therefore not ductile.

4. Discuss design issues: Ductility is important in designing products which can only be allowed to bend by a certain amount *(bridges, bicycles, furniture)* or that need to be flexible when used and return to their original shape when not in use *(rubber bands, plastic shopping bags)*. Ductility is also important in springs, which store energy *(vaulting poles, bungee ropes)*. Brittleness is important for objects that maintain their shape regardless of how much force is applied *(ceramic floor tile, wooden shelves)*.

Fatigue Test
Question: How much repeated stress can cause the material to fail or break?

Materials: 1 plastic multipurpose cable tie, 1 wooden craft stick, 1 metal paper clip. The same materials from the ductility test may be used.

1. Test: Bend each item back and forth as you count how many times it takes to break. Record the times. Be sure that students use the same amount of strength or stress when bending the material back and forth, over and over. *Because strength varies from student to student, the participants should recognize that there may be variety in the data collected.*

2. Rate materials: high, medium, low fatigue resistance.
Results: The plastic cable tie (polymer) has the highest fatigue resistance, followed by the metal paper clip. The wooden craft stick has the least fatigue resistance.

3. Discuss design issues: For what objects is fatigue important? *(Anything used repeatedly—paper clip, eating utensils, bridges, airplane wings)* For what objects is material fatigue not important? *(Anything that is disposable or doesn't experience repeated stresses.)*

Strength Test (Tensile Test)
Question: How much weight can the material hold without failing or breaking?

Materials: 8 inch x 1 inch (20 cm x 2.5 cm) strips of heavy-duty aluminum foil, heavy plastic bag, and paper; 2 buckets (1 large and 1 small, such as 10 quart [9 liters] and 5 quart [4.7 liters]); 5 lbs. (2.2 kg) of sand, rice, or beans (as weights), batteries or balance scale; 2 2-inch (5 cm) C-clamps

3A: Properties of Materials (continued)

1. Test: Attach a bucket with a C-clamp to the material to be tested and attach the material with a C-clamp to a table. Be sure to have a larger bucket below to catch the weights. Fill the bucket slowly with weights. How much weight will it take until the material breaks? Record results and compare.

Strength test

2. Rate materials: strong, medium, and weak in strength.
   Results: The aluminum (metal) should be the strongest followed by the paper (composite) and then the plastic (polymer).

3. Explain: It may be surprising that paper is so strong. This is a good place to explain more about composites. Composites are two or more distinct substances that are combined to produce a new material with properties not present in either individual material. Composites are often made to create a stronger material. There are synthetic composites that are manufactured and natural composites or biocomposites. Plywood is a manufactured composite. Thin sheets of wood are stacked and glued so that the end product is stronger than each material on its own. Whereas, wood, a natural composite, is made up of cellulose fibers.

4. Discuss design issues: Material strength is important in structural applications *(brick, stone, and concrete for bridges and buildings)*. Material strength is also important in transportation applications *(airplanes, cars, bicycles)*.

Electrical Conductivity Test
Question: Does electricity pass through the material easily?

Materials: 1 "D" size battery, 1 piece of wire, 1 small bulb (8 inch x 1 inch) (20 cm x 2.5 cm) strips of aluminum foil, paper, and plastic bag, piece of ceramic tile

1. Test: Make an electrical circuit with each material and see if the bulb lights by connecting the bulb, battery, wire, and each material.

3A: Properties of Materials (continued)

Electrical conductivity test

2. Rate materials: yes or no if the bulb lights.
   Results: The only material that will make the bulb light and therefore conducts electricity is the aluminum foil.

3. Discuss design issues: When is it important to use a material that conducts electricity? *(When an electrical charge needs to be transported.)* When is it important to use a material that does not conduct electricity? *(Anything that covers electrically conductive material, such as plastic on a TV, plastic around wire on electrical cord.)*

Thermal Conductivity Test
Question: Does heat pass through the material easily?

Materials: candle, matches, plus same test materials used in electrical conductivity test (aluminum foil, paper, plastic, and ceramic)

1. Test: Investigate the ability of materials to transmit heat by holding each material (at one end with the other end at the flame) a few inches from the candle flame for 15 seconds. Take the material away from the flame and compare how hot it is and how far the heat traveled through the material. A material that is very hot and where the heat has spread has higher thermal conductivity than a material that does not feel as hot and where the heat has not spread. Record results and repeat.

2. Rate materials: high conductivity, medium, low
   Results: Aluminum has the highest thermal conductivity, followed by paper, ceramic, and then plastic.

3. Discuss design issues: Thermal conduction is the rate of passage of heat through a material, such as metal. Thermal insulation is a barrier to the conduction of heat. Knowing how conductive a material is helps determine if the material is suitable to include in home construction, clothing, sports shoes, cooking products, and spacecraft design, for example. What are examples of objects that need a material that is a thermal

conductor *(baking sheets, heating radiators)*? When is the use of insulation materials necessary *(polystyrene and paper cups for hot drinks)*?

Optical Properties Test
Question: How easily does light pass through it? (Transparent, translucent, opaque)

Materials: flashlight, samples of a transparent material (such as a plastic bag), a translucent material (such as hazy plastic cup), and an opaque material (such as a colored plastic bucket)

1. Test: Compare materials by shining a light through them or hold up to a light.

2. Rate materials: transparent, translucent, opaque.

3. Explain: Light passes through a transparent material, and images can be viewed through it. Light passes through a translucent material; however, images cannot be seen easily or at all through it. Light cannot pass through an opaque material, and images cannot be seen through it.

4. Discuss design issues: What are examples of objects made from transparent materials *(car windshields, eyeglasses, plastic food containers)*, translucent materials *(shower doors for privacy and glass mugs for decoration)*, and opaque materials *(room-darkening curtains or blinds, sunscreens for car windshield)*? When are these properties important? Help the students find examples of these three characteristics in materials or objects where the passage of light and viewing of objects matters and may or may not be desired. In many cases, optical materials are chosen for their aesthetic qualities and not optical properties.

Wrap Up
Discuss students' results. Results may vary. Explain that when materials engineers test material properties, they do multiple tests, at least 10. So, students would have to do many tests to gather consistent results.

Follow With
In the next activity, *3B: Materials Applications*, students apply problem-solving skills to real-world material problems.

Properties of Materials

Handout: Session 3, Activity A

Materials engineers design new materials and determine which materials are best used for certain structures and devices. They determine this by understanding the properties of materials so that they can select the most appropriate material or combination of materials for a particular use.

In this activity, you will test materials to learn about their properties. After each test, record your results. Charts can be made and completed in your design notebook. For each property, come up with examples of objects where each property is important.

Material Properties Definitions

Property	Definition
Density	How heavy objects are that occupy the same volume
Ductility	How easily a material stretches when force is applied
Strength	How much weight a material can hold without failing or breaking
Fatigue	How easily a material withstands repeated stresses
Electrical conductivity	Whether or not electricity passes through the material
Thermal conductivity	How easily heat passes through the material
Optical properties	How easily light passes through it (transparent, translucent, opaque)
Corrosion	If the material degrades easily because of the physical environment

Density Test
Question: Which materials are denser?
Materials: a clay brick, block of wood, and block of Styrofoam* (all the same size)

1. Demonstration: Compare the density of a brick, a block of wood, and a block of Styrofoam.

2. Rate materials: high, medium, and low density.

Rating *(highest to lowest density)*	Material Tested	Material Class

3A Handout: Properties of Materials (continued)

3. Discuss design issues: Think of examples of other objects where high density is important. Think of examples of objects where low density is important.

Ductility Test
Question: How easily does the material stretch when force is applied?
Materials: 1 wooden craft stick, 1 plastic cable tie, 1 paper clip

1. Test: Bend the wooden craft stick, a plastic cable tie, and a metal paper clip. What happens? Which one is most ductile? What about ceramic tile, what would happen if you bent a piece of tile?

2. Rate materials: from the most ductile to the least ductile.

Rating *(most ductile to least ductile)*	Material Tested	Material Class

3. Discuss design issues: Ductility is important in designing products which can only be allowed to bend by a certain amount or that need to be flexible when used and return to their original shape when not in use. What are examples of applications where ductile materials are needed?

Fatigue Test
Question: How much repeated stress can cause the material to fail or break?
Materials: wooden craft stick, plastic multipurpose cable tie, metal paper clips (same materials as used in the ductility test)

1. Test: Bend each item back and forth as you count how many times it takes to break. Record the times. Be sure to use the same amount of strength or stress when bending the material back and forth over and over.

2. Rate materials: high, medium, low fatigue resistant.

Rating *(most fatigue resistant to least)*	Material Tested	Material Class

3A Handout: Properties of Materials (continued)

3. Discuss design issues: For what objects is fatigue resistance important? For what objects is material fatigue not important?

Strength Test (Tensile Test)
Question: How much weight can the material hold without failing or breaking?
Materials: 8 inch x 1 inch (20 cm x 2.5 cm) strips of: heavy-duty aluminum foil, heavy plastic bag, and paper; 2 buckets (1 large and 1 small, such as 10 quart [9 liters] and 5 quart [4.7 liters]), 5 lbs. (2.2 kg) of sand, rice, or beans (as weights); 2 2-inch (5 cm) C-clamps

1. Test: Attach a bucket with a C-clamp to the material to be tested and attach the material with a C-clamp to a table. Be sure to have a larger bucket below to catch the weights. Fill the bucket slowly with weights. How much weight will it take until the material breaks? Record results and compare.

2. Rate materials: from strongest to weakest in strength.

Rating *(strongest to weakest)*	Material Tested	Material Class

3. Discuss design issues: Material strength is important in structural applications. What are examples of this? Material strength is also important in transportation applications. What are examples of this?

3A Handout: Properties of Materials (continued)

Electrical Conductivity Test
Question: Does electricity pass through the material easily?
Materials: battery, wire, bulb, aluminum foil, paper, plastic bag, and ceramic tile.

1. Test: Make an electrical circuit with each material and see if the bulb lights.

2. Rate materials: yes or no if the bulb lights.

Rating *(yes or no)*	Material Tested	Material Class

3. Discuss design issues: When is it important to use a material that conducts electricity? When is it important to use a material that does not conduct electricity?

Thermal Conductivity Test
Question: Does heat pass through the material easily?
Materials: candle, matches, same materials used in electrical conductivity test

1. Test: Investigate the ability of materials to transmit heat by holding each material a few inches (centimeters) from the candle flame for 15 seconds. Take the material away from the flame and compare how hot it is and how far the heat has traveled. A material that is very hot and where the heat has spread has high thermal conductivity. Record results and repeat.

2. Rate materials: high, medium, or low conductivity.

3A Handout: Properties of Materials (continued)

Rating *(highest to lowest thermal conductivity)*	Material Tested	Material Class

3. Discuss design issues: What are other examples of objects that need a material that is a thermal conductor? When is the use of insulation materials necessary?

Optical Properties Test
Question: Does light pass through the material easily? (Is the material transparent, translucent, or opaque?)
Materials: flashlight or bulb and battery, plastic bag, plastic cup, colored plastic bucket (Alternate materials may be used.)

1. Test: Compare materials by shining a light through them.

2. Rate materials: transparent, translucent, or opaque.

Rating *(transparent, translucent, opaque)*	Material Tested	Material Class

3. Discuss design issues: What are examples of objects made that are transparent, translucent, and opaque? When are these properties important?

What Are Things Made Of?

Reading: Session 3, Activity A

From the Stone Age to the Information Age, humans have made use of a wide array of materials to improve their lives. Stroll through the halls of a museum and you will see that major epochs have been shaped and even defined by certain materials. From iron and steel to textiles and microprocessors, materials have a seemingly infinite range of properties and applications.

Not surprisingly, the field of materials science covers a wide range of disciplines. Materials engineers contribute to the field by evaluating materials for how well they distribute stress, transfer heat, conduct electricity, and meet other design specifications.

New materials are constantly being invented, and new uses for existing materials continue to emerge. In recent years, for example, researchers from Nike have figured out how to grind up used athletic shoes and create a new material for resurfacing running tracks and basketball courts. Researchers from Patagonia have developed a method to reuse the plastic in soda bottles to make a synthetic fiber that is spun into soft fleece for making sportswear.

Let's take a look at four of the major classes of materials.

Metals
Metals are a class of materials that include metallic elements, such as iron or gold, and combinations of metals, known as alloys. Metals usually are good conductors of heat and electricity. They tend to be strong but can be shaped, and can be polished to a high gloss. Iron, for example, has been important as a building material ever since humans learned to change its properties by heating and cooling it.

Ceramics
Ceramics are compounds made of metallic and nonmetallic elements and include such compounds as oxides, nitrides, and carbides. The term *ceramic* comes from the Greek word *keramikos*, which means burnt stuff. The properties of ceramics are normally achieved through a high-temperature heat treatment process called firing. Ceramics tend to be good at insulating, highly durable, and resistant to high temperatures and harsh environments. For example, dentists have developed a way to use ceramics for fillings despite the special demands of materials used inside the mouth. In adapting ceramics for dental use, materials scientists had to develop ceramics that would not be affected by acids, would have low thermal conductivity, would be resistant to wear from chewing, would not expand or contract when exposed to heat or cold, and would be appealing cosmetically.

Plastics
Polymers occur when molecules combine chemically to produce larger molecules that contain repeating structural units. Plastics, for example, are a large group of organic, man-made compounds based upon carbon and hydrogen. The basic building block of a plastic is the polymer molecule, a long chain of covalent-bonded atoms. Plastics are processed by forming and molding into shape. Usually, they are low density and may have a low melting point. Polymers have a wide range of applications, from synthetic fibers like nylon and polyester to car parts and packaging materials like Styrofoam*. Velcro*, a synthetic fabric used for fasteners, is

a well-known application of a polymer.

Composites

Composites can be synthetic or natural or biocomposites. Synthetic composites are manufactured whereas biocomposites are found in nature. Wood, silk, and cotton are examples of biocompsites. Composites consist of more than one material type, such as metal and ceramic. Fiberglass, a combination of glass and a polymer, is one example. Plywood, another composite, is made up of thin sheets of wood stacked and glued. The properties of composites depend on the amount and distribution of each type of material, but the idea is that the combination of materials will create a material with more desirable properties than possible with any individual material. One common use of composites is for sports equipment, such as golf clubs, tennis racquets, and bicycle frames.

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Session 3, Activity B

Materials Applications

Goal

Evaluate properties of materials for specific applications.

Outcome

Students apply problem-solving skills to select materials based on their properties.

Description

Using students' materials properties test results from the previous activity, students determine the best materials for a variety of material usage problems.

Supplies

None

Preparation

None

Procedures

Using Materials

1. Introduce the activity by explaining that students will work in groups to solve four materials problems. Each problem involves identifying materials properties, recognizing which materials have these properties, and selecting materials for the product. Each group will solve all the problems and then share and compare their solutions.

2. For each problem, have each group answer the following questions:
   - Which properties are important to solving the problem?
   - Which materials have the important properties?
   - What types of materials would you use to make this product?

3. Have students make a sketch of the object and label the materials.

4. Have groups present their solutions.

3B: Materials Applications (continued)

Problems
#1: Acme Foodstuffs has a problem. Acme started making a new product that requires using hot corn syrup. The corn syrup must be portioned out with a spoon into large bottles while it is still hot (350°F, 175°C). The operator will be using a big spoon that she will be holding for more than an hour a day. The company needs a new spoon to serve this purpose.
Important properties: thermal conductivity, density, fatigue

#2: A new golf club manufacturer would like to make lightweight, sturdy, and electrically nonconductive golf clubs but doesn't know where to start. The golf club heads should be hard and wear-resistant and must withstand repeated strokes of high force against the golf ball.
Important properties: density, strength, fatigue, electrical conductivity

#3: Hang Dry Clothespin Manufacturers is undertaking an aggressive campaign to encourage people to conserve energy by hanging their clothes out to dry. They would like to come up with a new modern clothespin that will appeal to the masses.
Important properties: fatigue, ductility, strength, density

#4: Phantom Phone Booths is trying to come up with a new public phone booth for the 21st century. Not only will the public phone booth contain pay phones, but will also be a private place for people to use their cell phones and plug in their laptop computers. The booth must be private, but allow for daylight to pass through and allow people to see if it is occupied.
Important properties: optical, strength

Wrap Up
Hold a discussion for each problem, comparing the solutions and discussing the benefits and challenges of certain material choices.

Read *3B Reading: Meet a Materials Engineer*.

Follow With
In *3C: Materials Choice*, students consider cost and environmental impact when selecting materials

Materials Applications

Handout: Session 3, Activity B

Using the materials properties test results from the previous activity, you will solve each problem to determine the best materials for particular uses.

For each problem, determine the following:

- Which properties are important to solving the problem?
- Which materials have the important properties?
- What types of materials would you use to make this product?

Make a sketch of the object for each problem and label the materials.

Problems

#1: Acme Foodstuffs has a problem. Acme started making a new product that requires using hot corn syrup. The corn syrup must be portioned out with a spoon into large bottles while it is still hot (350°F, 175°C). The operator will be using a big spoon that she will be holding for more than an hour a day. The company needs a new spoon to serve this purpose.

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Meet a Materials Engineer

Reading: Session 3, Activity B

Stephanie Kwolek: Developing a Miracle Fiber

Marketers call Kevlar* a miracle fiber. Police officers who wear vests reinforced with the stuff call it a lifesaver. And the chemist who developed the ultra-strong but lightweight synthetic material calls her famous invention "a case of serendipity."

Used in the manufacture of everything from bulletproof vests to puncture-resistant bicycle tires to flame barriers, Kevlar came about through a combination of scientific know-how, ingenuity, teamwork, persistence, and the willingness to follow a hunch.

Back in 1964, Stephanie Kwolek was working as a research chemist for DuPont. "I loved to solve problems, and it was a constant learning process. Each day there was something new, a challenge, and I loved that," Kwolek told the Smithsonian Institution in an interview after she had retired.

One of Kwolek's design challenges in the lab was to develop long chain molecules called polymers, used to make nylon and other synthetic fibers. Researchers saw a market for a new generation of materials that would be strong but lightweight and that would not melt, even at high temperatures.

An unexpected lab result led to the breakthrough that eventually yielded Kevlar. Ordinarily, a dissolved polymer solution looks like molasses—thick but translucent. When Kwolek dissolved certain polymers in a solvent, she wound up with a solution that looked watery and cloudy. When Kwolek stirred the solution, it separated into two layers. She tried filtering the solution and ruled out contamination as a factor. When she analyzed the flow and cohesive properties of the solution, she became more intrigued by her observations. "It had a lot of strange features," Kwolek later recalled. "I think someone who wasn't thinking very much, or just wasn't aware or took less interest in it, would have thrown it out."

Instead of tossing the mystery concoction, Kwolek set out to see what would happen if the solution was spun in a machine used to produce synthetic fibers. The coworker in charge of

3B Reading: Meet a Materials Engineer (continued)

the spinneret was skeptical and told her the solution was too watery to spin. She persisted, however, and he eventually agreed to run a test. "It spun beautifully," she recalled later. Researchers tested the spun fibers and found that they had remarkable strength and stiffness. Kwolek had revolutionized the polymers industry by developing the first liquid crystal polymer fiber.

It took a full decade of teamwork, testing, and product development before the first bulletproof vests made of Kevlar reached the market. By the time Kwolek was inducted into the National Inventor's Hall of Fame in 1995, the vests were credited with saving the lives of more than 3,000 law enforcement officers.

Kwolek retired from DuPont in 1986 with 17 patents to her name. She is a recipient of the Lifetime Achievement Award for innovation and invention given by the Lemelson-MIT Program. In 2003, at age 80, she was inducted in the National Women's Hall of Fame.

References

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Session 3, Activity C

Materials Choice

Goal
Students understand factors other than material properties when choosing materials.

Outcome
Students will be able to select materials with cost and environmental impact in mind.

Description
This activity introduces students to other factors, aside from material properties, that go into materials selection. Using a beverage container, students compare the cost of making a beverage container from different materials in order to understand the economic tradeoffs when choosing materials. Environmental impact is introduced to students as they design a container that can be reconstituted to make another product or reused for a secondary purpose.

Supplies
For display: 3 12-oz. (355 mL) beverage containers: 1 plastic, 1 aluminum, and 1 glass
Note: 12-oz. aluminum beverage containers are the most common size in the U.S. 16-oz (473 mL) containers may be used instead if it is difficult to find plastic or glass 12-oz beverage containers.

Preparation
Display a 12-oz (355 mL) plastic, aluminum, and glass beverage container to each group.

Procedures
Materials and Cost

1. Begin a discussion of cost. Explain that cost is often one of the most important design considerations when choosing materials. In most designs the aim is to minimize the cost. For most products material cost dominates design. This makes it difficult to introduce expensive, high-performance materials. Cost only becomes less important when product performance is everything to the customers and they are prepared to pay for it. Examples are top-of-the-line sports products (racing bicycles, sports cars, golf clubs) and medical implants (hip prostheses and heart valves).

2. Introduce beverage containers as a materials and engineering challenge. Containers must satisfy a number of physical and structural criteria, must be inexpensive, and should have a minimal impact on the environment.

3. Introduce the challenge: Your class has decided to go into the fruit juice business. You have already come up with delicious recipes and are now considering how you will

3C: Materials Choice (continued)

package the drinks. As employees, you have been asked by the owner (the facilitator) for your input on which type of beverage container to use. You are to do a cost analysis of aluminum, plastic, and glass, and make a case for one of these materials.

Cost Analysis of Beverage Containers
(This cost analysis is in U.S. dollars using pounds as the unit of weight measurement. It would need to be adapted for use with another currency.)

1. Explain that many cost factors go into determining what type of material to use for a product. Tell each group to analyze the charts and determine which type of material they feel is best for packaging the fruit juice. They should prepare an argument to support their position.

2. Explain that the first chart shows the number of containers produced per pound of material, the raw material cost per pound (in USD), the average shipping cost per pound, and the production cost per container.

Material	**Number of 12-oz./16-oz. Containers/lb.**	**Material Cost/lb.**	**Shipping Cost/lb.**	**Production Cost/ Container**
Aluminum	33.3/25.0	$0.70	$0.25	$0.10
Glass	2.3/1.8	$0.03	$0.25	$0.06
Plastic	14.3/11.1	$0.50	$0.25	$0.04

Using this information, have students rank aluminum, glass, and plastic in the total cost to produce and deliver 1,000 containers.

Results:
Step 1: Determine the weight of 1,000 containers. For example, aluminum:
1 / 33.3 = 0.030; .030 x 1,000 = 30 lb per 1,000 containers.

Step 2: Determine the material cost. For example, aluminum: 30 x 0.70 = $21.00 per 1,000 containers.

Step 3: Determine the shipping cost. For example, aluminum: 30 x. 0.25 = $7.50 per 1,000 containers.

Step 4: Determine the production cost. For example, aluminum: 1,000 x 0.10 = $100 per 1,000 containers.

Step 5: Add the material cost, shipping cost, and production cost. For example, aluminum: $21.00 + $7.50 + $100 = $128.50 per 1,000 containers.

3C: Materials Choice (continued)

Step 6: Compare the total cost to produce 1,000 containers for each material. Plastic is the cheapest followed by aluminum, and then glass.

3. Explain that the next chart shows the total cost of returning the material to a state where it can be reused to make a new container instead of using raw materials. This includes the market price to purchase and reprocess scrap material. Note that this processing includes cleaning the material, shredding or grinding, and melting. The chart also includes the cost of disposing the material into a landfill as an alternative to recycling.

Material	Scrap/lb.	Process Scrap/lb.	Disposal/lb.
Aluminum	$0.35	$0.15	$0.02
Glass	$0.01	$0.01	$0.02
Plastic	$0.10	$0.50	$0.02

Have students calculate the cost to purchase scrap material and reprocess it, and compare this amount to the cost of the raw material (in the previous chart) plus the cost to dispose of the material. This can be calculated for 1,000 containers. For each material, determine if it is more economically advantageous to recycle scrap material or dispose of it in a landfill.

Results:
Step 1: Compare the price to purchase the raw material and dispose of it with the price to purchase scrap material and reprocess it. For example, aluminum, new material plus disposal cost: 0.70 + 0.02 = 0.72

Step 2: To get the price for 1,000 containers, multiply the above number by 1,000. For example: 0.72 x 1,000 = $720

Step 3: Determine the price for scrap material and reprocessing. For example, aluminum scrap material and reprocessing: 0.35 + 0.15 = 0.50

Step 4: Multiply by 1,000 to get the price for 1,000 containers. For example: 0.50 x 1,000 = $500.

Step 5: Do the above steps for each material and compare. Students will see that it makes sense to recycle aluminum and glass, but it is cheaper to dispose of plastic.

4. Explain that global warming has been linked to the increase in carbon dioxide emissions to the atmosphere. Carbon dioxide is emitted by the burning of fossil fuels. Fossil fuels are burned to create energy that is used to manufacture and transport materials. Manufacturing beverage containers using recycled materials decreases the total carbon dioxide emissions because reprocessing consumes less energy than processing the raw material. The following chart summarizes the pounds of carbon dioxide emissions

3C: Materials Choice (continued)

avoided by using recycled materials. Ask: from which material do you gain the most benefit by recycling?

Material	Lbs. of CO^2 Avoided Per Lb. of Material Recycled
Aluminum	4.5
Glass	0.2
Plastic	0.8

Results: It is clear that it is cheaper and better for the environment to recycle aluminum, which explains why aluminum is probably the most recycled material.

Make a Case

1. Now that each group has done a cost-benefit analysis of three different types of beverage containers, have each group prepare an argument to lobby to the head of the beverage company to use plastic, glass, or aluminum beverage containers. Groups may also consider other factors aside from cost, such as materials properties, taste, and aesthetics.

2. Hold a debate to convince the company owner (in this case, the facilitator) how he or she should package the new beverage.

3. Discuss the tradeoffs between economic decision making and total cost decision making that incorporates environmental benefits.

Container Design: Extending the Life

1. Now that each group has chosen which material makes the most sense from a cost perspective, each group of students will consider how the life of the beverage container can be extended by coming up with a secondary use for the container.

2. Present the following design challenge: You have been asked to design a beverage container that would not be considered waste after its use. Consider how the container might be recycled and reconstituted for another use or how the container might be redesigned to achieve a secondary use.

3. Provide a few examples of this to get students to think innovatively.

   Emium (an Argentine container company) redesigned the shape of a bottle so that it could be a building block that can be attached to others to fulfill a wide range of recreational or functional structures. The bottles can be attached to one another lengthways or sideways by pressing the protruding knobs of one into the cavities of the other. The scope of use for these bottles include: children's toys or playhouses, furniture,

3C: Materials Choice (continued)

shelving, boxes, partitions. www.emium.com.ar/ingl*

Patagonia (United States, outdoor apparel company) became the first company to adopt a post-consumer recycled fleece into its product line. The fleece fabric is manufactured from PET soft-drink bottles. From 3,700 recycled 2-liter plastic soft-drink bottles, 150 long-sleeved fleece pullovers can be manufactured. This saves a barrel of oil and avoids approximately half a ton of toxic air emissions being released into the atmosphere. www.patagonia.com*

4. Have groups sketch their ideas.

Wrap Up
Have students share their designs. As an optional extension (to be done at home), they can create models of their designs.

Read *3C Reading: Meet an Environmental Engineer*.

Follow With
In Session 4: *Getting a Charge From Electricity*, students learn the fundamental principles behind electrical engineering.

Materials Choice

Handout: Session 3, Activity C

Did you know that when you purchase a beverage, you pay more for the packaging than the beverage itself? So, what does it take to produce a beverage container and how are decisions made about what type of container to use?

The challenge: Your class has decided to go into the fruit juice business. You have already come up with delicious recipes and are now considering how you will package the drinks. As employees, you have been asked by the owner for your input on which type of beverage container to use. You are to do a cost analysis of aluminum, plastic, and glass, and make a case for one of these materials.

1. This chart shows the number of containers produced per pound of material, the raw material cost per pound, the average shipping cost per pound, and the production cost per container.

   Using this information, rank aluminum, glass, and plastic in the total cost to produce and deliver 1,000 containers. You will need to first determine how much one container weighs.

Material	Number of 12-oz./16-oz. Containers/lb.	Material Cost/lb.	Shipping Cost/lb.	Production Cost/Container
Aluminum	33.3/25.0	$0.70	$0.25	$0.10
Glass	2.3/1.8	$0.03	$0.25	$0.06
Plastic	14.3/11.1	$0.50	$0.25	$0.04

2. The next chart shows the total cost of returning the material to a state where it can be reused to make a new container instead of using raw materials. The chart also includes the cost of disposing the material into a landfill as an alternative to recycling.

   Calculate the cost to purchase scrap material and reprocess it and compare this amount to the cost of the raw material (in the previous chart plus the disposal cost.) Do this for 1,000 containers. For each material, is it more economically advantageous to recycle scrap material or dispose of it in a landfill?

Material	Scrap/lb.	Process Scrap/lb.	Disposal/lb.
Aluminum	$0.35	$0.15	$0.02
Glass	$0.01	$0.01	$0.02
Plastic	$0.10	$0.50	$0.02

3C Handout: Materials Choice (continued)

3. Global warming has been linked to the increase in carbon dioxide emissions to the atmosphere. Carbon dioxide is emitted by the burning of fossil fuels. Fossil fuels are burned to create energy that is used to manufacture and transport materials. Manufacturing beverage containers using recycled materials decreases the total carbon dioxide emissions because reprocessing consumes less energy than processing the raw material.

   The following chart summarizes the pounds of carbon dioxide emissions avoided by using recycled materials. From which material do you gain the most benefit by recycling?

Material	**Lbs. of CO^2 Avoided Per Lb. of Material Recycled**
Aluminum	4.5
Glass	0.2
Plastic	0.8

4. What type of beverage container do you think the juice company should use? Make a case for aluminum, glass, or plastic.

Extending the Life of the Container

Design challenge: You have been asked to design a beverage container that would not be considered waste after its use. Consider how the container might be recycled and reconstituted for another use or how the container might be redesigned to achieve a secondary use. Be innovative! Sketch your design idea.

Meet an Environmental Engineer

Reading: Session 3, Activity C

Cindy Butler
Project Manager, Energy, Environment, and Systems Division
CH2M Hill, Portland, Oregon

They might be called in to clean up an industrial site. Design a way to avoid groundwater contamination. Plan a new project so that it meets environmental regulations. Get the mold out of a tropical high-rise hotel ventilating system. These problem-solving activities, and many more, are all in a day's work for environmental engineers.

Cindy Butler is a project manager in the environmental division of a large engineering and consulting firm, CH2M Hill, in Portland, Oregon. The best part of her job? "On a weekly basis, sometimes daily, I learn something I didn't know before."

Laying the Foundation

When she was growing up in upstate New York, Butler had friends whose parents were doctors and lawyers. Her dad worked for Xerox. "He was the only engineer I knew," she says. "Otherwise, I wouldn't have had any idea what engineers do."

She took his advice and pursued engineering studies—with a vengeance. Within five years of finishing high school, she had earned dual bachelor's degrees (one in civil engineering and another in an interdisciplinary major called engineering and public policy) from Washington University in St. Louis, plus a master's in civil and environmental engineering from Carnegie Mellon in Pittsburgh, Pennsylvania.

During college, she also found time for an internship that gave her some practical experience and exposure to the field of environmental affairs. "The internship experience is key. It helps you find out what interests you, and what doesn't." Her days were jam-packed, she admits. "Between school and work, I became pretty good at time management."

Some of her favorite classes were in civil engineering, taught in the evenings by professors who spent their days actively working in the field. "I liked the real-world applications and discovered I was more interested in applications than theory," she says. Although she started in electrical engineering—her father's field—she eventually shifted her academic focus to civil and environmental engineering.

3C Reading: Meet an Environmental Engineer (continued)

Focus on People
On a typical day at CH2M Hill, where she has worked for three years, Butler might meet with clients. Scope out a project. Analyze a budget. Pull together a team of engineers and planners to work on a specific project. Talk with staff from a regulatory agency. "Lots of communicating and lots of problem solving," she says. "Interpersonal skills are a big part of the job. Even if you're doing research, you work on a team. There might be a few engineers who sit in a cubicle and crank numbers," she adds, "but not most of us. It's a people-oriented career."

The projects she manages might involve cleaning up the chemicals left behind at a former wood processing site, or solving groundwater contamination at a chemical plant. "We do a lot of site investigations, testing, and remediation," she explains. Sometimes, that means visiting a site to get a firsthand look. "It helps you see what you can't get from a map—the 3-D reality of the space."

Earlier in her career, Butler did more of the hands-on work. "You start by collecting soil and water samples, then move into analyzing data," she explains. Now she takes a longer view, keeping a big project on track and meeting the client's goals.

She appreciates the depth of resources found at a large firm like CH2M Hill. The company is involved in everything from building roads and designing transportation systems to cleaning up Superfund sites to industrial design projects. "People are eager to share what they know. I like to be challenged and keep learning something new. I think that's a common personality in the sciences," she says.

On the Cutting Edge
One of the most exciting aspects of engineering, Butler adds, "is being on the cutting edge. Engineering is always on the forefront, whether it's in designing new cars or coming up with the next biomedical breakthroughs."

For students considering the field, she shares an insight worth keeping in mind when the courses get challenging: "I think you work harder in college. It's grueling, and you can't afford to fall behind. You have to learn all the structural building blocks, and that means you do a lot of work manually so that you understand the concepts. Later, much of that work will be automated. But you have to learn the fundamentals first."

When the going gets tough, she adds, "remember that it's OK to ask for help." Peer tutoring programs and informal study groups are common practice at engineering programs, laying the groundwork for the teamwork of the real world.

Materials Scavenger Hunt

Session 3 Home Improvement

Goal
Look at common objects and determine whether their materials make a difference in function and effectiveness.

Outcome
Gain an understanding of the connections between materials and function.

Description
Students walk through their homes looking at objects and analyzing what materials were used to make them.

Procedures

1. Explain that the young engineers will walk through their home like a detective, looking for objects and what they are made of, and why the materials matter.
2. Remind students, when they are looking at objects, to consider what properties are required for the product and why those materials were selected. Provide a few examples such as: an outdoor mat may need to be waterproof and nonslip, thus rubber is often used.

Ask students to consider the flooring in their home. Do they have different flooring in different rooms? Why? Consider how soft carpet materials, vinyl, and wood flooring serve different purposes based on functional needs.

Next Day
Share and compare observations, discussing how and why particular materials are used.

Materials Scavenger Hunt

Handout: Session 3, Home Improvement

Walk through your home like a detective. Look for objects where the choice of material matters! Write about each item in your design notebook; its uses, the properties it requires, and how the materials meet those properties.

What is it?

What does it do?

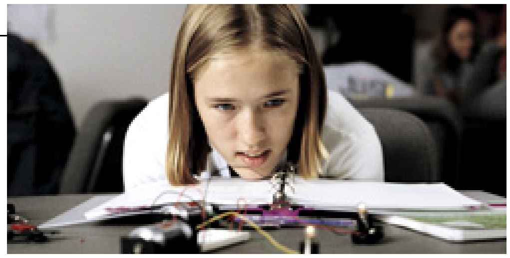
What properties does it require?

How and why do the materials matter?

Session 4

Getting a Charge From Electricity

Engineering Fundamentals



In This Session:

A) Basic Electrical Concepts in a Flash (20 minutes)
- Student Handout

B) Turn it On and Off (60 Minutes)
- Student Handout
- Student Reading

C) Short Circuits (20 Minutes)
- Student Handout

D) Light-Emitting Diodes (50 Minutes)
- Student Handout

Home Improvement
- Student Handout

In this session, the students work in pairs to explore electricity basics. These pairs can remain the same throughout the session or change with each activity. *4A: Basic Electrical Concepts in a Flash* reviews simple circuitry using a common household item: a flashlight. You may find that some students have built circuits before, and this is a review. The goal is to prepare them for any electrical circuitry that they may need to incorporate into their own projects later. An extension to this activity involves looking inside a dissected lightbulb that is prepared in advance. This can be done with a demonstration, in small groups, or may be skipped if you don't have enough time.

In *4B: Turn It On and Off*, students learn the differences between a simple, series, and parallel circuit. Here, they are introduced to using breadboards. They wire circuits on the breadboards with switches and buzzers (optional). In *4C: Short Circuits*, students learn about short circuits and the relationship between resistance and the current. An optional activity teaches them how to prevent a short circuit by making a fuse. In *4D: Light-Emitting Diodes*, students make their favorite numbers light up with an LED display. With each activity in this session, the students learn different electrical symbols and use the symbols in drawing diagrams. *Electric House Hunt*, the Home Improvement activity, entails having the students look at their own house from an electrical perspective.

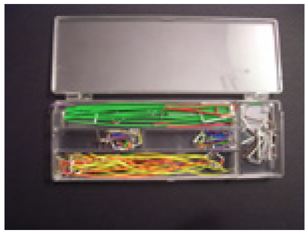
Supplies

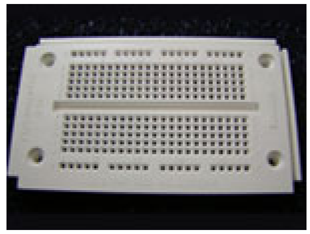
For Each Pair of Students

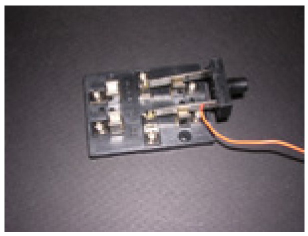
- 1 flashlight with batteries (preferably "D" size)
- 1 wire kit
- 1 wire cutters
- 1 breadboard (experimenter socket)
- 1 switch (knife switch)
- 1 mini buzzer (3VDC)
- 1 small screwdriver
- 1 rectangular piece of aluminum foil about 1 inch by 2 inches (2.5 cm x 5 cm)
- 1 LED number display (0.3 inches (8mm) LED number display)

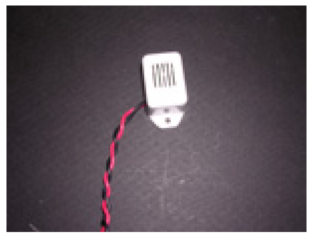
Session 4, Getting a Charge From Electricity (continued)

- 1 blinking 2.8 volt LED
- Gloves for each student
- Safety goggles for each student


Wire kit

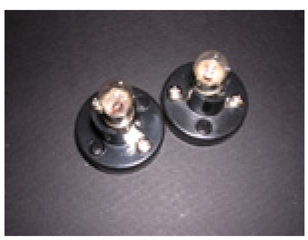

Breadboard


Switch


Mini buzzer

Two Per Pair of Students

- Screw-base lamps (2.47 volts
- Miniature lamp holders (for E-10 screw-base lamp with screw terminals)
- "D" size batteries (may be taken from flashlights)
- "D" size battery holders


Bulbs and bulb holders


"D" size batteries and holder

For Demonstration

- A few household clear lightbulbs

Getting a Charge From Electricity

Key Concepts: Session 4

In Session 4, students get a hands-on experience with wiring **electrical circuits** of various kinds and purposes in order to better understand how electrical devices work.

Key Concepts
All matter is electrical. Every atom of matter has a positive nucleus surrounded by negatively charged electrons. Depending on the material, electrons are somewhat free to move. Electricity is the result of the stationary and moving charges of protons and electrons. Sometimes electrons can be rubbed from one surface to another where they build up as static electricity; this accumulated electric charge releases as a spark, as when you separate a sweater from socks that have tumbled in the dryer. An electrical charge can also move through matter such as metal wires. The flow of charge is electric current.

Circuit
A circuit is a complete path for electrons to flow through. The electrons flow from the negative terminal of a battery through wires connected to devices that convert electric energy into other forms such as light or sound components. A circuit must have a complete path for the electricity to begin flowing from the negative terminal to the positive terminal of a battery.

Conductor
A conductor is a material (usually a metal, such as copper) that allows electrical current to pass easily through. This is opposed to an insulator (such as plastic coating around wires), which prevents the flow of electricity through it.

Series Circuit
A series circuit is wired with only one path for the current to flow through all the devices in a row and back to the starting point. The same current flows through each part of a series circuit. If the circuit is broken at any point then no current will flow. For example, if this circuit were a string of light bulbs, and one burned out, the remaining bulbs would also turn off.

Parallel Circuit
A parallel circuit is one that has two or more paths for the electricity to flow. It is like a river that has been divided up into smaller streams, but all the streams come back to the same point to form the river once again. For example, if the loads in a circuit were light bulbs and one burned out, the other bulbs would remain lit. Current continues to flow to the other light bulbs because there is still a complete circuit from the negative to positive terminals of the battery.

Measuring Electricity
Volts, amps, and watts measure electricity. Volts measure the "pressure" under which electricity flows. Amps measure the amount of electric current. Watts measure the amount of work done by a certain amount of current at a certain pressure or voltage. The relationship of these measurements can be thought of as water in a hose. Turning on the faucet supplies the force, which is like the voltage. The amount of water moving through the hose is like the electrical current, known as amperage. You would use lots of water that comes out really hard (like a lot of volts) to wash off a muddy car. You would use less water that comes out more slowly (like

Key Concepts Session 4 (continued)

less volts) to fill a glass. The total water used in each would be like measuring the watts or power needed. A multimeter is an instrument that can be used to measure voltage, resistance, or current across an element in an electrical circuit.

1 watt = 1 amp multiplied by 1 volt
1 amp = 1 watt divided by 1 volt

Ohm's Law
Ohm's Law is the relationship between current, voltage, and resistance. It was named after the German physicist George Simon Ohm (1787-1854). He determined that:

Current (amps) = Voltage (volts) / Resistance (Ohms)

This relationship is used in designing any electric device, such as a toaster. In the U.S., electricity is supplied to household outlets at 110 volts. As with any heating element that gets hot when current flows, a toaster has high resistance of 10 ohms. Using Ohm's law and dividing voltage (110 volts) by resistance (10 ohms), a toaster needs 11 amps of current flowing through it. (This is way above the amount of current that the "D" cell batteries used in this session can supply—1.5 amps.)

Breadboard
The electronic breadboard provides a quick means for temporarily connecting circuits. A breadboard has numerous holes into which wires attached to electrical components may be inserted. The holes are conductive sockets, some of which are connected internally. A breadboard is set up with rows and columns. The two long sets of holes along the outside (called channels) are connected. Within each of the two columns down the center of the breadboard, there are two sets of five holes. Each set of five holes in the middle of the board is connected, but the sets of holes are not connected to each other. It is easiest to use 22-gauge wire when wiring a breadboard. It is helpful to get as many colors of insulated wire as possible. The different colors help with organization—it is easier to see what goes where, and different colored wires can be used for different purposes.

Short Circuit and Fuses
In your standard household outlet, there is a wire that brings the electricity. This is called the hot wire. There is another wire, called the neutral wire, that allows the electric current to flow back. A third opportunity to carry electricity is called the "ground." It is either a bare wire or a metal wrapping for the other two wires. The metal wrapping is called sheathing. It usually doesn't carry electricity. Its sole purpose is to carry electricity during an emergency back to the ground. If a hot wire becomes loose at some metal electrical box (such as an outlet box, a switch box, or a junction box, where several wires meet and are connected), and touches the box that is grounded, the electricity will be able to flow with no resistance. This is called a short

Key Concepts Session 4 (continued)

circuit and will often result in more electricity flowing than the wires are supposed to permit. The wires may become very hot, and if the box is shaken, then sparks may fly where the wire touches the box. This could potentially start a fire. To prevent this from happening, a special kind of switch called a circuit breaker or fuse will trip or blow, and no electricity will flow to the circuit. The circuit breaker or fuse is a safety device that stops the flow of electricity before it enters the hot wire.

Switches
The lever you flip is attached to a metal piece that can move so that it makes a break in the circuit, preventing electricity from flowing through until you flip it back.

Diodes
Diodes are small one-way valves for electrical current. Diodes permit current flow in one direction and not in the opposite direction. A diode has two electrodes, called the anode and the cathode.

LED
LEDs, or light-emitting diodes, are diodes that emit light of one form or another. They are used as indicator devices. For example, an LED may light to indicate that a machine is on. They are useful because they have a low power requirement, are highly efficient, and have a long life. They come in several sizes and colors. An LED consists of two elements of processed material called P-type semiconductors and N-type semiconductors. These two elements are placed in direct contact, forming a region called the P-N junction. Integrated circuits (ICs) are complex circuits inside one simple package. LED displays are packages of many LEDs arranged in a pattern. The most familiar, and the one used in Session 4, is the 7-segment display for showing numbers (0-9). This is available in two versions: common anodes with all the LED anodes connected together and common cathodes with all the cathodes connected together. An LED passes current only when the cathode is negative with respect to the anode.

More About Electricity
Electricity Online, library.thinkquest.org*.
This Web site includes thorough lessons with animated demonstrations for student understanding of the theory and practical applications of electricity.

Rapid Electronics, www.rapidelectronics.co.uk*.
This is a good place to see pictures of electronic components.

Science Hobbyist, www.amasci.com/elect/elefaq.html*.
Find answers to frequently asked electricity questions at this site.

Institute of Electrical and Electronic Engineering, www.ieee.org/organizations/eab/precollege*.
This is a pre-college education site.

Session 4, Activity A

Basic Electrical Concepts in a Flash

Goal
Become familiar with electronic basics (a simple circuit) and what an electrical engineer does.

Outcome
Students can make and diagram a basic circuit.

Description
Students deconstruct a flashlight in order to learn how to build and diagram a simple circuit.

Supplies
For Each Pair of Students

- Flashlight with batteries (preferably "D" size), wire kit
- Gloves
- Safety goggles

Optional lightbulb dissection (for the facilitator): a few household clear lightbulbs, wire cutters

Safety Guidelines
Each student should have gloves and safety goggles to be worn throughout Session 4.

Preparation
For optional bulb dissection: Prepare a few dissected bulbs to hand out for observation. Using the wire cutters, make little snips around the base of the bulb. Cut all the way around the base just above the ceramic insulator and carefully pull the base off.

Procedures
Debrief Home Improvement

Discuss the materials that students found in their homes from the Home Improvement in Session 3.

Introduce Session

Explain that the purpose of this session is to help students learn basic electricity and electronics, something they may need in their designs.

A Flashlight

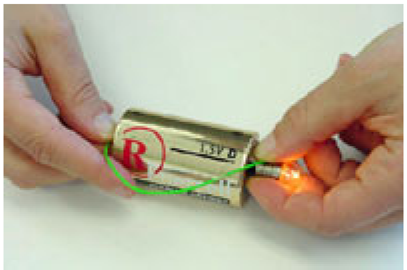
A flashlight offers an excellent tool to begin exploring electrical engineering concepts. Begin by discussing the purposes of a flashlight. Ask students to consider how these needs are met by

4A: Basic Electrical Concepts in a Flash (continued)

the design of a flashlight. Discuss the difference between necessary (such as the bulb) and useful (such as protective cover over bulb) parts of a flashlight.

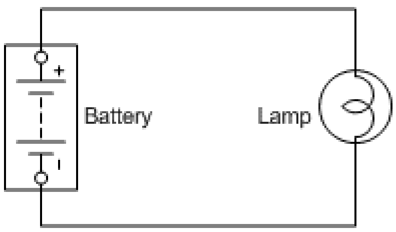
A Circuit

1. Distribute one flashlight to each pair of students. Have students look at the flashlight and consider how it works.
2. Instruct students to take the flashlight apart to see how it works. Have them take out the bulb and batteries.
3. Hand out one wire to each group. Explain that they should make the lightbulb light using only one battery, the bulb, and the wire.



Circuitry Diagramming

1. Introduce the symbols for wire, battery, and lamp (see handout).
2. Ask the students to draw a diagram using the symbols of how they made their bulb light.

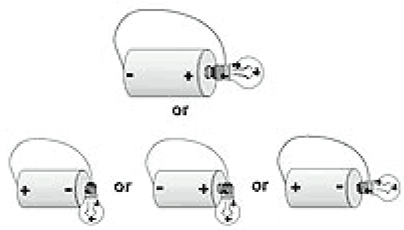


Simple circuit

3. Discuss what was necessary to light the bulb. (The wire had to go from one end of the battery to either the side or bottom of the bulb. Whichever bulb part, side or bottom, wasn't touching the wire had to touch the other end of the battery.)

4A: Basic Electrical Concepts in a Flash (continued)

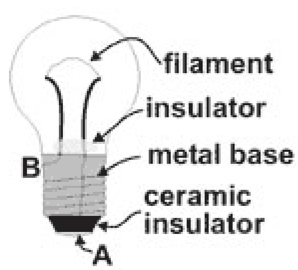
4. Explain that this is called a "circuit," which must have a source of electrons (battery) and a way for the electrons to flow from and back to that source. An easy way to understand a circuit is to think of it as a "circle." Define simple circuit: A combination of elements or components that are connected to provide paths for electrical current flow to perform some useful function.



5. Define an electric current: subatomic particles called electrons flowing through wires and electronic components. It is similar to the flow of water through pipes. Just as water is pushed through pipes by a pump, electric current is pushed through wires by a battery. In an electric current, like charges repel and unlike attract. That is, two negatives will repel each other; a negative and a positive will attract each other.

Optional Extension Activity: Bulb Dissection Demonstration

1. Distribute dissected lightbulbs. Have the students look inside the dissected bulb. In many bulbs, it is possible to see how one end of the filament is connected to the bottom of the bulb (A) and is connected to the side (B). In some bulbs, however, you may only be able to see the weld mark on the side of the bulb.



2. Looking inside the bulb, discuss how the bulb works. The current from the battery flows from one side of the metal side through the wire up to the filament. The filament is a very thin piece of wire that produces light and heat when an electrical current runs through it. The filament goes back down through the insulator (the little glass ball that holds the two wires apart) and down to the bottom of the bulb.

4A: Basic Electrical Concepts in a Flash (continued)

Wrap Up
Have students share their diagrams and discuss what challenges they faced when making a circuit.

Ask them if any ideas for design opportunities (needs, problems, or improvements) occurred to them today. They can add these to their list.

Optional: Read and discuss *4A Reading: What Do Engineers Do?*

Follow With
In *4B: Turn It On and Off*, students gain an understanding of the different types of circuits.

Basic Electrical Concepts in a Flash

Handout: Session 4, Activity A

Who invented the flashlight? It all started with an idea to light up a flower pot. Joshua Lionel Crown invented a flower pot that would light up when a button was pressed. However, it didn't sell. In 1898, he sold the idea to his salesman, Conrad Hubart, a Russian immigrant. Hubart took parts of the flower pot idea and turned them into an "electric hand torch." Because the bulbs and the batteries weren't very powerful, the torch gave only a "flash" of light. The company became the American Ever-Ready Company. Although Hubart arrived from Russia with no money, he died in 1928 with an estate worth over $15 million. Ever since then the company has kept going and going and going...

Directions
You should have a flashlight and some wire in front of you. A flashlight is a great way to understand how a simple circuit works. Take the flashlight apart and try to make the lightbulb light with a battery and a wire. This is called a simple circuit. Do the following activities and record your results in your design notebook.

Symbols

1. Draw a diagram of the circuit to show how you made the bulb light. Use the symbols above.

2. What additional features do you think would make a flashlight better or more useful? What would this flashlight look like? (Draw a sketch.)

What Do Engineers Do?

Reading: Session 4, Activity A

Engineers help to design and manufacture just about everything—from the tallest skyscrapers to the smallest computer chips, from cars to space shuttles, from miracle fabrics to artificial heart valves. Even though their efforts are all around us, the work of engineers can seem like a mystery to those outside the profession.

"You grow up knowing what teachers and doctors and lawyers do. But unless your parents happen to be engineers, you probably don't have a clue what their work involves," says a woman who grew up to be a successful environmental engineer.

What do engineers really do? Let's take a look.

Types of Engineering: The "Big Four"
In the most general terms, engineers are problem-solvers. They apply the concepts of mathematics and science to solving real-world challenges.

The engineering profession includes many different disciplines. In fact, engineering may offer more career options than any other profession. Engineers are a diverse group, contributing to projects that improve the quality of life on every continent. A background in engineering can also lead to a career in law, education, medicine, or public policy.

Here's a look at four of the largest categories within the profession: chemical engineering, civil engineering, electrical and computer engineering, and mechanical engineering.

Chemical Engineering
Take a walk through your grocery store, pharmacy, or paint store, and you'll see hundreds of examples of what chemical engineers create. Chemical engineers combine the science of chemistry with the principles of engineering to produce better plastics, fuels, fibers, semiconductors, medicines, building materials, cosmetics, and much more. Their know-how has helped to develop reduced-calorie sweeteners, lead-free paint, fibers that can withstand the heat of forest fires, and thousands of other products.

Chemical engineers work in a variety of settings, from research laboratories to food-processing plants to pharmaceutical companies. They tackle challenges relating to agriculture, environmental pollution, and energy production. Sometimes they even work at the molecular level to create brand-new synthetic materials.

Interested in the field of chemical engineering? Visit the American Institute of Chemical Engineers (AIChE) (www.aiche.org*) to learn how a chemical engineering background can prepare you for a career in manufacturing, research, biomedicine, quality control, law, sales and marketing, and related fields.

Civil Engineering
Civil engineers help to create the building blocks of modern society. From dams and highways to bridges and buildings, the products of civil engineering are all around us. Civil engineers

4A Reading: What Do Engineers Do? (continued)

belong to one of the oldest and largest branches of engineering. They use cutting-edge technologies and advanced materials to solve challenges in new ways.

A background in civil engineering opens the door to a variety of career options. According to the American Society of Civil Engineers, areas of focus include construction engineering, environmental engineering, geotechnical engineering, structural engineering, as well as transportation, urban planning, and water resources.

Interested in the field of civil engineering? Visit the American Society of Civil Engineers (ASCE), (www.asce.org*.)Also visit Manufacturing Is Cool!,(www.manufacturingiscool.com/cgi-bin/mfgcoolhtml.pl?/home.html*,) a K-12 site developed by the Society of Manufacturing Engineers which offers curriculum, displays, and resources.

Electrical and Computer Engineering
Electrical engineering has been one of the fastest-growing fields in recent decades, as breakthroughs in technology have led to rapid advancements in computing, medical imaging, telecommunications, fiber optics, and related fields.

Electrical engineers work with electricity in all its forms, from tiny electrons to large-scale magnetic fields. They apply scientific knowledge of electricity, magnetism, and light to solving problems that relate to cell phones, computer software, electronic music, radio and television broadcasting, air and space travel, and a wide range of other areas. According to the Institute of Electrical and Electronics Engineers, a background in electrical or computer engineering can lead to a career in aerospace, bioengineering, telecommunications, power, semiconductors, manufacturing, transportation, or related fields.

Electrical engineers often work in teams with other specialists to develop sophisticated devices such as lasers to use in medical treatments, or robots that can perform complex operations in space. In addition to technical expertise, engineers contribute problem-solving skills and interpersonal communications to successful team projects.

To find out more about the fields relating to electrical engineering, visit the Institute of Electrical and Electronics Engineers (IEEE), (www.ieee.org*.)

Mechanical Engineering
Mechanical engineers turn energy into power and motion. What does that mean? "Anything that moves or uses power, there's a mechanical engineer involved in designing it," explains a member of this large branch of engineering.

Mechanical engineers work in all areas of manufacturing, designing automobiles or sporting goods, water treatment facilities or ocean-going ships. In a field like biomechanics, their expertise can improve the quality of life by designing artificial joints or mechanical heart valves.

Interested in the field of mechanical engineering? Find out more about mechanical engineering from the American Society of Mechanical Engineers (ASME), (www.asme.org*).

4A Reading: What Do Engineers Do? (continued)

Other Engineering Disciplines

Aeronautical and Aerospace Engineering
Aircraft, space vehicles, satellites, missiles, and rockets are some of the projects that are developed by aeronautical and aerospace engineers. They get involved in testing new materials, engines, body shapes, and structures that increase speed and strength of a flying vehicle.

Aerospace engineers work in commercial aviation, national defense, and space exploration. Some engineers work in labs testing aircraft, while others investigate system failures such as crashes to determine the cause and prevent future accidents. They are specialists in fields such as aerodynamics, propulsion, navigation, flight testing, and more.

Agricultural Engineering
Agricultural engineers work with farmers, agricultural businesses, and conservation organizations to develop solutions to problems relating to the use and conservation of land, rivers, and forests. They look for solutions to problems such as soil erosion. They also develop new ways of harvesting crops and improving livestock and crop production.

Agricultural engineers also design and build equipment, machinery, and buildings that are important in the production and processing of food, fiber, and timber. For example, they might design specialized greenhouses to protect and grow exotic plants such as orchids.

For more information about agricultural engineering, visit the American Society of Agricultural Engineers, (www.asae.org*.)

Biomedical Engineering
Biomedical engineers, or bioengineers, use engineering principles to solve complex medical problems in health care and medical services. They work with doctors and medical scientists to develop and apply the latest technologies, such as microcomputers, electronics, and lasers.

Biomedical engineers might develop biomaterials to speed tissue repair in burn victims, or design medical devices that aid doctors in surgery. They might help to build bionic legs, arms, or hands to improve the lives of accident victims.

The biomedical field is changing rapidly as new technologies emerge. Bioengineers work in hospitals, government agencies, medical device companies, research labs, universities, and corporations. Many biomedical engineers have degrees in chemical or electrical engineering, and some go to medical school.

To find out more about biomedical engineering, visit the Biomedical Engineering Society (BMES), (www.bmes.org*.)

Environmental Engineering
Environmental engineers develop methods to solve problems related to the environment. They assist with the development of water distribution systems, recycling methods, sewage treatment

4A Reading: What Do Engineers Do? (continued)

plants, and other pollution prevention and control systems. Environmental engineers often conduct hazardous-waste management evaluations to offer solutions for treatment and containment of hazardous waste. Environmental engineers work locally and globally. They study and attempt to minimize the effects of acid rain, global warming, automobile emissions, and ozone depletion.

To learn more about the work of environmental engineers, visit the American Academy of Environmental Engineers, (www.aaee.net*.)

Industrial Engineering
Industrial engineers make things work better, more safely, and more economical. They often work in manufacturing—dealing with design and management, quality control, and the human factors of engineering. They are problem-solvers who analyze and evaluate methods of production and ways to improve the methods. Based on their evaluation, they may determine how a company should allocate its resources.

Interested in the field of industrial engineering? To find out more, visit the Institute of Industrial engineers, (www.iienet.org*.)

Materials Engineering
Materials engineers work with plastics, metals, ceramics, semiconductors, and composites to make products. They develop new materials from raw materials and improve upon existing materials. Whether it's creating higher performance skis or a biodegradable coffee cup, materials engineers can be found applying their expertise.

Materials engineers specializing in metals are metallurgical engineers, while those specializing in ceramics are ceramic engineers. Metallurgical engineers extract and refine metals from ores, process metals into products, and improve upon metalworking processes. Ceramic engineers develop ceramic materials and the processes for making ceramic materials into useful products. Ceramic engineers work on products as diverse as glassware, automobile and aircraft engine components, fiber-optic communication lines, tile, and electric insulators.

Mining Engineering
Mining engineers figure out how to get valuable resources out of the ground. Along with geologists, they locate, remove, and appraise minerals they find in the earth. Mining engineers plan, design, and operate profitable mines. They are also responsible for protecting and restoring the land during and after a mining project so that it may be used for other purposes.

For more information about mining engineering, visit the Society for Mining, Metallurgy, and Exploration Inc., (www.smenet.org*.)

Nuclear Engineering
Nuclear engineers research and develop methods and instruments that use nuclear energy and radiation. They may work at nuclear power plants and be responsible for the safe disposal of nuclear waste. Some nuclear engineers specialize in the development of nuclear power for

spacecraft; others find industrial and medical uses for radioactive materials, such as equipment to diagnose and treat medical problems.

Petroleum Engineering
Petroleum engineers are found wherever there is oil, working to remove oil from the ground. Petroleum engineers might be involved in drilling or developing oil fields. They might also ensure that the oil drilling process is safe, economical, and environmentally friendly.

To learn more about the field of petroleum engineering, visit the Society of Petroleum Engineers, (www.spe.org*.)

Systems Engineering
Systems engineers are like team captains who are responsible for bringing all the pieces of an engineering project together and making them work harmoniously, while still meeting performance and cost goals, and keeping on schedule. Systems engineering takes an interdiscipli0nary approach to a project, from concept to production to operation. Systems engineers consider both the business and technical needs of a project.

Sources

- Discover Engineering www.discoverengineering.org/home.asp*
- Engineer Girl! The National Academies—National Academy of Engineering www.engineergirl.org/nae/cwe/egcars.nsf/webviews/Careers+By+Engineering+Field?OpenDocument&count=50000
- Baine, Celeste, *Is There an Engineer Inside You? A Comprehensive Guide to Career Decisions in Engineering,* 2d ed. Ruston, LA: Bonamy Publishing, 2001.

Session 4, Activity B

Turn It On and Off

Goal
Understand series and parallel circuits using a breadboard.

Outcome
Participants learn how to use a breadboard to wire series and parallel circuits. They are also able to wire a switch to the circuit.

Description
Apply principles of a basic circuit to wire more complicated series and parallel circuits on a breadboard. Then apply this knowledge to wiring a switch. Wiring a buzzer is optional.

Supplies
For each pair of students: 1 breadboard, 2 batteries ("D" size), 2 battery holders (should have 2 wires attached), 2 screw-base lamps, 2 lamp holders, 1 wire kit, 1 small screwdriver, 1 knife switch, 1 buzzer (optional)

Preparation

1. In addition to the materials already distributed to each pair in *4A: Basic Electrical Concepts in a Flash*, now give each pair a breadboard with battery and bulb holders, another lamp, a switch, and a buzzer (for optional activity). In advance, attach a piece of wire 3-4 inches (7.5-9 cm) in length to each terminal of the battery holder. (You may need screwdrivers for this.)

2. Familiarize yourself with wire. Wire is measured in gauge which refers to the size of the wire. The higher the gauge number, the thinner the wire. The lower the gauge number, the thicker the wire and the more amps capacity it has to carry current further from the electrical source. This activity uses 22-gauge wire that is stripped 0.25" and bent 90 degrees. You may need to strip the wire if your wire is not pre-stripped. Use a wire stripper to strip insulation from wire and a wire cutter if wire needs to be shortened.

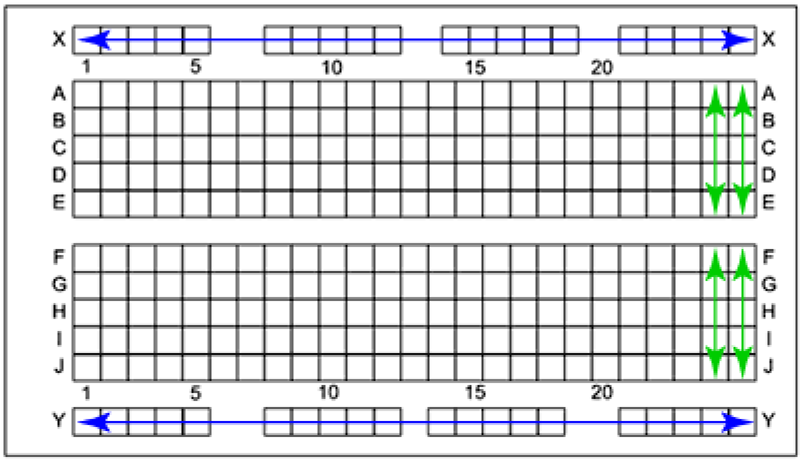
Procedures
Introduce Breadboards

1. Distribute breadboards and explain what a breadboard is. Explain that the purpose of the breadboard is to provide a flexible way to test circuits using a grid of pre-wired circuits. Electrical engineers use them to experiment with circuits before soldering them permanently to a circuit board.

2. Show how a breadboard is arranged: The two long sets of holes (called channels), labeled X and Y on the diagram, are connected horizontally. The power supply is connected to these rows. The other rows of holes (A-J) are connected vertically in blocks of five, (A-E) and (F-J) on the diagram. Each block of five holes is not connected to each other across the center between rows E and F. To make connections you only need to

4B: Turn It On and Off (continued)

stick the uninsulated ends of the wires into a set of holes. Underneath the plastic cover are little metal pieces that hold the wires and allow current to flow through them. Take off the plastic cover to demonstrate this.



Breadboard

Build a Simple Circuit

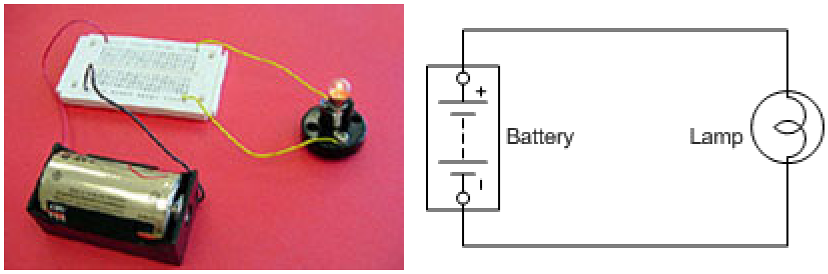
1. Instruct the students to begin wiring a simple circuit with one battery (in battery holder) and one bulb (in bulb holder) to explore how the breadboard works.

2. Insert the end of one of the battery wires into one of the holes in row X.

3. Insert the other battery wire into one of the holes in row Y. Ask if this is a complete circuit. *(No, the holes in the two rows are not connected to each other.)*

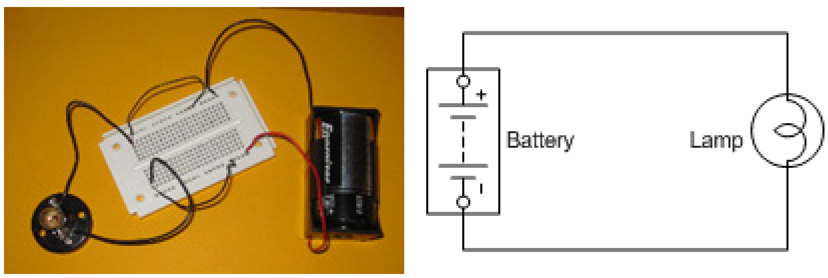
4. Insert one of the wires from the bulb holder into row X and the other into row Y. *(The bulb will now light because current is flowing from the battery through the channel to the lamp and back to the battery—a complete circuit.)* To understand how the breadboard is arranged, instruct students to move the wires around, testing which connections produce a complete circuit.

4B: Turn It On and Off (continued)



Simple circuit

5. Challenge students to wire the breadboard to light the bulb using two additional wires so that the lightbulb is not plugged into the power channels (rows X and Y).



Simple circuit

6. Explain that the bulb lights because electricity travels around the circuit in a circle.

Build a Series Circuit

1. Define series circuit: A circuit that contains only one possible path for electron flow supplied by a common voltage source.

2. Instruct the students that they will now build a series circuit with two batteries and two bulbs.

3. To build a series circuit, explain that they will need two batteries and two bulbs. Tell them to identify the positive (cathode) and negative (anode) terminals of the battery.

4. For the first battery, have them attach the positive wire to channel X on the breadboard. Next, tell them to attach the negative wire to any set of five holes in the middle of the board.

5. For the second battery, instruct them to attach the negative wire to channel Y on the breadboard. Next, tell them to attach the positive wire to the same set as with battery

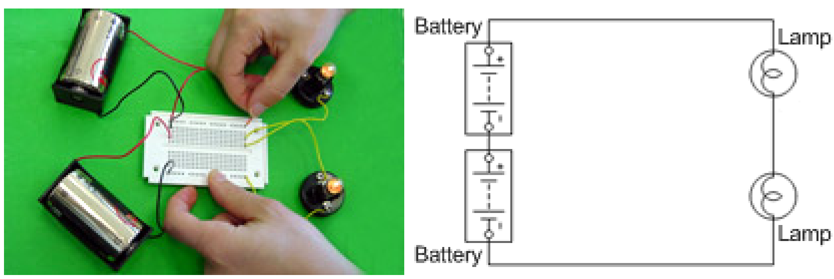
one.

6. For the first bulb, they should now plug one wire into channel X on the breadboard. Then they should plug the other wire into one of the five sets of holes in the middle of the board—and make sure it is not plugged into one of the sets of five holes that the batteries are plugged into.

7. Have them take the second bulb and plug one wire into channel Y on the breadboard. Now direct them to take the second wire and plug it into the same set of five holes that the other bulb is connected to. Both bulbs should now light!

8. Explain that the two bulbs and battery are now wired in a "series circuit." Remove the wire from one bulb and see that the other bulb goes out. Describe how increasing the number of bulbs reduces their brightness in a series circuit. Some students may remember old-fashioned Christmas lights in which one bulb burning out turns out all of the lights on the string.

9. Instruct the students to make a diagram of a series circuit using the symbols.



Series circuit

Build a Parallel Circuit

1. Define parallel circuit: Circuit that contains two or more paths for electron flow supplied by a common voltage source.

2. Explain that students will now make a parallel circuit with two batteries and two bulbs, keeping the two batteries wired as before in the series circuit.

3. Instruct them to remove the two bulbs from the breadboard from the previous steps.

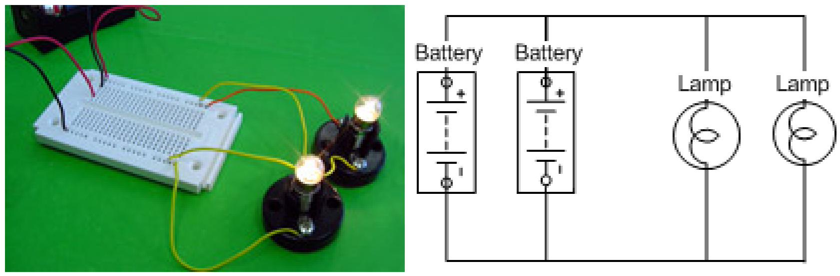
4. Direct them to take the first bulb and plug one wire into channel X on the breadboard and plug the second wire into channel Y. Now the bulb should light! Have them repeat this step for the second bulb. Both bulbs should now light!

4B: Turn It On and Off (continued)

5. Have them remove one wire from one of the bulbs and note that the other bulb remains lit. This is a parallel circuit. Tell them to repeat this for the other bulb.

6. Explain that parallel circuits are the types of circuits that are found in a house. Obviously, when you turn off your lamp, it doesn't turn off your TV. Connecting bulbs in parallel allows each to shine equally brightly.

7. Tell them to make a diagram of a parallel circuit using the symbols.



Parallel circuit

Add a Switch

1. Have the students look at the flashlights and ask what the purpose of a switch is. *(It breaks and connects circuits.)* Explain that the switch can be used to interrupt the circuit without removing a wire.

2. Essentially, students will be wiring a simple circuit and adding a switch. It is preferable to try to let them do this on their own—through inquiry. However, if they are struggling, you may give "hints" along the way to help them. Encourage students to "plan" the circuit design. They should study the switch and think about wiring it so it works.

3. First, have students wire the switch by attaching wires to the terminals of the switch (total of four wires).

4. Now tell them to wire a simple circuit.

5. Instruct them to remove the bulb wire from row X and place it in one of the sets of five holes in the middle of the board (rows A-E). They should then take another wire and insert one end in row X. Then, they should insert the other end of that wire into one of the sets of five holes in the middle of the breadboard (rows A-E). Have them make sure it is a different row than the one that the bulb wire is plugged into.

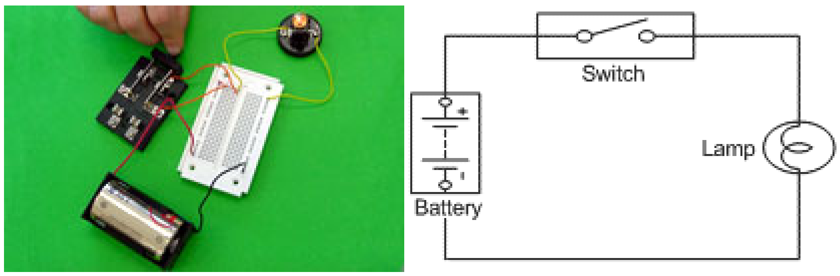
6. Have them take one of the switch wires and insert it into the same set of five holes in the middle of the breadboard as the bulb wire.

7. At this point, direct them to take the second switch wire and place it in the same row of five holes in the middle of the breadboard as the short wire (as in step 4).

4B: Turn It On and Off (continued)

8. Tell them to open and close the switch to turn the bulb on and off.

9. Show the students the symbol for switch (on their handout) and have them draw the diagram with the symbols.

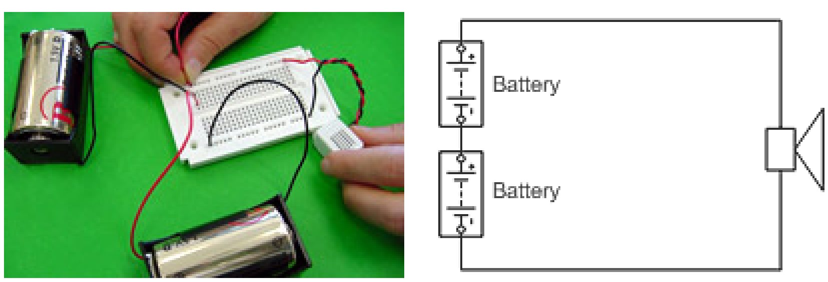


Wiring a switch

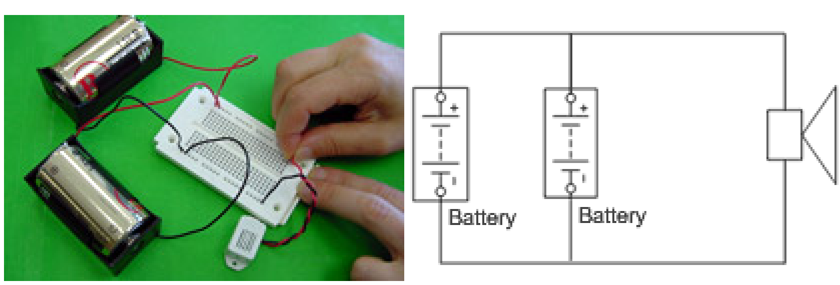
Optional: Add a Buzzer

1. Discuss doorbells and ask students how they think a doorbell works. Discuss the purpose and function of a doorbell. Ask them what electrical components they think doorbells have.

2. Ask them to show you how to wire a buzzer on the breadboard. Use the procedures from the previous activities to wire a parallel circuit and then a series circuit, but replace the light bulb with a buzzer.



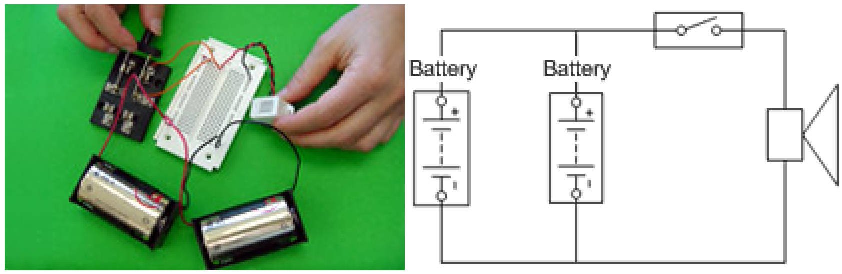
Series circuit with buzzer



Parallel circuit with buzzer

4B: Turn It On and Off (continued)

3. Challenge the participants to use two batteries, a light, a switch, and a buzzer.



Parallel circuit with buzzer and switch

4. Show them the symbol for speaker (see handout) and have them draw a diagram with all the symbols.

Wrap Up

Discuss the differences between a simple, series, and parallel circuit. Explain that parallel circuits are the most common.

Read *4B: Meet a Computer Engineer*. A computer engineer is one type of electrical engineer.

Follow With

In the next activity, *4C: Short Circuits*, students learn more about basic electrical concepts.

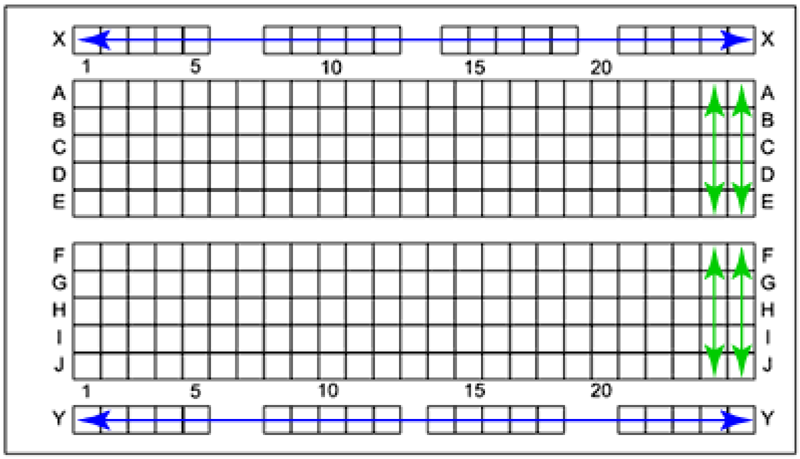
Turn It On and Off

Handout: Session 4, Activity B

You may find that you want to develop a prototype for a product that calls for the use of light or sound. If this is the case, you'll find that you need to wire some circuits. This activity will help familiarize you with the different types of circuits.

In this activity, you will be wiring on a breadboard. Electrical engineers use breadboads to test circuits before soldering them to a circuit board. The purpose of the breadboard is to provide a flexible way to wire circuits. Underneath the plastic cover are little metal pieces that hold wires and make connections between holes. You only need to stick ends of wire into the breadboard holes to make connections between electrical devices like lightbulbs and batteries.

A breadboard is arranged this way: The two long sets of holes (called channels), labeled X and Y on the diagram, are connected horizontally. The power supply is connected to these rows. The other row of holes (A-J) are connected vertically in blocks of five, (A-E) and (F-J) on the diagram. Each block of five holes is not connected to each other across the center between rows E and F.



Breadboard

Symbols

Directions for Wiring a Simple Circuit

1. Insert the end of one of the battery wires into one of the holes in row X.

2. Insert the other battery wire into one of the holes in row Y. Trace the flow of electricity. Is this a complete circuit?

4B Handout: Turn It On and Off (continued)

3. Insert one of the wires from the bulb holder into row X and the other into row Y. What happens? Trace the flow of electricity. Is this a complete circuit?

4. Explore how the breadboard circuitry is arranged. Move the wires to new holes and predict if the bulb will light or not. Trace the flow of electricity in each new arrangement.

5. Try to wire the breadboard to light the bulb using two additional wires so that the lightbulb is not plugged into the power channels (rows X and Y). Draw a diagram of this in your notebook.

Directions for a Series Circuit

1. To build a series circuit, you will need two batteries and two bulbs. Identify the positive (cathode) and negative (anode) terminals of the battery.

2. For the first battery, attach the positive wire to channel X on the breadboard. Next, attach the negative wire to any set of five holes in the middle of the board.

3. For the second battery, attach the negative wire to channel Y on the breadboard. Next, attach the positive to the same set as with battery one.

4. For the first bulb, plug one wire into channel X on the breadboard. Plug the other wire into one of the five sets of holes in the middle of the board—make sure it is not plugged into one of the sets of five holes that the batteries are plugged into.

5. Take the second bulb and plug one wire into channel Y on the breadboard. Plug the second wire into the same set of five holes that the other bulb is connected to. What happens?

6. Make a diagram of a series circuit in your notebook.

Directions for a Parallel Circuit

1. Remove the two bulbs from the breadboard from the previous steps, but keep the batteries wired as they were for a series circuit.

2. Take the first bulb and plug one wire into channel X on the breadboard and plug the second wire into channel Y. What happens? Now repeat this for the second bulb. What happens?

3. Remove one wire from one of the bulbs. What happens? What do you notice about the brightness of the bulb? This is a parallel circuit. Repeat this for the other bulb.

4. Make a diagram of a parallel circuit in your notebook.

Adding a Switch
If you decide to work on a project that requires some electronics, you may find that while you

4B Handout: Turn It On and Off (continued)

need a light or sound, you probably don't always want to have it on. Therefore, you'll need to learn to wire a switch. It should be easy now that you know how to wire a circuit.

1. Wire a simple circuit.

2. Be sure that the switch is wired and ready to go.

3. You will probably need to remove a wire and place it elsewhere—which wire is this? Remove it and place it where you think it should go.

4. How will you connect the bulb wire and the switch wire? (Hint: you may need to use a third wire that is not the bulb or switch wire.)

5. Where should the two switch wires go? Place them where you think they should go.

6. Try to open and close the switch to turn the bulb on and off. Does it work? If so, congratulations! You can now wire a switch. If not, keep trying!

7. Draw a diagram with symbols of a circuit with a switch in your notebook.

Wiring a Buzzer (Optional)
Ding dong! Ever wonder how a bell works? Here's your chance to wire a buzzer. It's easy now that you know how to wire circuits and a switch.

1. Wire a buzzer to the breadboard.

2. Now wire a light, switch, and buzzer with two batteries.

3. Draw a diagram using the symbols. You can use the speaker symbol for the buzzer.

Meet a Computer Engineer

Reading: Session 4, Activity B

May Tee
Computer Engineer
Portland, Oregon

A career in computer engineering has taken May Tee around the world, from the Pacific Northwest to New York to Italy. She has worked on everything from software applications for high fashion design to cutting-edge technical projects for the computer industry. Currently, as an engineer for Intel® Innovation in Education, she helps to develop online learning tools that teachers use with their students. What kind of student might be well-suited to her profession? "If you like fast change, new challenges, and being able to solve problems creatively," she says, "computer engineering could be the field for you."

An Unexpected Path

Tee grew up in Malaysia, dreaming of becoming an artist. She didn't see her first computer until she was in junior high school, and then was unimpressed. "The teacher did all this stuff to make the screen print out 'Hello.' I thought, that's it?" She was baffled by the whole idea of computer engineering. "I thought engineers only built concrete things, like bridges. But a computer screen is two-dimensional, not tangible. I had no clue what a computer engineer does."

Her high school teachers encouraged students to consider professions like medicine, law, or architecture. "In a developing country like Malaysia, those are the areas that are most needed," she says. Because she excelled in chemistry, she first planned to become a pharmacist. She came to the U.S. to start college and quickly changed gears. "Even though I was doing well in chemistry, I didn't like all the memorization. I only like the problem-solving part of chemistry." She explored other fields. "I took an accounting class, where I sat in the back row and fell asleep. When I wasn't sleeping, I was busy doing my homework for computer science. That class was much more interesting."

Tee says she was fortunate to have "a very good first instructor, so I fell in love with computer science. It takes a teacher who is knowledgeable in the field, and also good at teaching and explaining." Computer science can be hard to grasp at first, she admits, because the programming is hidden from what you see on the monitor. As she learned more about the field, she was attracted by "the problem-solving aspects. It's mathematical, logical. I used to play

4B Reading: Meet a Computer Engineer (continued)

chess, which takes step-by-step reasoning, so that's a thinking process I have."

After her first two years of college in Portland, attending both Portland Community College and Portland State University, she completed her degree in computer science at the University of Hawaii.

Launching Her Career
Tee graduated from college in 1996, when the technology sector was booming. The growth of the World Wide Web opened new opportunities, too, especially for a computer engineer with an eye for design and passion for visual art.

Her first engineering job, with Step Technologies in Portland, involved working on solutions using Microsoft software. She worked alongside veteran engineers, all with 10 to 15 years of experience. "I was the guinea pig, hired fresh out of college. They wanted to see what ideas some young blood would bring to an organization, and I was looking for someone to mentor me."

After three years there, she had a solid technical foundation and was ready for new challenges. "A lot of computer engineers have a creative side. They are photographers, artists, or musicians, something that's their passion." She followed her own passion and spent a few months in London studying art.

Back in the U.S., she took part in a complex project for Intel involving how users interface with computers. That let her bring together the technical side of how computers work with the graphic elements that affect the user's experience. "I could play with how things look on the screen, and saw how the right visual elements could help the user."

Tee's next projects took her to New York to work for Prada, a leading fashion house, and then on to Italy to see how computers are used in all facets of the textile industry. She enjoyed taking on each new set of challenges, using her technical skills to create a better result. "I began working directly with the people who use the software, seeing how they behave and what works for them. I could see the kind of frustration people have if the software does not meet their needs."

Each new assignment has made Tee's work more satisfying. "I realize I can make a difference visually, and that helps people feel like this is a usable tool. I love that part-to communicate to people through the software. It makes my work interesting and satisfying."

Always Something New
Currently, in her role of developing interactive tools for online learning, Tee works with diverse colleagues. She attends meetings to talk with clients and understand the design requirements and instructional purpose for each tool. She meets with graphic designers who bring in

4B Reading: Meet a Computer Engineer (continued)

expertise about color, typefaces, animations, and other visual elements. Human factor engineers add another perspective, bringing an analysis of how well tools will work for intended users. And through the whole process, Tee collaborates with fellow computer engineers, figuring out the technical solutions that will make everything work smoothly on the World Wide Web. "You learn so much from all these other people," she says.

Tee says her career moves may not be typical for engineers, but the variety has kept her excited about computer engineering and learning new skills. "I love the constant stimulation. It's the right fit for me," she says. "The creative part of computer science lets me fulfill my desire to be able to solve problems creatively, like an artist.

Advice for Students
Tee advises students heading into computer engineering to seek out the best professors they can find. "Ask your classmates. They always know who the best teachers are." And she encourages students to learn all they can by interviewing engineers and arranging internships. "That's the best way to see all the different aspects of the field. It's not just sitting in front of the computer."

Session 4, Activity C
Short Circuits

Goal
Understand short circuits.

Outcome
Students wire a series and parallel circuit to understand short circuits.

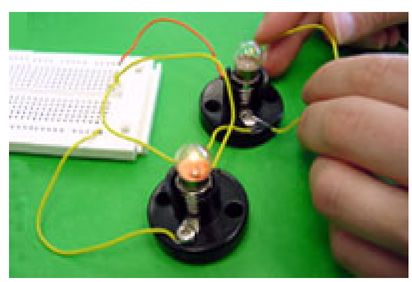
Description
See what causes a short circuit by understanding the relationship between resistance and the current.

Supplies
For each pair of students: 2 lamps, 2 "D" batteries, 1 wire kit, 2 lamp holders, 2 battery holders, 1 breadboard, 1 rectangular piece of aluminum foil about 1 inch by 2 inches (2.5 cm x 5 cm) (for optional fuse activity)

Preparation
Distribute materials to each pair.

Procedures
Put two pairs together. Explain that they are going to explore what happens in a short circuit. A short circuit is when electricity flows with no resistance and then more electricity flows than the wires are supposed to permit. The wires become very hot and sparks may fly. To prevent this from happening, a special kind of switch called a circuit breaker or fuse will trip or blow, and no electricity will flow to the current. This is a safety device that stops the flow of electricity before it enters the hot wire.

Wiring for a Short Circuit

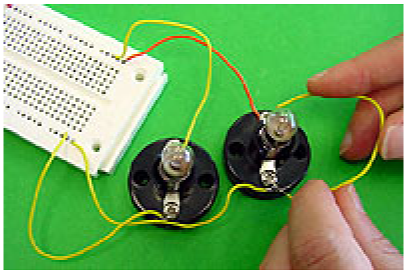


1. Instruct one pair in the group to make a series circuit with two bulbs and one battery.
2. Have everyone in the group look at the series circuit. Instruct the students to hold a wire *very briefly* so that one end touches one terminal on one side of the bulb holder and the other end touches the other terminal on the same holder. Ask what happens?
   (The other bulb gets very bright and the wire gets very hot.)
3. Explain that the bulb has resistance to the current flow. By replacing the lightbulb with the wire you are almost eliminating the resistance so the current increase is very large.

4C: Short Circuits (continued)

This large amount of current creates excessive heat that can burn out bulbs and melt wires.

4. Instruct the other pair to make a parallel circuit with two bulbs and one battery.



5. Repeat the same activity as in #2 with the parallel circuit. Ask what happens.
(Both bulbs go out.)

6. Explain that this is known as a short circuit. This means that the current in the wire across the "short" circuit is high because the resistance is so low. In a sense, it is easier for the current to flow through the wire than through the resistance of the bulb. The current flowing through the other lamp is too low to cause the bulb to light.

Optional: Fuses
Review what happened when parallel circuits were short circuited. *(The lights went out, and the wire got very hot.)* Explain that the more devices like lights, motors, or buzzers that are added to a parallel circuit, the more the current flows through the wires close to the battery. If the amount of current flowing through a wire increases, the wire gets hotter. If that happens, wire can get so hot that it starts a fire. Fuses are designed to burn and break the circuit before the wires get too hot.

Wiring a Fuse

1. Instruct the students to wire a parallel circuit with two batteries and two bulbs. Be sure everyone has wired a circuit in which both lights and batteries are wired in parallel. Have them refer to the wiring diagram on their handout. Tell them to ignore the fuse symbol for now.

2. Now have them change the wiring by moving one end of each bulb's wire from one power channel to the same inside block of holes (either A-E or F-J). They should then insert one end of a new a wire into the same block of holes in that channel and one end of another wire into the empty power channel. They should then touch the ends of those two wires together to test the circuits. The bulbs should light. Give the following instructions:

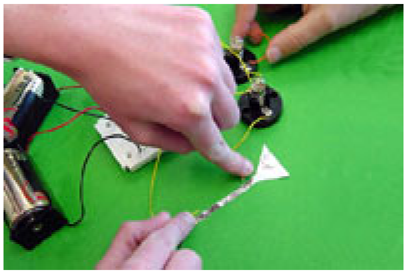
   A. Make a fuse by cutting a piece of aluminum foil (see handout for shape).

   B. Hold the two extra wires to the ends of the fuse (aluminum foil).

   C. Short out the circuit by holding another wire so that one end touches one terminal of one of the bulb holder and the other end touches the other terminal of that same bulb holder. Be very careful; you may see smoke!

4C: Short Circuits (continued)

D. Discuss what happened *(the fuse burned and broke the circuit)* and instruct students to write their observations and the reasons why they think it happened in their notebooks.



Wrap up
Discuss situations that would cause a short circuit; for example, a tree limb falling across a power line, a hair dryer that is plugged in falling into the bathtub, or a clothes dryer that is plugged into a circuit that cannot handle that much power.

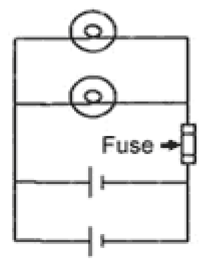
Follow with
In *4D: Light-Emitting Diodes*, students learn about LEDs and make numbers with LEDs.

Short Circuits

Handout: Session 4, Activity C

Imagine what happens when a tree falls across a power line, a hair dryer that's plugged in falls into the bathtub, or a clothes dryer is plugged into a circuit that can't handle that much power—a short circuit occurs. The current takes the easy route, the one with less resistance.

1. Your pair will join with another pair. One pair should make a series circuit with two bulbs and one battery.



2. Everyone in the group should look at the series circuit. Hold a wire *very briefly* so that one end touches one terminal on one side of the bulb holder and the other end touches the other terminal on the same holder. In your notebook, explain what happens.

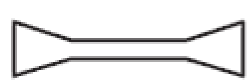
3. The other pair should make a parallel circuit with two bulbs and one battery. Repeat the same activity as above with the parallel circuit. Explain what happens.

Fuses (Optional Activity)
Have you ever had to change a fuse? If so, you probably know that fuses are designed to break a circuit before the wire gets too hot and catches on fire. In this activity, you'll see how a fuse works.

1. Wire a parallel circuit with two batteries and two bulbs. (Ignore the fuse symbol for now.)

2. Change the wiring by moving one end of each bulb's wire from one power channel to the same inside block of holes (either A-E or F-J). Then insert one end of a new a wire into the same block of holes in that channel and one end of another wire into the empty power channel. Now touch the ends of those two wires together to test the circuits. The bulbs should light.

   A. Make a fuse by cutting the shape below out of a piece of aluminum foil.



4C Handout: Short Circuits (continued)

B. Hold the two extra wires to the ends of the fuse (foil).

C. Short out the circuit by holding another wire so that one end touches one terminal of one of the bulb holders and the other end touches the other terminal of that same bulb holder. Be careful. You may see smoke!

Record your observations and explain what caused this to happen.

Session 4, Activity D

Light-Emitting Diodes

Goal
Learn about how light-emitting diodes (LEDs) work.

Outcome
Students learn how to wire an LED number display.

Description
Students explore wiring an LED number display. The number display uses eight LEDs to form numbers. Students experiment with different wiring combinations to light different LEDs in the display to make various numbers.

Supplies
For each pair of students: 1 blinking LED (2.8 volt) of various colors, 1 LED number display (0.3 inches LED number display), 1 breadboard, 1 wire kit, 2 batteries in battery holders, wire cutter/stripper

Preparation

1. Learn about LEDs.
   LEDs form the numbers on many digital clocks, tell you when your curling iron is on, send messages from your TV remote to your TV, and do many more things. There are all sorts of LEDs. Some emit infrared light (your remote control) and others produce light of different colors. The color is determined by the material used in the diode. As electrons move from the N-type material to the P-type material, electrons drop to a lower orbit and release energy. The distance the electrons have to drop depends on the material and determines the color of light.

2. Assemble materials and practice wiring the number display.
   Watch a short video clip that demonstrates how to make the LED display.

View a Video

Watch a short video clip that demonstrates how to make the LED display.

To view the video, select a player and then click on your connection speed.

Select a Player

Dialup High Speed

4D: Light-Emitting Diodes (continued)

Procedures

Introduction

1. Have students review the brief background information about LEDs on their handouts.

2. Lead a brief discussion about LEDs that students have seen in objects they use.

3. Distribute blinking LEDs and batteries and have students get a feel for how LEDs work by making them blink with a battery. They may need to use an extra wire to reach both sides of the battery since the LED leads are short, or they can use a breadboard.

4. Use the diagram on the handouts to explain how an LED works and why LEDs are used. LEDs have several advantages over conventional incandescent lamps. They don't have a filament that will burn out, so they last much longer. Additionally, the small plastic bulb is designed to be durable. LEDs also fit more easily into modern electronic circuits. But the main advantage is efficiency. In a conventional incandescent bulb, the light-production process involves generating a lot of heat (the filament must be warmed). LEDs generate much less heat. A much higher percentage of the electrical power is going directly to generating light, which cuts way down on the electricity demands.

Studying an LED Number Display

1. Distribute materials to each group. Have students study the LED number display and explain that there are eight LEDs arranged to form numbers when lit.

Wiring an LED Number Display

1. Power the breadboard by connecting two batteries in series to the power tracks.

2. Insert the LED number display so the pins on one side of the chip are in the E row and the other side are in the F row and the decimal point is at the bottom edge. If the display does not fit snugly on the breadboard, check to see that all pins are straight and press firmly.

3. Wire one cathode (referred to as a common cathode on the diagram) to the negative power track.

4. To light the different LED segments, experiment with connecting wires between the positive track to the different anodes.

5. Encourage students to take notes as they try different connections to light different segments.

4D: Light-Emitting Diodes (continued)

Wrap Up

Allow time for these electrical engineers to make a diagram with the LED symbol. Remind students to add to their list of design opportunities. They may be noticing problems with electronic devices.

Introduce the Home Improvement activity, *Electric House Hunt*, where students take a close look at their house to understand the electrical parts in a house.

Follow With

Session 5, *Making Machines*, introduces students to simple machines and mechanical engineering concepts.

Light-Emitting Diodes

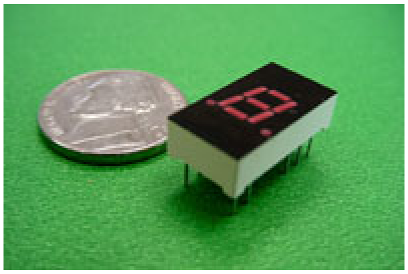
Handout: Session 4, Activity D

What Is an LED?
LED stands for "light-emitting diode." Basically, LEDs are tiny bulbs that fit easily into an electrical circuit. But unlike ordinary bulbs, they don't have a filament that will burn out, and they don't get very hot. They are illuminated solely by the movement of electrons in a semiconductor material. The light is emitted from the material used in the diode. Diodes are electrical components that allow the current to flow in only one direction. LEDs have an additional feature of lighting up when current is flowing through.

LEDs are everywhere—the numbers on digital clocks, the light on a curling iron or on the TV remote control perhaps. Collected together, they can even form images on a TV screen or illuminate a traffic light. Several LEDs are needed to display a number.

Try to make an LED light using a battery. What did you need to do?

Wiring an LED Number Display
In this activity you will experiment with different combinations of wiring to light up eight different LEDs that make up a number display. Study the LED Number Display chip and the information on the back of the packaging:



LED display (next to a U.S. nickel coin)

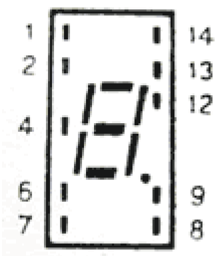


Diagram of pin location

Table of Pin Designations

1. Anode F	14. Anode A
2. Anode G	13. Anode B
3. No Pin Cathode	12. Common Cathode
4. Common Cathode	11. No Pin
5. No Pin	10. No Pin
6. Anode E	9. Anode RHDP
7. Anode D	8. Anode C

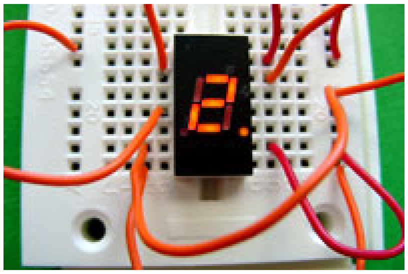
Follow the instructions below to light up the LED number display:

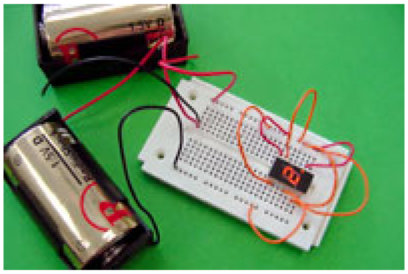
4D Handout: Light-Emitting Diodes (continued)

1. Power the breadboard by connecting two batteries in series to the power tracks.

2. Insert the LED number display so the pins on one side of the chip are in the E row and the other side are in the F row and the decimal point is at the bottom edge. If the display does not fit snugly on the breadboard, check to see that all pins are straight, aligned over holes, and press firmly.

3. Wire one cathode (referred to as a common cathode on the diagram) to the negative power track.


Close-up of LED number display with breadboard


LED number display circuit

4. To light the different LED segments, experiment with connecting wires between the positive track to the different anodes. Take notes on the results of your tests in your design notebook.

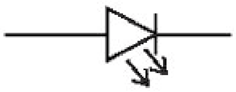
5. Try wiring the other cathode to the negative power track. Which wiring lights each segment? Did you figure out how to light up the right hand decimal point (RHDP)?

6. Now wire the necessary segments to display your favorite number.

7. Challenge: Can you wire a switch so that it displays your lucky number and then the lucky number of your partner? For example, one position of the switch will show the number "2" and the other position will show the number "6."

8. Bigger challenge: Wire a touch screen to display a number. How do you make a touch screen? How about using two pieces of aluminum foil arranged so that when you touch them in a particular place they complete a circuit? Take it from there!

9. Make a diagram of your circuit using an LED symbol.


LED

Electrical House Hunt

Session 4, Home Improvement

Goal
Identify electrical units in the home.

Description
Students look at their homes from an electrical point of view by locating the circuit breakers, LEDs, and switches.

Procedures
Explain to students that they will be investigating the electrical units in their homes in order to identify the things they have learned about in this session. They will need to find out where the circuit breakers are, find 10 household items that use LEDs, and find 10 household items that have switches.

Next Day
Have students compare their lists with a partner.

Electrical House Hunt

Handout: Session 4, Home Improvement

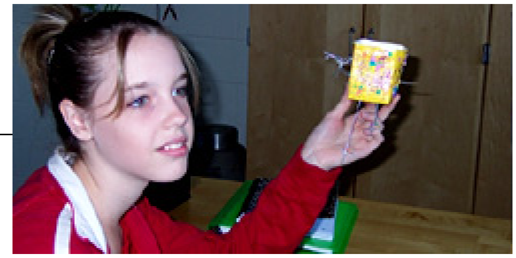
Have you ever considered the electrical units in your house? We are all accustomed to flipping a switch to turn on the lights or pressing a button on a microwave, but have you thought about how these things work? Here's a chance to take an electrical hunt through your home. Record your findings in your design notebook.

1. Locate circuit breakers (these act like fuses to prevent fires from short circuits). Where are they located?
2. Find 10 household items that use LEDs and list them.
3. Find 10 household items that have switches

Session 5

Making Machines

Engineering Fundamentals



In This Session:

This session really puts things in motion. In *5A: Design, Build, Make It Go*, students make rolling toys from a set of everyday materials in a mini-design challenge, and then recall prior experiences with simple machines. To understand that most machines are made of many smaller machines, students study the component machines in a lawnmower through a Web-based tutorial, in *5B: Not-So-Simple Machines*. Students also participate in a mini design challenge to create a simple machine. The activity *5C: Gears, Cranks, Crankshafts, and Belts* is an exploration of gears, cranks, crankshafts, and belts, and culminates in the design, conceptual drawing, and initial construction of a mechanical toy. As a Home Improvement activity, *Build a Mechanical Toy*, students take their plans and materials home and finish their toy.

Supplies

Examples of Stored Energy Toys

- Rubber band airplane, windup toys, paddleball, yo-yo, Slinky*, etc.

One "Rolling Kit" Per Student

- 1 film canister with lid, with holes drilled in both ends
- 2 size #30 or #31 rubber bands (dimensions 2.5" x 1/8" x 1/36" [6.5 cm x 3 mm x 0.7 mm], #31 is slightly heavier)
- 2 washers (either ½" or ¾" [1.25 cm or 2 cm] outside diameter)
- 1 piece of thick drinking straw the length of the canister

Simple Machine Examples

- Wedge: chisel, saw, screwdriver, scissors, door wedge, thumbtack, pins
- Wheel and axle: doorknob, roller skates, eggbeaters, pencil sharpener, skateboard
- Screw: nuts and bolts, jar lid, lightbulb, key rings, corkscrew
- Pulley: flagpoles, clotheslines, blinds, crane, fan belt
- Lever: see saw, wheelbarrow, hammer, crowbar, bottle opener, oar, fork, baseball bat
- Inclined plane: wheelchair ramp, slide, hill, roller coaster, escalator

Simple Machine Challenge

- 1 washer (either ½" or ¾" [1.25 cm or 2 cm] outside diameter) per group
- 1 plastic or paper cup per group
- Meter sticks
- Brads, clay or play-dough, clothespins, craft glue, craft sticks, dowels, drinking straws, foam pieces, gears, hot glue, magnets, paper clips, pipe cleaners, plastic bags, plastic spoons, plastic/paper cups, pulleys, rope, rubber bands, scissors, spools, springs, string, tape, wire

Optional Mechanical Parts

- Gears set
- Wheels set
- 1/4"-wide rubber band "belts" (size #64)
- Small wooden dowels (Bamboo skewers will work.)

One Crankshaft Kit Per Student

- Small box (8 oz. milk carton will do)
- 3 pieces 16-gauge steel wire: one 8" (20 cm) length, two 3" (7.5 cm) lengths
- 1 straw
- Electrical tape or long bead (for crank handle
- Several pairs of needle-nose pliers

Other

- Tools that use moving parts: eggbeaters, hand drills, winged corkscrews, flour sifters, ice cream scoopers, nut grinders, and manual can openers
- Miscellaneous gears, belts and wheels, wire, art supplies, and other materials of choice

Making Machines

Key Concepts: Session 5

Session 5 explores fundamental physical science concepts of **mechanical engineering**. A rolling-toy design challenge begins students thinking about machines. Students go on to explore the mechanics of simple machines and learn that most mechanical devices are really a set of simple machines working together. They learn how machine action can be transferred or change direction by experimenting with gears, wheels and belts, and crankshafts. The session culminates in the design, conceptual drawing, and initial construction of a mechanical toy.

Key Concepts
Simple and compound machines make work easier by multiplying the force we are able to exert. Imagine trying to break a piece of wood apart using your bare hands. Now think how an ax helps you accomplish this task. The ax is a wedge, one of six simple machines.

Machines provide mechanical advantage to make work easier. "Work" is defined as *the application of force to move a load over a distance*.

Work = force x distance

Any machine makes work easier by reducing the force required to move a load. This is known as mechanical advantage. Machines can change the force we exert but not the amount of work done.

Simple Machines
There are six basic or simple machines, which alone or in combination make up most of the mechanical devices we use.

1. **Lever:** A see saw is a lever familiar to everyone. A lever is a stiff rod or plank that rotates around a fixed point, or fulcrum. Downward motion at one end results in upward motion at the other end. Depending on where the fulcrum is located, a lever can multiply either the force applied, or the distance over which the force is applied. There are three kinds of levers, and which kind you have depends on where the fulcrum is set. These are all levers: see saw, wheelbarrow, hammer claw, crowbar, bottle opener, oar, fork, baseball bat, and scissors.

2. **Inclined plane:** The inclined plane can be best described as a ramp or slanted surface, which decreases the amount of force needed to move an object to a higher level. On an inclined plane, the object travels a longer distance, but it takes less force. These are examples of an inclined plane: wheelchair ramp, slide, roller coaster, and escalator.

3. **Wedge:** A wedge is an inclined plane with either one or two sloping sides. It converts motion in one direction into a splitting motion that acts at right angles to the blade. Nearly all cutting machines use the wedge. A lifting machine may use a wedge to get under a load. The following are all examples of wedges: chisel, saw, screwdriver, scissors, door wedge, thumbtack, pin, and nail.

Key Concepts Session 5 (continued)

4. **Screw:** The screw is an inclined plane wrapped around a cylinder. The advantage offered by the screw is that as it turns, rotary motion is converted into a straight motion. This motion can be used to move things apart (as in a car jack), or bring two objects together (a screw drawing two boards together). These devices are screws or have a screw component: jar lid, light bulb, piano stool, clamp, jack, wrench, key ring, and corkscrew.

5. **Wheel and axle:** When a wheel is locked to a central axle, as one is turned the other must turn. A longer motion at the edge of the wheel converts to a shorter more powerful motion at the axle. In reverse, a short, powerful force at the axle will move the wheel's edge a greater distance. The wheel and axle are the basis of these devices: doorknob, roller skates, eggbeaters, manual pencil sharpener, and skateboard.

6. **Pulley:** A single pulley reverses the direction of a force. When two or more pulleys are connected together, they permit a heavy load to be lifted with less force, because the force is spread over a greater distance. Fixtures on flag poles, clotheslines, blinds, cranes, and fan belts all rely on the pulley.

Compound Machines
A compound machine is made of simple machines acting together to perform work. For example, a rotary pencil sharpener is made up of a wedge, and a wheel and axle. Students will see that many mechanical devices are made up of component simple machines when they explore eggbeaters, winged corkscrews, manual can openers, and other everyday household implements.

Compound machines redistribute force with gears, belts, and crankshafts. Energy transfer between components of simple machines is what makes a compound machine work. Gears, belts, and crankshafts are mechanical components that often tie simple machines together, by either transferring a force or changing its direction.

Gear: The common or "spur" gear is a wheel and axle with lever "teeth." When force is applied to the gear, its teeth mesh with those of another gear, transferring the force to that gear. When one gear is larger than another, the turning rate changes. Adjusting relative gear sizes, or gear ratios, gives us a way to change how force is expressed. Anyone who has ridden a bicycle with multiple gears has changed force by adjusting *gear ratios*. Gears can change the direction of a force when their teeth are beveled, or when they are set at an angle to another gear. You can see this change in direction when you observe a rotary eggbeater in action.
Belt: Belts work with wheels and axles to transfer energy. A belt attached between two wheels or shafts transfers force from the one that is powered to the one that is not. A belt can change the direction of a force when the wheels or shafts are set at different angles. It is advantageous to use belts when you want to connect components that are far apart. As with gears, if a belt connects wheels or shafts of different sizes, these will turn at different rates.
Crankshaft: Crankshafts turn rotary (circular) motion into reciprocal (up and down) motion. Students will see how force changes direction when they make their crankshaft toy.

Key Concepts Session 5 (continued)

Potential and Kinetic Energy
Energy can be stored and then released in machines. Stored energy is called potential energy. Released energy is called *kinetic energy*. Think about a windup airplane. When you wind the propeller attached to a rubber band, your human energy is stored as potential energy in the wound rubber band. When you let go, the unwinding rubber band releases energy and powers the plane's propeller.

Friction
Friction is the resistance encountered when one body moves while in contact with another. Friction is the friend and the enemy of machines. In car brakes, friction from the brake shoe pressing against the drum is what causes the vehicle to slow. In this case, friction is an essential function. In other devices, friction causes problems. When component parts meet each other, friction between them can waste energy, produce unwanted heat, and degrade materials. To make machines run well, engineers choose materials carefully and design components to work together efficiently.

More About Simple and Compound Machines

Boston Museum of Science, http://www.mos.org/sln/Leonardo/InventorsToolbox.html*
The Inventor's Toolbox on this site provides information on simple machines.

Science Center, Columbus and Toledo, Ohio,
http://www.cosi.org/onlineExhibits/simpMach/sm1.html*
(Macromedia Flash Player* is required.)
This site is best used as a guided demonstration.

The Franklin Institute, http://sln.fi.edu/qa97/spotlight3/spotlight3.html*
Simple Machines section shows six simple machines in action.

University of Texas,
http://www.engr.utexas.edu/dteach/Experience/mechanisms/brief_overview.htm*
The Mechanisms site is a good review of the concepts of simple machines and mechanics.

Session 5, Activity A

Design, Build, Make It Go!

Goal
Recall and gain experience with motion and energy transfer.

Outcome
Make a rolling toy that travels 3-5 feet (1-1.5 meters) as an introduction to energy transfer.

Description
Students are given a set of materials and challenged to make a toy that rolls 3-5 feet (1-1.5 meters) on its own power. A follow-up discussion about design and students' tinkering experiences past and present help students recall engineering concepts of mechanical engineering. A "recipe" for success is provided so the presenter can make a working version of the rolling toy in advance and later guide the students' efforts.

Supplies
Examples of Stored Energy Toys

- Rubber band airplane, windup toys, paddleball, yo-yo, Slinky*, etc.

One "Rolling Kit" Per Student
- 1 film canister with lid, with holes drilled in both ends
- 2 size #30 or #31 rubber bands (dimensions 2.5" x 1/8" x 1/36" [6.5 cm x 3 mm x 0.7 mm], #31 is slightly heavier)
- 2 washers (either ½" or ¾" [1.25 cm or 2 cm] outside diameter)
- 1 piece of thick drinking straw the length of the canister


Rolling kit

Preparation

1. Bring in stored energy toys to review concepts of potential and kinetic energy.
2. Make holes in the flat ends of the film canisters and lids. The holes can be drilled with 1/4" (0.64 cm) drill bits.
3. Cut drinking straws into lengths. They should be the length of the canister. (You can also use small pieces of a broken pencil if the straw is not strong enough.)

5A: Design, Build, Make It Go! (continued)

4. Place the other materials (2 rubber bands, 2 washers, piece of drinking straw) inside the canister and put the lid on. This is a "design kit."

5. Write the design challenge on the board or poster paper: *Using any or all of the materials in your tiny design kit, make a rolling toy that travels 3-5 feet (1-1.5 meters) on its own power. It does not need to go in a straight line.*

6. Provide measuring tapes or precut lengths of string. Watch a short video clip that demonstrates how to make the rolling toy.

View a Video

Watch a short video clip that demonstrates how to make the rolling toy.

To view the video, select a player and then click on your connection speed.

Select a Player

Dialup High Speed

7. So that you can provide guidance as the students engage in the work, make a rolling toy of your own using the following "recipe" for success (but let the participants design their own varied solutions to the challenge!):

   - Put the rubber band halfway through one washer and thread it back through the loop of the rubber band. Pull on the washer to secure it.
   - Poke the rubber band through the hole in the end of the film canister so the washer is on the outside.
   - Adjust the rubber band so that the washer is flat on the canister.
   - Thread the other end of the rubber band through the hole in the lid and place the lid on the canister.
   - Put the loop of the rubber band through the second washer and then put the end of the straw through the loop. If there is slack in the rubber band, you may need to make a knot above the straw for a snug fit.
   - Adjust the straw so most of the length extends beyond the canister.
   - Turn the straw at least 30 times so the rubber band twists.
   - The second rubber band can be wound onto the non-capped end of the canister, to correct for its smaller circumference.

5A: Design, Build, Make It Go! (continued)

- Put your toy on the floor and let it go! (No one said the toys had to go in a straight line.)

Procedures

Debrief Home Improvement

1. Have students share and compare their lists from *Electric House Hunt* in Session 4.
2. Discuss how electrical units might be incorporated into their projects.

Tinker With Toys

1. Before the students begin the activity, introduce toys that move by storing energy. Lead a demonstration-discussion about stored or potential energy that transfers to kinetic energy as you operate each toy. Ask questions to engage students in a discussion about energy: *Where does the energy to move the toys come from? How is energy stored in these toys? How is energy transferred in the toys in order to make them move?* Remind the students to keep these principles of energy transfer in mind as they begin the design challenge.
2. As students come in, give them each a "rolling kit," direct their attention to the "Rolling Toy Design Challenge" on the board, and challenge them to build their rolling toy.
3. After 15 minutes or so of work time, give participants a 5-minute warning, and then let them demonstrate their toys to one another. (No one said the toys had to go in a straight line.) If they fail to make the toy roll, assure them that there is a method that works, and encourage them to continue trying later.
4. Guide a discussion, asking questions that cause budding engineers to reflect on the design process they just engaged in (successful or not), such as:
   - Is there any one "right" solution for this challenge? Why or why not?
   - What would you do differently if you had more time? Different materials?
   - Can anyone tell about their process; when and why they might have switched to a new idea?
   - What did you learn from watching each other?
   - It is said you have to have a breakdown before a breakthrough. Can anyone relate to that?

Develop Concepts

1. Develop the concept of energy transfer: Tell student pairs to discuss how the toy is powered and be ready with an agreed-upon explanation for the group. Have them report, and probe for answers to these questions:

5A: Design, Build, Make It Go! (continued)

- Where does the energy come from, and where does it go?
- At what point is energy transferred from you to the toy?
- At what point does potential (stored) energy change to kinetic (released) energy?
- Is this a machine?

Wrap Up

Explain that many devices are made up of mechanical component parts that transform energy in order to perform work. The next activities will give students more experience with moving parts. They may want to include moving parts in their personal design projects later on.

Have students read and then discuss *5A Reading: Slinky*.

Follow With

In *5B: Not-So-Simple Machines*, students study simple machine examples from everyday life.

The definitions of work and mechanical advantage are developed, and students participate in a design challenge involving simple machines.

Design, Build, Make It Go!

Handout: Session 5, Activity A

Make a Rolling Toy Design Challenge: Using any or all of the materials in your kit, make a rolling toy that travels 3-5 feet (1-1.5 meters) on its own power. (It does not need to go in a straight line.)

If you get stuck along the way, here are some hints:

- Consider a windup toy. How does it work? Take a look at some toys that store and release energy to produce some kind of motion.
- Windup toys convert potential energy into kinetic energy as they unwind.
- How is the energy stored and released? (Often this is a spring.)
- What could be used instead of springs to store and release energy?

Slinky

Reading: Session 5, Activity A

Patented by Richard James, Upper Darby, Pennsylvania for James Industries. Filed 1 November 1945 and published as GB 630702 and US 2415012.

This is the familiar toy which consists of coils that move downstairs, along the floor, or from hand to hand. Richard James was a mechanical engineer working for the U.S. Navy. While he was on a ship undergoing trials, a lurch caused a torsion spring to fall accidentally from a table to the floor. Its springy movement made him think. When he saw his wife Betty that night he showed her the spring and said, "I think there might be a toy in this." Two years of experimentation followed to achieve the right tension, wire width, and diameter. The result was a steel coil with a pleasant feeling when handheld, with an ability to creep like a caterpillar down inclined planes or stairs, and an interesting action when propelled along the floor. Betty came up with the name of Slinky*, from slithering.

James managed to persuade Gimbels, the department store, to give him some space at the end of a counter. He would demonstrate the toy and hope to sell some of his stock of 400. It was a miserable November night, and Betty and a friend were on hand to buy a couple to encourage sales. They never had the chance, as crowds gathered around and the entire stock went in an hour and a half. A company, James Industries, was set up to make the product. A machine was devised which coiled 24 meters in 10 seconds. The price for a Slinky was $1 in 1945, which had increased to $2 by 1994. More than 250 million have been made, with some variations, including brightly colored plastic models. The only substantial change in the design is that the end wires are now joined together to prevent loose wires damaging, for example, an eye. The trademark was registered in the United States in 1947 and in Britain in 1946.

Besides the obvious fun possibilities, the toy has been used by science teachers to demonstrate the properties of waves. NASA has used them to carry out zero gravity physics experiments in the space shuttle. And in Vietnam, American troops used them as mobile radio antennae.

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Van Dulken, Stephen. *Inventing the 20th Century, 100 Inventions That Shaped the World*. New York: New York University Press, May 2002. www.nyupress.nyu.edu*

Session 5, Activity B

Not-So-Simple Machines

Goal
Reinforce concepts about simple machines.

Outcome
Students identify the six types of simple machines found in everyday objects and participate in a challenge to see how machines aid work by providing mechanical advantage. Students understand that it may take more than one simple machine to perform a task (creating a compound machine).

Description
Students study simple machine examples from everyday life. The definitions of work and mechanical advantage are developed, and young engineers participate in a design challenge to see how simple machines operate as component parts of more complex machines. A final discussion sets the stage for the next activity, where moving parts are explored.

Supplies
Simple Machine Examples

- Wedge: chisel, saw, screwdriver, scissors, door wedge, thumbtack, pins
- Wheel and axle: doorknob, roller skates, eggbeaters, pencil sharpener, skateboard
- Screw: nuts and bolts, jar lid, lightbulb, key rings, corkscrew
- Pulley: flagpoles, clotheslines, blinds, crane, fan belt
- Lever: see saw, wheelbarrow, hammer, crowbar, bottle opener, oar, fork, baseball bat
- Inclined plane: wheelchair ramp, slide, hill, roller coaster, escalator

Simple Machine Challenge

- 1 washer (either ½" or ¾" [1.25 cm or 2 cm] outside diameter) per group
- 1 plastic or paper cup per group
- Meter sticks
- Brads, clay or play-dough, clothespins, craft glue, craft sticks, dowels, drinking straws, foam pieces, gears, hot glue, magnets, paper clips, pipe cleaners, plastic bags, plastic spoons, plastic/paper cups, pulleys, rope, rubber bands, scissors, spools, springs, string, tape, wire

Preparation

1. Learn about simple machines.

    - Simple machines help us do work. You are doing work when you use force to cause motion. When you exert a force (such as pushing or pulling) on an object over a distance you are doing work. Simple machines make work easier by lowering the effort required to move an object or by increasing the distance an object moves. Work = Force x Distance.

5B: Not-So-Simple Machines (continued)

- Simple machines provide a mechanical advantage when the machine puts out more force than is put in. An automobile jack shows a good example of mechanical advantage. The relatively small amount of force a person applies to the handle produces a large enough force to lift a heavy automobile. The automobile jack exhibits mechanical advantage.

2. Prepare a *short* demonstration of simple machines using a Web site. If time allows, view the COSI Science Center Web site (www.cosi.org/onlineExhibits/simpMach/sm1.html*) as an introductory presentation with your students. Allow about 10 minutes to go over the main concepts. Prepare for the presentation by following the steps below:

   - Spend time at the site and browse through all the pages you'll use.
   - Connect a projection device to one networked computer for presentation on a screen or blank wall.
   - Browse all the pages you'll be using in advance so they will be cached in the computer (this reduces load time during the presentation).

Presentation

1. At *The Essence of Simple Machines*, move the cursor over the simple machines, and watch them work. Notice that all of them have a force applied to them to complete work. Click on each machine and watch it go. During the tour of the Web site, highlight the definitions of work and mechanical advantage.

2. Return to the home page and click at the left and right links (in red) to learn about machines, work, and mechanical advantage. Ask students to give an example of how simple machines make work easier.

3. At the home page, go to the bottom link, *Find the Simple Machine*. Follow the directions and see if the students can spot all the machines in a lawnmower.

Procedures

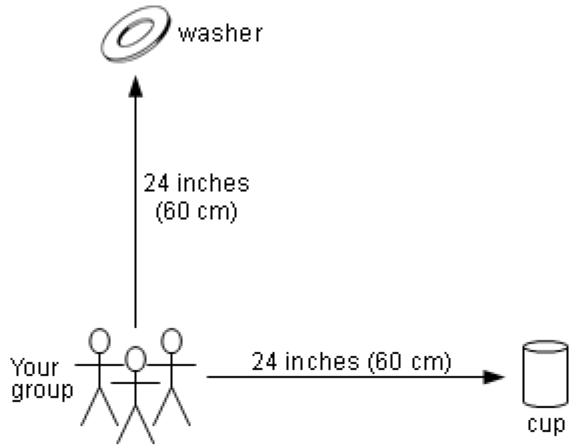
1. In a whole group discussion, demonstrate and define some basic terms—work, simple machines, and mechanical advantage—while showing examples of simple machines. (As an option, you may also bring in pictures of people using simple machines for the purpose of this review.) Ask students to sort the examples into the six simple machine categories: wedge, wheel and axle, screw, pulley, lever, inclined plane.

2. Keep the examples of simple machines sorted on a table so students can refer to them during their design challenge. Next, arrange students into groups of at least three to complete the simple machine design challenge.

5B: Not-So-Simple Machines (continued)

Design Challenge

Using at least one simple machine, design and construct a device that can move a washer that is placed 24 inches (60 cm) away from your group, 90 degrees, to a cup that is also placed 24 inches (60 cm) away. See diagram below:



Design Requirements

- Each group must use at least one simple machine in the device they build.
- The washer must be moved from its location to the fixed location of the cup without direct contact from any student.

Think about:

- What process will you go through in order to design a solution?
- Which simple machines can be used to solve the problem?
- What process will you go through in order to design a solution?

5B: Not-So-Simple Machines (continued)

Materials

Brads	Plastic bags
Clay or play-dough	Plastic spoons
Clothespins	Plastic/paper cups
Craft glue	Pulleys
Craft sticks	Rope
Dowels	Rubber bands
Drinking straws	Scissors
Foam pieces	Spools
Gears	Springs
Hot glue	String
Magnets	Tape
Paper clips	Wire
Pipe cleaners	

Have students share their solutions. While students are sharing, ask questions that cause students to reflect on the design challenge they just engaged in. Get students to discuss some of the key concepts in this session (work, mechanical advantage, compound machines) and how those concepts are related to their design solution.

Some questions you might ask:

- What simple machines did you use?
- Was your device made up of more than one machine?
- How did using a simple machine give you a mechanical advantage?
- How did the use of simple machines make the work easier to complete?

Supplementary Information
Simple machine sites:

- Inventor's Toolbox: The Elements of Machines:
  www.mos.org/sln/Leonardo/InventorsToolbox.html*
  and the page it links to: Gadget Anatomy:
  www.mos.org/sln/Leonardo/GadgetAnatomy.html*

- Edheads Simple Machines: http://edheads.org/activities/simple-machines

5B: Not-So-Simple Machines (continued)

Wrap Up

Discuss ways students might use simple machines in inventions. Challenge kids to find the mechanical action in the moving parts they'll use in the next activity.

Have students read and then discuss *5B Reading: Meet a Mechanical Engineer.*

Follow With

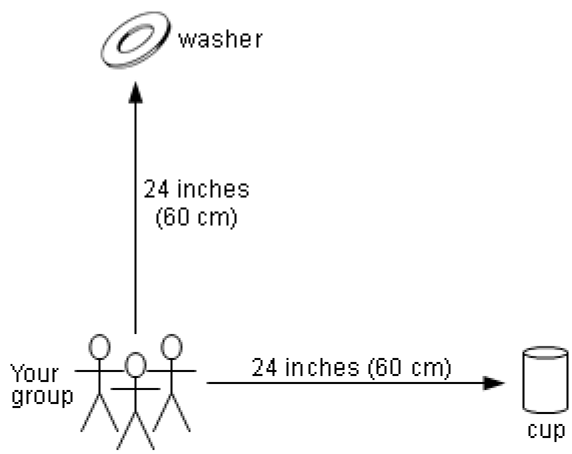
In *5C: Gears, Cranks, Crankshafts, and Belts*, students put moving mechanical parts to work. Collect a variety of mechanical devices that have visible moving parts (for example: eggbeaters and hand drills), enough for one device per group of three students. Consider asking students to bring devices from home in preparation for this activity.

Not-So-Simple Machines

Handout: Session 5, Activity B

Use what you know about simple machines to create a solution to the following design challenge.

Design Challenge
Using at least one simple machine, design and construct a device that can move a washer that is placed 24 inches (60 cm) away from your group, 90 degrees, to a cup that is also placed 24 inches (60 cm) away. See diagram below:



Design Requirements

- Each group must use at least one simple machine in the device they build.
- The washer must be moved from its location to the fixed location of the cup without direct contact from any student.
- You may use only the materials provided.

As you go through the design process, think about:

1. What problem is being solved?
2. Which simple machines can be used to solve the problem?
3. What process will you go through in order to design a solution?

Be prepared to share your design solution.

Meet a Mechanical Engineer

Reading: Session 5, Activity B

Alma Martinez Fallon
Northrop Grumman Newport News

Mechanical engineers help to shape nearly everything in the built environment, but their impact on communities isn't always visible. "Anything that moves, heats, cools, rotates, or flies, there's a mechanical engineer involved in it," says Alma Martinez Fallon. She engineered mechanical systems in support of nuclear submarines and aircraft carrier design before moving into management ranks at one of the nation's largest shipbuilders, Northrop Grumman Newport News. Although mechanical engineers are involved in the design and production of everything from cars to power plants to refrigerators, she adds, "the only time most people hear about engineers is if something fails."

As president of the Society of Women Engineers and an active member of the American Society of Mechanical Engineers, Fallon is helping to make sure that more young people know what engineers do and why the field offers a world of opportunities.

How She Got Interested

Fallon excelled at mathematics through high school, "but I didn't know where I could apply my skills, other than to teach." She didn't know any engineers in her neighborhood of Queens, New York, where her parents settled after immigrating from the Dominican Republic. And she didn't want to be a teacher.

Fallon says she took a "nontraditional path" into her profession. She worked full-time after high school and didn't return to college until age 25. By then, she had met some professional engineers who encouraged her to apply her interest and aptitude in math to an engineering degree.

At Old Dominion University in Norfolk, Virginia, she was one of a handful of women in her engineering classes. She was drawn in by the subject, as well as the chance to "give back to the community. Engineering touches everything. It's been a great fit for me," she says. "I like the practical side of applying math and science to problem solving. I was hooked right away."

5B Reading: Meet a Mechanical Engineer (continued)

Entering the Profession
To help pay the bills during college, Fallon took advantage of an opportunity to combine her studies with work experience. While still an engineering student, she began to learn about shipbuilding design and construction. The practical experiences shaped her course selection, and she decided to focus her undergraduate studies on mechanical engineering. When she graduated, Newport News offered her a position as an associate engineer, working on the design and engineering of *Seawolf* class submarines.

Before long, Fallon was discovering what many mechanical engineers find rewarding about their work. "Designing something and seeing it work—getting to see it run on a ship—that's a lot of fun," she says. Fallon's initial plan was to stay at the company for a few years to gain a solid technical foundation. Instead, she found herself moving up through the engineering ranks and into management. She also expanded her skills by earning a master's degree in engineering management from George Washington University. Now a 15-year veteran of Newport News, she manages a group of about 100 engineers, planners, and analysts involved in planning and manufacturing engineering.

Applying Diverse Skills
As a manager, Fallon draws on a wide range of skills, not all of them taught in engineering school. "You have to be able to communicate, to be strategic, to motivate people. You have to help excite the organization, move the goals and objectives forward, and provide results. It's different from what an engineer learns in school," she admits, "but I use my engineering training to work through the organization as a leader."

What does she like best? "The ability to develop people, to help them grow as individuals. That's number one. Also, I'm results oriented. My area can take on a difficult problem, and seeing it through to resolution and implementation can be very rewarding."

Advice for Students
For students thinking about a future in engineering, Fallon has some specific advice: "Stick to your math and science." In addition, she suggests looking for "programs outside of class that can expose you to career choices in the area of math and science." In her own career, she can see the value of mentors. "During my time at Newport News, I have found individuals who have taken an interest in supporting me." Now she has moved into the mentor role, helping young engineers as they enter the profession. Today's students can take advantage of online opportunities, she adds, no matter where they live. "Through e-mentoring, you can find a mentor who's interested in helping you."

The future looks bright for students who pursue mechanical engineering as a career, Fallon says. "Demands of the workplace continue to increase, especially as technology continues to be enhanced," she says. "Anything that moves, anything that involves heating or cooling, anything that generates power, there's a need for mechanical engineers to design and produce

5B Reading: Meet a Mechanical Engineer (continued)

it. The demand is going to be there."

In her role as president of the Society of Women Engineers, Fallon is an advocate for improving the number of women entering the field. Although women account for only about 20 percent of engineering school graduates, "some universities are doing very well. We want to understand why," Fallon says, and then find ways to build on that success.

Session 5, Activity C

Gears, Cranks, Crankshafts, and Belts

Goal
Study moving machine parts to learn how force can be transferred or change direction to accomplish work.

Outcome
Make a crankshaft mechanism and use it with other parts in a unique mechanical toy.

Description
After an introduction to the moving parts of machines (gears, cranks, crankshafts, belts, and wheels), students investigate these parts and make a crankshaft mechanism. Students begin work on a mechanical toy of their own design. They complete work on the toy at home.

Supplies
Optional Mechanical Parts

- Gears set
- Wheels set
- 1/4"-wide rubber band "belts" (size #64)
- Small wooden dowels (Bamboo skewers will work.)

One Crankshaft Kit Per Student

- Small box (8 oz. milk carton will do)
- 3 pieces 16-gauge steel wire: one 8" (20 cm) length, two 3" (7.5 cm) lengths
- 1 straw
- Electrical tape or long bead (for crank handle)
- Several pairs of needle-nose pliers

Other

- Tools that use moving parts: eggbeaters, hand drills, winged corkscrews, flour sifters, ice cream scoopers, nut grinders, and manual can openers
- Miscellaneous gears, belts and wheels, wire, art supplies, and other materials of choice
- Crankshaft model (see below)

Preparation

1. Collect a variety of mechanical devices that have visible moving parts (example: eggbeaters, hand drills), enough for one device per group of three students. A mounted

5C: Gear, Cranks, Crankshafts, and Belts (continued)

manual pencil sharpener in the room (cover removed) can serve as one device. (Consider asking students to bring devices from home at the end of the previous day.)

2. Collect tools, including needle-nose pliers, rulers or measuring tapes, and scissors.

3. Prepare a model crankshaft in a box. See *5C Handout: Gears, Cranks, Crankshafts, and Belts*.

> **View a Video**
>
> Watch a short video clip that demonstrates how to make the crankshaft toy.
> Select a player and then click on your connection speed.
>
> To view the video, select a player and then click on your connection speed.
>
> Select a Player
>
> Dialup High Speed

Procedures

Exploration: Look at Moving Parts

1. Distribute a variety of mechanical devices (egg beaters, etc.) that have visible moving parts, one to each group of three students. Ask these questions, and have each team answer and demonstrate:

   - Can you count the moving parts?
   - How do the moving parts connect to one another?
   - Can you name any of the moving parts (crank, gear, moving shaft, blade, spring)?
   - Can you find places where the force or motion changes direction? (Example: corkscrew wings press *down* causing the cork to pull *up*.)
   - Demonstrate how the device operates to perform work.

2. Introduce the concept of "mechanism." A mechanism is a set of moving parts that changes the direction of a force or motion. The next three component sets act as mechanisms.

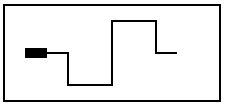
5C: Gear, Cranks, Crankshafts, and Belts (continued)

- Optional: Set out an array of connecting gears of different sizes, and show students how the direction of a force can be changed when they are flat or connected at the 45-degree bevel. Use skewers as cranks. Challenge students to find the relationship between the size of the gears and the relative number of times one turns another. Note: a single speed bicycle could be used instead.
- Ask: How many times does the small green one turn when the large red one turns around once? (A large gear might turn once, turning a smaller gear three or more times. This is the gear ratio.)

3. Demonstrate belts and wheels and how one wheel can turn another: With the help of a student assistant, put axles (such as a pencil) through two wheels, and connect the wheels with a rubber band "belt." Point out that one wheel is the drive wheel, and turning it causes the other wheel to move, by force of the turning belt. Ask:

   - Where have you seen wheels and belts in action (fan belt in car, conveyor belt on the grocery store checkout counter)?
   - What if a large wheel and belt turned a small wheel (recall ratios, as with gears)?

4. Introduce the crankshaft by showing a wire crankshaft made from a paper clip bent into the shape shown. Show how a crankshaft changes the direction of a motion from rotary to reciprocal.



5. Give students 10-15 minutes to investigate the components. Encourage them to consider using these parts in combination in mechanical devices they might make.

Construction

1. Make the crankshaft device, following directions on the handout. Students should take this basic device home and turn it into an appealing toy.

2. Have students engage in a short planning activity before they go home.

Wrap Up
Allow at least 30 minutes to get ready for the Home Improvement activity. Introduce the Home Improvement design challenge, and complete steps 1-5. Have designers present their toy ideas to the group for feedback. Direct them to take their materials home and finish their toy. The journal notes and sketches will be helpful for communicating their ideas to family members who can help.

Follow With
In Session 6, *One Problem, Many Solutions*, students consider the many designs of clock radios, and see how electrical and mechanical components make clocks tick.

Gears, Cranks, Crankshafts, and Belts

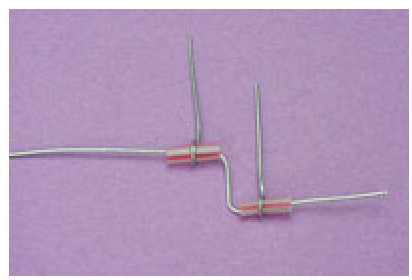
Handout: Session 5, Activity C

Make a Crankshaft Device
Do you remember playing with jack-in-the-box toys when you were small? They have a crank mechanism something like the toy you will make today. With this crankshaft toy, you will see how the direction of a force can be changed mechanically. Turning the crank around and around makes other parts go up and down!

Supplies

- Small box (8 oz. milk carton will do)
- 3 pieces 16-gauge steel wire: one 8" (20 cm) length, two 3" (7.5 cm) lengths
- 1 straw
- Electrical tape or long bead (for crank handle)
- Needle-nose pliers

Steps



1. Cut off the top of a milk carton to make a small box with one side open.

2. Turn the box so the opening is on the table, and drill or poke a hole toward the top third of the box at the same height on opposite sides.

3. Drill or poke two holes in the top, about an inch or 2 1/2 centimeters apart. They should be in a straight line with the other two holes.

4. Cut two short pieces of straw about 1/3 the width of the box.

5. Wrap the end of one of the small pieces of wire around one piece of straw. Tighten the wire so that it pinches the straw while allowing for another wire to pass through. Repeat with the other wire and straw.

6. Take the long wire; make two 90-degree bends, an inch or 2 ½ centimeters apart, leaving one side slightly longer than the other. The longer end becomes the crank handle.

7. Thread a straw with wire attached onto each end of the wire to the bend.

8. At the outside of each straw, make another 90-degree bend, making a “U” with the center section.

9. Find the halfway point of the center section of wire between the straws. Using this as a guide, bend the outer wires away from the center at that point.

5C Handout: Gears, Cranks, Crankshafts and Belts (continued)

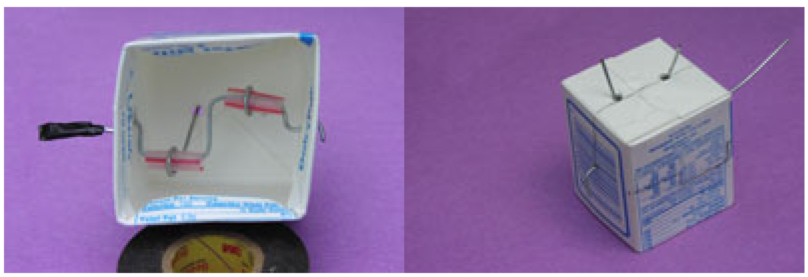
10. From the inside of the box, place the crack handle end of the wire through one of the side holes.

11. Reach into the underside of the box and gently turn the smaller wires so they poke through the holes in the top of the box.

12. Place the other end of the wire into the other hole. You may need to bend this and then re-straighten. Make a bend in the wire to secure it on the outside of the box.

13. Bend the crankshaft end to make a handle. Secure a large bead or electrical tape on the crank to finish the handle.

Crank the handle and watch the wires go up and down. It may need some adjustment to get the best motion. Now it's all up to you! How will you turn the up-and-down motion into something fun?



Design A Mechanical Toy

Session 5, Home Improvement

Goal
Discover ways to use moving parts, and get ready to make a unique mechanical toy at home.

Description
Students use the crankshaft mechanism that they built in the previous activity as the basis for a mechanical toy. They should sketch out details of the design, jot down notes, and then finish the toy at home.

During the Session
Complete steps 1-5 before inventors go home:

1. Ask students to consider what they'd like their mechanical toy to do. Have them make concept drawings in their journal to show what the toy might look like when completed. Encourage them to make a series of sketches; this is a thinking step.

2. Instruct them to describe their toy's function (what they'd like it to do) and then its form (finished toy and component parts).

3. Encourage them to keep drawing and writing and revising—these steps will help them refine their plan.

4. Tell them to use their writing and drawing to explain their plan to a friend and the facilitator.

5. Make changes as needed, collect materials, and begin!

At Home

1. Spend time fine-tuning the device so it works reliably.

2. Add fun elements to turn it into an eye-grabbing plaything.

3. Bring it in the next day for everyone to enjoy!

Examples of toys: jack-in-the-box, two dancers or acrobats, articulated animal (one cloth sleeve covers both wires to cause a rocking motion effect), wacky wires (twist top wires into spirals, thread beads onto them for an up-and-down motion).

Design A Mechanical Toy

Handout: Session 5, Home Improvement

Your mechanical toy can be as unique as you want it to be. Spend some time planning the toy and then finish making the toy at home. Plan your mechanical toy in your design notebook.

1. Describe your toy's function. What would you like it to do? How will it do this?
2. Draw your plans for your mechanical toy.
3. Spend time fine-tuning the device so it works reliably.
4. Add fun elements to turn it into an eye-grabbing plaything.
5. Bring it in the next day for everyone to enjoy!

Session 6

One Problem, Many Solutions

Engineering Fundamentals

In This Session:

A) Clocks of All Varieties (45 minutes)
- Student Handout
- Student Reading

B) Form Meets Function (45 Minutes)
- Student Handout

C) Tick Tock: How a Clock Works (60 Minutes)
- Student Handout

This session places students in the shoes of both engineers and product designers as they apply analytical skills to understand how the requirements of a product are met—in this case, a clock. To prepare for this session, you'll need a digital alarm clock and a mechanical clock for each participant, pair, or group. These can be donated by parents or guardians throughout the first sessions or purchased at a thrift store. It is important to know that they will be taken apart and may not be easily put together again.

In *6A: Clocks of All Varieties*, students look closely at the clocks and as a class come up with design requirements for clocks. In *6B: Form Meets Function*, they see how the requirements are met in different clock radios as they consider form and function. The activity *6C: Tick Tock: How a Clock Works* has the students disassembling the clock radios to see how the electronics and mechanics work to make a clock "tick."

Supplies

- A clock radio for each participant, pair, or group. Ideally, there is one clock radio for each pair.
- Screwdrivers
- Windup mechanical alarm clocks for each participant, pair, or group (at least one for demonstration)
- Flip chart and markers

One Problem, Many Solutions

Key Concepts: Session 6

In Session 6, students think as engineers and product designers and analyze the **design requirements** of a clock radio. As they compare different clock radio designs they begin to see the necessary tie between form and function. The comparison of mechanical and electric clocks allows students to see how the same design requirements can result in very different products. Writing design requirements is the key to getting what you want in a product.

Key Concepts
In this session, the focus is on developing accurate design requirements. Consider the basic requirements for a clock radio. A clock radio must play, have alarm settings, sit on a shelf with numbers visible, be reliable, have volume control, and have a mechanism for changing radio stations. The manner in which the product requirements are met can be extremely varied.

Requirements define *what* the project is ultimately supposed to do. Later on, students will develop requirements for their design project. They also develop specifications which define *how* requirements will be met. *Design requirements* are general product goals, while *product specifications* are much more detailed and should be clear enough to hand off to a production group to build. *User requirements* are another type of requirement designers and engineers rely on to describe the needs, goals, and characteristics of the proposed users.

Design Requirements
Requirements provide general statements of what you want your product to do or what qualities you want it to have. For example, a requirement you might have for a stereo is a way to control the volume. You might also require the stereo be able to hold multiple music CDs at one time.

Design Specifications
Specifications provide more detail and are often measurable. The specifications provide detailed statements that might deal with materials, proportions, and exact placement of specific components. Specifications guide the engineering of a product. A design specification for a stereo might state that the stereo will hold five music CDs which are loaded into a compartment at the top of the stereo.

Examples of design requirements and specifications are embedded throughout the *Design and Discovery* curriculum:

1C: Toothpaste Cap Innovations
8B Handout: Sample Design Brief
12A Handout: Thinking Again About Design

Session 6, Activity A

Clocks of All Varieties

Goal
To examine one object and see the different ways it can meet requirements.

Outcome
Students will begin to consider the relationship between form and function.

Description
Participants study a clock radio and consider how it meets requirements.

Supplies

- A clock radio for each student, pair, or group. (Ideally, there is one clock radio for each pair.)
- Flip chart and markers

Preparation
Gather digital clock radios beforehand. These should be clock radios that can be disassembled. Broken clocks are fine—they do not have to work. (Ideally, each student will have one clock radio.)

Set up a flip chart on which to write the requirements.

Procedures
Each participant, pair, or group should have a clock radio in front of them. Present the following questions to discuss as they look at their clock radios.

1. List the main functions of a clock radio.

2. Describe all the things yours can do in addition to the basics listed above.

3. Describe its size, shape, and materials—everything you can see—in detail.

4. Now think carefully about where it sits in a bedroom. How it is it used? What does a user have to do to use a clock radio? Be very specific. You are collecting data about a user.

5. When it is it used?

6. What are the conditions (time of day, user's attitude, etc.) under which someone usually uses it?

Wrap Up
Discuss and share responses. Generate a group list of the basics of what a clock radio is supposed to do. *(The radio must play, be easy to set alarm, sit on a shelf with numbers visible, be reliable, have volume control, and include the ability to change radio stations, etc.)* Explain

that these are called requirements.

Read *6A Reading: Meet a Project Manager*.

Follow With
In *6B: Form Meets Function*, students compare clocks and consider how problems are addressed.

Clocks of All Varieties

Handout: Session 6, Activity A

Have you ever been in an electronics store and seen how many different types of clock radios there are (or TVs and stereos, for that matter)? Clock radios are an excellent product for understanding form and function. To begin, look at one clock radio and consider what the basic requirements of a clock radio are. Record your observations in your design notebook.

1. List the main functions of clock radio.
2. Describe all the things the one in front of you can do in addition to the basics listed above.
3. Describe its size, shape, and materials—everything you can see—in detail.
4. Now think carefully about where it sits in a bedroom. How it is it used? What does a user have to do to use a clock radio? Be very specific. You are collecting data about a user.
5. When it is it used?
6. What are the conditions (time of day, user's attitude, etc.) under which it is used?

Meet a Project Manager

Reading: Session 6, Activity A

David Thorpe
Senior Project Manager
ZIBA Design

Introduction

Hello, my name is David Thorpe. When I was young, I was always making things, drawing and writing. I made puppets, wrote my own comic books, built things from a big bucket of Lego* blocks (not the prepackaged kits), and built tree houses, forts, and rafts for our pond. I went to college at Stanford University thinking that I was going to be a computer programmer, but after a few semesters of "flipping bits," I changed to the Product Design program in the Mechanical Engineering department. The Product Design program teaches problem solving, brainstorming, and sketching skills to engineers along with the technical aspects of engineering. After college, I worked at Hewlett-Packard designing and engineering inkjet printers for four years and then joined ZIBA Design in 1993.

A Typical Day

My day usually consists of a combination of meetings to make sure everybody knows what they are supposed to be doing, group brainstorms, and then some detailed design work on my own. I alternate between design on the computer and rough concept sketching. There is usually a lot of informal interaction with others in the office as we bounce ideas off one another, get updates on other projects, and banter back and forth.

Most Interesting Thing About My Job

I really enjoy the diversity of projects that I work on and interacting on a daily basis with talented, creative co-workers.

Advice

My advice to younger people entering the design or engineering field is to understand both the technical and creative side of both. There are plenty of great designers and engineers, but not as many that can bridge both disciplines.

Session 6, Activity B

Form Meets Function

Goal
To understand what is meant by "form follows function."

Outcome
Students will understand the difference between form and function and how form usually follows function. They will draw a design for a new and improved clock radio.

Description
Students examine various clocks in order to understand form and function.

Supplies
A clock radio for each participant, pair, or group

Preparation
Gather all the clock radios on one table for students to view at once. Show the requirements sheet that the students created in the last activity.

Procedures
Clock Radio Requirements

1. Have the students gather around the table with the clock radios and pose the following questions:

    - What do you notice about the radios around the table?
    - In what ways are the radios the same? Different?
    - Why are the radios all different?
    - Choose one requirement and examine five clock radios. Record how the five different clock radios met this requirement.
    - How do the requirements force products to be similar in function, yet allow for differences?
    - How do the requirements force products to be similar in function, yet allow for differences?
    - What does it mean when people say "form follows function"? How does this relate to the clock radios?

Form and Function

1. Explain that engineering is about function: Does the product work? Does it meet requirements? Can it be manufactured efficiently, etc.? The form of an object (how it is designed and constructed) should follow the task it is to perform. In other words, you must know exactly what you want something to do before you can design and build it. In the case of clock radios, once the electrical and mechanical aspects of the product are developed, many creative forms can follow.

6B: Form Meets Function (continued)

2. Encourage students to think like engineers, but with the benefit of the skills of good industrial designers who are attuned to the subtle but powerful influences of the "visual attraction" and "tactile appeal" of a product.

3. Pair students and have them each take a clock radio. In pairs, have them examine and compare two clock radios very closely. For each function, tell them to discuss the form it took on each clock and what they like or dislike about the form on each clock radio.

4. Ask the pairs to pick one requirement and improve upon it. They can draw a sketch of their ideal clock radio in their design notebooks.

Wrap Up
Have pairs share their sketches of their new and improved clock radio designs.

Follow With
Students will take a look inside the clock radio to see the inner workings in *6C: Tick Tock: How a Clock Works*.

Form Meets Function

Handout: Session 6, Activity B

In this activity, you will look at the clock radios closely and observe how the requirements are met.

1. Record the requirements that the class came up with for clock radios.
2. Choose one requirement and explain how five different clock radios met this requirement.
3. In pairs, consider one requirement and how you could improve upon it. Now, individually, draw a sketch of your ideal clock radio. This can be done in your design notebooks.

Session 6, Activity C

Tick Tock: How a Clock Works

Goal
To understand how clocks use electrical and mechanical components to make them tick.

Outcome
Students will disassemble the clock radios and mechanical clocks to see electrical and mechanical components at work.

Description
Students learn about the electronics and mechanics behind clocks.

Supplies

- A clock radio for each participant, pair, or group. Ideally there is one clock radio for each pair.
- Wind-up mechanical alarm clocks for each participant, pair, or group (at least one for demonstration)
- Screwdrivers

Dual Alarm Clock

View a short video of a student sharing her Dual Alarm Clock design solution.

To view the video, select a player and then click on your connection speed.

Select a Player

Dialup High Speed

Preparation
Each student (or pair) should have a clock radio and a wind-up alarm clock (if feasible). Provide enough screwdrivers (both flat head and Phillips, in different sizes) for them to take the radios apart.

Procedures
Inside a Clock

1. Ask students if they have ever looked at a clock and thought about how it works. Explain that they will have the opportunity to get inside clocks to see how they work and to compare mechanical and electric clocks. Explain what is needed to make a clock tick:

    - A source of power. In an electric clock radio, this is an electrical power supply, typically either a battery or 120-volt AC power from the wall. In a mechanical clock, the weights and springs provide the power.
    - An accurate time base that acts as the clock's heartbeat. In an electric clock, there is a time base that "ticks" at some known and accurate rate. In a mechanical clock, the pendulum handles this.
    - A way to gear down the time base to extract different components of time (hours, minutes, and seconds). In a digital clock, there is an electronic "gearing mechanism" of some sort. Generally, a digital clock handles gearing with a component called a "counter." In a mechanical clock, gears serve this role.

6C: Tick Tock: How a Clock Works (continued)

- A way to display the time. In a digital clock, there is a display, usually with either LEDs (light emitting diodes) or an LCD (liquid crystal display). In a mechanical clock, the hands and face do this.

2. Have the students explore the electrical and mechanical components of their clocks. They should be able to identify the following:

   - LEDs
   - Wires
   - Circuits
   - Buzzer
   - Speaker
   - Belts
   - Motors

3. As a demonstration, or individually, have students disassemble a mechanical clock to see how the gears work.

Wrap Up
Students can wander around the room and look at the insides of the different clock radios. Remind students to add to their list of design opportunities. They may want to consider electrical or mechanical ideas.

Follow With
In Session 7, *The 3 R's Of Problem Identification*, students begin to consider their own design opportunity.

Tick Tock: How a Clock Works

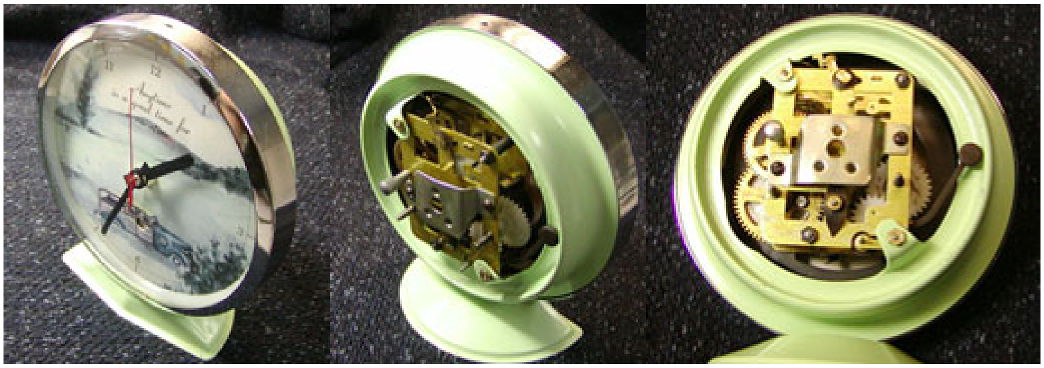
Handout: Session 6, Activity C

In this activity, you will have an opportunity to look inside clocks and see the inner workings of both mechanical and electrical clocks. As you examine the clocks, notice that they have the following:

- A source of power. In an electric clock radio, this is an electrical power supply, typically either a battery or 120-volt AC power from the wall. In a mechanical clock, the weights and springs provide the power.
- An accurate time base that acts as the clock's heartbeat. In an electric clock, there is a time base that "ticks" at some known and accurate rate. In a mechanical clock, the pendulum handles this.
- A way to gear down the time base to extract different components of time (hours, minutes, and seconds). In a digital clock, there is an electronic "gearing mechanism" of some sort. Generally, a digital clock handles gearing with a component called a "counter." In a mechanical clock, gears serve this role.
- A way to display the time. In a digital clock, there is a display, usually with either LEDs (light emitting diodes) or an LCD (liquid crystal display). In a mechanical clock, the hands and face do this.

Now identify the following components in the clocks:

- LEDs
- Wires
- Circuits
- Buzzer
- Speaker
- Belts
- Motors



Design and Discovery

Thinking Creatively

Students now delve into their own projects as they learn to identify problems and come up with innovative solutions. In *Session 7: The 3 R's of Problem Identification*, students gather information about the problems they have identified through market research, narrow down their problem, and begin to develop a solution using brainstorming techniques. *Session 8: A Brief Focus on Your Design Problem*, helps students look at their design ideas from the perspective of the user as they continue to develop their projects. They then gather all of their ideas into one document, a Design Brief, which is used as a blueprint throughout their project development. In *Session 9: A Solution Taking Shape*, students have an opportunity to go on the Internet to explore other innovators and to search the patent Web site to see what ideas may be similar to theirs.

Session 7

The Three R's of Problem Identification

Thinking Creatively

In This Session:

A) Revisit (45 minutes)
- Student Handout

B) Research and Refine (60 Minutes)
- Student Handout

C) SCAMPER to Solutions (45 Minutes)
- Student Handout
- Student Reading

So many problems to solve and improvements to make. How do you decide which one to tackle? In this session, students revisit and refine their broad list of problems, needs, and improvement ideas (started in Session 1, *Jump Into Design*) to identify one design opportunity as their project. They use a variety of observation and data collection strategies to consider what exactly needs fixing, developing, or improving.

In the first activity, *7A: Revisit*, students revisit their list of design opportunities started earlier in Session 2, *The Designed World*. Here, they develop the criteria for choosing a problem to pursue. In *7B: Research and Refine*, students refine their list of problems and conduct market research by gathering information about the nature of the problem. They do this by going off site to conduct a survey and collect data about the user, the user's preferences, and the realities of the user's life, environment, and behaviors. The SCAMPER brainstorm technique is used in *7C: SCAMPER to Solutions* to help students begin to think about the solutions for the design opportunity. By the end of this session, students should each have one project in mind and about five possible solutions.

Supplies
Clipboards (optional)

The 3 R's of Problem Identification

Key Concepts: Session 7

In Session 7, students use **product research** to gather information about the nature of their design problems in order to narrow their choices. Students then learn about user needs by conducting surveys and using the data to choose one design opportunity that is compelling to them. Once students know the design challenge they want to pursue, they move to Step 3 of the design process—Brainstorming Possible Solutions to the Problem.

Key Concepts
During this session students are introduced to product research methods to help refine their design problem. These methods include asking potential product users probing questions and studying user data through surveys and observations. Understanding the user of the product is critical to product design. This process, called market research, focuses on the collection and study of user preferences toward new or existing products.

Surveys allow for gathering data about a user, a user's preferences, and the context of a user's life and environment. When designers understand their users, they can design with them in mind. A survey provides a way for designers to get specific information about a user. Questions used in a survey should help gather data about the problem and the user.

Some question examples include:

- What do you find frustrating about this particular product?
- What aspects of the product do you find useful?
- What changes would you like to see made to this product?
- Would you purchase this product if (describe change)?
- How often do you use this product?

Surveys do have drawbacks because participants might give information about what they believe, not on what they do. An integrated approach to product research is often necessary to get a better understanding of the user.

An additional method for gathering information is through observations. Ethnography is a field of product research that uses observation as a method for gathering information. Ethnographic studies can be conducted by sending an observer to watch people use a specific product. By observing behavior researchers discover user needs that are not being met and possible design solutions that might meet those needs. IDEO www.ideo.com *, a product design firm, uses ethnographic studies as a method to come up with design solutions. IDEO designed a concept vacuum cleaner that follows the user during cleaning, after conducting many user observations to understand the limitations around current vacuums. The model they designed addressed numerous issues that frustrated vacuum cleaner users.

Key Concepts: Session 7 (continued)

More About Product Research

Industrial Designers Society of America (Editor) and Goodrich, Kristina (Introduction). *Design Secrets: Products: 50 Real-Life Product Design Projects*. Gloucester, MA: Rockport Publishers, 2001.

Kelley, Tom. *The Art of Innovation: Lessons in Creativity From IDEO, America's Leading Design Firm*. New York: Doubleday, 2001.

Session 7, Activity A

Revisit

Goal
Add and prioritize the list of problems and improvements that students began in Session 2, *The Designed World*.

Outcome
Identify three problems or improvements (design opportunities) to focus on.

Description
Students generate additional ideas to add to their list of design opportunities, looking for needs, problems, or improvements. They then go through a prioritization and selection process to narrow their list.

Supplies
None

Preparation
Be sure to ask students to take out their list of design opportunities from *2A Handout: Design Opportunities Are Everywhere*. (They should have been adding to this list throughout the sessions.)

Procedures
In this activity, students revisit their list of needs, problems, or improvements that they began earlier. This is Step 1 of the design process: Identify a Design Opportunity. Students should see that opportunities are everywhere and often come from a need, problem, or improvement to an existing solution.

Expanding the List

1. Provide some time for learners to add other ideas to their list that may have come up throughout the previous sessions. In doing so, their ideas should come from observations that they've made based on frustrations with particular everyday objects.

2. Give some examples here. For example, perhaps some students in the class are left-handed. They may have trouble using a computer mouse which is designed for a right-handed person. They might like to see adaptations made to a mouse so that it is suitable for a left-handed person.

3. Have students look around the room and choose something in the room. Now, ask them to consider what problems they have using this item. This might be a problem with the entire product or with one part of the item. Now, ask them to come up with a way that they would like to see it improved. Go around the room and ask students to share. You

7A: Revisit (continued)

might find, for example, that someone doesn't like the pencil sharpener in the room. She doesn't like the fact that you have to constantly take out your pencil to see if it is sharpened. She would like to see the sharpener indicate when a pencil is sharpened. Remind them to think about function as opposed to form, the way it works as opposed to the way it looks. Ultimately, the goal is for them to re-engineer a product to make a functional improvement.

4. Students can also apply the Activity Mapping technique that they learned in *2A: Design Opportunities Are Everywhere*, to help them identify a problem. They can do Activity Mapping individually for a problem that interests them. This is a useful strategy if they have difficulty coming up with a design challenge. Suggest that they choose an activity that is routine for them and try to identify problems in that activity. For example: eating breakfast, going grocery shopping, washing their dog, taking a hike, and so forth.

Activity Mapping

1) Pre-activity: Describes what is done before the activity

↓

2) Activity: Explains what is involved in the activity

↓

3) Post-activity: Includes what is involved after the activity

↓

4) Assessment: Involves how one knows if the activity has been successful

5. Now, have students add additional design problems to their list and be as specific as they can. Remind them of the question: "What *problems* would you like to solve or what *improvements* would you like to make on a current product?" Encourage the young designers to dream!

Refining the List

1. Ask the group to come up with some questions to help each other narrow down their list of design opportunities to select a few to focus on. Working in pairs, students should ask each other probing questions to help clarify what the need, problem, or improvement is and which holds the most promise for solutions. Sample probing questions are:

    - What about this product is frustrating?
    - Do you know of any similar products that have been adapted from this product?
    - What would you like to see this product do?
    - What part of the product would need to be changed, the whole thing or one part?
    - Would other people benefit from this improvement? If so, who?

7A: Revisit (continued)

2. Another option is to have students place their lists of design opportunities on their desks and walk around to look at everyone's list. Students may read the lists and write comments next to the problems that their peers addressed. They can then use the comments to help them narrow down their list.

3. Each student should be ready to select the top three design opportunity choices.

4. Ask them to consider where they could gather the most data about other people's use and impressions of the problem or improvement that they have identified.

Wrap Up
Students share their top three design opportunities with the whole group. Then, they discuss where they could gather the most data about the problems and improvements that they identified.

Follow With
In *7B: Research and Refine*, students learn how to conduct a survey to gather more data about problems and improvements.

Revisit

Handout: Session 7, Activity A

You will now begin to think about what design project you will work on and use the design process to plan your own design. This exercise will help you sort through and prioritize your list of problems and improvements. Remember the first step of the design process:

> Identify a design opportunity: Opportunities are everywhere and often come from a need, problem, or improvement to an existing solution.

Add to your list. What problems would you like to solve or what improvements would you like to make on a current product? Write down everything that comes to mind. No editing; you can do that later. Have fun dreaming! Feel free to use the Activity Mapping as part of your brainstorming process. Do this in your design notebook.

Activity Mapping

1) Pre-activity: Describes what is done before the activity

↓

2) Activity: Explains what is involved in the activity

↓

3) Post-activity: Includes what is involved after the activity

↓

4) Assessment: Involves how one knows if the activity has been successful

After reviewing the list with your partner, now prioritize the list and select your top three based on your discussion with your partner and your interest in pursuing this problem. Next to each, explain why you chose that one.

Where could you gather data about other people's uses and impressions of the problems and improvements that you identified?

Session 7, Activity B
Research and Refine

Goal
Students gather data about design opportunities to help them select a design project.

Outcome
Students collect data about design problems and choose one to solve with a design project.

Description
Students observe, shadow, and interview people to collect data on how people interact with products, what frustrations people have, and how products can be improved. Students then focus on one design problem. This one design opportunity may change as ideas are refined in an iterative design process.

Supplies
Clipboard for surveying (optional)

Preparation
Review students' lists and ideas for data collection.

Arrange for a walking field trip. Ideally, the location will reflect the students' feedback from the previous activity about places to collect data. This might mean a visit to the local grocery store, the mall, the hardware store, and so forth. If possible, arrange for mentors to attend this session. If mentors are available to come along, divide students into groups (with a mentor for each group) and send them to different places. If a walking field trip is not possible, ask mentors to visit your site and have students survey mentors about product use.

Students should have their lists from the previous activity, *7A: Revisit*.

Procedures
In this activity, students focus on Step 2 of the design process: Research the Design Opportunity. This is where they gather lots of information about the nature of the problem. They find out about the user, the users' preferences, and collect data about the context and realities of the users' life, environment, and behaviors. In short, market research. The idea is for students to get feedback on the design opportunity before refining their choice even further.

Explain that students can use a variety of methods to collect data on the design problem. Introduce the methods and have them prepare for the field trip. The methods may also be used as students collect data on their own time.

7B: Research and Refine (continued)

Observing

1. Encourage students to observe and record behavior within its context, without interfering with people's activities.

2. Explain that this helps to see what people actually do within real contexts, what problems people face, and how they overcome the problem. For example, the student who created the dual alarm clock needed to observe how people use alarm clocks. To do this, she might wake up early and observe how her family members use the functions on an alarm clock. Or, she might observe how people explore the functions on an alarm clock when shopping for a new clock.

Shadowing

1. Suggest that students go along with people to observe and understand their day-to-day routines, interactions, and contexts. This may help reveal design opportunities and show how a product might affect or complement users' behaviors.

2. Tell students to take notes and bring along a camera (if available) to take photos.

Narration

1. Introduce the narration method. Explain that students can ask participants to describe aloud what they are thinking while they perform a process or execute a specific task.

2. Explain that this is a useful method to understand users' motivations, concerns, perceptions, and reasoning.

Interviewing and Asking the Five Whys

1. Explain that students can gain insight into a problem by talking to people about it. Have them prepare interview questions ahead of time and identify the type of people they plan to interview.

2. Demonstrate how to use the Five Whys method, which asks "Why?" questions in response to five consecutive answers. By doing this, people are forced to examine and express the underlying reasons for their behaviors and attitudes.

Surveying

1. Encourage students to survey a variety of people to learn more about their design opportunity. Surveying can reveal trends in attitudes and behaviors.

2. Be sure that students have survey questions prepared in advance and decide how they are going to conduct the survey (by asking people the questions or by having them fill out a survey form).

7B: Research and Refine (continued)

3. Students should survey at least 10 people.

Preparing for Data Collection

1. Have students decide how they will do their data collection.

2. If students are surveying or interviewing, have them prepare questions. Questions might be about uses' frustrations with a product, changes to a product, frequency of usage of a product, and so forth.

3. If students are observing or shadowing, have them make a list of the kinds of things they will be observing, for example, how people are using a product, what kinds of things people appear to be having trouble with, and so forth.

4. Be sure that students are prepared. They can draft a script with an introduction, explaining who they are, what they are doing, and the purpose of their work.

5. Have them practice the script in pairs.

Research Etiquette

1. Remind students to respect their participants, who are often strangers who are willing to give their time and share their thoughts and feelings.

2. Here's some principles to share with students:

    - Approach people with courtesy.
    - Identify yourself and your intent.
    - Describe how the information will be used and why it's valuable.
    - Get permission to use the information and any photos that you take.
    - Keep all information anonymous and confidential.
    - Let people know that they can choose not to answer questions or stop participating at any time.
    - Keep your opinions to yourself.
    - Maintain a relaxed and nonjudgmental atmosphere.

Doing Market Research

1. Students are now ready to get out in the field and do market research.

2. Encourage students to continue this work on their own.

7B: Research and Refine (continued)

Narrowing the Design Project

1. Back in class with their market research in hand, students should spend time sorting through the data that they collected. In doing so, their goal is to narrow their list of design opportunities. They should think about which problem would be most possible for them to work on. They can begin to do this by listing the pros and cons for each possibility based on their research. Remind them that they are still focusing on problems; however, it's natural to have ideas for solutions "popping up," and this may guide them as they narrow their focus.

2. As they narrow down their choices, remind them to consider what aspect of a particular design they would like to see improved or developed. They could decide to choose the whole product or just a part of the product.

3. In small groups, students share their lists of pros and cons and get feedback from each other to help them choose one design opportunity.

4. They are now ready to make a decision. Encourage them to make a decision by selecting one or two problems that are most compelling to them. Explain that their decisions are not permanent; they may find that they change their design choice a few times throughout this process. Do not force or rush the process!

Developing the Problem Statement

1. Now that they have narrowed their list to one design opportunity, they need to formulate a "problem statement" that expresses the "heart" of the situation.

2. Discuss the features of a problem statement using the toothpaste example:

    - Begins with a clear, concise, well-supported statement of the problem to be overcome.

      Teeth brushing can be a messy operation. Toothpaste often gets all over the cap and even on the sink. Sometimes the cap is dropped onto a dirty floor or into the sink drain. Includes data collected during the survey/observation in order to better illustrate the problem.

      After observing my family members brushing their teeth, I noticed that they all use toothpaste with a screw cap. I observed my younger sister leaving the cap off and on the sink, my dad putting the cap down on the sink and leaving toothpaste behind after putting the cap back on, and my mom dropping the cap on the floor. When talking to people about their use of the screw cap, they reported similar problems.

7B: Research and Refine (continued)

- Establishes the importance and significance of this problem.

  These problems with the screw cap seem to be widespread. With a little innovation, this problem can be solved.

- Describes the target population.

  While I realized that everyone uses toothpaste, I also observed that it is primarily women who purchase the toothpaste. Therefore, my product design will need to appeal to women in particular.

3. Tell them to write the problem clearly so that it could be explained to anyone.

Wrap Up
Have students discuss how easy or difficult it was to narrow their lists and why this was the case.

Follow With
In *7C: SCAMPER to Solutions*, students begin to consider solutions to their problems.

Research and Refine

Handout: Session 7, Activity B

You will now have a chance to do some market research on the three design challenges.

Choose a Method

Observing
This method involves observing and recording behavior within its context, without interfering with people's activities. Just watch people and record what you see.

Shadowing
Tag along with people to observe and understand their day-to-day routines, interactions, and contexts. Be sure to take notes and bring along a camera (if available) to take photos.

Narration
This method involves asking participants to describe aloud what they are thinking while they perform a process or execute a specific task.

Interviewing and Asking the Five Whys
Talk to people about the design problems. Be sure to prepare questions in advance. Use Five Whys method, which asks "Why?" questions in response to five consecutive answers.

Surveying
Survey a variety of people to learn more about their design opportunity. Be sure to have survey questions prepared in advance and decide how you are going to conduct the survey (by asking people the questions or by having them fill out a survey form). Survey at least 10 people.

Prepare

1. Prepare your opening script for introducing who you are and what you are doing.

2. Develop an observation, shadowing, or narration plan. Prepare questions for interviewing and surveying. Remember, you probably do not want too many questions. In a survey; you are looking for short answers.

3. Come up with a list of things that you will be looking for as you watch people interact with the products.

4. Practice with a friend.

Remember

- Approach people with courtesy.
- Identify yourself and your intent.
- Describe how the information will be used and why it's valuable.
- Get permission to use the information and any photos that you take.

7B Handout: Research and Refine (continued)

- Keep all information anonymous and confidential.
- Let people know that they can choose not to answer questions or stop participating at any time.
- Keep your opinions to yourself.
- Maintain a relaxed and nonjudgmental atmosphere.

Review the Results

5. Using your results, write the pros and cons next to each item.

6. Select one design opportunity that seems most compelling.

Develop a Problem Statement

7. Write a clear problem statement. This is intended for someone who knows nothing about this problem. The problem statement should:

    - Begin with a clear, concise, well-supported statement of the problem to be overcome.
    - Include data collected during the survey/observation in order to better illustrate the problem.
    - Establish the importance and significance of this problem.
    - Describe the target population.

Session 7, Activity C

SCAMPER To Solutions

Goal
Students brainstorm possible solutions to their design project.

Outcome
Students generate several solutions for their design project.

Description
Using the SCAMPER process, students develop a list of possible solutions to their problem or improvement.

Supplies
None

Procedures
SCAMPER

1. This activity is Step 3 of the design process: Brainstorm Possible Solutions to the Problem. Now that students have one design project in mind, they are ready to consider solutions to their problem. In doing so, they should first consider what the desired outcome is. That is, how will they know when the problem is solved? The goal of this exercise is to have them come up with five solutions to their design challenge. This is similar to what they did with the backpack in *2D Handout: SCAMPER and Backpack*. However, now they are doing SCAMPER for their own design projects.

2. Ask: What is the desired outcome of the design? What do you want the product to do?

3. From the previous activities, students should be familiar with the creative thinking processes. Revisit the SCAMPER technique for brainstorming. Have students review SCAMPER and the SCAMPER process applied to a backpack from *2D: SCAMPER and Backpack*.

   Substitute (What else can be used instead? Other ingredients? Other materials?)
   Combine (Combine other materials, things, or functions.)
   Adapt (Can it be used for something else?)
   Minimize/Magnify (Make it bigger or smaller.)
   Put to other uses (New ways to use as is? Other uses if modified? Other people or places to reach?)
   Eliminate/Elaborate (Remove some part or materials, or make one section more detailed or refined.)
   Reverse/Rearrange (Flip-flop some section of the item or move parts around. Interchange components? Different sequence? Turn it upside-down?)

7C: SCAMPER To Solutions (continued)

4. Using SCAMPER, learners should try to come up with different solutions for their design challenge. Remind them that they do not have to use all the steps of SCAMPER during this process.

5. SCAMPER should help them generate several ideas for solutions to their design challenge.

Revisit Activity Mapping

1. Using the Activity Mapping from *7A Handout: Revisit*, students can focus on one of the cycles (pre-activity, activity, post-activity, or assessment) where they identified problems and can now brainstorm solutions.

Solution Criteria

1. Now that learners have a number of ideas that can serve as possible solutions to their problem, it's time to evaluate them systematically. Have them generate a variety of criteria and analyze their solutions with the criteria. This might include such things as:

    - It is practical.
    - It can be made easily.
    - It is safe.
    - It will not cost too much to make or use.
    - It is a new idea.
    - It is not too similar to something else.
    - It addresses the problem.

2. Have students review each solution. Using the criteria, they should identify and evaluate the relative strengths and weaknesses of possible solutions.

3. Depending on which of their solutions meet the criteria, ask students to further narrow their list of solutions to three that they will investigate in greater depth.

Wrap Up
Remind students to keep careful notes of their decision-making process in their design notebooks. Have them review their notes and ensure that they are keeping clear records of their process.

Have students read *7C Reading: Meet a Design Planner.*

Follow With
In Session 8, *A Brief Focus on Your Design Problem*, students prepare a design brief.

SCAMPER To Solutions

Handout: Session 7, Activity C

You will now begin to think of the solution for your design. In doing so, it is important to consider the outcome of the design—what do you want the product to do? Use SCAMPER to come up with some solutions. You do not have to use all the steps of SCAMPER.

Substitute (What else can be used instead? Other ingredients? Other materials?)
Combine (Combine other materials, things, or functions.)
Adapt (Can it be used for something else?)
Minimize/Magnify (Make it bigger or smaller.)
Put to other uses (New ways to use as is? Other uses if modified? Other people or places to reach?)
Eliminate/Elaborate (Remove some part or materials, or make one section more detailed or refined.)
Reverse/Rearrange (Flip-flop some section of the item or move parts around. Interchange components? Different sequence? Turn it upside-down?)

What are your design solution ideas? Write them in your design notebook.

What criteria will you use to choose a solution? Use the criteria to narrow your solution list to three solutions. Circle the three solutions above.

Meet a Design Planner

Reading: Session 7, Activity C

Bob Sweet
Senior Project Manager/Senior Design Planner
ZIBA Design

Background
I started with ZIBA Design in 1994. The new Director of Research was looking for someone with solid writing skills to crank out research reports. With a college degree in English and a fair bit of journalism experience, I soon found myself collecting data in the field, moderating focus groups, and brainstorming with designers. After a year, I left ZIBA Design for two years in Romania, where my wife had taken a job doing business development work. I returned to ZIBA Design in 1997 as a research analyst, then design planner, and project manager. Initially, I thought of myself as a creative person, let other people deal with the clients, I'll just gather information and write reports. But the more I've worked with clients, the more I've gotten to enjoy understanding their industries, how they operate and the types of problems they're trying to solve. That last bit is important; it involves much more than research or product concepts.

A Typical Day
Every day is truly different. It depends on what the workload is, who the clients are, and what stages my projects are in. In research mode, I'm out on the road interviewing an airline mechanic, spying on consumers at Target, or following a FedEx courier up and down the Sears Tower. In report mode, I'm working with a group of ZIBITES to pull together a good story for the client (report and presentation). In project management mode, I'm probably running around the office, making phone calls to vendors, generating proposals and contracts, keeping the project team together and focused on a vision, touching base with the client to exchange information, getting people the tools and materials they need to get their jobs done.

Favorite Things About the Job
I like working with very creative people who have different skills, training, and backgrounds than I do. I like working with clients from many different industries; everything from consumer goods (air fresheners, power tools, sports equipment) to services (banks and overnight package delivery). I like putting together and telling stories. That's really the heart of what we do-use research and design to tell stories about which products to make, or how they should be made.

Advice to Young People
No matter how distasteful it might seem, network like crazy. Go beyond product design and development. Learn all kinds of businesses and make good connections. All of your experiences, such as traveling, cooking, writing, biking, climbing, and fishing, will help you in product development.

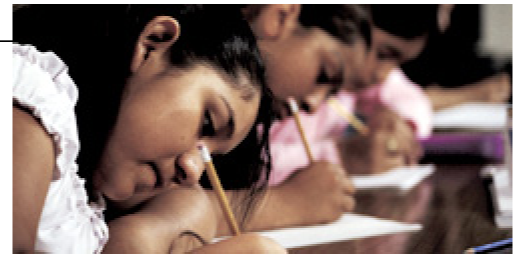
7C Reading: Meet a Design Planner (continued)

About ZIBA Design
ZIBA Design is an international design firm that has designed products from many global companies, including FedEx, Microsoft, Intel, Fujitsu, Black & Decker, Sony, Pioneer North America, Dial, and Clorox. www.ziba.com*

Session 8

A Brief Focus on Your Design Problem

Thinking Creatively



In This Session:

A) User Profile
(40 minutes)
- Student Handout
- Student Reading

B) Sample Design Brief
(30 Minutes)
- Student Handout

C) My Design Brief
(60 Minutes)
- Student Handout

D) Mentor Matching
(20 Minutes)
- Student Handout

In preparing a design brief, students refine and focus on a problem to solve from the perspective of the users' needs. They write a problem statement, a description of the context for the problem, and a proposed solution. They also draw a sketch of their idea, and come up with suitable materials for constructing a solution. To understand a design brief, they look at the design brief of a former *Design and Discovery* student.

In the first activity, *8A: User Profile*, students dig into who the users of their product will be and how they will design the product to meet the users' needs. In *8B: Sample Design Brief*, students read and discuss the parts of the design brief as a group, analyze the sample, and think about writing their own. In the third activity, *8C: My Design Brief*, students prepare their own design brief. They end the activity with a short (brief!) presentation of their problem and proposed solution. The final activity in this session, *8D: Mentor Matching*, gives students the opportunity to consider their mentor needs so that an appropriate mentor match can be made.

Supplies
None

A Brief Focus on Your Design Problem

Key Concepts: Session 8

In Session 8, students begin to formalize their ideas by developing a **design brief**. A design brief is another formal tool written by professional designers and engineers to begin to gather and describe important details about the idea, the solution, and other facts. While the design process informs the steps that students follow to develop their projects, the design brief is used to record their own ideas and guide them through the design process. In this session, students start to think about realistic aspects of their projects, such as who will be using their product. This is a perfect time to bring in mentors who assist students as they develop their projects.

Key Concepts

> **Design brief:** A written plan that identifies a problem to be solved, its criteria, and its constraints. The design brief is used to encourage thinking of all aspects of a problem before attempting a solution.

Creating a Design Brief
A design brief is the blueprint or road map for a project. Writing down ideas helps students think through the problem and their ideas for a solution. The design brief is an evolving document that can and should be changed throughout the design process. In helping students develop their design brief, it is best to encourage them to think big and not limit themselves at this stage. They should do what they can to understand the problem through observation and visualizing a solution. At this point, they may even have multiple solutions. They should not see the design brief as limiting their thinking, but rather as a place to record, track, and communicate their ideas.

Session 8 provides an example of a design brief for your use, and using it as is will be helpful and sufficient. The act of writing down ideas and plans strengthens critical thinking.

Students are introduced to a design brief in *8B Handout: Sample Design Brief*. Read an example of a design brief (listed below).

> **Sample Design Brief**
> Erika is a *Design and Discovery* student. She has played the string bass for a few years and remembers as a beginner struggling with keeping her fingers together. This is Erika's design brief.
>
> **Project Name: Bass Space**
>
> 1. **Describe the problem.** Write a statement that focuses on what's wrong and not working. Recall the features of a problem statement:
>
> - Begins with a clear, concise, well-supported statement of the problem to be overcome.

Key Concepts: Session 8 (continued)

- Includes data collected during the survey/observation in order to better illustrate the problem.
- Establishes the importance and significance of this problem.

When people start playing the string bass, most beginners cannot hold their hand correctly, preventing them from being able to play properly. As a string bass player, I have had personal experience with this and have seen other beginner string bass players also struggle with this.

2. **Describe how the current product is used.** Provide a context for the problem and explain any related solutions that resemble or relate to the problem but have failed to address the problem.

   Currently, there is not a product for this. Sometimes, a string bass teacher may tell her students to tape their fingers together.

3. **Describe a typical user (user profile).** This addresses who uses the product and how their needs are or are not met. How will they benefit from a different product?

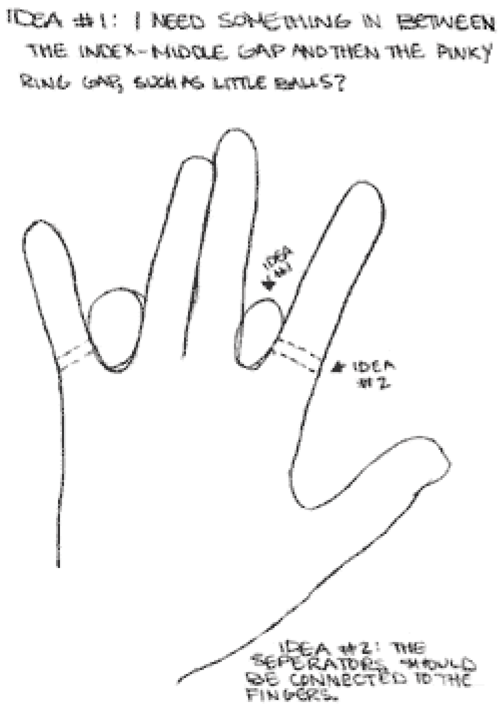
   A typical user is a beginning string bass player. They struggle with holding their hand correctly and keeping their fingers in place. They will benefit from a product that helps them keep their fingers and hands in the correct form to learn to play the string bass. They will be much more comfortable and able to practice for longer periods of time.

4. **Propose a solution.** Describe how it will work, and how it solves the problem. Explain the features.

   I'm not sure what type of material I would use, but the Bass Space would allow the player to keep her two middle fingers together and separate from her pointer finger and pinky. It would be adjustable in size depending on the size of the person's hands.

5. **Draw a quick sketch of your ideas.** This is a rough sketch and can include drawings of different angles of the solution.

Key Concepts: Session 8 (continued)



6. **Describe the basic requirements that will best suit the proposed product.** For example, this describes the quality (for example: flexible or sturdy), and the type of materials (for example: metal or plastic.)

   The material needs to be stiff yet flexible to allow hand movement, it cannot break easily, it has to be adjustable for different size hands, will need to slide on and off easily, must be low on the fingers to allow the fingers to bend, must be cost efficient, must hold hand correctly, and it must be comfortable.

User Considerations
As students develop their projects, it is important for them to remember that not all users will be like them. In the real world, design agencies develop user profiles and usability requirements by gathering information about users. There are different strategies for this—definition and observation of different kinds of users, conducting formal usability studies, or doing surveys. They will want to understand, for example, people who are most likely to use a new product and people who are hesitant to use new products. Interviews are another means to acquire user data.

Learning about users takes place through observation as well as interviews. It seems that when people are asked questions, as is typically done in market research, they may not

Key Concepts: Session 8 (continued)

answer honestly. There is a difference between what people say and what they do. Students begin to consider who might use their products. Developing a user persona helps them to keep in mind the end user throughout the design process. Encourage students to observe people using similar products to the one they are improving upon or creating and keep in mind the typical user as they develop their project.

More About Design

The resources provided below are design agencies. Reviewing these Web sites may be helpful in learning how professional companies develop products.

IDEO, www.ideo.com/*

ZIBA Design, www.ziba.com/*

ECCO Design, www.eccoid.com/*

I.D. Magazine, www.idonline.com/*

Session 8, Activity A

User Profile

Goal
Learn how to define the user of the product.

Outcome
Identify a typical user of the product in order to help focus the development of the product.

Description
Students look at a variety of familiar objects from the perspective of a typical user. They learn how to identify users of products and ultimately define their user base for their projects.

Supplies
None

Preparation
Bring in a variety of familiar objects that appeal to different ages and genders. This might include toys (for different ages), kitchen items, tools, and so forth.

Procedures

1. Show the group one of the familiar objects. Ask them:

    - Who typically uses this product?
    - What is their gender? Age? Experience with this type of product?
    - How is the product designed for this type of person (user)?
    - Where does the user use this product?
    - What motivates the user to use it?
    - Now, describe a scenario of someone using this product:

        - Give the person an identity (name, age, gender, occupation, etc.).
        - Describe the setting in which the person is using the product.
        - Explain what the person's goals are. What do they want to get out of this experience?
        - Tell how they use this product.
        - Summarize how their goals are met by this product.

2. Follow the first procedure for a few other familiar objects.

3. Ask students how this exercise can help them with their projects. Creating an identity of the user helps the experience of designing something become more concrete. Without

8A: User Profile (continued)

narrowly defining the user, a product that tries to please too many different types of people will most likely fail.

4. Now ask students to consider their own projects and who they see as the typical user. They should come up with a user scenario on their handouts.

Wrap Up
Students can share their user scenarios in small groups and get feedback from each other.

Have students read *8A Reading: Meet an Industrial Designer*.

Follow With
Activity *8B: Sample Design Brief* provides a model of how to draft a design brief.

User Profile

Handout: Session 8, Activity A

In this activity, you will have an opportunity to consider how designers and engineers design products for specific types of people. You will look at familiar objects and come up with user scenarios, and then develop a user scenario for your idea. Do this in your design notebook.

Think about your product idea. Consider the following questions:

- Who will use this product?
- What is the person's gender? Age? Experience with this type of product?
- Where will they use this product?
- Why will they use this product?
- What will they be doing to operate or use this product?

Now, using the above information, describe one person who will be the user. What are their characteristics, and the scenario in which they will use the product? You may include a drawing of the person using the product, if that helps.

What considerations will you need to keep in mind when you design the product to meet the needs of the user?

Meet an Industrial Designer

Reading: Session 8, Activity A

Dana Reinisch
Industrial Designer
ZIBA Design

Introduction
Hi, my name is Dana Reinisch and I am a 32-year-old woman who grew up all over the United States. We moved around the country a lot, and finally when I was in high school we settled in southern California. I am an Industrial Designer at ZIBA Design.

My Job
I have worked as an Industrial Designer for four years at ZIBA Design, which is a product development firm in Portland, Oregon. I have designed a wide range of products including kitchen appliances, computer printers, medical products, and watches.

Background
While growing up, I always had a strong interest in the arts (drawing, graphics, jewelry making) and the sciences. In high school, I took a lot of classes in both these areas where I excel. I have always looked at products very differently from my friends. I want to see how I can improve them functionally and aesthetically. In college, I majored in fine arts with a minor in art history and received a BA in fine arts from Lewis and Clark College. After college I applied to a product design program at Art Center College of Design in Pasadena, California. I attended school there on the campus and for a semester at their campus in Switzerland. I completed two internships and graduated with a BS in industrial design.

A Typical Day
My typical day really depends on what I am working on and where in the design process I am. Some days I am brainstorming and sketching with other designers on new product concepts. Other times I will be modeling products in 2-D and/or 3-D on the computer. I may also be sanding foam or designing a hard model to physically represent my design ideas. In designing a product, I typically work with the client and other disciplines in my company. Frequently we have design reviews at ZIBA Design with just the design team. In presenting the design to the client, I will create a presentation and story around each of the design concepts with images and word call outs.

Favorite Things About Job
Working at a design consultancy, I get to work on a wide variety of projects. I have exposure to many different companies and get to see how they work. Having worked on so many different

8A Reading: Meet an Industrial Designer (continued)

products, I also understand different manufacturing processes from sheet metal bending, injection molding to paper tube winding.

Advice to Young People
As far as advice goes, there seem to be many different routes a designer can take. You can work for a consultancy that works on many types of products for large corporations, work for a corporation designing one specific type of product, and/or design your own products. Industrial design involves a lot of hard work, good sketching and visualization skills, and having an open and creative mind.

About ZIBA Design
ZIBA Design is an international design firm that has designed products for many global companies, including FedEx, Microsoft, Intel, Fujitsu, Black & Decker, Sony, Pioneer North America, Dial, and Clorox. www.ziba.com*

Session 8, Activity B

Sample Design Brief

Goal
Learn the contents of a design brief.

Outcome
Students learn how to write their own design brief.

Description
Group review of a sample design brief for a string bass hand holder allows students to study the contents and purpose of a design brief before writing their own. Following a short introduction on what a design brief is and what it does, students read the sample design brief. A group discussion of each part of the brief assures that students understand what they will be preparing in the next activity. They have time at the end to review their notes and share their plans for the design brief with a partner.

Supplies
None

Preparation
Review *8B Handout: Sample Design Brief*.

Procedures

Design Brief

1. Introduce the activity as Step 4 in the design process, Draft a Design Brief. Explain that they will be writing a design brief after studying a sample.

2. Describe what a design brief is and what it does.

   What it is. A design brief is a short description of a design problem and a proposed solution. It describes the typical users and their needs, and states a proposed solution in terms of how it will solve the problem. A design brief includes a sketch or sketches of the solution. The design brief provides a planning tool for the project and is a living document that may be changed throughout the design process.

   What it does. The design brief is a way to clarify the problem that the designer-engineer is trying to solve. It doesn't provide a lot of detail about the solution but puts on paper the thinking and research about the problem to solve. Often the act of writing and communicating the problem and proposed solution helps the designer move along in the design process. The design brief also serves to introduce the idea to others for feedback.

3. Have students read *8B Handout: Sample Design Brief*.

8B: Sample Design Brief (continued)

4. Review and discuss each section:

    1. **Describe the problem.** This is a statement that focuses on what's wrong and not working. Recall the features of a problem statement from *7B, Research and Refine*. A problem statement:

        - Begins with a clear, concise, well-supported statement of the problem to be overcome.
        - Includes data collected during the survey/observation in order to better illustrate the problem.
        - Establishes the importance and significance of this problem.

    2. **Describe how the current product is used.** This provides a context for the problem and explains any related solutions that resemble or relate to the problem but have failed to address the problem.

    3. **Describe a typical user (user profile).** This addresses who uses the product and how their needs are or are not met. How will they benefit from a different product?

    4. **Propose a solution.** This explains how the product will work, and how it solves the problem. It describes the features.

    5. **Draw a sketch of the solution.** This is a rough sketch and can include drawings of different angles of the solution.

    6. **Describe the basic requirements that will best suit the proposed product.** This describes the quality (for example: flexible or sturdy), and the type of materials (for example: metal or plastic).

5. Provide time and direction for students to review their work from Sessions 2 and 7, thinking about their problem, the users' needs they hope to meet, and their idea(s) for a solution.

6. Have them discuss their problem with a partner or a mentor and get feedback about what they will write. They should make notes of words that help communicate their idea with their partner. They should sketch a few views of their solution.

Wrap Up
Organize students for writing rough drafts of the design brief.

Follow With
Students write and present their own design brief in *8C: My Design Brief.*

Sample Design Brief

Handout: Session 8, Activity B

A Design Brief

What it is. A design brief is a short description of a design problem and a proposed solution. It describes the typical users, the users' needs, and states a proposed solution in terms of how it will solve the problem. A design brief includes a sketch or sketches of the solution. The design brief provides a planning tool for the project. The design brief is a living document and may be changed throughout the design process.

What it does. The design brief is a way to clarify the problem that the designer-engineer is trying to solve. It doesn't provide a lot of detail about the solution but puts on paper the thinking and research about the problem to solve. Often the act of writing and communicating the problem and proposed solution helps the designer move along in the design process. The design brief also serves to introduce the idea to others for feedback.

Erika was a *Design and Discovery* student. She has played the string bass for a few years and remembers as a beginner struggling with keeping her fingers together. This is Erika's design brief.

Sample Design Brief: Bass Space (patent pending)

1. **Describe the problem.** Write a statement that focuses on what's wrong and not working. Recall the features of a problem statement:

   - Begins with a clear, concise, well-supported statement of the problem to be overcome.
   - Includes data collected during the survey/observation in order to better illustrate the problem.
   - Establishes the importance and significance of this problem.

When people start playing the string bass, most beginners cannot hold their hand correctly, preventing them from being able to play properly. As a string bass player, I have had personal experience with this and have seen other beginner string bass players also struggle with this.

2. **Describe how the current product is used.** Provide a context for the problem and explain any related solutions that resemble or relate to the problem but have failed to address the problem.

   Currently, there is not a product for this. Sometimes, a string bass teacher may tell her students to tape their fingers together.

8B Handout: Sample and Design Brief (continued)

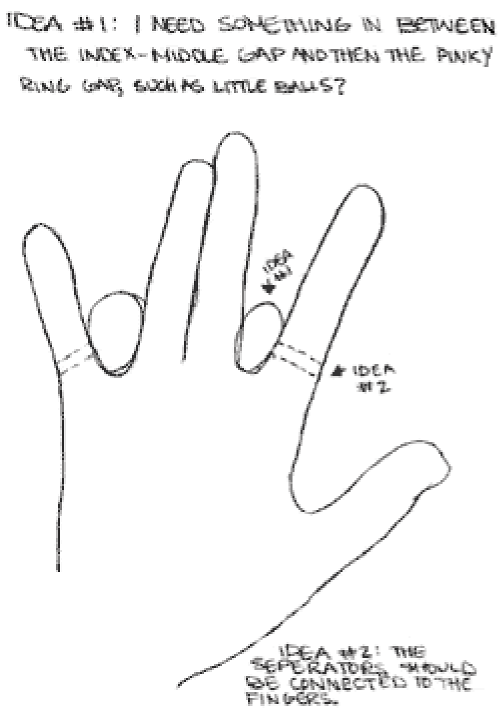
3. **Describe a typical user (user profile).** This addresses who uses the product and how their needs are or are not met. How will they benefit from a different product?

   A typical user is a beginning string bass player. They struggle with holding their hand correctly and keeping their fingers in place. They will benefit from a product that helps them keep their fingers and hands in the correct form to learn to play the string bass. They will be much more comfortable and able to practice for longer periods of time.

4. **Propose a solution.** Describe how it will work, and how it solves the problem. Explain the features.

   I'm not sure what type of material I would use, but the Bass Space would allow the player to keep her two middle fingers together and separate from her pointer finger and pinky. It would be adjustable in size depending on the size of the person's hands.

5. **Draw a quick sketch of your ideas.** This is a rough sketch and can include drawings of different angles of the solution.



6. **Describe the basic requirements that will best suit the proposed product.** For example, this describes the quality (for example: flexible or sturdy), and the type of materials (for example: metal or plastic.)

8B Handout: Sample and Design Brief (continued)

The material needs to be stiff yet flexible to allow hand movement, it cannot break easily, it has to be adjustable for different size hands, will need to slide on and off easily, must be low on the fingers to allow the fingers to bend, must be cost efficient, must hold hand correctly, and it must be comfortable.

Session 8, Activity C

My Design Brief

Goal
Refine and describe a problem to solve and a proposed solution.

Outcome
Each student introduces his or her idea by completing and presenting a design brief.

Description
Students use this time to prepare a draft of the design brief and draw rough sketches in their design journals. They write a final draft and draw sketches on the design brief handout or in their journals. Each student uses the design brief to give a short presentation about the problem and proposed idea.

Supplies
None

Preparation
None

Procedures

1. Students work on their own design briefs.

2. Allow enough time for presentations and wrap up. Announce a deadline for the final draft and sketches.

3. Students should plan a 2-minute presentation of their problem and the proposed solution.

    - State the problem and describe the needs of the user.
    - Describe the solution.

Wrap Up
Have students reflect and write about: In what ways did writing my design brief help me with a solution?

Follow With
Activity *8D: Mentor Matching* allows students to consider the help they may need with their project.

My Design Brief

Handout: Session 8, Activity C

Writing your own design brief should help you clarify your ideas and think about them systematically. This is a working document; it will be your road map as you develop your ideas. Be sure to do this in your design notebook. First give your project a name.

1. **Describe the problem.** Write a statement that focuses on what's wrong and not working. Recall the features of a problem statement:
    - Begins with a clear, concise, well-supported statement of the problem to be overcome.
    - Includes data collected during the survey/observation in order to better illustrate the problem.
    - Establishes the importance and significance of this problem.
2. **Describe how the current product is used.** Provide a context for the problem and explain any related solutions that resemble or relate to the problem but have failed to address the problem.
3. **Describe a typical user (user profile).** This addresses who uses the product and how their needs are or are not met. How will they benefit from a different product?
4. **Propose a solution:** Describe how it will work, and how it solves the problem. Explain the features.
5. **Draw a quick sketch of your ideas.** This is a rough sketch and can include drawings of different angles of the solution.
6. **Describe the basic requirements that will best suit the proposed product.** This describes the quality (for example: flexible or sturdy), and the type of materials (for example: metal or plastic).

Session 8, Activity D
Mentor Matching

Goal
To identify appropriate mentors for students.

Outcome
Students establish what type of mentor would be most helpful to them and are matched with a mentor.

Description
Because students may be doing some of their work on their individual projects outside *Design and Discovery* time, having mentors can be invaluable. This activity allows students to consider and articulate their needs so they can be matched with the most appropriate mentor.

Supplies
None

Preparation
Become familiar with the available mentors.

Procedures

1. Explain to students that you are going to try to match them with a mentor who can help them with their project since some of the work will be done on their own time.

2. Have them answer the questions on the Student Handout.

Wrap Up
Be sure to encourage students to speculate what their needs will be. Of course, their project ideas and needs may change. Be sure to review the Mentor section in *Implementation* for tips on mentor matching.

Follow With
Session 9, *A Solution Taking Shape*, gets students investigating their solution ideas.

Mentor Matching

Handout: Session 8, Activity D

To help you with the remainder of your project, you will be assigned a mentor. Please answer the following questions so you can be matched with a suitable mentor.

1. Please describe your proposed project.
2. What sort of mentor do you feel would be helpful to you?
   Describe qualifications and areas of expertise.
3. What can a mentor do to help you?

Session 9

A Solution Taking Shape

Thinking Creatively

In This Session:

A) Invitation to Invent
(45 minutes)
- Student Handout

B) Patents
(60 Minutes)
- Student Handout
- Student Reading

C) How Stuff Works
(45 Minutes)
- Student Handout

Home Improvement
- Student Handout

This session involves online research using computers with Internet access. It is ideal for each student to have his or her own computer to use during this session. If you do not have access to computers, try to arrange a visit to the local library where students can use computers. In this session, students plan out one of their design solutions by following Steps 5 and 6 of the design process.

The first activity of this session, *9A: Invitation to Invent*, exposes students to inventors and inventions throughout history, to see how others applied creative thinking to solve problems. In the second activity *9B: Patents*, students use the U.S. government's official patent Web site to dig into the world of patents, looking for products that might be similar to their idea. This helps them refine their solution. In the third activity, students visit the Web site, *HowStuffWorks*, which provides them with online tutorials about the inner workings of things.

The Home Improvement activity, *Project Analysis*, provides students with guiding questions and encourages them to talk to others about their project idea before making a final decision about their solution.

Supplies

- Computer with Internet connections
- Optional: Parts Catalogs

A Solution Taking Shape

Key Concepts: Session 9

In Session 9, students concentrate on the improvement and refinement of their design solutions by gathering information about inventors and inventions through the research of **patents**. The session concentrates on the improvement and refinement of students' design solutions by gathering information about inventors and inventions. The use of the Internet is critical in making this research process effective. As students begin to explore the development of inventions on various Web sites, they may think of new ideas that will further refine their design solutions. Key to this session is the idea that designers and inventors take many different approaches to solving problems, and the result is a wide variety of design solutions.

Key Concepts
A **patent** is granted to the inventor by a country's government, and it gives the inventor the right to make, use, and sell an invention for a set period of time. In the United States, this time period is up to 20 years from the date the patent application is filed. Patents cannot be renewed. They may be extended through a special act of Congress under certain circumstances. You can search patents at the U.S. Patent and Trademark Office www.uspto.gov* to see if an invention has already been patented by someone else.

Gaining a patent can be a costly and involved process. A patent attorney or agent is often sought out when applying for a patent, due to the complexity of the procedure. A patent application needs to be completed and submitted to the U.S. Patent and Trademark Office. A patent application consists of several parts: (1) the abstract; (2) the specification; (3) the claims; and (4) drawings. A brief abstract summarizes the invention. The specification describes the method and process of making and using the invention. Claims conclude the specification section and legally define the boundaries of patents. The claims describe any unique features of the invention that need to be protected. The final piece of the patent application is drawings which illustrate the invention.

Trademarks protect words, names, symbols, sounds, or colors that identify goods and services from those sold by others. Trademarks can be renewed indefinitely. Some trademark owners use a TM (trademark) or SM (service mark) symbol to indicate that they are claiming rights to the use of the trademark. The Nike® swoosh is a familiar trademark symbol. The ® designation is used once a trademark is registered in the U.S. Patent and Trademark Office.

Copyrights provide the right to reproduce, distribute, perform, display, or license original writing, music, and works of art. Copyright covers the expression of ideas and not the idea itself.

More Information on Patents and Inventions
Kid Primer, www.uspto.gov/go/kids/kidprimer.html*
The U.S. Patent and Trademark Office publishes a Web site for kids, and it offers a great question-and-answer section on patents, trademarks, and copyrights.

Enchanted Learning, www.enchantedlearning.com/inventors/us.shtml*
This site proudly depicts U.S. and Canadian inventors and inventions categorized by time period, type of invention (food, science/industry, medicine, etc.).

Key Concepts: Session 9 (continued)

The Great Idea Finder, www.ideafinder.com/history/of_inventions.htm*
Investigate invention facts and myths at this site.

The Lemelson Center, http://invention.smithsonian.org/home/*
This site is an exploration of the world of invention. Explore the playful side of invention with virtual exhibits and tools.

Session 9, Activity A

Invitation to Invent

Goal
To "think outside the box" for creative solutions to problems.

Outcome
Students gain insight into the creative thinking process and apply these insights to their design.

Description
Students develop the ability to think beyond the obvious by exploring invention Web sites for inspiration and ideas for their own projects.

Supplies
Computers with Internet connections

Preparation
Ideally, each student will work on his or her own computer. Students can work effectively in pairs but need to take turns at the keyboard and mouse. Another option with limited computer access is to rotate students into the computer area and provide reading and discussion activities using printed materials from the patent and invention Web sites.

If no computers are available, you may print out the suggested examples from each Web site.

Procedure
Thinking Outside the Box

1. Do a quick exercise to get kids to "think outside the box." Try this exercise: Ask students what half of 15 is. Most likely they will say 7 1/2 or 7.5.

2. Encourage them to think about it in new ways and ask again, "What is half of 15?" You may want to model an answer such as "1 and 5"; write "fifteen" on the board and erase the lower half; separate fifteen by writing "fif" and "teen"; or the Roman numerals X and V; or say "siete y media" which is "7 and 1/2" in Spanish; and so on.

3. Ask the students, "Remember back when we started how you thought there were only a couple of answers to the question 'What is half of 15?' Well, now you know, there's always another answer!"

Simple Inventions That Changed Lives

1. Students may find inspiration at the Rolex* Awards for Enterprise Web site, www.rolexawards.com/*.

2. Show them *Inventions* under *Special Features*.

9A: Invitation to Invent (continued)

3. View a couple of the examples of the simple but effective solutions to problems. Discuss the inventions and what makes them successful.

4. Emphasize that students do not need to come up with complex solutions; sometimes the simpler, the better.

Why Didn't I Think Of That?

Give students a little time to explore others' inventions and how they came to be.

1. Direct them to National Inventors Hall of Fame, www.invent.org/index.asp *.

2. Have students view a timeline of inventions, www.cbc.ca/kids/general/the-lab/history-of-invention/default.html* and look for trends in inventions. Discuss: What kinds of things were invented first? Most recently? How does history affect inventions?

Wrap Up
Discuss what they learned about execution of an invention plan.

Follow With
In the next activity, *9B: Patents*, students access the U.S. Patent Web site to identify and learn from similar design solutions to their own.

Invitation to Invent

Handout: Session 9, Activity A

Have you ever thought about who invented bubble gum and how? In this activity, you will have some time to peruse others' inventions and learn about what inspired them. Let their inventions inspire the creative thinker in you!

Simple Inventions That Changed Lives

1. Go to the Rolex* Awards for Enterprise Web site, www.rolexawards.com/*.
2. Click on *Inventions* under *Special Features*.
3. Look at a couple of the examples of the simple but effective solutions to problems.
4. What makes these inventions successful?

More Inventions

1. Go to National Inventors Hall of Fame*, www.invent.org/index.asp*.
    a. In the upper left-hand corner, move your cursor to *Hall of Fame* (in light gray print).
    b. Underneath Hall of Fame, click on *Invention Channels*.
    c. Notice that you can choose from the following categories: computer; communications, agriculture, electricity, chemistry, imaging, medical, industrial, and Nobel Prize Winners.
    d. Click on *Chemistry*.
    e. Notice that within this category there are various inventions to choose from. Click on *Kevlar*.
    f. You find that Kevlar* was invented by Stephanie Louise Kwolek. Remember her?
    g. Repeat this procedure for other categories and inventions. Check out the *Imaging* category and click on *multiplane camera*: Who was the inventor?
2. Select one invention that interests you and read about how it was invented. On the National Inventors Hall of Fame, you will need to select the *Invention Channels*, and then choose a category. Consider the following:
    a. What is the invention?
    b. Was the invention accidental or intentional?

9A Handout: Invitation to Invent (continued)

c. What problem was the inventor trying to solve?

d. Was it an adaptation of something already invented or something completely new?

e. What kinds of things did the inventor need to know about or learn about when developing the invention?

f. What was the impact of the invention?

g. What other inventions can you think of that have been adapted from this invention? How are they improvements?

3. Now view a timeline of inventions, www.cbc.ca/kids/general/the-lab/history-of-invention/default.html* and look for trends in inventions.

    a. What kinds of things were invented first?

    b. Most recently?

    c. How does history effect inventions?

Session 9, Activity B

Patents

Goal
Use research on similar design solutions to refine ideas.

Outcome
Solutions are further refined or revised after research.

Description
In this activity, students explore the U.S. Patent Web site (or choose a patent office for your country) to find and learn from patents similar to their idea.

Supplies
Computers with Internet connections

Preparation
Ideally, each student will have a computer to work on for this activity. If computers are not available, you may print out suggested examples of patents from the Web site.

Procedures
Patent Scavenger Hunt

1. Introduce patents by having students go on a short scavenger hunt around the room. Have them look at manufactured objects (furnishings, electronic devices, appliances) in the room and see if they have a manufacturer's label on them with a patent number (or the words Patent Pending.)

2. Discuss the purpose of patents. At the very basic level, according to the U.S. Patent Office, "A patent is a grant issued by the U.S. government giving inventors the right to exclude all others from making, using, or selling their inventions within the United States, its territories, and possessions." The patent system protects inventors and records new inventions.

Patent Search for an Idea or a Problem

1. A patent search can provide useful information at any point in the design process. It can be used to see if someone else has had the same idea or a similar idea and to get ideas to enhance one's design.

2. Begin by having students learn how to search the U.S. Patent and Trademark Web site, www.uspto.gov*. (Note: This site may load slowly.) For non-U.S. students, find the patent office for your country from the Worldwide Patent offices Web site, www.patentlawlinks.com/patoff.htm*.

3. Explain that students can use the patent site to search the problem that they are addressing to see what solutions others came up with for the problem, or they can

9B: Patents (continued)

search their solution to see if there are similar solutions to theirs. Show how to conduct a search.

4. First, choose a problem, such as toothpaste getting all over everything when it is used. Ask students what key words they would search with for this problem (for example, "messy" and "toothpaste"). Conduct a search, and choose a sample patent to explain the information on the patent. Now, ask how they would conduct a search for this problem by a product, for example, someone might come up with a toothpaste cap that makes less of a mess. Search "toothpaste" and "cap" and see what patents exist. Discuss how this search would help someone designing a new type of toothpaste cap.

5. Note: If you do not have computer access for all students, it is suggested that you print a few examples of patents (the first page) and the images.

Patent Search for Your Design Solutions

1. Now that students are familiar with how to do a patent search, they can conduct a search for their own design solutions. This process helps them to see if anyone else thought of an idea like theirs, and if so, how those solutions are similar to or different from their ideas.

2. To begin, they will need to come up with key words to search. Help students come up with key words for their own search.

3. Once they conduct a search and find the results, they can explore each separate patent to find out about other inventors' approaches to problems and see that there are quite a variety of engineering solutions, materials, and design ideas for the same problem!

4. As they conduct the search, they should ask themselves the following questions:

    a. How do other inventors view the nature of the problem?

    b. In looking at the various patents that are similar, are the inventors designing for the same "user"? How do the different solutions show that inventors may consider different aspects of a user's life, environment, and behaviors?

    c. What materials have other inventors used to address the problem?

    d. What do other inventors' sketches/designs look like? What are the similarities/differences in the design solutions?

    e. What components have other people used? Have they considered similar or very different components for their design solutions? Have they used the same essential components but arranged them in a different way? Do different parts of the various inventions captivate you?

9B: Patents (continued)

f. How can you recombine their ideas to improve on the solution to the original problem?

5. Students may find themselves stimulated by the ideas on the patent site. They may want to use others' ideas to improve upon their own design ideas and solutions. Encourage them to mingle their ideas and see what new and creative ideas they can come up with.

6. Students should not get discouraged if they find a patent of a similar idea to their design solution. Remind them that many patents are never made and that there are often slight differences in designs that seem similar.

Wrap Up
Students should be keeping detailed records in their design notebooks; be sure that they record any changes and additions throughout the process and date everything!

Have students read *9B Reading: Meet a Student Engineer*.

Follow With
Next, students explore *How Stuff Works* by visiting a Web site.

Patents

Handout: Session 9, Activity B

In this activity, you will become familiar with the U.S. Patent Web site (or the patent site for your country) and find inventions that are similar to your own ideas. Many times another solution can help you refine your own ideas.

Patent Search for a Problem or Idea

Go to the U.S. Patent and Trademark Web site, www.uspto.gov*.

1. We'll practice with the example of finding other solutions to the toothpaste problem. Click on *Patents*.

2. Click on *Search*, under *Patents* on the left side of the Web site.

3. Under *Issued Patent*, click on *Quick Search*.

4. Come up with key words to search. For example, in term 1, enter *toothpaste*, and in term 2 enter *cap*, and click on *Search*.

5. Your results: Notice the different patent titles that address toothpaste caps.

6. If you click on one of these, you'll find information about that patent design. Click on *images* at the bottom to see sketches of the idea. Explore each separate patent to find out about other inventors' approaches to problems and see that there are quite a variety of engineering solutions, materials, and design ideas to the same problem!

Patent Search for Your Design Solutions

1. Now that you are familiar with how to do a patent search, you can use the patent site for your own research on design solutions. This process will help you see if anyone else thought of an idea like yours, and if so, how those solutions are similar to or different from your ideas. It should also help you plan your solution. Here's how to do a search:

    a. Decide if you are going to conduct your search by the problem or solution.

    b. Come up with key words to search.

    c. Once you have some results, explore each separate patent to find out about other inventors' approaches to problems and see that there are quite a variety of engineering solutions, materials, and design ideas to the same problem!

    d. As you conduct the search, ask yourself the following questions:

        - How do other inventors view the nature of the problem?

9B Handout: Patents (continued)

- In looking at the various patents that are similar, are the inventors designing for the same "user"? How do the different solutions show that inventors may consider different aspects of a user's life, environment, and behaviors?
- What materials have other inventors used to address the problem?
- What do other inventors' sketches/designs look like? What are the similarities/differences in the design solutions?
- What components have other people used? Have they considered similar or very different components for their design solutions? Have they used the same essential components but arranged them in a different way?
- Do different parts of the various inventions captivate you? How can you recombine their ideas to improve on the solution to the original problem?

2. In your design notebook, describe any revisions on new ideas you have for your solution based on the patent site research.

Meet a Student Engineer

Reading: Session 9, Activity B

Ryan Patterson: "All Technology Should Be Assistive"
While he was still in high school, Ryan Patterson invented an electronic device to improve the lives of deaf and hearing-impaired people. His Sign Language Translator uses a golf glove equipped with wireless microprocessor circuitry to translate American Sign Language into letters that can be read on a small, portable handheld display screen, eliminating the need for a human interpreter.

Patterson says the idea came to him when he was watching a group of deaf people try to place an order at a fast-food restaurant. They needed an interpreter to translate American Sign Language so that the restaurant staff could understand them. Patterson saw an opportunity to harness technology to solve a communications challenge. "All technology should be assistive, if it's worth anything," he believes.

To make his idea work, Patterson embarked on a research and engineering project that required learning several computer programming languages and overcoming technical challenges that sometimes "felt like I was hitting a concrete wall."

It's all been worth the effort, he says. The invention earned Patterson top honors and generous college scholarships at prestigious science fairs, including the Intel International Science and Engineering Fair in 2001 and the Intel Science Talent Search in 2002. It also catapulted him into the media spotlight, including coverage in *People Magazine*, interviews with CNN, and a spot in the National Gallery for America's Young Inventors.

Currently an engineering student at the University of Colorado, Patterson continues using problem-solving strategies to solve new challenges and engineer new products. As an undergraduate, he has his own research laboratory outfitted with state-of-the-art equipment. "I feel like the luckiest person in the world," he says.

An Early Start
Patterson's interest in engineering goes way back. As a toddler, his favorite toys were extension cords and screwdrivers. By elementary school, he was asking questions about electricity that stumped his parents and teachers. A teacher recruited John McConnell, a retired particle physicist, to mentor the inquisitive young student. For the next seven years, the two spent nearly every Saturday working together in the mentor's workshop on projects that involved electronics and other technical fields.

For Patterson, those early experiences "helped me get a foundation in science." His mentor introduced him to technical concepts through hands-on activities, such as building robots and

9B Reading: Meet a Student Engineer (continued)

wiring electronic circuitry. McConnell was also modeling what it means to be a scientist, engaged in the process of asking questions and seeking answers.

By high school, Patterson was ready to work independently on his own research projects. His mentor was still there as a sounding board and supporter. For example, Patterson faced a host of technical challenges in making his glove device work. His mentor "taught me what a scientist does when he gets stuck: He researches, reads books, and consults experts. John taught me I could email experts, like the people who make chips or circuit boards, and ask them my technical questions. I went through the same cycle that a professional engineer would do."

One quality came instinctively, says the mentor. "Ryan has the tenacity to dig and dig and dig." McConnell says he could see that drive in the student the first time they met. "You could see he had that focus, that intensity. I said to myself, 'Wow! This kid is extraordinary.' I realized I had to do something to encourage him."

Value of Patience

As he has pursued college studies in engineering, Patterson has also come to appreciate the importance of patience. "It can take years of development before an idea is available for people to use," he says.

For now, work on his Sign Language Translator is on hold while Patterson tackles other problems. A current research project involves using a handheld device to assist persons with cognitive disabilities, such as brain damage, function more easily in daily life. "This could lead to an assistive technology that helps a person understand where he is, instead of having to rely on a caregiver," he explains.

What keeps Patterson motivated, whether he's studying for a tough engineering class or working on his next invention? "You do it for the love of it," he says simply. "Once you get a past a challenge, your confidence grows. It's just like being a mountain climber. Why do they keep at it? It's the same kind of thing for me."

Session 9, Activity C

How Stuff Works

Goal
Begin planning the development of the design project.

Outcome
Develop an initial idea of how to proceed on the design project.

Description
Students should now have their design solutions narrowed and begin thinking about how they are going to create their product. This activity will help them to begin to think about the systems, subsystems, parts, and components of their design. Using the Web site, *HowStuffWorks*, students learn about the parts and components of things. In an extension activity, they also examine parts catalogs that they might need.

Supplies

- Computers with Internet connections
- Optional: Parts catalogs

Preparation
None

Procedures
Sample Search on *HowStuffWorks*

1. Introduce junior engineers to *HowStuffWorks**, www.howstuffworks.com*. Explain that this Web site can help them understand how to make their idea happen, to get from "think" to "thing".

2. Walk them through an example of a mechanical toy using directions on their handout.

Your Own Search on *HowStuffWorks*

1. Students should now see that their pursuit of knowledge can be endless. Or, they can read what they need to know about torque or gears and get back to their own designs!

2. Before conducting a search, students should ask themselves the following questions:

    - What is my design similar to?
    - What are the different parts of my design?

9C: How Stuff Works (continued)

3. To conduct a search that will help them with their own designs, they can do the following:

    - If it is an adaptation to an existing product, search for the product. Learn about how the product is made, including the systems, components, and materials.
    - Search for a similar product and see how that is made.
    - If they are planning to make a change to a particular part of a product, search for the part (such as gears in the example) to learn more about that part.

4. Instruct them to search the site to learn more about how they might go about developing their design.

Optional Extension: Parts

1. Bring in some parts catalogs.

2. Have the students spend some time looking through the catalogs and identifying what parts are available for their designs. They can begin to generate a list of materials for their project.

Wrap Up
In small groups, students can share their ideas for design solutions and get feedback from one another. They should revisit their design brief and make notes and any changes necessary.

Introduce the Home Improvement activity, *Project Analysis*, where students carefully examine their solution ideas.

Follow With
In Session 10, *Bicycle Breakdown: Systems, Components, and Parts*, students learn more about parts and components as they meddle with bicycles.

How Stuff Works

Handout: Session 9, Activity C

In this activity, you will begin to plan the development process of your design. The Web site, *HowStuffWorks**, can help you learn about how things are made.

Sample Search on *HowStuffWorks*

1. Go to http://www.howstuffworks.com*.
2. Go directly to the left side of the page where it says Explore Stuff.
3. Let's say you want to build a mechanical toy, and that the toy will need wheels and gears, but at this point you know little about them.
4. Type *gear* into the *Search* field.
5. Notice that *HowStuffWorks* gives you results from the Web and from *HowStuffWorks*. For this activity, we will use results from *HowStuffWorks*.
6. At the bottom of the page, click on *Next*... and keep clicking on *Next*. You have a lot of results!
7. Perhaps you should narrow your search. But before you do, look through some of the results; the perfect link may be right on the first page, as the best matches to your search term are listed first. Even on the first page, you have quite a choice: *How Bicycles Work; How Gears Work; How Gear Ratios Work...*
8. Click on *How Gears Work*.
9. Notice the terms *gear reduction*, *power*, and *torque* link to more information. The amazing thing about the *HowStuffWorks* Web site is that you can delve as deeply as you wish into a subject area. Before you click on the next link, however, go to the end of this article and notice the *Table of Contents* area. You can click on a link related to *How Gears Work* and investigate the *Basics; Spur Gears, Helical Gears, Bevel Gears...*
10. Go back and click on *torque*.
11. What do you find here? Everything you may have wanted to know about torque, complete with illustrations. But if not, go to the end of the article and see the links.

Your Own Search on *HowStuffWorks*

1. Before conducting a search, ask yourself the following questions:
   - What is my design similar to?
   - What are the different systems or components of my design?

9C Handout: How Stuff Works (continued)

2. To conduct a search that will help you with your own design, do the following:

    - If it is an adaptation to an existing product, search for the product. Learn about how the product is made: the systems, components, and materials.
    - Search for a similar product and see how that is made.
    - If you are planning to make a change to a particular part of a product, search for the part (such as gears in the example) to learn more about that part.

3. Search the site to learn more about how you might go about developing your design.

4. Remember to take good notes in your design notebooks. Record keeping is very important in this process!

Project Analysis

Home Improvement: Session 9

Goal
To carefully examine solution ideas.

Description
Students review their solution and consider the feasibility from different angles such as safety, cost, and durability. They get feedback from other people about their solution.

Before Going Home
Tell students that they need to carefully examine their solution before proceeding to the next steps. They should be sure that their solution is feasible. It is not too late to revisit the other problems and/or solutions from the earlier sessions if they come across stumbling blocks. Encourage them to talk to as many people as possible about their idea. They will need to do testing throughout their project development to ensure that their project is safe, durable, and works the way they want it to.

Next Day
Students should be prepared to check in with the leader before moving ahead.

Project Analysis

Handout: Session 9, Home Improvement

Now that you have narrowed your design solution, you are ready for the second part of Step 5 of the design process: Refine Your Solution. Analyze the solution for cost, safety, and practicality. Give your design project more thought and answer the following questions about your design solution. You will need to do testing throughout your project development to ensure that your project is safe, durable, and works the way you want it to. Respond to the following questions in your design notebook.

1. Is my idea practical? If so, how?
2. Can it be made easily? How?
3. Is it as simple as possible? Explain.
4. Is it safe? How?
5. Is my product durable? Will it withstand use, or will it break easily? Explain.
6. Will it cost too much to make or use? Explain.
7. Is my idea really new? Explain.
8. Is my idea similar to something else? Explain.
9. Will people really use my product? How?

Now, survey your friends and family using these same questions and see what they think about your idea.

Design and Discovery

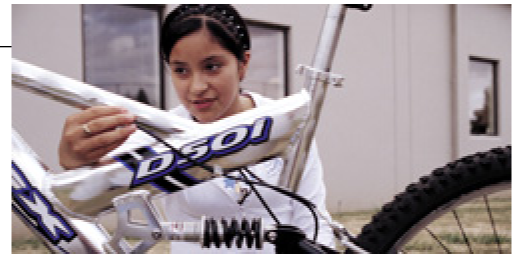
Making, Modeling, and Materializing

These sessions prepare students for making a model of their design idea. In *Session 10: Bicycle Breakdown: Systems, Components, and Parts*, the bicycle is used as an example for helping students think about the systems in a product and how to identify the systems, components, and parts of their own project ideas. In *Session 11: Design Requirements and Drawings*, students develop design requirements for their projects and draw their ideas in order to help them plan their models. *Session 12: Planning for Models and Tests*, further prepares students for building their models as they think through materials and consider the principles of collapsibility. *Session 13: Making It! Models, Trials, and Tests* is a model-making working session.

Session 10

Bicycle Breakdown: Systems, Components and Parts

Making, Modeling, and Materializing



In This Session:

A) Systems and Synergy (50 minutes)
- Student Handout
- Student Reading

B) Sum of the Parts (100 Minutes)
- Student Handout

This session uses the mechanisms of a bicycle to help students think about the systems in a product that must be designed. It offers student engineers a strategy for tackling a complex solution that they might have in mind. It provides practice with breaking big ideas into manageable, designable parts by identifying systems and/or components that need design and engineering. This session requires either a field trip to a bike shop or assistance from adult bicycle enthusiasts among the leaders, parents, mentors, or other volunteers. If a field trip is not possible, then you will need to have students bring in bicycles for demonstration and study.

In the first activity, *10A: Systems and Synergy*, students learn the difference between systems, components, and parts as they identify them on a bicycle. The second activity, *10B: Sum of the Parts*, involves a field trip to a bike store or a demonstration on a bicycle's systems, components, and parts.

Supplies

- 8-10 bicycles and tricycles of different kinds, shapes, and sizes (brought by the students and mentors)
- Additional specialty bicycles (recumbent, folding or collapsible, track and racing bikes, BMX freestyle, fat tire coaster bikes)
- Bike repair stands (to raise and support bikes off the floor for study)
- Bicycle parts, 1 or 2 examples of each system or a few parts in each system:
    1. Drive systems: pedals, cranksets (crank and chainwheel), chains, axles, wheels
    2. Steering system: handlebars, front wheel, headset bearings
    3. Brake systems: brake levers, cables, and calipers (attached as a system)

Session 10, Bicycle Breakdown: Systems, Components, and Parts (continued)

4. Structural system parts:
    - Frames: without any components attached—any size, style
    - Wheels: different sizes and designs (some missing spokes or out of true is fine)
    - Handlebars: downswept and straight
    - Seats (or saddles): different shapes and designs

- Markers (highlighters) of different colors
- Old rags or paper towels for wiping grease and dirt off hands and bikes
- Optional: Erector* set (toy construction set)

Bicycle Breakdown: Systems Components and Parts

Key Concepts: Session 10

Students begin planning the development of their design solutions by first looking at how designed objects can be broken down into **systems**, **components**, and **parts**. In Session 10, students look at a familiar object—the bicycle—in order to understand how this process happens. Students get hands-on experience with bicycle systems either by visiting a bike shop or by bringing experts in to demonstrate the systems.

Key Concepts
Designed things can be deceiving. At first glance, they can appear functional and seem so simple to use. But being simple to use does not necessarily mean something is easy to engineer. An important skill is the ability to analyze, to break a design solution into the smaller systems, subsystems, components, and parts that work together to make a functioning product. A valuable design step is having students look at devices as systems and start asking and answering questions—What are the subsystems that make up the my design? What kinds of components and parts will I need to design to build the system as a whole?

Systems are important to engineering and design. They make the design and production processes much easier. Imagine if you had to design a Boeing 777 airplane, a huge and complex task. However, the task becomes more manageable if the Boeing 777 system is divided into subsystems and then further into components and parts. One team might be assigned to design the wing system, another team of engineers designs the landing gear system, another team designs the fuselage system, and so on.

A mechanical system is made up of subsystems, components, and parts that connect to perform a function. Help your students understand these terms:

> **System:** A group of related subsystems or components that form a whole functioning device.
> **Subsystem:** A system of components and parts that is part of a larger system.
> **Component:** A group of parts that work together that perform a specific function in a system or subsystem.
> **Part:** The smallest piece of a design.

In the case of mechanical systems, the boundaries between a system, subsystem, component, and part are relative and are determined by the complexity of the starting system. Think about using the brakes on a bike—the braking *subsystem* of the bicycle *system*. There are several components (each with *parts*) that make up the brake subsystem. On most bikes today, you stop by grasping brake levers. The lever is a component that has parts to attach to the frame and other parts that connect to cables that move as you pull. As cables are pulled, the brake arm component has parts that squeeze together on brake shoe parts that grip on the wheel and slow it down.

In the case of a simpler device, a flip-top toothpaste cap, the system could be the toothpaste dispenser. A subsystem is the cap. There is no real separation between the final part or component, the hinged cap.

Key Concepts: Session 10 (continued)

More About Systems
The American Association of the Advancement of Science states the following science literacy benchmarks in its Project 2061 (www.project2061.org/tools/benchol/ch11/ch11.htm*): "By the end of the 8th grade, eighth grade, students should know that

- "A system can include processes as well as things.
- "Thinking about things as systems means looking for how every part relates to others.
- "Any system is usually connected to other systems, both internally and externally. Thus a system may be thought of as containing subsystems and as being a subsystem of a larger system."

Exploratorium Science of Cycling, www.exploratorium.edu/cycling/index.html*
At this site, explore the wheel, drivers and gears, frames and materials, braking and steering, aerodynamics, and human power.

Session 10, Activity A

Systems and Synergy

Goal
Learn about analyzing a complex product for its designed systems and components.

Outcome
Students understand the difference between systems, components, parts, and connections that make up designed products.

Description
Following a warm-up activity about what the students already know about bicycles, students discuss a short reading about bicycles and compare the systems, components, and parts of a bicycle to other "wholes."

Supplies
Markers (highlighters) of different colors

Preparation

1. In advance, send home information or announce that students should bring or ride bicycles to this session—one bike for every two to four students will work. Let them know that you are interested in a variety of bikes: all sizes, types, state of repair, etc. Ask for or send home information requesting help to locate bike enthusiasts to help out with this session. Ask for any parts on the materials list.

2. Get familiar with bicycles, the history of their development, and how they work:

   - The Exploratorium: www.exploratorium.edu/cycling/index.html*
   - HowStuffWorks: www.howstuffworks.com/bicycle.htm*
   - The Pedaling History Museum: www.pedalinghistory.com*

Procedures
Debrief Home Improvement

1. Check in with student's progress on the Home Improvement for Session 9, *Project Analysis*.

2. Discuss how students will test their projects. Have them share their ideas with the group.

10A: Systems and Synergy (continued)

Bicycle Brainstorm

1. Warm up with a 15-minute discussion to collect what the group knows about bicycles in two areas. Write questions on flip chart paper or the board and add responses:

    - What do we know about what bicycles do?
    - What do we know about bicycle parts?
    - What do we know about what makes bicycles work?

2. Conduct this as a brainstorm—anything that anyone knows is fair game. The goal is to get students thinking about bicycles. Save the responses for the wrap up to the next activity, *10B: Sum Of the Parts*.

Systems, Components, and Parts

1. Introduce the purpose of the activity: To analyze a designed product and separate it into systems and components, and practice with a strategy for breaking complex solutions into manageable, designable parts by identifying systems and/or components that need design and engineering.

2. Have students read *10A Reading: What's a System?* Take turns reading aloud. Discuss and share understanding about the difference between systems, components, and parts in other contexts:

    - Analyze systems in another means of transportation such as a car or boat.
    - Analyze systems in a different context: For example, a house and the systems it has, such as plumbing or heating. Try analyzing a non-mechanical context such the body and its systems (skeletal, circulatory, and digestive systems).

Bicycle Systems, Components, and Parts

1. Using the chart on the handout and any bicycle systems, components, and parts that you have, explain the chart.

2. Once they have an understanding for systems, components, and parts, students should color code the systems of the bicycle on their handout.

Wrap Up
Call students' attention to the definition of synergy at the top of the reading. Ask them: What does this mean in relation to a bicycle? In relation to a design team?

Follow With
The activity *10B: Sum Of the Parts* gives students a hands-on exploration and study of four bicycle systems.

Systems and Synergy

Handout: Session 10, Activity A

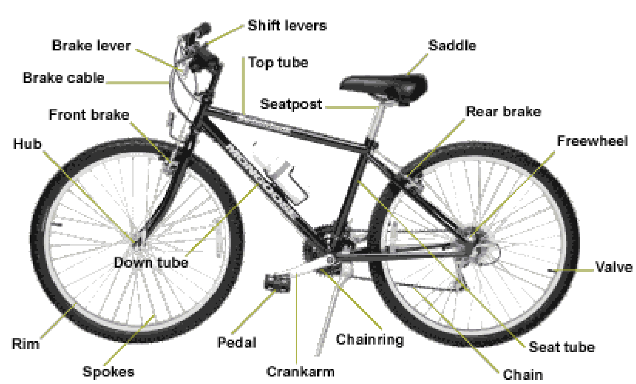
Sample Title

The bicycle can be organized into four major systems (see table below). Sometimes a bigger system is made up of smaller systems, or subsystems. Systems can also share the same components. For example, every system listed below makes use of the wheels.

A bicycle has four major systems:

Major System	Purpose	Example Components
1. Drive System	Power you along efficiently under your own steam	Pedals, chain, gears, wheels, transmission subsystem
a. Transmission Subsystem	Shift gears and allow you to adjust for changes in terrain	Gear shifter, cables, derailleur, derailleur gears, hub gears
2. Braking System	Make the bicycle stop reliably at a moment's notice	Wheels, caliper brake subsystem, or coaster brake subsystem
a. Caliper Brake Subsystem	Apply pressure to rim of tire	Brake lever, cables, caliper arms, brake pads
3. Steering System	Turn the bicycle	Handlebars, stem, wheels, frame system
4. Structural System	Support and connect you and the other systems together during operation	Frame, handlebars, wheels, suspension subsystem
a. Suspension Subsystem	Allow wheels to move up and down to absorb bumps in a road	Shock absorber with spring and damper parts

Using the diagram below, highlight the different systems. Each system should be one color—include a color key.



What's a System?

Reading: Session 10, Activity A

System: A group of related subsystems or components that form a whole functioning device.

Synergy: The combined power of a group of things when they are working together which is greater than the total power achieved by each working separately.

Important problems often have very simple solutions. But what is simple? A solution may be very elegant and seem obvious until you start to examine how to make it. Designed things can be deceiving. At first glance, they are so functional and seem so simple to use. But being simple to use does not necessarily mean it is easy to engineer. A very important skill is the ability to analyze, to break down your design solution into the smaller systems and components that work together to make a functioning product. It will help you to think about systems within your product as you design and create a prototype.

Systems are very important to engineering and design. They make the design process much easier. Imagine if you had to design a Boeing 777 airplane, a huge and complex task. However, the task becomes more manageable if you were on a team to design the wing system, another team of engineers designs the landing gear system, another team designs the fuselage system, etc.

Are Bicycles Simple?
Bicycles are everywhere; they are so familiar you almost take them for granted, right? Most of us have ridden bicycles or tricycles. It's pretty easy to think about different things you expect a bicycle to do. Take a minute to analyze how you use a bicycle: You sit on it comfortably, make it go, you make it stop, you make it go fast on flat places, and you make it go up steep hills. In many ways bikes seem so simple. Yet each of these things that you expect a bicycle to do requires a different system. Each system has essential components, and each component may be made of several parts.

What Makes a System?
A mechanical system is made up of components and parts that connect to perform a function. Think about using the brakes on a bike. There are several components (each with parts) that make up the brake system. On most bikes today, you stop by grasping brake levers that have parts to attach the levers to the frame and other parts that connect them to cables that move as you pull. As cables are pulled, brake arms squeeze together on brake shoes that grip on the wheel and slow it down.

Session 10, Activity B

Sum of the Parts

Goal
Learn about the mechanisms of four bicycle systems: Study the components, the parts, and connections for each.

Outcome
Students identify and distinguish systems (drive, braking, steering, and structural) and components (frame, wheels, and seats) in a bike.

Description
During a field trip to a bike shop or on-site with students' own bikes and loaned parts, students study four systems on a bicycle: power, braking, steering, and structural. They isolate and observe the operation of each system. They also study examples of individual components and parts removed from the bicycle in a rotation through "study stations" organized around the four systems.

Supplies

- 8-10 bicycles and tricycles of different kinds, shapes, and sizes (brought by the students and mentors)
- Additional specialty bicycles (recumbent, folding or collapsible, track and racing bikes, BMX freestyle, fat tire coaster bikes)
- Bike repair stands (to raise and support bikes off the floor for study)
- Bicycle parts, 1 or 2 examples of each system or a few parts in each system:

    1. Drive systems: pedals, cranksets (crank and chainwheel), chains, axles, wheels
    2. Steering system: handlebars, front wheel, headset bearings
    3. Brake systems: brake levers, cables, and calipers (attached as a system)
    4. Structural system parts:
        - Frames: without any components attached—any size, style
        - Wheels: different sizes and designs (some missing spokes or out of true is fine)
        - Handlebars: downswept and straight
        - Seats (or saddles): different shapes and designs

- Old rags or paper towels for wiping grease and dirt off hands and bikes
- Optional: Erector* set (toy construction set)

10B: Sum of the Parts (continued)

Preparation

1. Set up an outside location where the bike study will take place.

2. Gather all bike materials. Arrange for four facilitators to lead bicycle systems "study stations" among the bicycle enthusiasts who are willing to help (parents, mentors, leaders).

3. Send guest facilitators copies of the session materials. Have them be prepared to facilitate a short hands-on demonstration/experience of the components and parts for the system at their "study station" of a system: drive, braking, steering, and structural systems.

4. Organize placement of bikes and parts for hands-on study of systems, components, and parts. Set up workspace for:

    - Bike systems study: teams of two to three students to study four systems on one bike
    - Components and parts study: "study stations" of components and parts grouped by each of the four systems
    - Specialty bicycle study: recumbent, racing or track, folding, coaster, BMX, and unicycle

Optional: Bike Shop Field Trip
As an option to having students bring bicycles, it may be easier to arrange a field trip to a bicycle shop where students can study bike systems, components, and parts as outlined in the procedures. If this is possible, be sure to familiarize the bike shop manager with the purpose of the field trip. Meet together and plan the experience ahead of time together.

Procedures
Examining Bicycles

1. Have students read the handout and get organized for studying the bicycles.

2. Divide students into teams to examine and observe the mechanisms (components, parts, and connections) for four systems on the available bicycles. If bicycle stands are not available, demonstrate how to turn the bike over and with one person supporting it so that the wheels turn freely during the observations. Or, with smaller bikes demonstrate how to be a human bike stand: Hold the rear tire off the ground by straddling the rear tire and raising the bike with the seat. Hold on firmly.

3. Rotate teams to each study station to examine and operate components and parts. Have students jot down notes about how parts connect and work together in each system. Their notes may be sketches.

10B: Sum of the Parts (continued)

4. In a whole group, have a rider demonstrate each specialty bike. Have students identify each of the systems.

Optional: Erector Set Vehicles
In the classroom, students can use Erector sets for hands-on construction and application of systems. Ask students to build model vehicles (cars, scooter, bicycles, and so forth) to demonstrate their understanding of systems

Wrap Up
Return to the classroom and revisit the three lists that were generated during the *10A: Systems and Synergy* activity. Ask, what do we know about what bicycles do? What do we know about bicycle parts? What do we know about what makes bicycles work?

Ask students to share or write about new understanding of bicycles as a result of studying its systems, components, and parts.

Discuss what do you know about bicycles now?

Take a bike ride!

Follow With
In Session 11, *Design Requirements and Drawings*, students develop design requirements and technical drawings for their design and engineering project.

Sum of the Parts

Handout: Session 10, Activity B

Chances are you have had some experience with bicycle mechanisms. Perhaps you've had to fix or adjust something on a bicycle or have watched while someone else did quick maintenance during a ride. Have you ever really looked at a bike and studied how it works? A bicycle has a set of mechanical systems that are familiar and easy to observe.

Directions
Study four systems on your bicycle. You'll also be able to observe and operate the components and parts of each system that are removed from a bike. This will give you another way to observe how things connect and work together.

Systems Study

1. Drive system: Support the bike with the rear wheel off the ground (turn the bike on its side, use a stand, or have a partner hold the bike up.) Slowly power the bike using the pedals and study how the energy you add transfers through the drive system to the wheels. Switch partners.
2. Braking system: Study how the brakes work as you press and release the brake lever. Trace the operation of the brakes through components and their parts. Notice the connections.
3. Steering system: Study how you steer a bike. Trace the steering through the handlebar to the wheels. Notice the connections.
4. Structural system: Study the frame and how all the systems connect to it.

Components and Parts Study
Observe and take notes about how parts connect and work together in each of the systems. Which systems seem simple and require few parts? Which systems seem complex and require more parts and complicated connections? Which systems seem easy to break down? Which systems seem easy to repair? Your notes may consist of words or sketches.

Drive system:

Braking system:

Steering system:

Structural system:

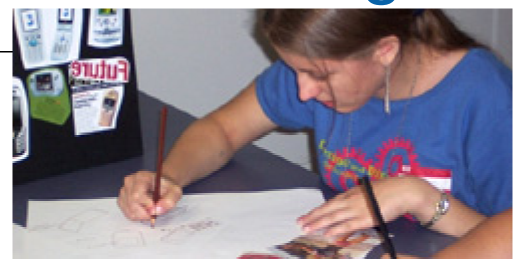
Specialty bikes: Identify and study the four systems in each of the specialty bikes. Compare them to the systems in the more traditional bicycle. What did you observe?

Optional: Using an Erector* set for parts, make your own model vehicle. Try to incorporate the four systems you studied: structural, drive, steering, and braking.

Session 11

Design Requirements and Drawings

Making, Modeling, and Materializing



In This Session:

A) Checking in on the Design Process (45 minutes)
- Student Handout

B) The Perfect Fit: Meeting Needs Through Design (45 Minutes)
- Student Handout
- Student Reading

C) Conceptual Drawing: Thinking on Paper (60 Minutes)
- Student Handout
- Student Reading

In this session, students refine their design efforts with product requirements and drawings. In *11A: Checking in on the Design Process*, they look at a checklist of steps that follow the design process to determine how far they've come, and look ahead to the next steps. Next, in activity *11B: The Perfect Fit: Meeting Needs Through Design*, students learn how a designer considers the needs of the user to define minimum requirements for a design, and students then develop design requirements for their own projects. In a third activity, *11C: Conceptual Drawing: Thinking on Paper*, students learn how drawing helps the thinking process, then put pen to paper to make a series of conceptual drawings. By the end of the session, students have a more fully developed project and are ready for the next steps, modeling and testing their ideas.

Supplies

- Pencils and pens, rulers, graph paper (if not in design notebooks)

Design Requirements and Drawings

Key Concepts: Session 11

Session 11 aids students in furthering their design plans by helping them to come up with **design requirements** for their project and by providing instruction for translating their ideas into **drawings**. The session helps students develop a better understanding of the visual aspects of the project as they make detailed drawings of their projects to communicate needs and to help refine the project.

Key Concepts
A key component of the design process is the making of sketches and diagrams to go along with the project. In fact, many products have come about because of "napkin drafting," a more crude and simplistic way to communicate ideas. Encourage students to doodle, sketch, and make diagrams before the actual construction occurs. This session concentrates on using elements of mechanical drawing to show the students how the visualization of a project can help to refine the needs of the design.

Although mechanical drawing is commonly carried out by computers now, especially in the revision stage of design, drawings are still the most widely used communication tool in the engineering community. The primary reason for this is because drawings often serve as documentation of requirements. Drawings are used to produce quotes, determine manufacturing methods or processes, and inspect parts to ensure they meet the requirements defined within the drawings. Making a readable drawing is key to assuring that design team members can look at it and understand what's required.

Drawing the design of the project is an important step in refining the project and identifying some issues with the design. It is a good idea to stress to the students that if they change something in the design to get around an issue, they should write out what the issue was and why they changed it. Remind the students that in three months, they might not remember why they made that change and might try to change it back.

Drawing Methods
This session serves as an introduction to basic drawing techniques. It begins with students learning to draw lines and circles using graph paper. Students should come to understand that showing their project from all angles and with component parts will help them to identify potential problems and to refine the project without having to build it first. It is useful to have a basic understanding of the different types of sketches.

Orthographic sketches show a three-dimensional object in two dimensions by displaying the front, top, and side view. When drawn, each view is evenly in line with each other. The front view is located at the bottom left. The top view is directly above the front view. The side view is directly to the right of the front view.

Other types of sketches include (not addressed in the session) include: isometric, oblique, and perspective. An **isometric sketch** is a three-dimensional drawing in which the horizontal axes form a 30-degree angle with the true horizontal line. An **oblique sketch** is a pictorial drawing in which the front view of an object is shown as true size and shape. The top and side view is at a

Key Concepts: Session 11 (continued)

30-degree angle. A **perspective sketch** is a pictorial drawing in which lines move "away" from the view and converge.

More About Conceptual Drawing

Lo, Jack. *The Patent Drawing Book*. Berkeley, CA: Nolo Press, 1997.

Walker, J. R. *Exploring Drafting*. Tinley Park, IL: Goodheart-Wilcox, 1996.

Session 11, Activity A

Checking in on the Design Process

Goal
Understand the design project timeline.

Outcome
Students know where they are and what comes next on their design project.

Description
Students review a checklist for their design project and look ahead to what they will be doing. It is not a direct and linear progression through the series of steps. The steps may be repeated, and there may be small cycles between some of the steps. While they see that checklist steps follow the design process, students also discuss the non-linear nature of design.

Supplies
None

Preparation
None

Procedures

1. Introduce the session by asking students to think about where they are with their project—closer to the beginning, or to the end? Somewhere near the middle? How can they tell? Introduce the checklist handout as an organizer for the work they have done and will be doing in order to complete the design project—a refined working prototype.

2. Discuss the steps in the checklist and point out that while the checklist follows the design process, the design process is not linear with one step always following another. Some steps are revisited time and again; others cause the designer to change direction. The process changes as the designer's ideas change.

3. Review the schedule. Discuss goals and work time available in and out of class time.

4. Allow time for students to review their progress, complete the checklist, and discuss any questions that come up.

Wrap Up
Discuss any questions about the design process and review expectations for the project work ahead.

Follow With
In *11B: The Perfect Fit: Meeting Needs Through Design*, students define design requirements for their project that focus on the needs of the user.

Checking in on the Design Process

Handout: Session 11, Activity A

The Design Process: Getting From "Think" To "Thing"
The checklist below is adapted from the design process steps. This is a tool to keep you organized and thinking about where you have been and where you want to go.

1. Identify a design opportunity. (Session 7)

- ☐ Identified many design opportunities (needs, problems, or cool things to design).
- ☐ Narrowed the list of opportunities to three for further research.

2. Research the design opportunity. (Session 7)

- ☐ Refined my design opportunities with interviews and other data-gathering research.
- ☐ Selected one design opportunity to address.
- ☐ Wrote a problem statement to clarify and explain to anyone what I will solve with a design solution.

3. Brainstorm possible solutions to the problem. (Session 7)

- ☐ Expanded my possible solutions using SCAMPER and other research.
- ☐ Evaluated my solutions using criteria that we determined.
- ☐ Narrowed my solutions to three possibilities.
- ☐ Began thinking about the types of materials I could use for my solutions.

4. Draft a Design brief. (Session 8)

- ☐ Wrote a design brief with a problem statement, a description of user needs, a proposed solution, and a sketch of the solution.

5. Research and refine your solution. (Session 9)

- ☐ Researched and refined my proposed solution using the U.S. Patent Office Web site and other resources.
- ☐ Took notes and wrote down information from my research.
- ☐ Interviewed experts and possible users to analyze my project for feasibility, safety, and other implications of my solution.
- ☐ Researched materials and methods that would be appropriate for constructing my project.
- ☐ Conducted a project analysis to consider any changes to my solution.

11A Handout: Checking in on the Design Process (continued)

6. Prepare design requirements and conceptual drawings. (Session 11)

- ☐ Developed design requirements that focused on the needs of the user.
- ☐ Completed conceptual drawings.

7. Build models and component parts. (Sessions 12, 13, and 14)

- ☐ Analyzed my project design for its systems, components, and parts.
- ☐ Planned models to build and what each model would test or be able to demonstrate.
- ☐ Built a model or models of components of my design.
- ☐ Developed a project plan for completing my design.

8. Build the solution prototype. (Session 15)

- ☐ Conducted further research, model building, and testing, as needed to complete a working prototype.
- ☐ Developed specifications.
- ☐ Completed first working prototype.
- ☐ Analyzed prototype for functional improvements.

9. Test, evaluate, and revise your solution. (Session 16)

- ☐ Prioritized improvements needed and built new or revised prototype to meet priorities.
- ☐ Evaluated prototype for function, feasibility, safety, aesthetics, and other criteria.

10. Communicate the solution (Session 18)

- ☐ Presented my solution to an audience.
- ☐ Gathered feedback and made appropriate changes to prototype.

Session 11, Activity B

The Perfect Fit: Meeting Needs Through Design

Goal
Fine-tune a project design by taking a closer look at the needs of the user.

Outcome
Students fine-tune their project design by producing parallel lists of user needs and the project design requirements that address those needs.

Description
The activity starts with an example of a product—the Terry* bicycle—that was improved when the needs of the user were given a closer look. Students look at the design innovations that improved this product and the user needs that prompted the improvements. Next, students consider the needs of their intended users and write design requirements for their own projects.

Supplies

- Print pictures of the Terry bicycle from www.terrybicycles.com/index.html*.

Preparation
None

Procedures
A Look at Design Requirements: The Terry Bicycle, www.terrybicycles.com/index.html*.

1. On *11B Reading: The Perfect Fit: Meeting Needs Through Design*, read together the story of Georgina Terry, a bike racer who saw that there was no production of women-specific bikes and started her own company to produce bikes for women. Ask: Given the woman bicyclist's physical needs, what design features should be considered in making a better bike for her? List these user features on the board one at a time.

User Needs	**Design Requirements**
Shorter arms and torso	Shorten the distance from the handlebars to the seat (the cockpit length) by making the top tube length shorter.
Smaller hands	Shorten reach to brake levers.
Narrower shoulders	Make narrower handlebars.
Shorter legs	Shorten crank arms for more efficient spin.

11B: The Perfect Fit: Meeting Needs Through Design (continued)

2. Explain: Many everyday bikes have a good deal of adjustability. The seat can be moved forward, the brake lever reach adjusted, and the seat stem raised. Higher performance road bikes are another problem. The big difference is when a bike is sized more compactly for women, a new problem arises. The tight geometry of the racing bike doesn't work with regular racing wheels; you run into toe-wheel overlap, where the tips of your shoes hit the front wheel when turning and pedaling at the same time. This was the biggest problem Terry took on in her new design.

3. Discuss how she might have solved this problem. Then explain that she solved the problem by designing a new, smaller front wheel, allowing the bike to have the same geometry with the smaller frame. Suggest that this new problem get added to the list.

4. Ask: What was her new problem? What was the design solution? Show students pictures of the Terry bike.
   Terry's biggest innovation:

User Needs	**Design Requirements**
Smaller bicycle frame causes toe-wheel overlap	Smaller front wheel

Your Design Requirements

1. Have student designers look at their users' needs, and turn them into minimum requirements. Suggest that they refer back to the user characteristics and scenario that they came up with in *8A Handout: User Profile*.

2. Suggest that students use the same process that Georgina Terry used. She looked at the users' needs to determine the requirements. Discuss specific factors that designers consider when they look at their users' needs, and suggest that students consider these as well:

   - Appropriate weight and size
   - Durability
   - Ease of use (functionality)
   - Safety

3. Have students fill out the chart on their handout.

4. Provide work time, and encourage students to discuss their ideas with one another as they work. When they finish, have students get in groups of four or five and explain their users' needs and design requirements to each other. Feedback from members of the group will help designers refine their efforts.

11B: The Perfect Fit: Meeting Needs Through Design (continued)

Wrap Up
Have students refer to the design process checklist and ask them which step they are on (Step 6). Ask if there are any steps they want to revisit after looking at design requirements—a common next step is a return to a previous step!

Follow With
The next activity, *11C: Conceptual Drawing: Thinking on Paper*, gives students a chance to analyze their projects in a visual way.

The Perfect Fit: Meeting Needs Through Design

Handout: Session 11, Activity B

Your Design Requirements
Now consider the user of your product and what requirements might be necessary in order to meet the needs of the user. Refer back to the character identities and scenarios that you did in *8A Handout: User Profile*. Make a chart like the one below in your notebook and fill out the requirements.

User Needs	Design Requirements

The Perfect Fit: Meeting Needs Through Design

Reading: Session 11, Activity B

Many products have been improved when the needs of the user were given a closer look, including the Terry* bicycle. After looking at this design innovation based on the users' needs, you'll consider the needs of your intended users.

A Closer Look at Design Requirements: The Terry Bike Success Story

Georgina Terry, a bike racer, felt disadvantaged when she raced using a man's bike. She thought she could perform better if the bike fit her better. Even though she had a bicycle that was designed for a rider her height, and even though she had adjusted the seat and handlebars just so, it still didn't seem right. She realized that her bike might be designed perfectly for a man her height, but a woman is put together differently, and needs a different bike design.

She looked into the physical differences between men and women, and here's what she found out: When a woman and man of the same height are compared, the woman typically has longer legs, shorter arms, and a shorter torso than the man. She has smaller hands and feet, a wider pelvis, and less muscle mass as well. Design requirements for a women's bicycle emerged from her research:

User Needs	Design Requirements
Shorter arms and torso	Shorten the distance from the handlebars to the seat (the cockpit length) by making the top tube length shorter.
Smaller hands	Shorten reach to brake levers.
Narrower shoulders	Make narrower handlebars.
Shorter legs	Shorten crank arms for more efficient spin.
Smaller bicycle frame causes toe-wheel overlap	

The Problem

When a bike is sized more compactly for women, a new problem arises. The tight geometry of the racing bike doesn't work with regular racing wheels; you run into toe-wheel overlap, where the tips of your shoes hit the front wheel when turning and pedaling at the same time.

The Solution

How do you think she solved this problem? After studying pictures of a Terry bike, what was her solution? Add her solution to the design requirements chart above.

The Terry bicycle is popular with women, because, as she puts it, "a woman isn't just a smaller version of a man." In her first year, 1985, she sold 20 women's bikes; the following year, 1,300;then 5,000, and today it's a multimillion-dollar enterprise.

Session 11, Activity C

Conceptual Drawing: Thinking on Paper

Goal
Learn how conceptual drawings help fine-tune a design.

Outcome
Learners make conceptual drawings of their projects that show all the parts of the design.

Description
Student designers take their project another step farther along the design process as they make conceptual drawings of their project ideas. They learn that the drawing process is a helpful part of refining a design concept, bringing to light practical concerns that need to be resolved, such as how component parts fit together. Drawing from a variety of perspectives helps illustrate all the features of a design and helps the designer communicate ideas to others.

Supplies
Pencils, pens, rulers, graph paper (if not in design notebooks)

Preparation
None

Procedures
Drawing Basics

1. Pass out rulers and pencils for initial drawing. Students are usually more comfortable drawing, initially, in something that can be erased and corrected. Rulers help with straight lines.

2. Learning how to use graph paper is a good first step in developing mechanical drawing skills. The grid provides a ready scale that aids in sketching proportionally by counting the squares within the object to be drawn.

3. Explain and have students practice drawing a straight line using the following method:

    - Place a dot where you want the line to begin and one where you want the line to end. In sketching long lines, place one or more dots between the end dots.
    - Tell students to swing their hand in the direction that they want the line to go, and then back again a couple of times before touching pencil to paper. In this way, they get the feel of the line. They should then use the dots to guide their eye and hand to draw the line.
    - Draw lines with a series of short strokes instead of one stroke. This provides better control of the direction of the line and the pressure of the pencil to paper.
    - Suggest holding the pencil about an inch from the point to help with seeing the drawing. Vertical lines are usually sketched downward on the paper. Slanted

11C: Conceptual Drawing: Thinking on Paper (continued)

lines may be drawn from either end toward the other. For better control, students can rotate the paper.

4. Tell students to sketch lightly at first. Essential lines can then be darkened.

5. To sketch circles and arcs, instruct students to do the following:

    - To draw a circle on grid paper, decide the diameter of the circle and the placement and then make tick marks at the 12 o'clock, 6 o'clock, 9 o'clock, and 3 o'clock positions.
    - Draw the arcs between the tick marks. Alternatively, use a straight line to draw a circle. Do this by drawing two straight lines that cross each other at right angles. The point at which they cross is the center of the circle. The four lines radiating from the center will serve as the radii of the circle.
    - Measure an equal distance on the on each radius from the center. Sketch a square.
    - Now sketch a circle, using the angles of the square as a guide for each arc.

6. Use this as practice to get the students out of the "I can't draw" mindset. Have students draw three different views of an object with a lot of straight lines—like an overhead projector or the blackboard or an easel and stress to them that you do not want a 3-D view of the object, but you want to see what it looks like from the side, the top, and the front. Using the graph paper, they can apply the basic drawing techniques.

7. Have students trade drawings with someone else that they normally don't work with, and see if each student can identify parts.

Drawing Different Views

1. Discuss how that, in addition to drawings made along the way, final drawings are made, too, before a product can go into production. Why? Drawings are needed if the designer applies for a patent; also, before the product is manufactured, drawings aid communication between the designers, engineers, and the manufacturer.

2. Discuss how seeing the object as a set of shapes is important to sketching ideas. If you know how to draw each of the shapes, then drawing the object is easier. Explain that designers show an object from several views. Have students look at the first drawing on the handout and discuss what the different views show about the object. Tell students that drawing their project might involve two or three drawings, one of each unique side, and maybe the inner workings as well. They may want to label parts and use arrows to show how parts move.

3. For the second set of drawings, have students to try to match the objects shown in 3-D on the top row in their front, side, and top views.
   (answers: A=3, B=2, C=1, D=4, E=9, F=8, G=5, H=6, and I=7)

11C: Conceptual Drawing: Thinking on Paper (continued)

4. Ask students if they recognize the next set of drawings *(different views of the crankshaft toy)*. Can they tell what views they are seeing? Have them label each figure with its viewpoint: top, interior, and side. Each drawing helps show different aspects of the device. Then, direct them to look at the last drawings done by former *Design and Discovery* students.

Imagine...

1. Before having students draw their projects, do a visual imagery activity. Have students close their eyes or rest their heads on their arms and try to picture their project. Speak slowly with thinking time between the questions and statements.

    - Try to get a picture of your project in your mind. Can you see it?
    - Try to picture the user using the product. Can you picture the device doing its job?
    - Imagine its size. How big is it?
    - Can you picture the materials it's made of?
    - How about the parts? Try to imagine each of them. Imagine one part connecting to another. Can you see how they work together?

2. Ask students to look up and talk about their ability to visualize their design. Ask how knowing what it looks like helps a person design a product *(knowing the end result makes it easier to design; it's a way of refining and improving a design; lets the person look at parts in relation to the whole; conceptual and practical problems that need work will become evident)*.

Begin Drawing

1. Decide if you prefer students to use pencil or pen at this point. However, it is recommended that students get used to drawing with pen so that they keep a record of their drawings and changes made to their drawings.

2. Start students on drawing a series of sketches of their design in their design notebooks. The first sketches will help them think through their design; others will be attempts at showing it as they see it in their mind's eye. Suggest that they may want to start with the most obvious features of the design and then move toward the ones that have not been resolved. Labels, notes, and arrows showing the motion of moving parts are helpful.

3. If the student doesn't know what the internal workings of their project will be, have them concentrate on the outside views and what is needed for the project to interact with the user. Have them go through the user needs and requirements *(11B Handout: The Perfect Fit: Meeting Needs Through Design)* and make sure all of them are addressed.

4. Discuss that drawings are used to describe and document designs. It is important that the sketch is easy to understand and tells the story behind your design intent.

11C: Conceptual Drawing: Thinking on Paper (continued)

5. Encourage students to draw repeatedly and not worry about making a perfect rendering—this is a thinking step, and the successive drawings are a helpful record of their thinking process. Remind them to draw the device from top, side, and front views, and even an interior cutaway view if it is helpful.

6. After 10 or 15 minutes of drawing, have students pause for a moment, and encourage them to talk about their efforts. Ask them to recommend tricks and tips they are finding that might be helpful to their fellow drafters—their suggestions can be really encouraging at this stage. Remind students to draw their design from all sides, and draw each view large enough to label parts and motion, and then have them continue.

7. Emphasize that the drawing doesn't have to be perfect, but that the resulting figure should be clear and detailed enough to tell someone who doesn't know anything about their project what it is and does.

Wrap Up
Have students talk about their drawings and show them to one another. What do they like about them? What new design considerations came up as a result of drawing? Is there a drawing technique they can recommend? The next step will be to model their design, and having a strong image of it will be helpful. Suggest that students continue drawing and refining their ideas before the next session.

Also suggest that students may want to make other visual representations of their ideas such as collages.

Read *11C Reading: Meet a Communication Designer*.

Follow With
Session 12, *Planning for Models and Tests*, has students planning models to test their ideas.

Conceptual Drawing: Thinking on Paper

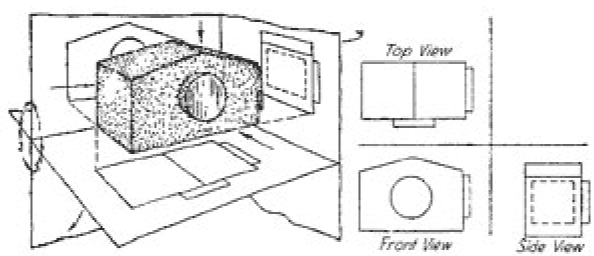
Handout: Session 11, Activity C

Drawing From All Sides

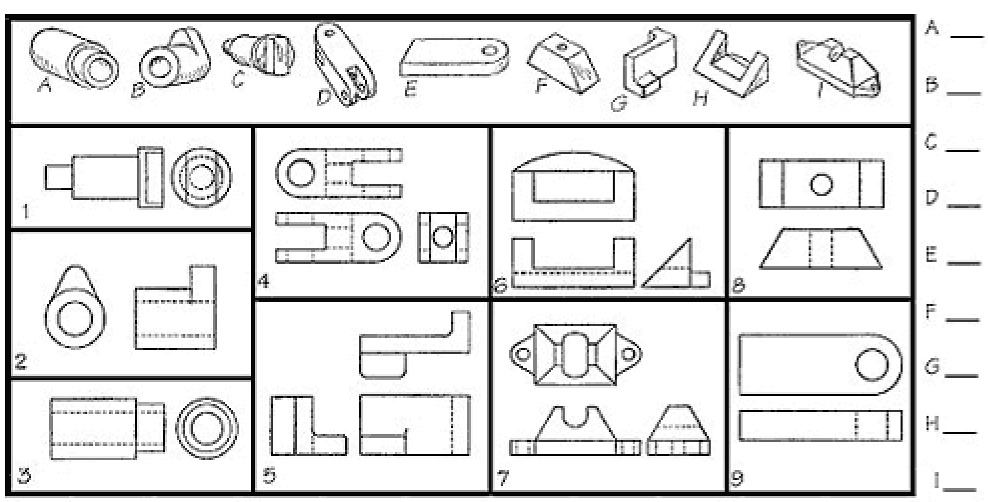
Drawing your ideas can help you visualize your plan and will be very useful when you make your model. You may find it helpful to draw the different components and parts of your project—from different perspectives. You will probably have several drawings of your project as your ideas evolve.

This activity begins by learning some basic mechanical drawing techniques. You'll learn how to draw a line and a circle on graph paper. You will then use these techniques to draw an object in the room. This should be done in your design notebook.

1. Compare the 3-D drawing of the object below to the three views of the object on the right. What do the three views show you about the object that you didn't know from the 3-D version?

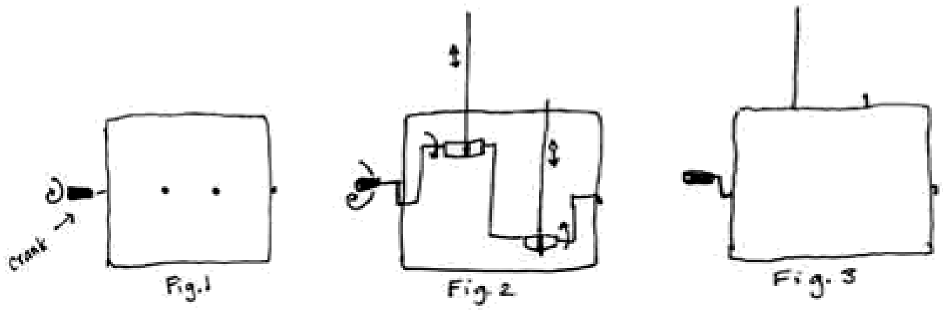


2. Match the object in the top row with its orthographic sketch.



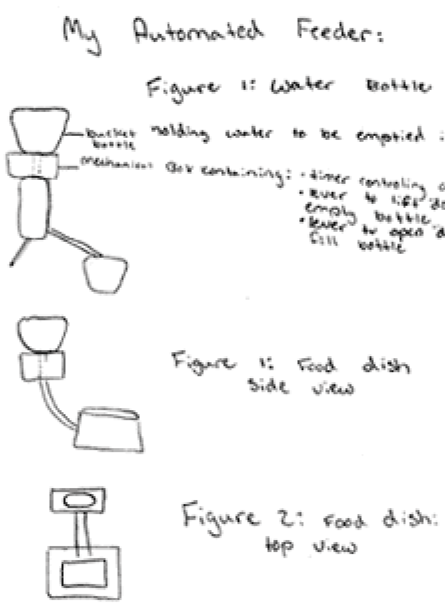
11C Handout: Conceptual Drawing: Thinking on Paper (continued)

3. What object is shown here? Label the different figures: interior, top and side.



____________________ ____________________ ____________________

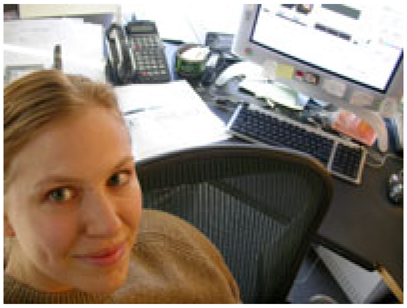
4. Here are some samples of past *Design and Discovery* students' drawings. Can you tell what they are?



5. Now, in your design notebook, try your hand at conceptual drawings for your project. Be sure to draw different views as well as individual drawings of the components and parts. Make many drawings. You can't have too many. Make your drawings large enough to label components and show the direction of any movement that may be appropriate to your design.

Meet a Communication Designer

Reading: Session 11, Activity C



Chelsea Vandiver
Senior Communication Designer
ZIBA Design

Introduction
Hello, my name is Chelsea Vandiver. I am a senior graphic designer at ZIBA Design. I studied graphic design at the University of Washington. After graduation, I worked as a conventional graphic designer, designing packaging, letterheads, and brochures that were destined for the recycling bin days after coming off the printing press. I didn't find the work satisfying. I knew that I wanted to add value, not clutter to people's lives. Fortunately, I found a job at a product development firm. Now, at ZIBA Design, I work on projects like signage systems, user interfaces, and products that improve people's day-to-day lives.

A Typical Day
I spend a large part of my day participating in collaborative brainstorms and work sessions with an inspiring group of product designers, environmental designers, brand specialists, and engineers. The beauty of working together on a multidisciplinary team is that the result is larger and greater than what any of us could have developed on our own.

Challenges
I've worked at ZIBA Design since 1997, and every day I learn something new. Each project has its own set of unique challenges that force me to continually grow and expand in new ways.

Advice
My advice to younger people entering the design or engineering field is to not be afraid to collaborate and share your work with your friends and teachers.

About ZIBA Design
ZIBA Design is an international design firm that has designed products for many global companies, including FedEx, Microsoft, Intel, Fujitsu, Black & Decker, Sony, Pioneer North America, Dial, and Clorox. www.ziba.com*

Session 12

Planning for Models and Tests

Making, Modeling, and Materializing

In This Session:

A) Thinking Again About Design (45 minutes)
- Student Handout

B) Materials and Modeling Plans (45 Minutes)
- Student Handout
- Student Reading

C) Structural Considerations (60 Minutes)
- Student Handout

This session prepares students for building models and testing systems or components of their design project. This is Step 7 of the design process. In an opening activity, *12A: Thinking Again About Design*, students review their experience of the design process and think about their revisions up to now. They see that the design process is not linear; there are cycles or iterations of review, testing, revision, and change. In the second activity, *12B: Materials and Modeling Plans*, students survey available materials for constructing models and plan their first constructions. In the final activity *12C: Structural Considerations*, students learn about collapsible objects and the principles of collapsibility. They then review structural considerations related to storing, moving, and assembling their projects.

Supplies

A variety of materials to build models.
Supplies for Structure

- Foam (Styrofoam* in sheets and several shapes, including foam tubes for pipe insulation)
- Foam core board
- Balsa wood (sheets and pre-cut strips from craft supply stores)
- Modeling clay
- Aluminum foil
- Pipe cleaners and plastic straws
- Cardboard (tubes, boxes of all sizes, flat pieces)
- Paper (including poster board or card stock weights)
- Erector* set
- Lego* set
- Dowels, bamboo skewers
- Wheels

Other Optional Structural supplies

- Recyclable materials such as wine corks, aluminum soda cans, bubble wrap, packaging peanuts, and twist ties

Session 12, Planning for Models and Tests (continued)

- Sample items (for students to acquire and use in larger constructions): PVC pipe and connectors, lumber (plywood and 2x4s) of different sizes

Parts and Materials To Connect Things

- String
- Wire
- Rubber bands
- Rubber tubing
- Tape (duct, masking, packaging, and electrical)
- Glues (epoxy, superglue, glue sticks, glues for hot glue gun, and rubber cement)
- Hinges
- Nuts and bolts, washers, assorted screws
- Nails, thumbtacks

Tools

- Several sets of each: pliers, saw, hammer, screwdriver, hot glue gun, and tin snips

Collapsible Items Suggestions

- Umbrella, folding chair, window blinds, stackable cups, sleeping bag, fold away rain jacket, tent, fold up map, pop-up book, paper lantern, easel, ladder, pocket scissors, glasses, Swiss Army knife, measuring tape, stackable measuring cups and spoons, balloon, inflatable raft, rubber band, plastic bag, jump rope

Planning for Models and Tests

Key Concepts: Session 12

In Session 12, students begin to make their ideas tangible—going from what's in their mind to things in their hand. They build initial **models**. This could be a model of the overall design, a model of a single working component, or a test of materials for a single part. Later, students will build working **prototypes** to test form and function of their designs.

Key Concepts
Both models and prototypes are constructions that determine if a design or components of a design will work in both form (how does it look and feel) and function (does it work?). Both models and prototypes are used to:

- Test and trial a concept.
- Test and trial the way something looks or feels to the user.
- Try out dimensions and fit between components.
- Test a mechanism or subsystem of a design.

Models tend to be smaller in scope than prototypes; they are not as concerned with representing a final product in functionality, size, materials, and scope.

Model: Models can be visual representations of a total design that is nonfunctional. Or, they represent some aspect (form or function) of a specific component.

Prototype: Prototypes tend to demonstrate some aspect of the design as a whole, either its form, function, or both.

More on Models and Prototypes
The Intel QX3 progression of models and prototypes in *12A Handout: Thinking Again About Design*. In Session 12, students study the progression of models and prototypes in the development of the QX3 digital microscope.

Dial* soap dispenser models and working prototypes in *14A Reading: ZIBA Designs a Soap Dispenser*. In Session 14, students study the progression of models and prototypes in the development of the Dial soap dispenser.

Models Plus
www.modelsplusinc.com/html/body_prototypes.html*
The company, Models Plus, Inc., has a nice display of prototypes. View prototypes for a Motorola cell phone and learn what materials were used to make the prototype.

Session 12, Activity A

Thinking Again About Design

Goal
Understand that the design process involves many cycles of revision as each step presents new information and ideas for refinement of a design.

Outcome
Students know that change and possibly even complete redesign of their solutions are part of the process of good engineering and design.

Description
This activity begins with a review of the design process as students have experienced it up to now. A group reflection and discussion encourages them to think about the value of the revisions to their idea along the way. The design process has many cycles or iterations that lead to changes and improvements to their original solution. A review of Intel QX3 microscope prototypes reinforces the process of modeling, testing, and prototyping.

Supplies
None

Preparation

1. Students will need their notebook, design brief, design requirements, drawings, and any other notes about their design project.

2. Try to arrange for mentors to attend this session.

3. Optional: Arrange for actual prototypes and/or models from a design firm, if possible.

Procedures
Project Progress

1. Have students take a few minutes to review and think about the changes to their projects as they have moved through the design process. Discuss and share examples:

    - Do you have exactly the same solution in mind since the beginning?
    - Which steps take longer?
    - Which steps produced the most change to your original idea?
        - Developing a design brief (Step 4)?
        - Getting research and feedback from others (Step 5)?
        - Analyzing feasibility of solution (Step 5)?
        - Developing design requirements and drawings (Step 6)?

12A: Thinking Again About Design (continued)

2. It is likely that all students will have modified and revised their projects to some extent already. Discuss how this is an important part of the process:

    The design process is really not a set of linear steps but has many cycles (or iterations) of revision and change that lead to improvements to their original solution. In fact, with each step that makes the idea more real (moving from "think" to "thing"), revisions get more comprehensive—even to throw out a solution and back up to an earlier idea.

Models and Prototypes

1. Distinguish prototypes and models

    Model: Models can be visual representations of a total design that is nonfunctional. Or, they can represent some aspect (form or function) of a specific component.
    Prototype: Prototypes tend to demonstrate some aspect of the design as a whole, either its form, function, or both.

    Students will eventually build a working prototype of their idea, but at this step, they construct models. These allow students to test or trial their concept, try out dimensions and fit between components, or test a mechanism or some system in their project.

2. Review QX3 microscope development. Discuss the progression of prototypes shown in the images on the handout.

3. Review other examples of models and prototypes. Take a look at the Leatherman* Web site to see the history of this useful product, from idea to inception, www.leatherman.com* (Go to *About Leatherman* and select *History*.)

Follow with
Activity *12B: Materials and Modeling Plans* has students surveying the materials for building models and planning what they will build.

Checking in on the Design Process

Handout: Session 12, Activity A

The steps of the design process rarely happen one after another but often are repeated or revisited in many cycles (or iterations) of change that lead to improvements. For example, drawing your idea may have caused you to revise your requirements in some way. In fact, with each step in the process that makes your idea more real (moving from "think" to "thing"), revisions can get more comprehensive as you see new ways of looking at your idea—you might even throw out a solution and go back to an earlier idea.

It's time to make project ideas tangible—to go from what's in your mind to things in your hands. You are now at the stage of building models—a way to test, revise, and improve your design. Models allow you to see your idea as a "trial run." You might build a model to test dimensions and fit between components. Or you might build a model to test a mechanism or some system in your project. Eventually you will build a prototype—a model that works.

Model: A small but exact copy of something
Prototype: A working model of a machine or other object used to test it before producing the final version

Even your first working prototype will go through revisions. Follow the progression of prototypes that resulted in the Intel QX3 microscope:

QX3 Requirements

- Fun to use computer microscope
- Meet $99 retail cost target
- Must really work technically
- Must be mobile, capture images at the source
- Easy to use; plug-and-play simplicity
- Everything included ("just add specimen")
- No batteries, no AC adapter, no external lighting
- Fully exploit computer capabilities: capture, time lapse, collection, printing

Proof Of Concept, May 1998

This is the first model to test the concept of transferring a magnified image to a computer for viewing, saving, and manipulating. This is a demonstration or "works-like" prototype. It used a standard off-the-shelf microscope, external lighting, with circuitry and a ribbon cable for connection to the computer. It was tested with kids to see if they felt that a computer-connected microscope had "play value" (was fun). It also allowed the engineers to ask kids questions about what they would want to look at and what magnifications were interesting to them.

12A Handout: Thinking Again About Design (continued)

Microscope in a Box, May 1998

This version was an exciting breakthrough... in function. The box fit in your hand and included the necessary lighting and electronics for capturing the image. It proved that you could take the microscope to what you want to see instead of bringing the object to the microscope. Clearly, this version proved the function (with form to follow). The key was that this prototype had the light source on the top (as opposed to the bottom for conventional microscopes). It didn't have a base and could be pointed at just about anything in the environment. It allowed children to explore objects that were opaque or too large or heavy to fit under a traditional microscope. This was a major fun feature. Kids wanted to look inside their mouth, in their ears, and the weave on their sweaters, their pets, and so on. This later became the "handheld" mode of operation of the QX3 product, where the unit can be lifted out of the base and used exactly like that.

A First Look, June 1998

This version is all form and no functionality; it was the very first industrial design foam model to combine the traditional microscope mode (in the base) and handheld mode into a single design. The vertical piece is removable. This model represents desired form (without function). This version was developed prior to knowing the size and dimension specifications.

A Working Prototype, October 1998

Here is the first working prototype with full functionality. It works, but the wires on the outside belong inside. The ideal shape or color weren't right yet, and the designers didn't know yet what they should be.

12A Handout: Thinking Again About Design (continued)

Getting Closer, January 1999

This second working prototype has functionality, but the power supply is still on the outside. This one was called the "albino" model. The shape is very close to final. The engineers knew that everything inside (electronics, optics) would fit inside this shape; it also fit the size of kids' hands well, and looked good.

Looking Good, February 1999

This version tested a new look for a debut at a national toy tradeshow. It looks good with transparent plastic, but it wasn't fully functional—the power supply was still external.

Presenting QX3, September 1999

The final product—the QX3 is born!

Session 12, Activity B

Materials and Modeling Plans

Goal
Learn about available materials and plan model(s) to build.

Outcome
Know about available materials, select those useful for their needs, and plan model building.

Description
After a brief introduction to the variety of materials available for modeling, students have time to study the materials and plan what models they want to build. The materials are organized into three groups: materials for structure, materials for connections, and tools.

Supplies
A variety of materials to build models.

Supplies for Structure

- Foam (Styrofoam* in sheets and several shapes, including foam tubes for pipe insulation)
- Foam core board
- Balsa wood (sheets and pre-cut strips from craft supply stores)
- Modeling clay
- Aluminum foil
- Pipe cleaners and plastic straws
- Cardboard (tubes, boxes of all sizes, flat pieces)
- Paper (including poster board or card stock weights)
- Erector* set
- Lego* set
- Dowels, bamboo skewers
- Wheels

Other Optional Structural Supplies

- Recyclable materials such as wine corks, aluminum soda cans, bubble wrap, packaging peanuts, and twist ties
- Sample items (for students to acquire and use in larger constructions): PVC pipe and connectors, lumber (plywood and 2x4s) of different sizes

Parts and Materials To Connect Things

- String
- Wire
- Rubber bands

12B: Materials and Modeling Plans (continued)

- Rubber tubing
- Tape (duct, masking, packaging, and electrical)
- Glues (epoxy, superglue, glue sticks, glues for hot glue gun, and rubber cement)
- Hinges
- Nuts and bolts, washers, assorted screws
- Nails, thumbtacks

Tools

- Several sets of each: pliers, saw, hammer, screwdriver, hot glue gun, and tin snips

Preparation

1. Gather the materials well in advance of this session. Send home information to parents and request donations of used building materials or any of the suggested recyclable items. Purchase what is not supplied or donated.

2. On the day of the session, lay out the modeling materials organized by: a) things to build with, b) things for connecting and attaching, and c) the tools.

Procedures
Planning

1. Introduce the modeling materials. Explain, demonstrate, and answer students' questions about any unusual or unfamiliar materials or tools. Build a common vocabulary as you introduce and students study the materials.

2. Plan what to model. Have students write down the following questions and answers in their design notebooks:

   - What do you want or need a model of? (List at least three possibilities.):
   - For each model possibility
     - Is this a system or a component of your design project?
     - What will this model help you understand about your idea?
     - Will it be a small or full-scale version?
     - What will you need to build it?
     - What materials on hand will work for your model?
     - What is not on hand for building your model?

3. During this planning time, students should select and manipulate different materials as they plan. Encourage them to make notes about the materials that they study: their flexibility, strength, and their suitability as a modeling material. Note: It may be helpful to have students review the *13A Handout: Making Models*.

12B: Materials and Modeling Plans (continued)

Sharing

1. While students are planning, have mentors meet with students and discuss their plans. Mentors should help students articulate the purpose of the model and answer the above questions as they plan. It is important that students are intentional during the model building. They should have a purpose, something they'd like to test or trial in each model.

2. Remind them that they can model different systems, subsystems, and components as well as the whole product. Encourage them to make large enough models so that they can see, test, and understand the systems, parts, and components.

Wrap Up
Ensure that each student has a plan and a clear purpose for constructing at least one model.

Have the students read *12B Reading: Meet a Modelshop Manager*.

Follow With
Activity *12C: Structural Considerations* provides the opportunity for students to consider the structure of their projects.

Materials and Modeling Plans

Handout: Session 12, Activity B

In this activity, you will start to plan your model. Like anything, the more planning you do in advance, the better your chances of achieving what you want. It's best to put answers to the questions below in your design notebooks.

1. What do you want or need a model of? (List at least three possibilities.)

2. For each model possibility, consider the following questions and answer them in your design notebooks:

    - Is this a system or a component of your design project?
    - What will this model help you understand about your idea?
    - Will it be a small or full-scale version?
    - What will you need to build it?
    - What materials on hand will work for your model?
    - What is not on hand for building your model?

3. As you plan, you may select and manipulate different materials. Be sure to make notes about the materials that you study: their flexibility, strength, and suitability as a modeling material.

Tip: When planning your model, it is better to plan to build a bigger model so that the details can be seen, tested, and understood.

Meet a Modelshop Manager

Reading: Session 12, Activity B

Bruce Willey
Modelshop Manager
ZIBA Design

Background

I'm originally from St. Paul, Minnesota. I've worked at ZIBA Design for almost eight years. I decided to study modelmaking after I had graduated from college and taught English in Japan for two years. I enrolled at Bemidji State University in Minnesota and took Industrial Technology and modelmaking courses for two years. I performed a three-month internship at an architectural modelshop in Boston, Massachusetts. After that I got a job at the Industrial Design Center for NCR in Dayton, Ohio. I worked there for five years, then I visited Portland, got a job offer, and moved here. I became the manager of the modelshop about four years ago. In each case, my managers and co-workers have mentored me. Since a new person often brings new skills into a workplace, I sometimes have taught my manager and I've been taught by those who work for me.

A Typical Day

In a typical day I discuss the current and upcoming work schedule with the other modelshop staff and project managers and their team members who bring us the work to do. I will often order modelmaking supplies by phone or Internet from a variety of vendors, and I might have to arrange to have an outside modelshop do work for us if we don't have the time or resources. I have to fill out paper or electronic forms to order things or hire outside shops or schedule projects. There is a project meeting or a group meeting or a management meeting or a brainstorm meeting on almost any given day.

If there is still any time left or if there is a tight deadline, I will do model work too. Sometimes that is just spending a couple of hours painting things or using a table saw or band saw to cut material up and using hand tools like chisels and files and sandpaper to form it. Sometimes I work on very complicated models that take weeks to finish and involve planning, measuring, using computer aided design (CAD) and computer aided machining (CAM) software, sanding, polishing, painting, and careful assembly.

Favorite Thing About Job

I like having such a wide variety of different activities to do every day.

12B Reading: Meet a Modelshop Manager (continued)

Advice To Young People
You have to decide if you are interested in how things go together and work. You should be comfortable using tools and working with your hands. You will be using math and science and art skills. Any kind of commercial and industrial arts classes and art or craft classes or hobbies will help you a lot. All designers and engineers and almost all modelmakers use computers very frequently. Take computer classes and classes that expose you to advanced technology. Watch carpentry shows and similar programs to see if you are interested in solving problems by designing and making things.

About ZIBA Design
ZIBA Design is an international design firm that has designed products from many global companies, including FedEx, Microsoft, Intel, Fujitsu, Black & Decker, Sony, Pioneer North America, Dial, and Clorox. www.ziba.com*

Session 12, Activity C

Structural Considerations

Goal
Consider structural decisions about the project before making a model.

Outcome
Students consider and make structural decisions about their project.

Description
Will it fold? Expand? Roll? Inflate? Many products are collapsible; they fold out for action and fold up for storage. Students take a look at some of these objects and consider collapsibility issues for their project.

Supplies
Samples of collapsible items such as umbrella, folding chair, window blinds, stackable cups, sleeping bag, fold-away rain jacket, tent, fold up map, pop-up book, paper lantern, easel, ladder, pocket scissors, glasses, Swiss Army knife, measuring tape, stackable measuring cups and spoons, balloon, inflatable raft, fireplace bellows, rubber band, plastic bag, or jump rope.

Preparation
Bring in as many samples of collapsible items as possible. Alternatively, have students bring in collapsible items. Spread them all out on a table.

Prepare cards with the collapsible principles below for students to sort the objects.

Procedures
Collapsible Items

1. Have students gather around the collapsible objects on a table.
2. Ask what the items have in common. Define collapsible: Objects that can be folded and unfolded again and again.
3. Review the chart below. Ask them to sort the items into different mechanical categories by collapsible principles (written on cards). Many collapsible objects apply more than one of these principles

Collapsible Principles	Definition	Examples
Stress	1. Something that is stressed (compressed) for storage and relaxed for action 2. Something that is stressed (stretched) for action while relaxed for storage	Sleeping bag, rubber band

12C: Structural Considerations (continued)

Collapsible Principles	Definition	Examples
Folding	Soft materials that are flexible and directionless can be folded	Clothes, blankets, towels, tents, curtains, flags, plastic bags, jump ropes
Creasing	Something that can be folded along preset lines or creases giving an object (folded and unfolded) neater appearance, may also facilitate the act of folding and unfolding	Maps, pup-up books, newspapers, boxes
Bellows	Used where a flexible and sealed connection is needed	Airport bellows gates, hanging fabric shoe-shelving, paper lanterns
Assembling	The whole is separated into parts for storage	Jigsaw puzzles, Lego* blocks, motorized wheel chairs
Hinging	Objects with flexible joints	Laptop computers, pianos, mobile phones, handheld computers, umbrellas, ladders, glasses, folding scissors, scooters, folding bicycles, strollers, pocket knives
Rolling	Objects that are rolled and unrolled repeatedly	Extension cords, tape measures, roll-up dog leashes
Sliding	Collapsibles that expand and contract as their parts slide open or closed	Telescopes, car antenna, sliding ladders, autofocus camera lenses, lipstick
Nesting	Two or more objects that fit together to occupy less space than they do individually	Russian dolls, measuring spoons/cups, shopping carts
Inflation	Something that blows up to expand	Balloons, inflatable rafts, inflatable neck cushions
Fanning	An object that has a pivot that holds its leaves together to allow multiple leaves to be viewed at the same time	Fans, sample color swatches, fan-mounted Allen wrench keys
Concertina	Collapsibles that have a number of equal rods connected by pivots to form a string of Xs which can be expanded and retracted	Retractable mirrors/lights

12C: Structural Considerations (continued)

4. Explain that collapsibility is never the purpose function—it is always the support function. Discuss the benefits of each collapsible item (such as space saving, can perform different functions when open and when collapsed, safety.)

Structural Considerations

1. Ask students to consider what structural principles would improve their own projects. In doing so, they can consider the following questions:
    - How will their project be stored?
    - How will their product be moved?
    - Will their product need to be disassembled? If so, how?
    - Where will their product be placed? Are there any structural considerations to keep in mind based on its placement?
2. Students can sketch any structural improvements to their projects.

Chart adapted from Mollerup, Per. *Collapsible: The Genius of Space-Saving Design.* San Francisco: Chronicle Books, 2001.

Wrap Up
Review and share students' ideas.

Follow With
In Session 13, *Making It! Models, Trials, and Tests*, students build models and test the results.

Structural Considerations

Handout: Session 12, Activity C

Have you ever noticed how many products change shape depending on their usage or non-usage? For example, an umbrella is quite different when in use and when not in use. In this activity you will study collapsible items and make structural considerations for your project.

1. In your notebook, fill in the "Examples" for each Collapsible Principle like chart below. These may be items that are in your class or items that you discuss.

Collapsible Principles	**Definition**	**Examples**
Stress	Something that is stressed (compressed) for storage and relaxed for action Something that is stressed (stretched) for action while relaxed for storage	
Folding	Soft materials that are flexible and directionless can be folded to create new direction	
Creasing	Something that can be folded along preset lines or creases giving an object (folded and unfolded) a neater appearance; may also facilitate the act of folding and unfolding	
Bellows	Used where a flexible and sealed connection is needed	
Assembling	Something whole is separated into parts for storage	
Hinging	Objects with flexible joints	
Rolling	Objects that are rolled and unrolled repeatedly	

12C Handout: Structural Considerations (continued)

Collapsible Principles	**Definition**	**Examples**
Sliding	Collapsibles that expand and contract as their parts slide open or closed	
Nesting	Two or more objects that fit together to occupy less space than they do individually	
Inflation	Something that blows up to expand	
Fanning	An object that has a pivot that holds its leaves together to allow multiple leaves to be viewed at the same time	
Concertina	Collapsibles that have a number of equal rods connected by pivots to form a string of Xs which can be expanded and retracted	

2. What structural principles would improve your project? Consider the following questions:

   - How will your project be stored?
   - How will your product be moved?
   - Will your product need to be disassembled? If so, how?

Session 13

Making It! Models, Trials, and Tests

Making, Modeling, and Materializing

In This Session:

A) Making Models (150 minutes)
- Student Handout
- Student Reading

Students' design projects move to the tangible and testable. This session provides time to build and test models of components, systems, or the product itself. In the single activity for the session, *13A: Making Models*, students are encouraged to be methodical as they build and report on their models, tests, and results in their design notebooks. This is a session where mentors can support students' work and help them take time to reflect on results and be thoughtful about appropriate next steps.

Supplies

A variety of materials to build models.

Supplies for Structure

- Foam (Styrofoam* in sheets and several shapes, including foam tubes for pipe insulation)
- Foam core board
- Balsa wood (sheets and pre-cut strips from craft supply stores)
- Modeling clay
- Aluminum foil
- Pipe cleaners and plastic straws
- Cardboard (tubes, boxes of all sizes, flat pieces)
- Paper (including poster board or card stock weights)
- Erector* set
- Lego* set
- Dowels, bamboo skewers
- Wheels

Other Optional Structural supplies

- Recyclable materials such as wine corks, aluminum soda cans, bubble wrap, packaging peanuts, and twist ties
- Sample items (for students to acquire and use in larger constructions): PVC pipe and connectors, lumber (plywood and 2x4s) of different sizes

Session 13, Making It! Models, Trials, and Tests (continued)

Parts and Materials To Connect Things

- String
- Wire
- Rubber bands
- Rubber tubing
- Tape (duct, masking, packaging, and electrical)
- Glues (epoxy, superglue, glue sticks, glues for hot glue gun, and rubber cement)
- Hinges
- Nuts and bolts, washers, assorted screws
- Nails, thumbtacks

Tools

- Several sets of each: pliers, saw, hammer, screwdriver, hot glue gun, and tin snips

Session 13, Activity A

Making Models

Goal
Learn how models contribute to design.

Outcome
Build models, evaluate results, and consider design modifications.

Description
Students work on their models of the project or trials of components, systems, or subsystems. They are encouraged to be methodical by keeping records of what they plan to construct and why, and what the results show for next steps or modifications to their design. Mentors assist with constructing and testing their models by helping students analyze design issues as they build their models.

Supplies
A variety of materials to build models.

Supplies for Structure

- Foam (Styrofoam* in sheets and several shapes, including foam tubes for pipe insulation)
- Foam core board
- Balsa wood (sheets and pre-cut strips from craft supply stores)
- Modeling clay
- Aluminum foil
- Pipe cleaners and plastic straws
- Cardboard (tubes, boxes of all sizes, flat pieces)
- Paper (including poster board or card stock weights)
- Erector* set
- Lego* set
- Dowels, bamboo skewers
- Wheels

Other Optional Structural supplies

- Recyclable materials such as wine corks, aluminum soda cans, bubble wrap, packaging peanuts, and twist ties
- Sample items (for students to acquire and use in larger constructions): PVC pipe and connectors, lumber (plywood and 2x4s) of different sizes

13A: Making Models (continued)

Parts and Materials To Connect Things

- String
- Wire
- Rubber bands
- Rubber tubing
- Tape (duct, masking, packaging, and electrical)
- Glues (epoxy, superglue, glue sticks, glues for hot glue gun, and rubber cement)
- Hinges
- Nuts and bolts, washers, assorted screws
- Nails, thumbtacks

Tools
Several sets of each: pliers, saw, hammer, screwdriver, hot glue gun, and tin snips

Safety Guidelines

1. Cut away from the body.
2. Never push into the palm.
3. Stabilize what is being cut.

Preparation
Invite mentors to this session

Procedures

1. Have students review the handout.

2. Discuss some model building tips:

    - Use found materials to construct models. Point out that the initial model for the Apple* computer mouse, for example, was a butter dish with parts glued to hold the rolling ball.
    - It is easy to get carried away by the fun of making an exciting model, but the materials must not outshine the design concept.
    - The range of materials used in model making is endless. Experiment with different materials or use them in inventive new ways.
    - Respect the physical properties of materials. Revisit the materials' test results from *3A: Properties of Materials*. Try running materials' property tests for materials you may be considering.

13A: Making Models (continued)

- Know the differences between adhesives. Read labels on glue to understand which glues work best for different applications. Use the least amount of glue possible.
- Always place cardboard or some sort of cutting board underneath the material being cut.
- For straight cuts, cut against a metal edge.

3. Emphasize the value of good records as students build and learn about their design. Point out that they need to take the time to be methodical and write down what they plan to do and why. As they build and think about what the modeling process shows them, they should keep records about what the design issues come up as they build models. When students complete a model, they "test" it, gather data about results, and write notes about modifications and next steps which may be another model, depending on time available.

4. Clean up and organize storage or transport of models home for further work.

Wrap Up
Have all model makers show what they built and state one or two things that they learned in the process.

Optional: Have students read *13A Reading: Meet Materials Engineers*.

Follow With
Session 14, *Prototype Practicalities*, allows students to develop the next stages of the project.

Note: If you are running a two-week summer camp, you may need to end project work with this session and move to *Session 17: Fairly There*.

Making Models

Handout: Session 13, Activity A

It is helpful to keep good records of your model-building efforts. Good records allow you to adjust your design based on what you learn from each model you build. For each model record your plans, purpose, tests and results, and next steps using the questions below. Use your design notebook for these records.

Plans
What do you want to build a model of? Is this a system or component of the product? Is this a full-scale model?

Purpose
What will this model help you understand about your design?

Tests and Results
What did your model show you about your design? What features did you test? Does it meet requirements? Did it function as intended? Did the form suit you? Are the materials suitable? What modifications do you need to make? What new ideas do you have for your design?

Next Steps
What do you want to do next? Adjust this model? Build another version of this model? Build a model of something else?

Meet Materials Engineers

Reading: Session 13, Activity A


Pratima Rao and Jill Barrett
Materials Engineers

When it comes to designing or improving a product, finding just the right material is a critical step. From artificial knees to firefighters' uniforms to fiber optic cables for the ocean floor, everything that gets manufactured benefits from the expertise of materials engineers. Two *Design and Discovery* mentors developed an early interest in materials engineering.

Early Interests

When Jill Barrett was growing up, she and her two sisters routinely turned their garage into a laboratory for conducting science and engineering investigations. Their enthusiasm wasn't dampened even when they ruined the family pots and pans by cooking up a pot of paper pulp. Looking back, Barrett can see how developing projects for school science fairs was a natural step toward her career in materials engineering. She earned a bachelor's degree in materials science from North Carolina State University and did master's studies in metallurgical and materials engineering at the Colorado School of Mines.

For Pratima Rao, being on a high school Science Olympiad team motivated her to pursue scientific studies in college. She originally planned to become a doctor. During her undergraduate studies at Rensselaer Polytechnic Institute in New York, she decided that materials engineering was a better fit for her interests. She also liked the idea of contributing to the development of new and improved materials that would benefit society. Rao eventually earned a Ph.D. in materials science and engineering.

On the Job

Materials engineers work on a range of projects, from large industrial plants to laboratories where research focuses on the molecular structure of substances. Plastics, metals, wood, textiles, medicine, ceramics, and semiconductors are only a few of the fields where breakthroughs have come about through the efforts and insights of materials engineers. "Materials engineers are on the cutting edge in almost every field," says Rao.

Barrett's career has involved her in everything from steelmaking to testing the properties of

13A Reading: Meet Materials Engineers (continued)

components that go into basketball shoes. She typically gets involved after initial product development is underway and brings her expertise to focus on process improvement during manufacturing.

Rao has worked in the field of photonics, improving photosensitive glass used in the telecommunications industry. She enjoys taking scientific research concepts and applying them in practical ways in manufacturing. She also likes the hands-on nature of her work, from melting powders to making glass samples to operating a transmission electron microscope. While she worked at Corning, Inc., in New York, she was part of a research team that received a patent for an invention called "Lens Array and Method for Fabricating the Lens Array."

Materials engineers often work as part of a team, contributing their technical knowledge to evaluate a product or improve the production process. As Barrett explains, "You talk with the design team about how a product is supposed to work. You ask a lot of questions about different materials: Is it too sharp? Too brittle? Will it break easily? Will it melt if exposed to heat? Can it be molded?" Engineers also pay attention to costs, evaluating whether using a certain material will be economical or drive production costs over budget.

Designing tests to evaluate whether different materials will meet design specifications is another part of the job. The engineer's role is not only to find what works but to rule out what doesn't. "You should never be afraid of failure," Barrett stresses. "Failure teaches you more than success ever will."

Being able to communicate and ask good questions are important job skills, too. "Communicating your ideas clearly is crucial to your success," Barrett says.

Career Preparation
Barrett and Rao credit their career success to family support and encouragement. "My parents always told me I could be anything I wanted. I heard that early and often," says Barrett. During college, they found themselves in the minority as women in engineering. Both women say they benefited from internships and hands-on experiences that gave them insights into the real world of engineering. Rao says persistence is a quality worth cultivating, and so is "learning how to ask for help. This is a valuable lesson. Support from others is important as we work to overcome obstacles." Barrett shares a final tip for anyone considering a career in engineering: "Make friends. Make lots of friends. They'll help you every step of the way."

Design and Discovery

Prototyping

Now that students have developed a model, they are ready to move towards creating a working prototype of their idea. In *Session 14: Prototype Practicalities!*, students create project specifications, consider materials, and prepare a budget. *Session 15: Develop It!* is a working sessions for prototype development. In *Session 16: Test It!* students conduct user testing to collect feedback from users and plan revisions to their prototype.

Session 14

Prototype Practicalities

Prototyping

In This Session:

A) Prototype Planning (30 minutes)
- Student Handout
- Student Reading

B) Prototype Materials (60 Minutes)
- Student Handout

C) Budget (60 Minutes)
- Student Handout

Home Improvement
- Student Handout

In this session students begin planning how they will construct their prototypes. In *14A: Prototype Planning*, prototypes are reintroduced as students strategize plans and create their specifications for developing a prototype. In *14B: Prototype Materials*, students consider what materials they will use to develop their prototypes. Finally, in *14C: Budget*, they use a spreadsheet program to develop budgets for the project. The Home Improvement activity, *Your Work Schedule*, helps students structure their time for working on their prototypes.

Supplies

- Spreadsheet software program
- Computers
- Materials to demonstrate what may be used in prototypes:
  - Wood
  - Foam
  - Plexiglass
  - Metal
  - Canvas fabric
  - Bubble packing
  - Cotton balls
  - Duct tape
  - Tubing
  - Sandpaper
  - Sponges
  - Steel wool pads
  - String or twine
  - Glue
  - Masking tape

Session 14, Activity A

Prototype Planning

Goal
Understand what a prototype is.

Outcome
Students will be ready to begin building their prototypes.

Description
This is the first part of Step 8 of the design process: Build the Prototype—develop project specifications and create a working prototype. Revisit the difference between a model and a prototype. Students begin to think about how they are going to develop prototypes and get ideas from one another.

Supplies
None

Preparation
None

Procedures
What Is a Prototype?

1. Have students refer back to the design process checklist in *11A Handout: Checking in on the Design Process*, Step 8: Build the Prototype.

2. Ask students the difference between a model and a prototype (this was introduced in *12A: Thinking Again About Design*).

   Model: A visual representation of a total design (or some aspect of the design) that is nonfunctional.
   Prototype: A working model used to demonstrate and test some aspect of the design or the design as a whole. A prototype is produced before the final version.

3. Discuss the purpose of prototypes (learning, communication, integration, and milestones):

   - Learning: Prototypes are often used to answer two types of questions: "Will it work?" and "How well does it meet the users' needs?"
   - Communication: Prototypes allow better communication of product ideas. They are visual, tactile, three-dimensional representations of a product.

   - Integration: Prototypes are used to ensure that components and subsystems of the product work together as expected.

14A: Prototype Planning (continued)

- Milestones: Prototypes are used to demonstrate that the product has achieved a desired level of functionality—providing tangible goals and demonstrating progress.

4. For an example of the development of a prototype, refer to *14A Reading: ZIBA Designs Dial Soap Dispenser*.

Prototyping Suggestions

Discuss the following prototyping suggestions:

1. Prototype early and often: Don't wait until you have the final design. To see if something will work, make a quick prototype.
2. Divide and conquer: Divide large problems into smaller challenges and solve these through prototyping.
3. Flatten the problem: Translate three-dimensional problems into two dimensions to make simpler prototypes that demonstrate a concept.
4. Make it simple: Use simple materials; the goal is to test an idea or a concept quickly and cheaply so that you can improve the design.
5. Go big (or small): Build a full-scale version of the prototype. Something that looks good on paper may not feel good in your hand or be too small or big to manufacture.
6. Mix it up: Mix up your materials when prototyping—use anything that will make it easy to build and test your concept.

From Requirements to Specifications

1. Have students take turns getting feedback from each other (and mentors) about their ideas for creating prototypes.
2. Explain the difference between *requirements* and *specifications*. Requirements are general ways that the designer-engineer will meet the needs of the users. Specifications are more specific and often measurable needs for the product design; they serve as guidelines for designing and engineering the product.
3. Have students develop a set of specifications for their prototypes. Spell out in precise, measurable detail what the product should do and what is required in order to achieve this. This can be done by building on their chart that they developed for design requirements in *11B Handout, The Perfect Fit: Meeting Needs Through Design*. Ask a few students to share their design requirements charts and discuss the specifications that they might include in their charts.

14A: Prototype Planning (continued)

Name of Product: Bass Space

Brief Description: A device used to hold a beginner bass player's fingers together in the correct bass playing position.

User Needs	Design Requirements	Design Specifications
Device needs to fit different sized hands	Material needs to be ductile so that it can change form depending on size of hands	Thermoplastic material that can be molded onto one's hand

4. Remind students that as they plan their prototypes, they will have lots of sketches of their ideas before developing the prototype and may develop a few prototypes.

Wrap Up
Be sure that students have a clear idea of the difference between making a model and building a prototype.

Follow With
In *14B: Prototype Materials*, students consider materials for their projects.

Prototype Planning

Handout: Session 14, Activity A

Now that you have a model made, it's time to move on to the next step: building a prototype. Remember the differences between a prototype and a model. Plan your prototype in your design notebook.

> **Model:** A visual representation of a total design (or some aspect of the design) that is nonfunctional.
> **Prototype:** A working model used to demonstrate and test some aspect of the design or the design as a whole. A prototype is produced before the final version.

1. What ideas do you have for developing your prototype?

2. What suggestions do your peers have for you?

3. In *11B Handout: The Perfect Fit: Meeting Needs Through Design*, you should have come up with your design requirements. You are going to use those to develop design specifications. Requirements are general ways that the designer-engineer will meet the needs of the users. Specifications are more specific and identify measurable needs for the product design—they serve as guidelines for designing and engineering the product. Using the chart from *11B Handout* add specifications to the chart.

Name of Product: ___________________ Brief Description: _____________________

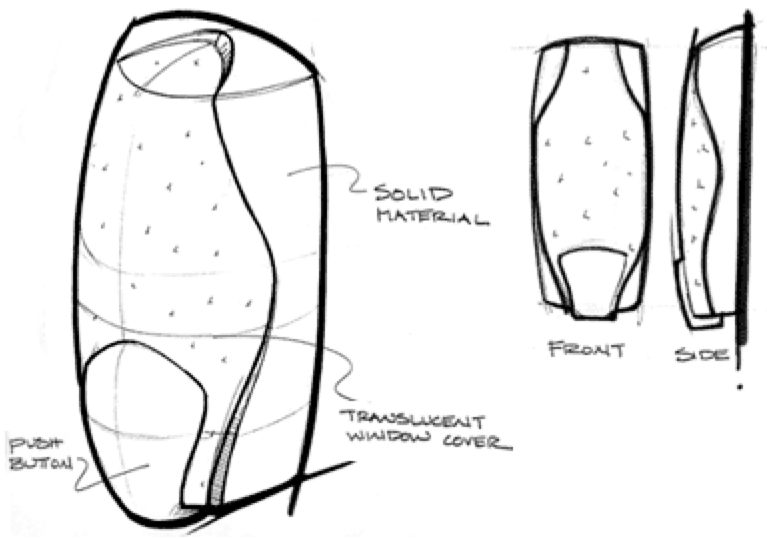
User Needs	Design Requirements	Design Specifications

ZIBA Designs a Soap Dispenser

Reading: Session 14, Activity A

ZIBA Design designed a new Dial* soap dispenser for commercial use in restrooms. Follow the process that ZIBA engineers and product designers used to develop this product.

Sketch of Dial Soap Dispenser



A new Dial soap dispenser needed to meet the following requirements:

- Dispenser has a semi-translucent cover for viewing soap levels.
- Dispenser uses a rounded push button for easy interaction.
- Spout needs to indicate where soap comes out.
- Space should be available on the inside of the cover for distributor label.
- The Dial brand should be recognizable.

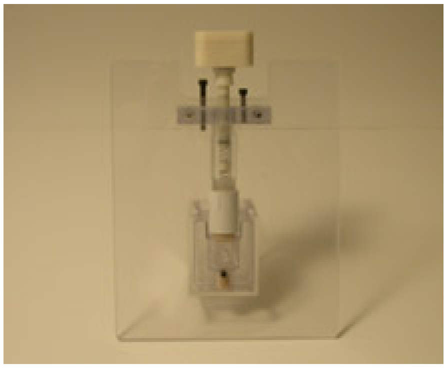
14A Reading: ZIBA Designs a Soap Dispenser (continued)

This first sketch shows the initial concept from a front, and side view.

Computer Model

This shows a computer model of the soap dispenser. A computer model is used to help product designers plan the design and dimensions more accurately than a hand-drawn sketch. This computer rendering is used to guide the development of the soap dispenser model.

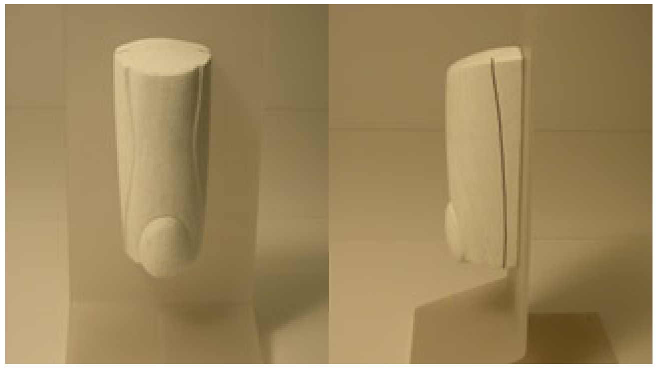
Mechanical Model



The next step is figuring out how the parts of the dispenser will work. In this case, a model was made of the mechanical component, the soap-dispensing mechanism. With this model, engineers can trial and test how the mechanism will work.

14A Reading: ZIBA Designs a Soap Dispenser (continued)

White Foam Visual Model

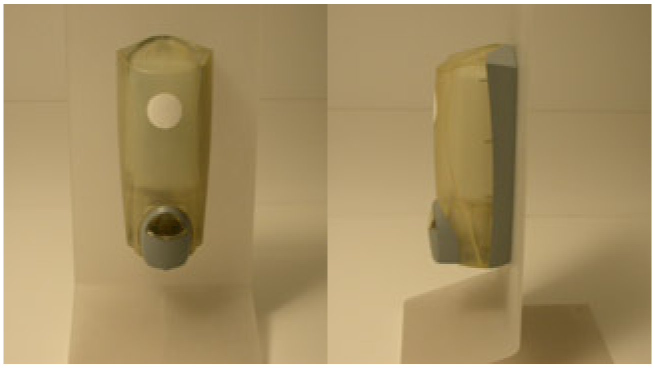


A white foam visual model is a quickly built model to evaluate early visual concepts and different product configurations. A white foam model is used for non-detailed, configuration explanation in the early phase of a design project. A front and side view are shown here.

Urethane Functional Model

A urethane foam model is a more detailed model used to evaluate a refined visual design. Details such as parting lines for manufacturing, and button details can be shown.

Mechanical Functional Prototype



14A Reading: ZIBA Designs a Soap Dispenser (continued)

A mechanical functional prototype is a complete mechanical and visual model used to evaluate all aspects of a product before proceeding to the manufacturing stage.

Production Product

The production product is the final design that rolls off the manufacturing line and is sold to customers.

Session 14, Activity B

Prototype Materials

Goal
Consider the materials for developing a prototype.

Outcome
Students decide what materials they will use for their projects.

Description
In this activity, students explore possible materials for developing their prototypes. Ideally, this will involve a visit to a local hardware store where they can get a sense of the materials available to them.

Supplies
Materials to demonstrate what may be used in prototypes:

- Wood
- Foam
- Plexiglass
- Metal
- Canvas fabric
- Bubble packing
- Cotton balls
- Duct tape
- Tubing
- Sandpaper
- Sponges
- Steel wool pads
- String or twine
- Glue
- Masking tape

Materials to demonstrate what may be used in prototypes: wood, foam, plexiglass, fiberglass, metal, canvas fabric, bubble packing, cotton balls, tubing, sandpaper, sponges, steel wool pads, string or twine, glue, masking tape, and duct tape.

Preparation
Invite a guest who is knowledgeable about materials, such as a machinist, a product designer, material engineer, handy person, and so forth.

Plan a visit to a hardware store in advance.

Bring in sample materials to show possible materials for prototypes.

14B: Prototype Materials (continued)

Procedures
Consider Materials

1. If possible, show sample prototypes and ask students what types of materials they see used. Remember that the goal of a prototype is to test and ultimately demonstrate how the final product will work.

2. Explain that material choice should be based on property characteristics of the design. For example, do they need a material that bends? Do they need something to be strong? It makes sense when choosing materials to think of it this way:

   Function → desired property → material selected

3. Have students sketch the prototypes that they are planning. In doing so, they should label the properties that each part of their prototypes requires. Then, have them refer to the properties' test results from *3A: Properties of Materials* and decide which class of material makes sense for each application. They may want to run material property tests to compare materials.

4. If possible, hold a feedback session with a guest expert on materials. In a whole-group discussion, have students share their ideas for their prototypes and the materials they are considering. They should also refer to their specifications to see what materials will meet these specifications. Ask for advice from peers and the experts.

5. Remind them that when selecting materials, it is important to consider the following:

   - How much does the material cost?
   - How big will the prototype be? How much of each material will they need to buy?
   - Where can they find the materials?

6. Explain that deciding what materials to use and where to find them will take some exploration. This exploration may include:

   - Taking a trip to a hardware store to get ideas
   - Looking at parts catalogs to get an idea of what's available
   - Talking to a variety of people about different options for materials

Wrap Up
Review students' material choices to be sure their selections are realistic.

Follow With
The next activity, *14C: Budget*, gets students planning their materials budgets.

Prototype Materials

Handout: Session 14, Activity B

Building a prototype can be fun and challenging. Here are a few tips to keep in mind:

1. Make it large enough. Remember that others will want to see the detail, and you will want to make sure all the parts work.
2. Pay attention to detail. Be sure that you show all the parts and components.
3. Make it strong. Use durable materials.
4. Make it "green." Use recyclable materials when possible.
5. Make it realistic. The prototype should be as close to the real product as possible.

Answer the following question to plan your prototype:

1. What materials are you considering using for your prototype?

2. Now, in your design notebook, draw a sketch of your prototype and label the materials.

Session 14, Activity C

Budget

Goal
Consider the budget for developing a prototype.

Outcome
Students create a budget for their materials using a spreadsheet.

Description
In this activity, students begin to develop a budget for their materials using a spreadsheet.

Supplies
Spreadsheet software program, computers

Preparation

1. Be sure, if you are going to have students develop budgets on a spreadsheet program, that you have enough computers with the appropriate software for students to do so.

2. You may want to set up a basic template that will help novice spreadsheet-users get started.

3. Decide what students' budgets will be (if you are providing the resources).

Procedures
Make a Budget

1. Get students started on a spreadsheet to prepare a materials budget for their project. Use an electronic spreadsheet program to do this. If students are not familiar with spreadsheets, this may take some time to explain how to set up a spreadsheet.

2. Include the following in the budget: material, quantity, and price. Students should list the materials that they selected in the previous activity, figure out how much they will need of each material, and the price for that quantity.

3. Depending on who is doing the shopping for the material (the facilitator or the student), students either give their budgets and materials lists to the facilitator or take them home to serve as a shopping list.

Wrap Up
Review students' budgets to be sure they are realistic. Discuss the Home Improvement activity, *Your Work Schedule*, which helps students plan their work time outside of class.

Follow With
In Session 15, *Develop It!* Students work on their prototypes.

Budget

Handout: Session 14, Activity C

Using a spreadsheet program, prepare a budget for your project. Include the materials, how much you will need of each material, the cost for each material, and the total cost.

Materials	Quantity	Cost
		Total Cost =

Your Work Schedule

Home Improvement: Session 14

Goal
Help students to structure concentrated work time for developing their prototypes.

Description
Students develop a method for structuring their time. This chart that shows progress of a project may be done electronically or on paper. The calendar should include their work sessions, class meetings, mentor meetings, science and engineering fair deadlines, and so forth.

Preparation
Bring in examples of calendars and other schedule organizers.

Procedures

1. Decide how you would like students to develop a calendar: Will you leave it up to them to choose or will you choose for them?
2. Provide examples of calendars and other schedule organizers.
3. Have periodic check-ins with students to see if they are on track. This may be done face-to-face or by email.
4. Suggest that students pair up with a partner for frequent check-ins to make sure they are both on track.

Next Day
Review students' calendars. Be sure to schedule regular meetings with them to check on their progress.

Your Work Schedule

Handout: Session 14, Home Improvement

By now, you will have set goals for yourself such as participating in a science fair. Because you will probably be doing much of the work for the remainder of the project at home, it is important to pace yourself and budget your time wisely. Creating a work calendar can help with this. Here are some suggestions for your calendar.

- Get a Yahoo personal account and use the Yahoo Calendar. http://calendar.yahoo.com/*
- If you use Microsoft Outlook* for email, you can use the calendar there.
- Make your own calendar.
- Use a store-bought calendar to plan your work schedule.

Things to include in your calendar:

- Work time and specific deadlines
- Personal dates such as vacations, family trips, and school events
- Class meetings
- Mentor meetings
- Partner check-ins
- Leader check-ins
- Science and engineering fair deadlines

Review your calendar and ask yourself:

- Do you have all fixed deadlines on the calendar?
- Do you have projected completion dates for goals and subgoals?
- Did you include research and information gathering time?
- Did you allot realistic time blocks to allow for setbacks?

Session 15

Develop It!

Prototyping

In This Session:

A) Prototype Work Session (150 minutes)
- Student Handout

Student designers' ideas take on new forms as they develop their prototypes. These should be working prototypes with full functionality. Of course, students may find that as they refine and test their ideas they develop several working prototypes. This session has one activity, *15A: Prototype Work Session*, devoted to prototype development.

Supplies

Materials to demonstrate what may be used in prototypes:

- Wood
- Foam
- Plexiglass
- Metal
- Canvas fabric
- Bubble packing
- Cotton balls
- Duct tape
- Tubing
- Sandpaper
- Sponges
- Steel wool pads
- String or twine
- Glue
- Masking tape

Tools

- Several sets of each: pliers, saw, hammer, screwdriver, hot glue gun, and tin snips

Session 15, Activity A

Prototype Work Session

Goal
Learn how to develop a working prototype.

Outcome
Build a working, fully functional prototype.

Description
Students work on their prototypes of the project. Be sure to have them keep records to document their progress. Encourage a culture of experimentation. The goal is not to get the prototype done, but to try out different ways that the product could work and find the best solution. Mentors should be available to assist with the development of prototypes.

Supplies
Materials to demonstrate what may be used in prototypes:

- Wood
- Foam
- Plexiglass
- Metal
- Canvas fabric
- Bubble packing
- Cotton balls
- Duct tape
- Tubing
- Sandpaper
- Sponges
- Steel wool pads
- String or twine
- Glue
- Masking tape

Tools
Several sets of each: pliers, saw, hammer, screwdriver, hot glue gun, and tin snips

Preparation
None

15A: Prototype Work Session (continued)

Procedures
Debrief Home Improvement

1. Check in with students to review their calendar from the Home Improvement activity in Session 14.
2. Show samples of students' schedules.

Work session

1. Discuss the purpose of a prototype. Refer back to the purposes from *14A: Prototype Planning*: learning, communication, integration, and milestones. Be sure to emphasize that prototypes are still part of the experimental stage.
2. Remind students that they are wearing two hats: that of an engineer and that of a designer. As an engineer, they should be sure that the prototype demonstrates that the product is feasible, possible, manufacturable, and cost-effective. As a designer, they should keep in mind the idea of user-centered design and continue to ask: Is it useful, usable, and desirable?
3. Have them take out their design specifications from *14A Handout: Prototype Planning* so that they can use the specs when developing their prototypes.
4. Reiterate the value of good records as they develop their prototypes. Remind them that they need to take the time to be methodical and write down what they plan to do and why.
5. Discuss the value of testing and data gathering. Give examples of kinds of testing and how to be systematic. For example, stress and load testing on straps. This can be done by adding successive weights to measure up to specifications. Determine how much weight the strap can hold.
6. Clean up and organize storage or transport of prototypes home for further work.

Wrap Up
Have each junior engineer stand up and show what he or she developed so far and state what he or she is planning to do next.

Follow With
In Session 16, *Test It!*, students develop the next stages of the project.

Prototype Work Session

Handout: Session 15, Activity A

It is helpful to keep good records of your prototyping efforts. Good records allow you to adjust your design based on what you learn from each step of the process. The questions below can help with this record keeping.

Plans
How do you plan to build your prototype

Purpose
What will this prototype be able to do?

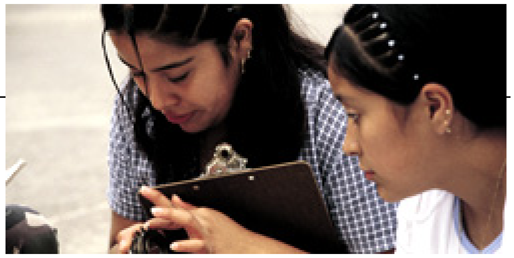
Testing
Will the prototype meet your specifications? How will you test this and what data will you gather?

Next Steps
What do you want to do next? Adjust this prototype? Build another version of this prototype?

Session 16

Test It!

Prototyping



In This Session:

A) User Testing (90 minutes)
- Student Handout

B) Evaluation and Revision (60 Minutes)
- Student Handout
- Student Reading

Being an engineer requires trial and error! Students learn this as they continue with the design process: Step 8, Build a Solution Prototype and Step 9, Test, Evaluate, and Revise. As they develop working prototypes, students test and evaluate the prototypes for function, feasibility, safety, and aesthetics, and make modifications. This process of testing and modification continues until they have a final working prototype. In the first activity, *16A: User Testing*, students gather feedback from users as they try out their ideas on an audience. In *16B: Evaluation and Revision*, they consider the feedback from the user testing and prioritize the revisions.

Supplies

None

Session 16, Activity A

User Testing

Goal
To get user feedback on function, appeal, and value of the product.

Outcome
To know if the product does what it is supposed to do.

Description
Developing a product does not happen in a vacuum. It is important to remember that the goal is to develop something that others will use. In this activity, students conduct user testing to determine their next steps.

Supplies
None

Preparation
Invite a variety of people to participate in user testing. Ideally, you will ask students to characterize a typical user of their product (as they did in *8A: User Profile*) and invite people who represent these users.

Review user testing rules for Intel ISEF-affiliated fairs if students are participating in a fair, www.sciserv.org/isef/students/wizard/index.asp*.

Procedures
User Testing Techniques

1. Ask students to refer back to *8A Handout: User Profile* and *11B Handout: Meeting Needs Through Design*. Have them look at the user characteristics and scenarios that they created. Ask them if this has changed, and if so, who their user is now.

2. Explain that they will conduct user testing to see how their product is received by others.

3. Remind them that when they talk to users, they will need to step away from their personal involvement and understanding of the product and focus on the user. They should listen carefully to what people say, jot down notes, and then decide which comments seem helpful and valid, and which do not.

4. Testing more than one prototype is preferable because the comparison helps people see what they like and what they don't.

5. Explain that the best feedback comes when the designer is as invisible as possible. They can give the user the minimum information necessary and then let the user try the prototypes. The designer should step back and observe.

16A: User Testing (continued)

6. After giving the user time to use the product, designers may ask questions. Be sure that these questions are objective and do not contain any biases. Another strategy is to have the user verbalize what he or she is doing and thinking while trying out the product.

User Testing Strategies

1. When observing, designers should look for:

   - What does the user do with this product?
   - What are the user's perceptions of the product?
   - How successful or unsuccessful does the user think the product is?
   - How does it meet or fail to meet the user's needs?
   - How safe is the product?

2. When interviewing, designers can ask the following questions:

   - What do you like and dislike about this product?
   - What do you think this product should do?
   - What could be done to make you want to use this product more?
   - What do you think of the way this product looks (the aesthetics)?
   - Is this product efficient, safe, and comfortable to use? If not, how could it be improved to make it more ergonomic?
   - What do you see as some problems with this product?
   - What can be done to solve these problems?

3. If students are participating in Intel ISEF-affiliated fairs, be sure that they understand the user testing rules. They can look at the ISEF Rules Wizard, www.sciserv.org/isef/students/wizard/index.asp*. This site indicates specific instructions and safety precautions for testing on humans or nonhumans, the testing location, types of testing, groups to be tested, and chemicals involved in testing.

4. Conduct user testing.

Wrap Up
Discuss how students will use the feedback from the user testing.

Follow With
In *16B: Evaluation and Revision*, students analyze the feedback from their user testing and plan their next steps.

User Testing

Handout: Session 16, Activity A

User testing will help you to know if your product does what you want it to do. For example, does it work the way it is supposed to? Do people like the way it looks? It's best to conduct user testing with people whom you think will be using this product and have more than one prototype (if possible) for them to compare.

In order to make the user testing most useful, answer the following questions and select appropriate people to do the user testing and appropriate conditions to conduct the testing.

1. Who will be the users of your product? Refer back to your characterization from *8A: User Profile* and *11B: The Perfect Fit: Meeting Needs Through Design*. Note if this has changed or not.

2. Where will they use your product?

During user testing you will probably want to ask questions, observe the user, and listen to the user explain what he or she is doing while trying out the product.

Sample Questions

1. What do you like and dislike about this product?

2. What do you think this product should do?

3. What could be done to make you want to use this product more?

4. What do you think of the way this product looks (the aesthetics)?

5. Is this product efficient, safe, and comfortable to use? If not, how could it be improved to make it more ergonomic?

6. What do you see as some problems with this product?

7. What can be done to solve these problems?

Additional Questions
Write your own questions in your design notebook.

Observations

1. What does the user do with this product?

2. What are the user's perceptions of the product?

3. How successful or unsuccessful does the user think the product is?

16A Handout: User Testing (continued)

4. How does it meet or fail to meet the user's needs?

5. How safe is the product?

Additional Observations
Add other observations to your design notebook.

Other Notes
What else will you be looking for?

Session 16, Activity B

Evaluation and Revision

Goal
Evaluate feedback from user testing to plan changes to the prototype.

Outcome
Students will have conceptualized and prioritized changes to their prototype.

Description
Students plan their modifications based on the valuable feedback from user testing.

Supplies
None

Preparation
None

Procedures

1. Students should use the chart on the handout to categorize and prioritize the feedback they received from their user testing.

2. Next, have them plan which revisions they will make and how they will make these changes.

3. Students can get feedback from their peers and/or mentors in planning their next prototype.

4. They should consider additional materials they will need and make any necessary changes to their budgets.

5. Check in with each student to ensure they are on track.

6. Remind them to continue work on their prototypes at home.

Wrap Up
Review the charts and discuss what changes are realistic.

Have students read *16B Reading: Meet a Project Manager*.

Follow With
Session 17, *Fairly There*, helps students and facilitators make presentation decisions.

Prototype Materials

Handout: Session 16, Activity B

Now that you have feedback from your user testing, you need to organize the information in order to figure out which suggestions you will incorporate into your revisions. Make a chart in your notebook. After completing the chart, decide which revisions are most feasible and what your process will be.

Priority - Decide how this problem ranks.

H = High Priority
M = Medium Priority
L = Low Priority

Problem - Describe the problem.

Criteria - Decide what type of change it is:

- Functional
- Safety
- Aesthetics
- Feasibility
- Other:

Revision - Describe what changes would be needed.

Priority	Problem	Criteria	Revision

Meet a Project Manager

Reading: Session 16, Activity B

Michael Moon
Project Manager
ZIBA Design

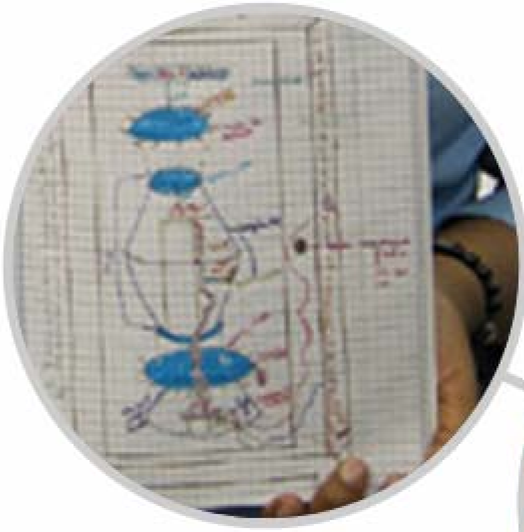
Introduction
My name is Michael Moon, and I'm one of ZIBA Design's project managers. I've been here about four years, working in both the research and interactive groups before becoming a dedicated project manager. My role can be summed up as "the guy who makes sure our work makes it to market."

A Typical Day
As a project manager I work with the project team to create a schedule, set deadlines, and define deliverables. I'm also the clients' main contact, working with them to understand their needs and making sure we can meet them. At the end of the day, it's my job to make sure that projects finish on time and on budget, while maintaining the high quality of work ZIBA Design is known for.

Background
My background is not typical for someone in this industry. I studied at Cornell University, majoring in English, economics, and political science. Though this is not the recommended education for someone seeking a job as a designer or engineer, the breadth of my studies, combined with a lot of exposure to technology growing up, allowed me to apply my skills to user research and design planning, as well as to developing the structures behind Web sites and computer applications.

Favorite Things About Job
The best part about my job is seeing the projects I've worked on make it onto store shelves, into product catalogs, and onto the Web. Because we put so much effort into understanding the way people work, what they need, and the kind of experiences that can improve their lives, seeing our work making a difference is the ultimate reward.

About ZIBA Design
ZIBA Design is an international design firm that has designed products from many global companies, including FedEx, Microsoft, Intel, Fujitsu, Black & Decker, Sony, Pioneer North America, Dial, and Clorox. www.ziba.com*



Design and Discovery

Final Presentations

Design and Discovery culminates with students showcasing their projects. *Session 17: Fairly There* describes the different types of fairs that can be planned, including information on how students can participate in an Intel ISEF-affiliated fair (International Science and Engineering Fair). Students are also given direction on how to prepare a display board for a fair. Fair preparation continues as students practice presenting to their peers in *Session 18: Dress Rehearsal*

Session 17

Fairly There

Final Presentations

In This Session:

A) Fair Choices (60 minutes)
- Student Handout: Solutions Showcase
- Student Handout: Mini-Engineering Fair
- Student Handout: Intel ISEF- Affiliated Fair
- Student Reading: Intel ISEF Finalists
- Student Reading: Interview

B) Design Your Display (90 Minutes)
- Student Handout

Fairly There helps students prepare for the fair. Before beginning the session, facilitators should read through the session and decide what type of fair they wish to have the students do: a Solutions Showcase or a Mini-Engineering Fair. They should also familiarize themselves with the Intel International Science and Engineering Fair (Intel ISEF).

In the first activity, *17A: Fair Choices*, students learn from past fair participants and an engineer about the benefits of participating in a science fair. This introduces fairs to the students, and they organize committees to begin planning for the event. The second activity, *17B: Design Your Display*, is a work session where students prepare display boards for the fair.

Supplies

- Science/engineering fair forms
- 3-panel display boards
- Scissors
- Colored paper
- Rubber cement
- Markers
- Scrapbooking supplies
- Glue sticks
- Other art materials

Session 17, Activity A
Fair Choices

Goal
Learn what is needed to participate in a science/engineering fair and begin to plan for participation.

Outcome
Students begin preparing for the fair that they are going to participate in.

Description
Here's an opportunity to become inspired by former Intel International Science and Engineering Fair (Intel ISEF) participants and a young woman whose science camp and science fair experiences inspired her to pursue a career as an engineer. After students hear from these young engineers, they plan their own fair.

Supplies
Science/engineering fair forms

Preparation
Decide which fair(s) you would like to prepare for. More information on each of these is available in Participating in Fairs .

- Intel ISEF-affiliated fair
- Solutions Showcase for parents and community members
- Mini-Engineering Fair for younger students and peers

In advance, conduct research on science and engineering fairs to determine which fairs your students could participate in. These might be regional, local or even school fairs. It is important to note that all participants who attend the Intel International Science and Engineering Fair (Intel ISEF) must participate in and be selected by their local Intel ISEF-affiliated fair. Each affiliated fair can send two individual project finalists and one team project to compete in the Intel ISEF. More information about Intel ISEF-affiliated fairs is available at Science Service, www.sciserv.org/isef/aff_fairs*. Also, be aware that participating in an Intel ISEF-affiliate fair with an engineering project will require some adaptations to fit the scientific methodology.

Prepare copies of necessary paperwork for the science/engineering fair.

If possible, invite a local science/engineering fair representative to answer students' questions about the fair.

Procedures
What Is a Science/Engineering Fair?

1. Ask students if any of them have participated in a science fair. If so, have them share their experiences.

17A: Fair Choices (continued)

2. Discuss the purpose of science fairs—conduct a brainstorm of students' ideas.

Science/Engineering Fair Testimonials

1. Have students read *17A Reading: Intel ISEF Finalists*, which profiles three projects:
    - Crayon Creations
    - Recycled Plastic
    - To Live or Not to Live? A Machine to Test for Signs of Life in a Chicken Egg
2. Students can also see more Intel ISEF student and project profiles at Intel ISEF Profiles of Success, www.intel.com/education/isef/profiles.htm.
3. Discuss these examples and what students think made these projects Intel ISEF finalists.
4. Ask students what the participants gained from their experience.
5. Have students read and then discuss *17A Reading: Engineer's Inspiration: Interview With Jenna Burrell*. Ask students to consider influences, both people and events, in their lives. Do they have a mentor? What is the value of mentors?
6. Now refer to one of the following (depending on which you plan to have your students prepare for).

A Solutions Showcase for Parents and Community Members

1. Consider having a volunteer student committee plan the details of the event, such as guest speakers, common dress or standard of dress, snacks, sequence of events, and room arrangement.
2. Students might like to make individual invitations for family, friends, and their mentors. Have the details of date, time, place, and duration of the event on display for them to copy.
3. A chalkboard or chart pad in the presentation area should be set up so students can write or illustrate key points of their presentation as they talk.
4. Assign photography duties to a parent volunteer, and ask that they photograph each student during presentations.
5. Optional: Make a computer slideshow, with a few slides for each student. The slideshow can serve as a backdrop for each student during his or her presentations. It might

include a drawing or photograph of the design, design specifications, or other information that supports the presentation.

A Mini-Engineering Fair for Younger Students and Peers

The Audience

1. Discuss who will be invited to the engineering fair. This may be decided by the leader, or in some cases, by the students.

2. Possible audiences include peers, younger students in a similar program, community members, and parents.

The Format

1. Discuss the format of the event, including the time, length, and location—these may be predetermined.

2. Explain the purpose of the event:
    a. To recognize students' hard work and celebrate their accomplishments
    b. To share engineering expertise with others
    c. To practice presenting projects to an audience in a similar format as an Intel ISEF-affiliated fair
    d. To get feedback on their projects: display boards, prototypes, and presentations
    e. To participate in a service project

3. Consider inviting a keynote speaker to the event. This might be a community figure or an engineer, for example.

Committees

1. For more efficient planning, divide students into the following committees to plan the engineering fair.

    - Logistics: This committee is responsible for room layout, student assignments/rotations, organization, prizes, and food.
    - Advertising: This committee is responsible for promoting the event. This may take the form of flyers, newsletter/newspaper articles and advertisements, posters, emails, or a bulletin on the school TV network.
    - Engineering activities: This committee is responsible for selecting and structuring the engineering activities for the visitors. These may include scaled-down versions of some of the activities done during *Design and Discovery*, such

as *1A: Build a Better Paper Clip*, *2D: SCAMPER and Backpack*, or *5C: Gears, Cranks, Crankshafts, and Belts*. Younger students may want to choose some activities from the PBS program, Zoom Into Engineering*, www.asce.org/150/zoom.html*. This group is responsible for getting the material list to the leader.

- Passport Scavenger Hunt: This committee is responsible for planning and creating the Passport Scavenger Hunt. A passport is given to each visitor and includes specific questions about each project. When the visitors ask the questions, they get a stamp from each project. Each visitor with a complete passport gets a prize. This group will need to collect and compile questions from all the groups. If there will be different age groups of students at the fair, they may need to prepare different age-appropriate passports. They can get creative with the passports—include photographs of the projects, and so forth.

2. All groups: Set aside 5 minutes at the end of the session for each committee to share their plans. Tell students that they need to write up questions about their project for the passport scavenger hunt. Depending on who is invited to the fair, students may need to write different questions for different age levels.

An Intel ISEF-Affiliated Fair

1. Having already decided which fair you would like students to participate in, distribute the forms for students to fill out. This may require them to get parent signatures. Also, they may want to wait awhile until they are absolutely sure about their project before completing the forms. Review the forms in detail.

2. If possible, invite a local fair representative to answer questions about the fair.

3. Be sure that local fair dates and deadlines are clearly communicated.

4. Have students complete the handout.

5. Note that it is highly recommended that, even if students prepare for an Intel ISEF-affiliated fair, you still have a culminating fair for *Design and Discovery*.

Wrap Up
Allow time for students to ask questions about the science/engineering fair.

Follow With
In *17B: Design Your Display*, students create their display boards.

Solutions Showcase

Handout: Session 17, Activity A

You will have the exciting opportunity to share your ideas with an audience. The group will decide who to invite.

The details of the showcase are:

Date:

Time:

Location:

1. What committee are you on? What does your committee need to do?

2. You may be asked to prepare a slide for a slideshow. If so, plan it with storyboards in your notebook.

Mini-Engineering Fair

Handout: Session 17, Activity A

In order to prepare for the Mini-Engineering Fair, you will join a planning committee. Depending on the committee you are on, your responsibilities are the following:

Logistics
This committee is responsible for planning the organization of the event.

1. Room layout: How will the room be arranged? Where will the display boards be? Where will the engineering activities take place?
2. Student assignments/rotations: What assignments will there be, such as greeters, activity leaders, and so forth?
3. Organization: What will be the order of activities for the event? How will everything be organized?
4. Prizes: What type of prizes will there be? Where will you get them? You may want to consider trying to get prizes donated from a business.
5. Food: Will you serve food? If so, what?

Advertising
This committee is responsible for promoting the event. This may take the form of invitations, flyers, newsletter/newspaper articles and advertisements, posters, emails, or a bulletin on the school TV network.

Engineering Activities
This committee is responsible for selecting and structuring the engineering activities for the visitors. These may include scaled-down versions of some of the activities done during *Design and Discovery*, such as *1A: Build a Better Paper Clip*, *2D: SCAMPER and Backpack* , or the crankshaft toy for example in *5C: Gears, Cranks, Crankshafts, and Belts*. Younger students may want to choose some activities from the PBS program, Zoom Into Engineering*, www.asce.org/150/zoom.html*. Be sure to give a materials list to the leader so that he or she can get the materials for the event.

Passport Scavenger Hunt
This committee is responsible for planning and creating the Passport Scavenger Hunt. A passport is given to each visitor and includes specific questions about each project. When visitors ask the questions, they get a stamp from each project. Each visitor with a complete passport gets a prize. This group will need to collect and compile questions from all the groups. Depending on the age of the visitors, you may need to create different passports for different age groups. Be sure to make enough copies of the passports for all the intended visitors. Feel free to get creative with the passports.

Everyone
Develop questions about your project to include in the passport. You will need to write different questions for the different ages of children who will be at the fair. Give questions to the Passport Scavenger Hunt committee.

An Intel ISEF- Affiliated Fair

Handout: Session 17, Activity A

Science/engineering fairs offer an opportunity for you to share your ideas, be recognized for your hard work, and compete for prizes. Participating in a fair requires advanced planning and being aware of and closely following the guidelines. Complete the following information to help you get started with the planning process.

1. What is the date of the local fair?
2. Where is it held? What is the address?
3. Who can I contact if I forget or need more information?

   Name:
   Phone Number:

4. I have completed the following forms:
5. The name of my adult sponsor is:
6. I have a pretty good idea of what more I have to do to be ready for entering the local science fair. Here are the things I still need to do:

Intel ISEF Finalists

Reading: Session 17, Activity A


Crayon Creations
Meghan
Malvery, Arkansas, U.S.A.

The Inspiration

Meghan is an Intel ISEF "old timer," having competed for two years. In her first year, Meghan designed "Crayon Creations" to recycle old crayons. Her dad is an art teacher at an elementary school for the deaf, and she felt the students wasted too many crayon bits in his class. She wanted to devise a way to melt the broken pieces of crayons into new shapes using a simple machine and invented Crayon Creations.

The Original Crayon Creation Machine

In her first year, Meghan invented a chrome crayon machine that:

- Melted crayon bits into interesting new shapes
- Used safe heat from a light bulb
- Could be completed in a day
- Was easy enough for young children to use
- Made crayons that kids would actually choose to use again

Overcoming Roadblocks

Meghan notes, "I had one teacher who did not think the idea was worth pursuing. She was a roadblock. But I knew it was a good idea and kept at it. When I won at state she finally said, 'Good job.' My dad supported me. I've had a lot of fun. It's meant a lot of long nights, and hard work, but it's been a really good payoff."

17A Reading: Intel ISEF Finalists (continued)

Design Improvements
In her second year, Meghan wanted to continue her research on Crayon Creations. She wanted to make improvements to the machine from the prior year. The modifications include:

- Three "hoppers" and feeding tubes so that more crayons can be melted at a time
- Plastic tubing for feeding tubes instead of brass so that it is possible to tell how full the machine is (and to give the machine more visual appeal)
- Pop rivets to attach the hoppers to the machine instead of a metal epoxy, to make the machine more durable
- Addition of a dimmer switch to control heat from the light bulb and air temperature inside the machine
- Addition of a thermometer to measure the inside temperature of the machine

Definition of Success
"I wanted a two-year-old to be able to use it and I've done that this year. I have a friend that has a two-year-old son and he plays with it and he loves it!"

Recycled Plastic: The Building Blocks of Tomorrow Phase II
Amanda
Moultrie, Georgia, U.S.A.

The Product
Amanda set out to produce a replacement for conventional bricks. The new bricks are made of recycled plastic soda bottles and will lessen plastic's impact on landfills. Amanda is now 15 years old yet first thought of her idea two years ago. To make her "Building Blocks" the first year at Intel ISEF, Amanda mixed cement, sand, and recycled plastic soda bottles. In her second year, Amanda's goal was to find an aggregate to replace sand that would increase the strength of the bond between the plastic and cement. She tested her new bricks for strength and

17A Reading: Intel ISEF Finalists (continued)

durability. The tests performed included: water and sound absorption, thermal conductivity, and compression strength. Her product met or exceeded industry standards for conventional brick and concrete blocks in all tests that were performed—now that's a success story!

Lightbulb Moment
"I was watching a home improvement show, and I saw that they were creating boards for decking. They'd used Styrofoam*, taking out the air and mixing it with sawdust. So they had this new board that wouldn't warp and absorb water. The next day the show was about mortaring brick and the brick-making process. I thought if there was some way that you could combine these two, it'd be a very good thing for the environment. I began to research this project and noticed that landfills were overflowing with garbage. Eleven percent of the weight and 24 percent of the volume in landfills is plastic. Type I plastic, the kind used in soda bottles, is the most common plastic in landfills, so it's the most accessible. If you're going to take some of that out you can prolong the life of the landfill. I decided to use plastic as the recyclable material in my bricks."

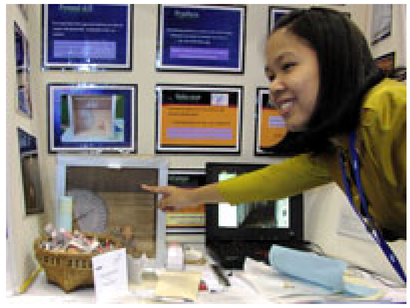
"Building Block" Benefits

- Prolongs the life of landfills by reducing the amount of plastic disposed
- Manufacturers can receive tax incentives from the government for producing recyclable products
- Recyclable products are in demand by the public
- Superior sound absorption makes the product ideal for retaining walls near freeways

This Year's Breakthrough
Amanda explained that last year the plastic and the cement did not stick to each other well. This year she thought of using clay. Because it has the same chemical composition as sand but is finer, the brick's components adhere much better. About her breakthrough idea, Amanda says: "My dad was taking me home from school and on the highway they were building a technical college. As we passed it, he looked over and said, 'there's a lot of red clay right there.' I wondered if that would work instead of sand. It was out of the blue. We went to get some clay, tried it, and it worked!"

Support
"I had a lot of parental support because both my parents are teachers. My dad's a math teacher so he helped me out with the equations that I didn't understand.

17A Reading: Intel ISEF Finalists (continued)



To Live or Not to Live? A Machine to Test for Signs of Life in a Chicken Egg
Atchavadee
Nakhon Ratchasima, Thailand

Invention Inspiration
"We live in the city but we have a hen and a rooster at our home. I wanted to test the eggs to see which to incubate."

The Problem
Atchavadee explained: "At present, testing whether the embryo in a chicken egg has developed and is alive, is done by visual inspection, by holding the egg against a light source and observing how well the tissue has developed. This method can only be used reliably during the first 3-15 days after the egg has been laid and its accuracy depends to a large degree on the expertise of the inspecting individual."

Invention Design
"Our machine is based on the observation that a living embryo is moving continuously. The egg is placed onto a spring that is set in motion by the embryo's movement. An attached needle makes these vibrations visible, and a sensor converts them into digital signals that are fed into a computer for visual display and further processing."

"Tests have shown that our machine can be used reliably from the twelfth day after the egg has been laid onwards. Being portable, it is well suited for practical applications, and it can easily be enlarged to handle many eggs at a time."

Support
"My father is in the Department of Livestock—he helped me with biology—and my mother is a teacher."

Path to Intel ISEF and Future Plans
Atchavadee was the winner in Thailand of Intel ISEF and has applied for a patent for her invention in Thailand. In the future, she may study math or engineering because it's fun and because she enjoys making and designing things.

An Engineer's Inspiration: Interview with Jenna Burrell

Reading: Session 17, Activity A

Who Is Jenna Burrell?

Jenna Burrell is a young woman who is an Applications Concept Developer for Intel's People and Practices Research (PaPR) group. The group is composed of engineers, designers, psychologists, anthropologists, and social scientists who give Intel a fresh perspective on designing technology that meets real world needs. They do so by engaging in ethnography; the study of people to observe what people really do in their daily lives. In doing so, they are looking for new concepts to develop things that people can use. Essentially, the group provides insights into the relationship between human behavior and technology.

Here's what Jenna Burrell has to say about the work she does.

People and Practices Work Group at Intel

We are in charge of going out and exploring environments, lifestyles, and the work processes of people. We don't necessarily think about technology, but just look at people and how they do their jobs, you know, how they keep themselves entertained, even in other countries. For example, other people in the group have studied families in Europe and recently studied people in Latin America.

After interviewing and exploring an environment, the next step is to take the needs people have—needs they may not even be aware of—and see if there are ways that technology can aid those work processes or help people in those different environments. We are trying to find new places for computing technology in a way that makes sense.

Burrell's Current Project

I am looking at alternative environments for technology. Right now I'm doing a study on computing in agriculture. We [the People and Practices Research group] spend some time visiting local vineyards and interviewing vineyard managers, workers, and wine makers. Out of that we've come up with an idea for a way of sensing information in the vineyard. I've been responsible for programming these little sensing devices to detect temperature and keep track of that kind of information over time and to communicate wirelessly. The hardware for the device was originally designed at UC Berkeley, and we are trying to take it to the next step—from hardware to something that actually has an application.

17A Reading: An Engineer's Inspiration: Interview with Jenna Burrell

Burrell's Role in Her Work Group
I do just about every part in the process: interviewing, concept or idea development, and programming. I have a bachelor's degree in computer science, but I tried to structure my undergraduate program so that it was very interdisciplinary because I was also interested in social science and art. I also took a lot of psychology and organizational behavior classes.

I got my start working in manufacturing at Intel as an intern. I spent a summer studying fabrication technicians (the people wearing the "bunny suits" in the manufacturing "clean rooms") and their work process and how automation technology was or wasn't supporting that work process.

Working in a Group
As a group we all try to cross-pollinate and share ideas and talk about the themes we think are interesting. All day long, people are constantly emailing links to news articles or things like that. I think a lot of my projects come out of my personal interest. Since I am a woman in engineering, I think it's great that I'm able to take what interests me, bring it in, and try to open other people's eyes to what's interesting or valuable about that trend or technology.

What's to Love About the Job
I love the diversity and flexibility of my job. I pretty much pick my own projects so I can figure out what I'm interested in and go after them. We try to accomplish something significant in a three-month time frame but then, if it's going well, I might pick a second stage of the project and continue for another three months.

Early Influences on Career Choice
We always had a computer in the house. I had unrestricted access to computers my whole life and I got a lot out of it. I programmed and designed Web pages early on. It was always a hobby that I was really passionate about.

I was also involved in a number of different programs: I did science fairs in middle school. I liked them, although it was always hard picking a topic, but once I got going it was always really interesting. I liked being self-directed and pursuing my own questions and structuring a whole study. For the eighth-grade science fair, I was looking for evidence of ice age floods in a local nature preserve. I did all sorts of data gathering in the field and took pictures. I had a science teacher who said, "This is really good. You should consider pursuing science further in high school and as a career." I liked that project but don't think I took it that seriously until he made that comment.

The summer between eighth and ninth grade, I participated in Pacific University's science camp for girls. This was another experience where I said to myself "Oh, people think I should pursue science and I like it and maybe that makes sense, I mean, it's certainly a practical thing to do—there are good job prospects..." At the science camp, I got along well with all the girls involved, and it was rewarding in that sense. We did a lot of fun interesting projects. For instance, we built a telescope out of cardboard and some little lenses and stayed at the beach for the weekend to look for tide pools. We also worked with computers. At that point, I think I realized I had above-average knowledge of computers. I already knew how to work with databases and spreadsheets so I thought "Okay, I guess this is an aptitude that I have—that's good to know."

Two professors ran the camp. They were both women, and one was a physics professor. In fact, everyone involved in teaching and running the program was in science. That was valuable.

School Choices
In high school, my parents encouraged me to take science classes so I took physics and advanced chemistry and biology.

When I decided to go to college I was interested in art and computer science about equally. I thought computer science sounded like a bit easier path in life because after graduating there would be no question that I'd have somewhere to go. I continued to feel like I had an aptitude for computer science in my early college computer science classes. Some people were struggling yet I seemed to be doing fine, so I kept going.

Recent Graduate of Cornell University
I graduated in 2001 from Cornell University. I grew up in Oregon, went away to school, and now I'm back. I don't consider myself to be purely an engineer just because I do so much of this other work. I think that it is a really good fit for me because I've got broad interests. I like engineering, but I also like talking to people, exploring vineyards, or wandering around Intel fabrication sites!

Mentors Important in Career Development
I benefited from a lot of great mentors. The summer I spent as an intern with Intel, I had a manager who understood my interests and my abilities. He was the person who asked me to do the project studying the fabrication technicians and their work process. He was very sensitive to the kind of person I was and what my interests were and was able to find me the position within Intel that really fed that interest.

I also worked in a research lab at Cornell University, the Human Computer Interaction Lab. The professor that ran the lab was also really encouraging. For example, I did this project design "Location Aware Hand-Held Tour Guide," and she encouraged me to do things like write papers and submit them to conferences. Just having someone say "this is the next thing I think you should do," and "I think you can do it" helped a lot. In fact, I remember one day she came into the lab and said, "You should write a paper about this and submit it to the Universal Usability Conference" and handed me the guidelines. So I went home that weekend and wrote up what I'd been doing and what my findings were and submitted it to the conference. I got in, went to the conference, and presented my paper! Having that extra kick was really great.

Advice
Girls: Go where the boys are—more women are needed in computer science and engineering. I learned how to relate to guys really well because I didn't have any choice. There were just more men than women so I was around a lot of guys, not only in computer science, but in my math and science classes. I always thought, "this is stupid—there should be more women here", but I don't think I ever felt intimidated or out-of-place. From a social aspect though, it would have been nice to have more girls.

Session 17, Activity B

Design Your Display

Goal
To create presentation boards for the fair.

Outcome
Students summarize their projects on presentation boards. This work party gets students started on their presentation boards for the fair. In the process, students learn some graphic design principles.

Supplies

- 3-panel display boards
- Scissors
- Colored paper
- Rubber cement
- Markers
- Scrapbooking supplies
- Glue sticks
- Other art materials

Preparation
In advance, tell students to bring things they may want to put on their boards.

If possible, arrange for a graphic artist to visit, explain graphic design principles, and help with the boards.

Procedures

1. Each student (or project group) should be given a 3-panel display board.

2. Using a sample display (or other design samples), conduct a mini-lesson on design principles (or have a graphic artist present them.) Review the design principles on the handout, asking the junior designers to point out examples of the design elements on the sample.

3. Before beginning the display boards, suggest that students create a mock-up version to follow.

4. Discuss the purpose of the presentation boards and the types of pieces that can be included on the boards.

    - Typed description of the problem and solution
    - Photographs of different stages of the project
    - Graphs showing survey results
    - Project explanations (tests and revisions)

17B: Design Your Display

- Design brief
- Sketches

5. Now, have a work party for students to begin working on their displays. It is useful to have computers and printers available to make charts, do word processing, and so forth. You may need to show students how to make charts.

Wrap Up
Students will probably need to complete their presentation boards at home. Tell them that at the fair, they should be prepared to answer people's questions!

Follow With
In Session 18, *Dress Rehearsal*, students get ready for the fair.

Design Your Display

Handout: Session 17, Activity B

You will now design your display for the fair. If you are planning to participate in another science fair, this will give you an opportunity to practice and get feedback on your project and display. When designing your presentation board, it is important to keep in mind several design principles. Attention to the principles of graphic design will make your presentation more exciting and easier for others to use. Good design should attract viewers' attention to your project, and then guide their understanding of the information you wish to convey.

Consistency

- Establish a style for your display and stick to it. Too much variation will make your display seem disjointed. Be consistent with all the elements.

Clarity

- Keep questioning whether your message is being conveyed clearly. Do the illustrations and charts convey what they are supposed to?
- Think about the clarity of your visual presentation. Is it cluttered? Question any possible unnecessary elements like cute stickers, doodles, patterns, etc.

Attention to Detail

- Judges will notice if a display has grammar and spelling errors. Get people to proof your work.
- Make a checklist of the points you want to cover in your display and double-check that you present each.
- Make sure all your pieces are cut out with straight lines (use a ruler) as this will make your presentation look more polished and professional.

Elements of Your Design

Color

- Limit your color palette to two or three colors. Use tints and shades of these. A large number of colors make designs seem less planned and inconsistent.
- Determine how color will be used and why. For example, you might want all your headers to be one color and text blocks to be another, so the headers will stand out.
- Keep in mind that different colors have different connotations and a power of their own. For instance, red usually demands attention. It can be used effectively for this purpose, but only if used in moderation.

Type

- Pick only one or two fonts for the text so your display will look consistent and unified. A large number of fonts, like too many colors, can seem disjointed and confusing.
- Decide on one or two techniques for emphasis in your type style. Some possibilities are: bold, italic, all caps (capitalizing all the letters of a word), color, and choice of font.
- Don't use underlining if you have italic available. Underlining was designed to represent italic for typing since typewriters don't have italic.

17B Handout: Design Your Display

- Avoid writing words vertically (with the letters stacked) as this will minimize readability.
- All caps are less readable than standard text, so if you choose to use them, do so only with small quantities of text, such as titles.
- Narrow columns of text are easier to read than wide columns of text. Left-justified or full-justified text is easier to read than centered text (for longer items).

Session 18

Dress Rehearsal

Final Presentations

In This Session:

A) Presentation Prep (70 minutes)
- Student Handout

B) Take One! (60 Minutes)
- Student Handout

C) Fair Logistics (20 Minutes)
- Student Handout

Home Improvement
- Student Handout

Get ready for the big event! In this session, students plan their presentations in *18A: Presentation Prep* and practice them before their peers in *18B: Take One!* Friendly feedback from peers helps students further refine their presentations and get ready for the fair. In *18C: Fair Logistics*, the final details are worked out, and the venue is prepared for the fair. The Home Improvement activity, *Project Reflection*, gives students the opportunity to reflect on their own progress and their experience in *Design and Discovery*.

Supplies

- Flip chart and markers
- Video camera
- Tripod
- Videotapes (one 15-minute tape per student)
- Supplies for hands-on activities (if needed)
- Copies of Passport Scavenger Hunt (if needed)
- Copies of feedback forms
- Room decorations
- Food
- Prizes for scavenger hunt

Session 18, Activity A

Presentation Prep

Goal
Develop presentation criteria and plan presentations.

Outcome
Students plan their own presentations.

Description
The facilitator gives a mock presentation to the students. The students then critique the content and presentation skills and develop criteria for their own presentations. They then plan their own presentations.

Supplies
Flip chart and markers

Preparation
Prepare a brief presentation of a product that you "designed." This can be any product. Include the product, drawings, and models of the product. These can be pretty crude.

Procedures
Sample Presentation

1. Do a mock presentation for the students, modeling the content and delivery for their presentations. After the presentation, ask them to consider the following:

    - What did the presenter need to do in order to organize the presentation?
    - How was the presentation organized?
    - What did the presenter show during the presentation?
    - What presentation skills helped the presentation?
    - What could the presenter do to improve the presentation?
    - What will you need to explain in the presentation?
    - What will you need to show in the presentation?
    - What presentation skills will make your presentation successful?

2. Based on the discussion about the sample presentation, conduct a brainstorm on a flip chart of the following:

    - What will you need to explain in the presentation?
    - What will you need to show in the presentation?
    - What presentation skills will make your presentation successful?

18A: Presentation Prep (continued)

Presentation Criteria

1. Length of presentation: This will vary depending on the number of students, time available, and structure of the presentation. Most likely, if you are doing a Solutions Showcase, a 5-10 minute presentation with 3-5 minutes for questions and feedback is a workable time allotment. If you are doing a Mini-Engineering Fair, then students will be presenting either one-on-one or more informally to small groups.

2. With the group, develop criteria to help students prepare for their presentations. Criteria could include these items:

   Presentation Content
   - Problem clearly described
   - Solution clearly explained
   - Design process articulated
   - Drawings, models, and prototypes explained
   - Documentation on hand for questions

   Drawing, Models, and Prototypes
   - Design drawn in detail
   - Models show how project works. Model may include parts and components
   - Prototype is a working prototype
   - Drawings, models, and prototypes explained in detail

   Presentation Skills
   - Presenter speaks clearly and explains project in detail
   - Presenter is knowledgeable about all aspects of project and can answer questions
   - Presenter is well prepared
   - Speaker holds interest (maintains eye contact, uses gestures, varies voice inflection)

Your Presentation

1. Provide designers time to prepare their presentations. They can begin by completing the handout.
2. They can prepare note cards or an outline for their presentation.

Wrap Up
Time permitting, students may practice their presentations with one another. Encourage students to practice their presentations at home.

Follow With
The next activity, *18B: Take One!,* gives students time to practice their presentations and receive feedback from their peers.

Presentation Prep

Handout: Session 18, Activity A

To help you prepare for your presentation you will have an opportunity to see a sample presentation. Consider the following as you watch the presentation:

- What did the presenter need to do in order to organize the presentation?
- How was the presentation organized?
- What did the presenter show during the presentation?
- What presentation skills helped the presentation?
- What could the presenter do to improve the presentation?

As a group, we will come up with criteria for the presentations to help you develop a successful presentation. Record the final criteria that we develop.

Use the following questions to guide your own presentation preparation.

1. How will you start your presentation?
2. Describe the problem as you see it. Capture what's wrong or not working in a problem statement. This will be built upon what you wrote in the design brief. You will need to add more specific information to what you wrote.
3. Describe how your project works, and how it solves the problem. What is the rationale for your solution? What are the benefits of your solution?
4. How will you use your drawing to help explain your project?
5. How will you use your model and prototype to help explain your project?
6. What do you really want others to know about your project?
7. What challenges did you face throughout this design process? How did you overcome them?
8. What kind of feedback do you want?
9. How will you end your presentation?

Session 18, Activity B
Take One!

Goal
This activity gets students ready to share their ideas and projects in a more formal way.

Outcome
Students are ready for the fair.

Description
Students brainstorm guidelines to give each other constructive feedback during their presentations. They then practice presenting to their peers and receive constructive critique from one another to refine their presentations.

Supplies

- Flip chart and markers
- Video camera
- Tripod
- Videotapes (one 15-minute tape per student)

Preparation
Have a flip chart ready to record the brainstorm.

Set up the camera on a tripod. Ideally, purchase enough 15-minute videotapes so students can take them home and watch them.

Procedures
Friendly Feedback Guidelines

1. Explain that students will have a chance to practice their project presentations.

2. Discuss the purpose of practicing the presentations for each other. Ask students to consider what type of feedback they would like from their peers (this was question nine from the previous activity, *18A: Presentation Prep.*)

3. Together, use a flip chart to brainstorm some guidelines for giving friendly feedback to each other, such as:

    - Offer suggestions not just criticism.
    - Say something positive before saying something negative.
    - Consider how your comment will help the presenter.
    - Take turns.
    - Be polite.

18B: Take One! (continued)

4. Review the criteria from the previous activity so that students can keep this in mind when watching each other.

Practice Presentations

1. Ask learners to have the criteria handy and be prepared to take notes based on the criteria. They should take notes on a separate piece of paper and not write on the backs of the paper. Explain that after each presentation, they will have an opportunity to provide verbal feedback.

2. Explain the format of the presentations:
    - Introduce project
    - Explain what type of feedback you would like to receive.
    - Present project using drawings, models, prototypes, and display boards.
    - Ask for questions.
    - Receive friendly feedback.

3. Videotape presentations so that each student can view them at home.

4. Have students present, answer questions, and receive feedback.

5. Have students tear their papers and distribute their feedback to each other.

6. If time permits, pair up students and have them plan with a partner how they will incorporate the feedback that they received.

Wrap Up
Ask students to consider the feedback that they received and revise their presentations accordingly-they should try to find some practice time before the fair.

Follow With
Activity *18C: Fair Logistics* helps students plan the final details for the fair.

Take One!

Handout: Session 18, Activity B

Feedback for Designers
During the presentations, remember to refer to the criteria that you developed in the previous session and jot down notes on separate pieces of paper to give your peers friendly feedback. Your notes can take the following format:

Name:

Project Title:

Strengths:

Areas of Improvement:

Suggestions for Improvements:

Session 18, Activity C

Fair Logistics

Goal
Students get last-minute details together for the fair.

Outcome
The fair is organized.

Description
Students should set up the room for the fair and prepare any other logistics needed.

Supplies

- Supplies for hands-on activities (if needed)
- Copies of Passport Scavenger Hunt (if needed)
- Copies of feedback forms
- Room decorations
- Food
- Prizes for scavenger hunt

Preparation
None

Procedures
Setting Up

1. Students should complete the feedback forms on the handouts so that the facilitator can make several copies for each of the projects.

2. The room should be set up. Depending on the format of the fair, you may have the chairs arranged facing a presentation area (for a Solutions Showcase) and the display boards around the edge of the room.

3. For a Mini-Engineering Fair, you will probably have tables scattered throughout the room with the display boards and projects on the tables. You will also need to set up stations for the engineering activities.

4. Be sure to have a place established for the welcoming address and/or keynote speaker.

5. The event should open with a welcoming address and/or a keynote speaker.

6. If serving food, designate a food area.

7. Decorate the room.

8. Have prizes ready for the scavenger hunt.

18C: Fair Logistics (continued)

9. Prepare certificates for the Design and Discovery students and plan time to present them.

10. Be sure to document the event with photographs.

11. Discuss students' roles.

Tips

Share the following tips with students:

- Be enthusiastic. The more enthusiastic you are the more others will be interested in your project.
- Dress professionally. Your attire represents your attitude towards the event. Dress for success!
- Be confident. You worked hard and you deserve to show off your work. Don't hesitate to share your knowledge with others.
- Smile. A smile invites people to talk with you.
- Initiate feedback. Here's your opportunity to get feedback from others about your ideas. Ask lots of questions and record the feedback.

Wrap Up
Encourage students to visit each other's projects during the fair.

Introduce the Home Improvement activity, Project Reflection, where participants reflect on their experience. This will be completed after the fair.

Follow With
Session 18 *Home Improvement, Project Reflection*, allows students to reflect on their accomplishements.

Fair Logistics

Handout: Session 18, Activity C

To make the fair a valuable experience, you will want to get feedback from the visitors. Decide what kind of feedback you would like and prepare some questions. The facilitator will make copies of the questions to distribute to the guests. You may find that you want to take your design project a step further based on the feedback. Write your questions on a separate piece of paper.

I am looking for the following feedback:

Project Reflection

Home Improvement: Session 18

Goal
To reflect on the fair, students' *Design and Discovery* experience, and to plan for next steps.

Description
Time should be set aside after the fair to reflect on the fair and students' Design and Discovery experience in general. Students who are planning to attend another science/engineering fair can begin to plan their project and presentation board revisions.

Procedures

1. After the fair, students should review the Project Feedback forms.
2. Ask students to take some time to answer the reflection questions individually.
3. Be sure to check in with students who are planning to participate in another science fair. Discuss their revision plans.
4. Thank students for their hard work and participation in *Design and Discovery*. Encourage them to pursue their interests in science and engineering.

Project Reflection

Handout: Session 18, Home Improvement

Project Reflection

1. In general, how do you feel about the fair? What did you like or dislike about it? How would you change it if you were to hold the fair again?
2. How did *Design and Discovery* meet or not meet your expectations?
3. Would you recommend *Design and Discovery* to a friend? Why or why not?
4. How did *Design and Discovery* influence the career you are considering?
5. How do you feel about your project?
6. Do you plan to submit your project to another science fair? If no, why not?
7. What changes are you planning to make on your project or presentation board?