Design and Discovery

Student Guide

Curriculum

Table Of Contents

Curriculum

Overview

Understanding the Design Process

The first *Design and Discovery* sessions help you to begin to look at the world from a designed perspective.
The design process is introduced and is used throughout the curriculum.

Session 1: Jump Into Design
Re-think and re-engineer everyday objects to practice design and engineering processes. Practice a 10-step design process in hands-on activities.

Session 2: The Designed World
Design opportunities are everywhere! Build your ability to analyze existing objects for improvements and identify good problems to solve with design and engineering.

Engineering Fundamentals

These sessions provide background in materials, electrical, and mechanical engineering principles that you may need to incorporate in your design.

Session 3: Materials for Design
From spaceships to beverage containers, materials make the difference in successful performance of a product. Test materials' properties, determine the best materials for certain applications, and consider cost and environmental impact when choosing materials.

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

Session 5: Making Machines
Explore the mechanics of simple machines, and then apply what you learn to make a mechanical toy of your own design.

Session 6: One Problem, Many Solutions
Wake up your observation skills by analyzing the form and function of a digital clock radio. Then compare clock radios to see how the functions are implemented in different designs.

Thinking Creatively

In these sessions, you will identify interesting problems and develop ideas for solutions.

Session 7: The 3 R's Of Problem Identification
It's time for the 3R's of Problem Identification: Revisit, Refine, and Research. Using a variety of techniques, narrow down your list of design opportunities.

Session 8: A Brief Focus on Your Design Problem
Prepare a design brief to help you focus your understanding about a problem and propose a solution.

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

Making, Modeling, and Materializing

Turn your thinking into things and begin several cycles of building models and testing your ideas.

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

Session 11: Design Requirements and Drawings
Design requirements help designers focus on the user and fine-tune design details. Learn how to use drawings to help you plan your project details and move from "think" to "thing."

Session 12: Planning for Models and Tests
It's time to make your project ideas tangible- to go from what's in your mind to things in your hand. Reflect on changes to your 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! Tinker with pieces, parts, and connections to make models of a system, a component, or the product itself.

Prototyping

In these sessions, you will refine your project into a working prototype.

Session 14: Prototype Practicalities
Projects are taken to the next level as you plan how to develop your working prototype. Consider the product specifications, materials, and budget.

Session 15: Develop It!
This is a work session for you to construct your prototype. Like all other stages in the design process, you may need to make several prototypes as you conduct trials and tests of the product.

Session 16: Test It!
Conducting user testing allows you to try out your product, get feedback, evaluate the feedback, and plan your revisions.

Final Presentations

In the final sessions, you will plan or participate in an event to showcase your project and get feedback.

Session 17: Fairly There
Start preparing for a culminating celebratory event to share your project and your engineering and design expertise—either a showcase or a mini-engineering fair.

Session 18: Dress Rehearsal
Get ready for the big event! Practice your presentation and receive feedback from your peers. Following the event, take some time to reflect on your *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 introduces the design process that guides the work of engineers and designers. In these sessions, you will engage in three hands-on activities that build understanding of the role of engineering and design in producing effective solutions to real-world problems.

In *1A: Build a Better Paper Clip* carefully examine the form and function of standard paper clips. Then with a set of wires and tools, 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 your own project, 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*, examine a designed solution to the problem of conventional screw-top toothpaste caps as you walk through the steps of the design process.

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.

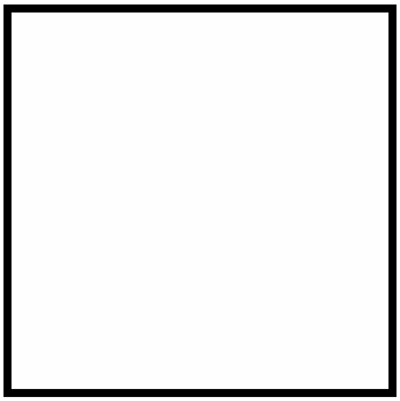
Try out all your ideas and make drawings of your designs. Choose one design to engineer and test. Be prepared to present your model.

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.

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.

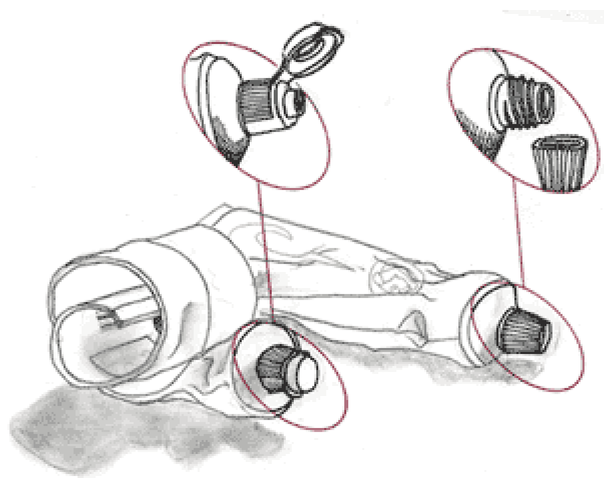
The work of designers and engineers overlaps as well. Both seek to develop solutions to specific and immediate problems and needs. While design is involved in the entire process, engineering is the more specific process of making the idea meet specifications and function. One is useless without the other.

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.

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

The Designed World helps build appreciation for the designed world around us and prepares you for finding a design and engineering project. You will learn to identify problems that lead to opportunities for new design solutions and develop skills by thinking creatively about designed things that you use everyday. The first activity, *2A: Design Opportunities Are Everywhere*, involves a short field trip or walking tour to practice recognizing problems and needs around us. The activity ends with developing a list of design opportunities that interest you and that can be used as the first step of your project development. The next activity, *2B: Mapping Out a Problem*, introduces Activity Mapping, a technique used to help you identify problems and design opportunities.

In *Activity 2C: Design Improvements*, 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*, helps you make distinctions between functional and superficial improvements with objects in your own home.

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.

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

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.*

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

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

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

Materials for Design introduces the principles behind materials selection. Like materials engineers, learn to differentiate and select materials based on their properties. In *3A: Properties of Materials*, test samples of metals, ceramics, polymers, and composites to compare their properties. Test for density, ductility, strength, fatigue, electrical and thermal conductivity, and optical properties. In *3B: Materials Application*, now apply your 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*, gain an understanding of the economics of material selection through a cost analysis of a beverage container made of different materials. Lastly, think innovatively about how to design a beverage container that can be put to another use.

In the Home Improvement activity, *Materials Scavenger Hunt*, look at objects and analyze what materials were used to make them.

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.

References
Pizzo, Patrick P. *Exploring Materials Engineering*, Chemical and Engineering Department, San Jose State University, (September 15, 2003). www.engr.sjsu.edu/WofMatE*

The Minerals, Metals, and Materials Society. *Materials Science and Engineering Career Resource Center*. www.crc4mse.org*

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.

#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.

#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.

#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.

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

Brown, David E. *Inventing Modern America: From the Microwave to the Mouse*. Boston, MA: The MIT Press, 2001.

Howell, Caitlyn. "Kevlar®, The Wonder Fiber." *Innovative Lives*. Washington, DC: Smithsonian Institution, 1999. www.si.edu/lemelson/centerpieces/ilives/lecture05.html*

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

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?

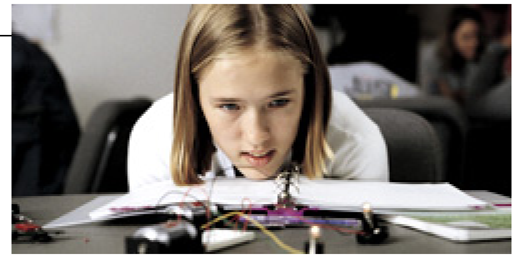
What properties does it require?

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 *Getting a Charge From Electricity,* you will work in pairs to explore electricity basics. *4A: Basic Electrical Concepts in a Flash* reviews simple circuitry using a common household item: a flashlight. This helps prepare you for any electrical circuitry that you may need to incorporate into your own project later.

In *4B: Turn It On and Off*, learn the differences between a simple, series, and parallel circuit. Here, you are introduced to using breadboards. Then try wiring circuits on the breadboards with switches and buzzers (optional). In *4C: Short Circuits*, learn about short circuits and the relationship between resistance and the current. In *4D: Light-Emitting Diodes*, make your favorite numbers light up with an LED display. *Electric House Hunt*, the Home Improvement activity, entails looking at your own house from an electrical perspective.

Basic Electrical Concepts in a Flash

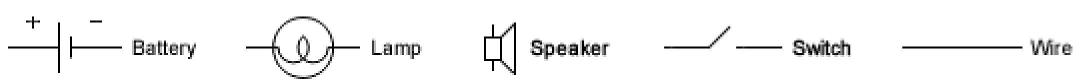
Handout: Session 4, Activity A

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

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

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

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.

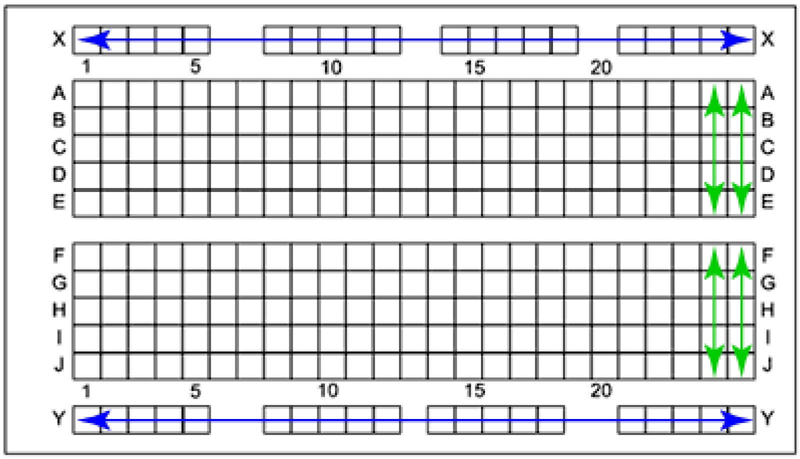
Turn It On and Off

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 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.

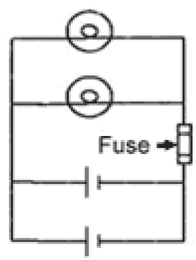
Advice for Students
Tee advises students heading into computer engineering to seek out the best professors they can find. "Ask your classmates. They always know who the best teachers are." And she encourages students to learn all they can by interviewing engineers and arranging internships. "That's the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

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.

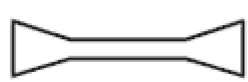
3. The other pair should make a parallel circuit with two bulbs and one battery. Repeat the same activity as above with the parallel circuit. Explain what happens.

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.

Light-Emitting Diodes

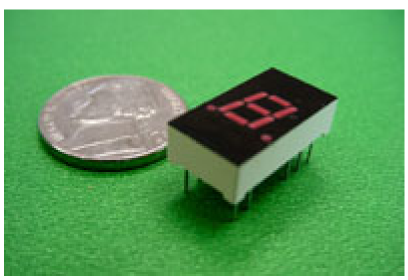
Handout: Session 4, Activity D

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)

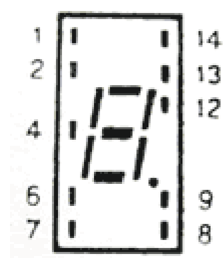


Diagram of pin location

Table of Pin Designations

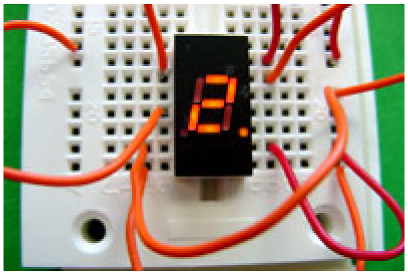
1. Anode F	14. Anode A
2. Anode G	13. Anode B
3. No Pin Cathode	12. Common Cathode
4. Common Cathode	11. No Pin
5. No Pin	10. No Pin
6. Anode E	9. Anode RHDP
7. Anode D	8. Anode C

Follow the instructions below to light up the LED number display:
4D Handout: Light-Emitting Diodes (continued)

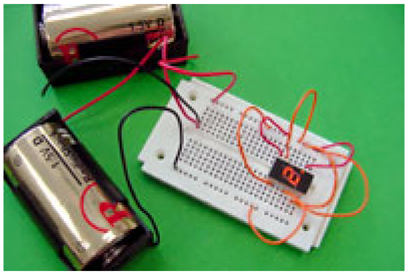
1. Power the breadboard by connecting two batteries in series to the power tracks.

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.

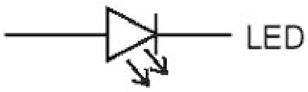
5. Try wiring the other cathode to the negative power track. Which wiring lights each segment? Did you figure out how to light up the right hand decimal point (RHDP)?

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.



Electrical House Hunt

Handout: Session 4, Home Improvement

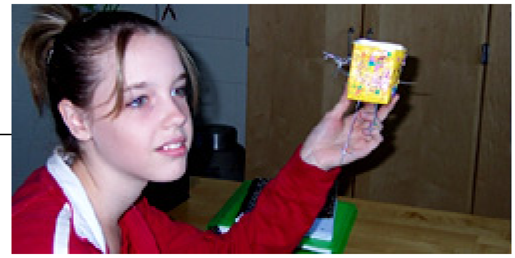
Have you ever considered the electrical units in your house? We are all accustomed to flipping a switch to turn on the lights or pressing a button on a microwave, but have you thought about how these things work? Here's a chance to take an electrical hunt through your home. Record your findings in your 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



Making Machines really puts things in motion. In *5A: Design, Build, Make It Go*, make a rolling toy from a set of everyday materials in a mini-design challenge, and then discuss your experiences with how energy is transferred. To understand that most machines are made of many smaller machines, study the component machines in a lawnmower through a Web-based tutorial, in *5B: Not-So-Simple Machines*. 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*, take your plans and materials home and finish your toy.

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.

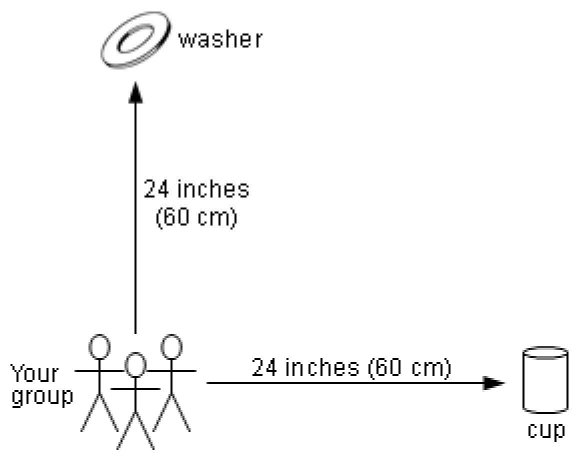
Reproduced with permission:
Van Dulken, Stephen. *Inventing the 20th Century, 100 Inventions That Shaped the World*. New York: New York University Press, May 2002. www.nyupress.nyu.edu*

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.

Gears, Cranks, Crankshafts, and Belts

Handout: Session 5, Activity C

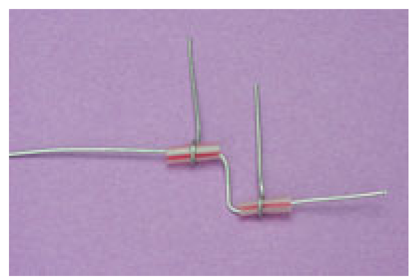
Make a Crankshaft Device

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

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

In *One Problem, Many Solutions,* take on the role of an engineer and apply analytical skills to understand how the requirements of a product are met—in this case, a clock.

In *6A: Clocks of All Varieties*, take a close look at the clocks and as a class come up with design requirements for clocks. In *6B: Form Meets Function*, see how the requirements are met in different clock radios as you consider form and function. Then, in *6C: Tick Tock: How a Clock Works,* disassemble the clock radios to see how the electronics and mechanics work to make a clock "tick."

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.

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.

Tick Tock: How a Clock Works

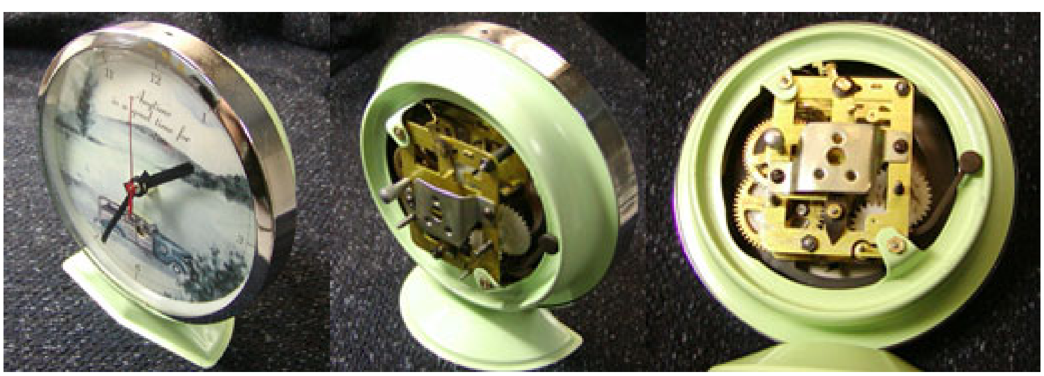
Handout: Session 6, Activity C

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

So many problems to solve and improvements to make. How do you decide which one to tackle? In *The 3R's of Problem Identification,* revisit and refine your broad list of problems, needs, and improvement ideas (started in Session 1, *Jump Into Design*) to identify one design opportunity as your project. Use a variety of observation and data collection strategies to consider what exactly needs fixing, developing, or improving.

In the first activity, *7A: Revisit*, revisit your list of design opportunities started earlier in Session 2, *The Designed World*. Here, you'll develop the criteria for choosing a problem to pursue. In *7B: Research and Refine*, make changes to your list of problems and then conduct market research by gathering information about the nature of the problem. You will probably go 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 you begin to think about the solutions for your design opportunity. By the end of this session, you should have one project in mind and about five possible solutions.

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?

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.

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.

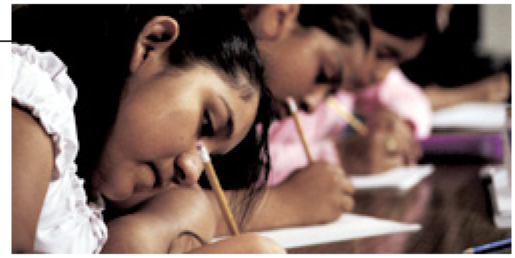
7C Reading: Meet a Design Planner (continued)

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 *A Brief Focus On Your Design Problem,* you will prepare a design brief. In preparing a design brief, you'll refine and focus on a problem to solve from the perspective of the users' needs. You'll write a problem statement, a description of the context for the problem, and a proposed solution. You will also draw a sketch of your idea, and come up with suitable materials for constructing a solution. To understand a design brief, you'll take a look at the design brief of a former *Design and Discovery* student.

In the first activity, *8A: User Profile*, dig into who the users of your product will be and how you will design the product to meet the users' needs. In *8B: Sample Design Brief*, read and discuss the parts of the design brief, analyze the sample, and think about writing your own. In the third activity, *8C: My Design Brief*, you'll prepare your own design brief. The activity ends with a short (brief!) presentation of your problem and proposed solution. The final activity in this session, *8D: Mentor Matching*, gives you the opportunity to consider your mentor needs so that an appropriate mentor match can be made.

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*

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)

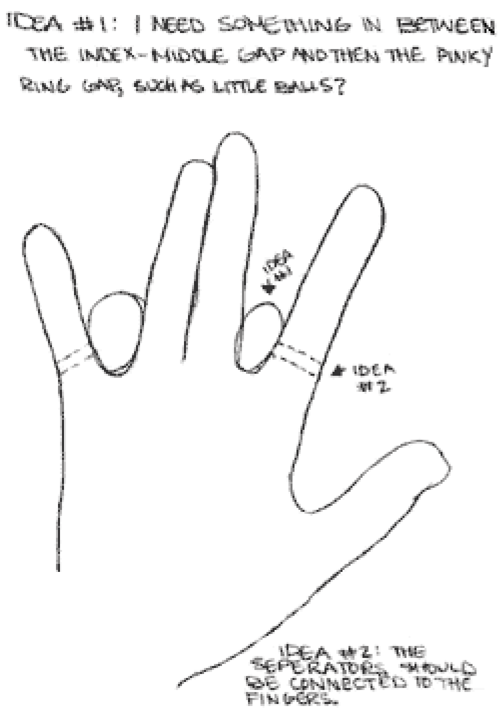
3. **Describe a typical user (user profile).** This addresses who uses the product and how their needs are or are not met. How will they benefit from a different product?

   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.

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).

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

A Solution Taking Shape involves online research. In this session, plan out one of your design solutions by following Steps 5 and 6 of the design process.

The first activity of this session, *9A: Invitation to Invent*, exposes you to inventors and inventions throughout history, to see how others applied creative thinking to solve problems. In the second activity *9B: Patents*, 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 you refine your solution. In the third activity, visit the Web site, *HowStuffWorks*, which provides online tutorials about the inner workings of things.

The Home Improvement activity, *Project Analysis*, helps you refine your ideas before making a final decision about your solution.

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?

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."

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

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

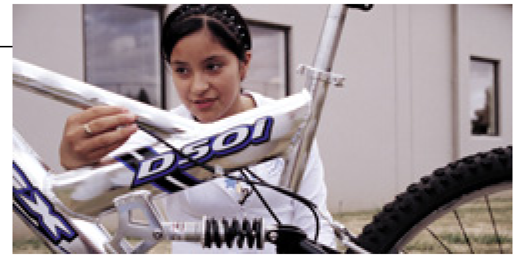
Making, Modeling, and Materializing

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

Bicycle Breakdown: Systems, Components, and Parts uses the mechanisms of a bicycle to help you think about the systems in a product that must be designed. It offers a strategy for tackling a complex solution that you 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.

In the first activity, *10A: Systems and Synergy*, learn the difference between systems, components, and parts as you 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.

Systems and Synergy

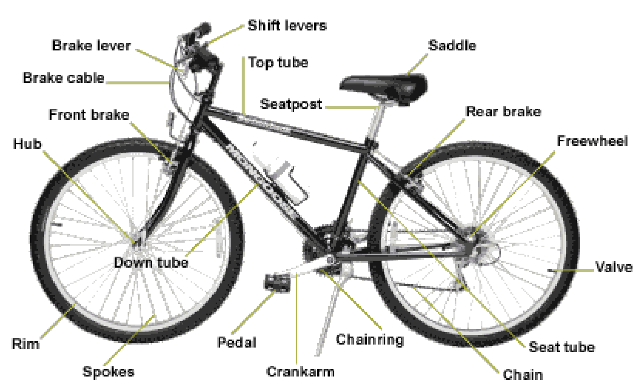
Handout: Session 10, Activity A

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.

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:

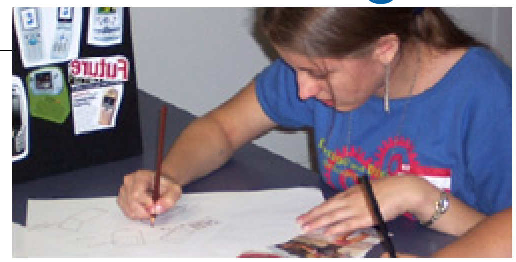
Specialty bikes: Identify and study the four systems in each of the specialty bikes. Compare them to the systems in the more traditional bicycle. What did you observe?

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 *Design Requirements and Drawings,* you will refine your design efforts with product requirements and drawings. In *11A: Checking in on the Design Process*, look at a checklist of steps that follow the design process to determine how far you've come, and look ahead to the next steps. Next, in activity *11B: The Perfect Fit: Meeting Needs Through Design*, learn how a designer considers the needs of the user to define minimum requirements for a design, and then develop design requirements for your own project. In a third activity, *11C: Conceptual Drawing: Thinking on Paper*, 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, you should have a more fully developed project and are ready for the next steps, modeling and testing your ideas.

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.

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.

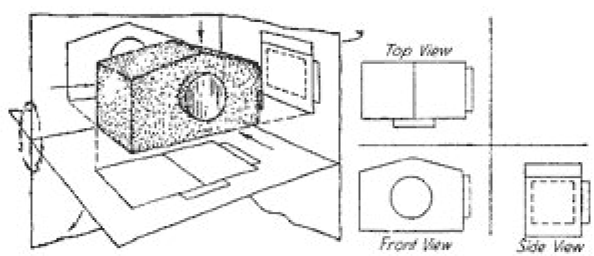
Conceptual Drawing: Thinking on Paper

Handout: Session 11, Activity C

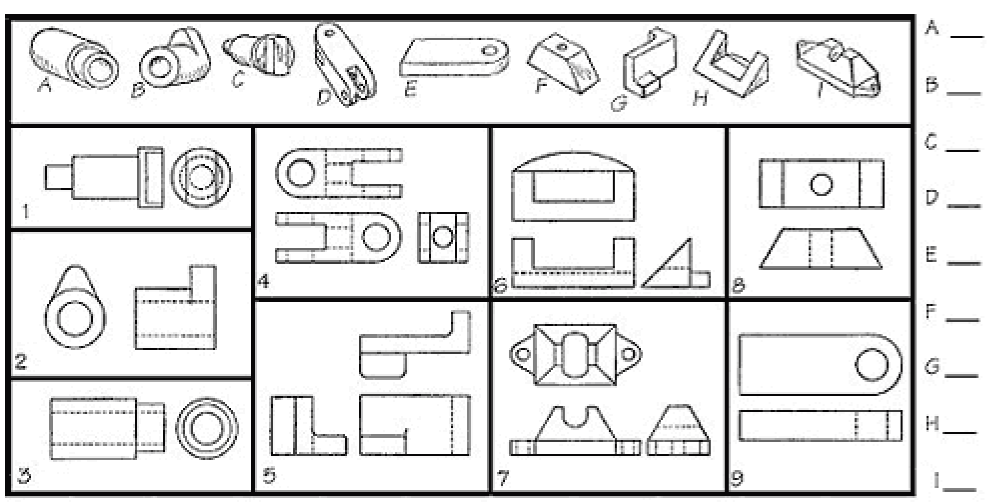
Drawing From All Sides
Drawing your ideas can help you visualize your plan and will be very useful when you make your model. You may find it helpful to draw the different components and parts of your project—from different perspectives. You will probably have several drawings of your project as your 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?

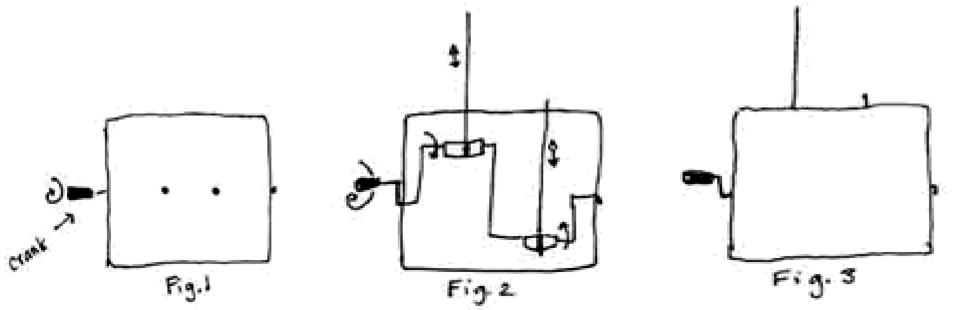


2. Match the object in the top row with its orthographic sketch.



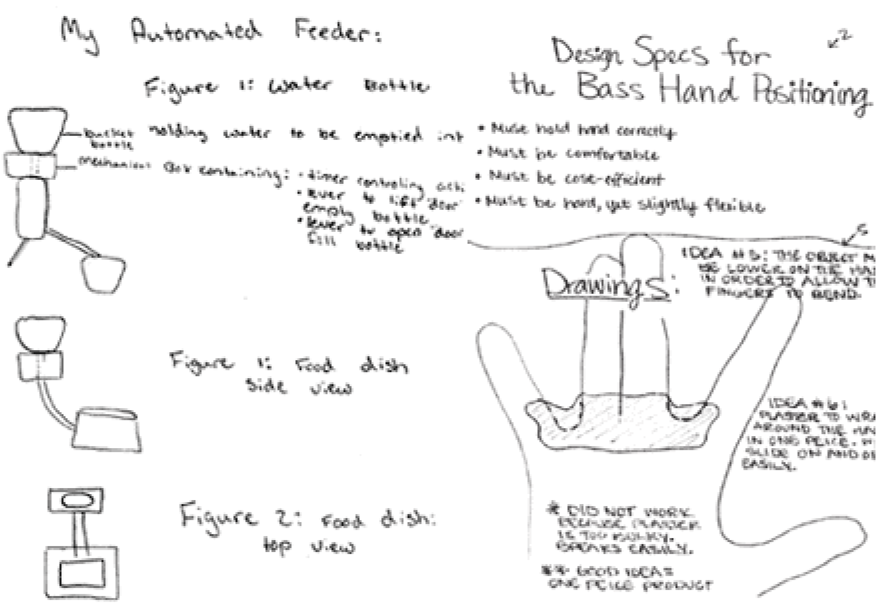
11C Handout: Conceptual Drawing: Thinking on Paper (continued)

3. What object is shown here? Label the different figures: interior, top and side.



____________________ ____________________ ____________________

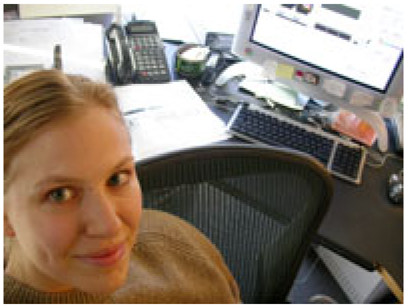
4. Here are some samples of past *Design and Discovery* students' drawings. Can you tell what they are?



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

Planning for Models and Tests prepares you for building models and testing systems or components of your design project. This is Step 7 of the design process. In an opening activity, *12A: Thinking Again About Design*, review your experience of the design process and think about your revisions up to now. You'll notice 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*, survey available materials for constructing models and plan your first constructions. In the final activity *12C: Structural Considerations*, learn about collapsible objects and the principles of collapsibility related to storing, moving, and assembling their projects.

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!

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*

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

In *Making It! Models, Trials, and Tests* your design project will start to take shape as it moves 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*, try to be methodical as you build and report on your model, tests, and results in their design notebook.

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 *Prototype Practicalities* you will begin planning for construction of your prototype. In *14A: Prototype Planning*, prototypes are reintroduced as you strategize plans and create your specifications for developing a prototype. In *14B: Prototype Materials*, consider what materials you will use to develop your prototype. Finally, in *14C: Budget*, use a spreadsheet program to develop a budget for your project. The Home Improvement activity, *Your Work Schedule*, helps you structure your time for working on your prototype.

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: _____________________

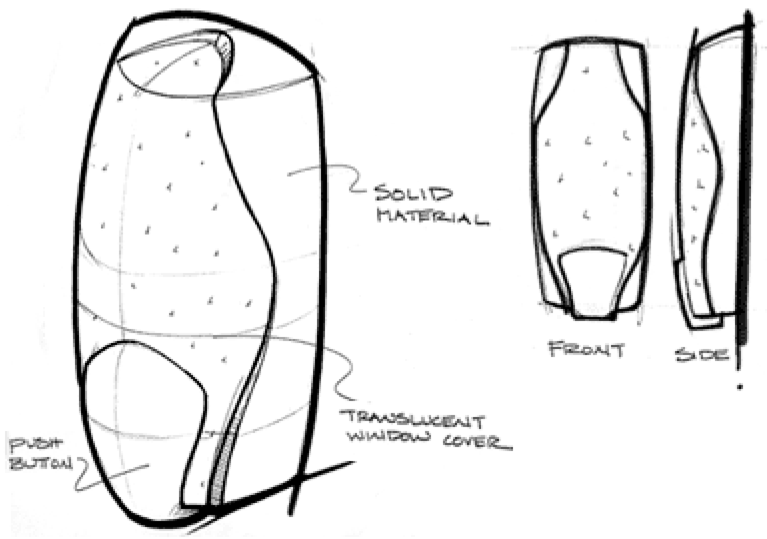
User Needs	Design Requirements	Design Specifications

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.

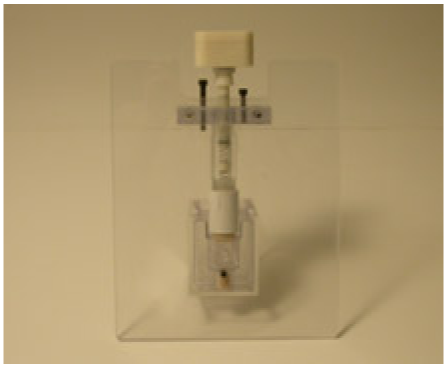
14A Reading: ZIBA Designs a Soap Dispenser (continued)

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.

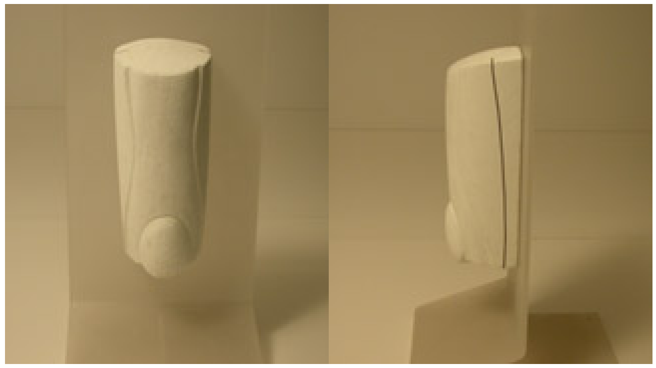
Mechanical Model



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

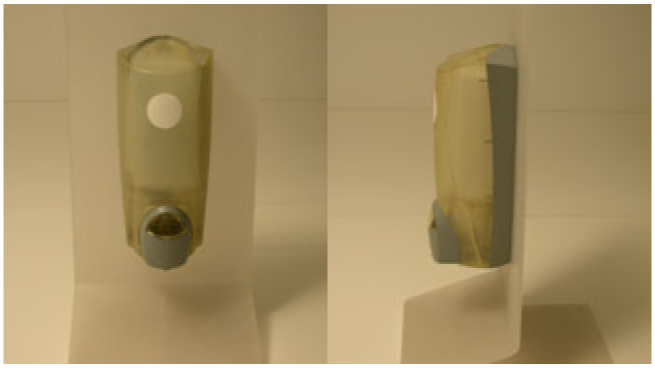


A white foam visual model is a quickly built model to evaluate early visual concepts and different product configurations. A white foam model is used for non-detailed, configuration explanation in the early phase of a design project. A front and side view are shown here.

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.

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.

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

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

In *Develop It!* your ideas take on new forms as you develop your prototype. This should be a working prototype with full functionality. You may find that as you refine and test your ideas that you develop several working prototypes. This session has one activity, *15A: Prototype Work Session*, devoted to prototype development.

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?

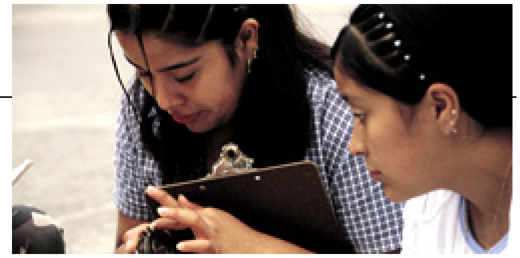
Testing
Will the prototype meet your specifications? How will you test this and what data will you gather?

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! In *Test It!* you will learn this as you continue with the design process: Step 8, Build a Solution Prototype and Step 9, Test, Evaluate, and Revise. As you develop a working prototype, test and evaluate the prototype for function, feasibility, safety, and aesthetics, and make modifications. This process of testing and modification continues until you have a final working prototype. In the first activity, *16A: User Testing*, gather feedback from users as you try out your ideas on an audience. In *16B: Evaluation and Revision*, consider the feedback from the user testing and prioritize the revisions.

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?

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

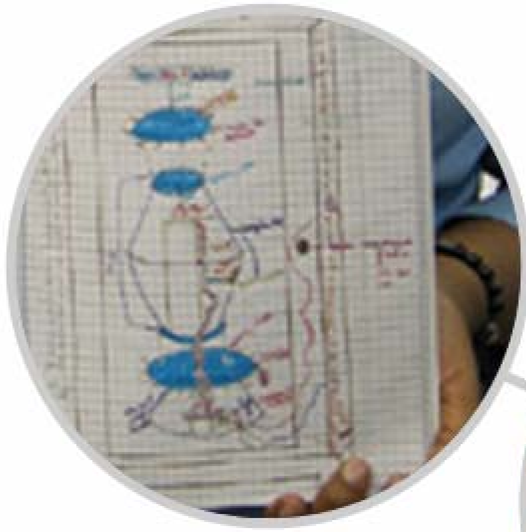
Introduction
My name is Michael Moon, and I'm one of ZIBA Design's project managers. I've been here about four years, working in both the research and interactive groups before becoming a dedicated project manager. My role can be summed up as "the guy who makes sure our work makes it to market."

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 prepare you for the fair. In the first activity, *17A: Fair Choices*, learn from past fair participants and an engineer about the benefits of participating in a science fair. Then begin planning the fair. The second activity, *17B: Design Your Display*, is a work session where you prepare a display board for the fair.

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."

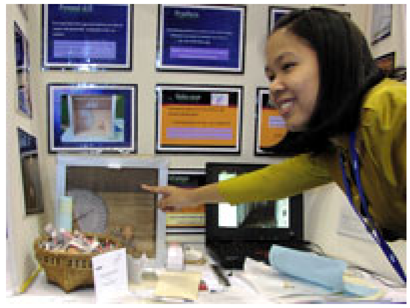
"Building Block" Benefits

- 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.

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 *Dress Rehearsal*, plan you presentation in *18A: Presentation Prep* and practice it before your peers in *18B: Take One!* Friendly feedback from peers will help you further refine your presentation 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 you the opportunity to reflect on your own progress and their experience in *Design and Discovery*.

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?

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:

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

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?