Intel® Innovation in Education

Institutes

An Introduction to Design and Discovery

Experiencing Engineering Through Design

Design and Discovery Goals

- Introduce youth to the principles of engineering and design
- Build problem-solving skills through a hands-on experience
- Prepare students for Intel ISEF-affiliated fairs or other engineering and science fairs
- Create awareness of engineering as a career option

Workshop Goals

- Become familiar with the *Design and Discovery* Web resource
- Understand how to implement *Design and Discovery*
- Participate in a Design and Discovery hands-on experience

Agenda

1. How Do We Learn About Engineering?

2. Explore the Resource
   - Introductory video
   - *Design and Discovery* Web Resource

3. Curriculum
   - Navigation, activities, and printable curriculum

4. Optional: Design and Discovery Experience

5. Build a Better Paper Clip

6. The Design Process

7. Implementation

8. Resources

9. Design and Discovery in Your Community

How Do We Learn About Engineering?

Take time to write your answers to the following questions then share them with a partner.

- Do you know an engineer?
- Did you ever want to become an engineer?
- What experiences introduced you to engineering?
- What experiences introduce young people to engineering?
- How do we interest young people in engineering?

The Designed World

Look around the room and begin to notice design opportunities.

Do you see anything that you think could be improved? What improvements would you make?

What things, services, or processes that you use regularly could be improved? Make a list of design opportunities and share these with a partner.

A Video Introduction

Write down any questions or comments you have about the *Design and Discovery* Program.

Design and Discovery Curriculum

Overview and Sequence

Design and Discovery is a comprehensive inquiry-based curriculum, which introduces engineering through design. It is organized into 18 sessions. Each session is 2.5 hours and includes two to four 20-90 minute hands-on activities or explorations which are done in small groups.

Each activity includes a leader's instruction page and a student handout with directions for students; however, students are encouraged to do their work in a design notebook. Supplies are listed for each session as well as for each activity. Many activities also include a student reading. The readings often provide real-world examples of professionals working in the design and engineering world. Some sessions include a Home Improvement activity, which should be completed at home with input from family members. A few field trips are included in the curriculum, while more are suggested in *Implementation*. More information about the curriculum structure is also available in *Implementation.*

The *Facilitator Guide and Student Guide* are formatted for easy printing with page numbers. The *Student Guide* should be printed and distributed to each student. The *Supplies* section lists all materials and tools for each activity.

Understanding the Design Process

Students are introduced to the designed world and then practice the design process that is revisited throughout the curriculum.

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

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

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Design and Discovery Curriculum Overview (continued)

Engineering Fundamentals

These sessions provide background in electrical and mechanical principles that students may need to incorporate in their designs.

Session 3: Materials for Design
From spaceships to beverage containers, materials make the difference in successful performance of a product. Students 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, students explore simple, series, and parallel circuitry with bulbs, batteries, wires, and breadboards. Students should be charged up from their introduction to basic electronic concepts. They then build on these concepts by learning about short circuits, fuses, and then wiring an LED number display to light up their favorite numbers.

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

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

Thinking Creatively About Problems and Solutions

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

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

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

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

Design and Discovery Curriculum Overview (continued)

Making, Modeling, and Materializing

Students turn their thinking into things and begin several cycles of building trials and testing their ideas.

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

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

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

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

Prototyping

In these sessions, students refine their project into a working prototype.

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

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

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

Design and Discovery Curriculum Overview (continued)

Final Presentations

In the final sessions, students plan or participate in an event to showcase their projects and get feedback.

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

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

Session 1, Activity A

Build a Better Paper Clip

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

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

Outcome
Design and engineer a new paper clip that meets requirements.

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

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

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

Preparation

1. Read *1A Reading: The Perfect Paper Clip.*
2. Review Hooke's Law that is described on the *1A Handout: Build a Better Paperclip.*
3. Optional: Invite mentors to the first activity. Review the mentor section in *Implementation* for more information on mentors.

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Build a Better Paper Clip (continued)

Procedures

Introduction

1. Briefly review the purpose and importance of keeping notes, sketches, and ideas in a design notebook. Point out the value of putting dates on notebook pages.

2. Pair the students with a mentor (optional). Refer to the handout with the design requirements, and allow time for students to read it thoroughly. (Note that "Requirements" refer to broad criteria the solution must meet. Initially, students will focus on developing *requirements* for a model of their design product. From Session 14 on, as they develop prototypes, they will focus on "specifications," which are more specific and measurable criteria for the product.)

3. Describe the materials and tools for the design challenge and review requirements as needed.

Exploration

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

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

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

Design

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

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

Build a Better Paper Clip (continued)

Wrap Up

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

Follow With

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

Design and Discovery

Build a Better Paper Clip

Handout: Session 1, Activity A

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

Exploration
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; 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 (the metal) allow each to do the job of fastening paper together?

Design
You have wire, tools, and examples of paper clips. You must now design a prototype of a new paper clip that meets several design requirements listed below. Try out your ideas and make drawings of your designs. Choose one to engineer and test it. 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 may have features of other clips.
- It can be no bigger than 2 inches square.
- 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 be a hazard to small children.
- You should use paper to draw your various designs.

Design and Discovery

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 around 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.

Design and Discovery

The Design Process

Handout: Session 1, Activity B

Getting From "Think" To "Thing"

We will be using a design process to guide the development of a project from your 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.**
   Notice that design opportunities are everywhere and often come from a need, problem, or improvement to an existing solution. The goal is to identify many design opportunities and then narrow them down later.

2. **Research the design opportunity.**
   Gather lots of information about the nature of the problem in order to narrow your choices down. Find out about user needs and similar products.

3. **Brainstorm possible solutions to the problem.**
   Try to come up with five to ten ideas for solving the problem or addressing the design opportunity. Brainstorming may involve the use of SCAMPER and other techniques.

4. **Write a design brief.**
   Define the problem clearly in a problem statement. Describe the user needs and a proposed solution. Draw a sketch of the solution.

5. **Research your solution.**
   Do a literature review and talk to experts to find similar solutions and other approaches.

6. **Refine your solution.**
   Analyze the solution for feasibility, safety, and implications of the idea. Consider materials and methods for constructing the project.

7. **Prepare design requirements and conceptual drawings.**
   Write up the criteria the solution must meet (requirements) and sketch drawings.

1B Handout: The Design Process (continued)

8. **Build models and component parts.**
   Analyze the project design for its systems, components, and parts. Now build a model of the entire design and/or its systems.

9. **Build the prototype.**
   Develop project specifications and create a working prototype.

10. **Improve your solution. Test, evaluate, and revise.**
    Evaluate the prototype for function, feasibility, safety, aesthetics, and other criteria. Revise or build another prototype.

Project Examples

Dual Alarm Clock

Brenda, a *Design and Discovery* participant, saw the need for a better alarm clock. Here's how she engineered a solution.

What do people hate most about alarm clocks? "They're loud and annoying. And they wake up everybody, not just the person who needs to get up early," says a middle school student named Brenda. Because she shares a bedroom with her sister, she knows just how irritating it can be to have one clock disrupting two people.

While taking a summer camp enrichment course that uses the *Design and Discovery* curriculum, Brenda set out to build a better alarm clock. In the process, she learned about engineering and design, how to conduct consumer surveys, and how to carry out product testing. And she has also set her career sights on the field of engineering. "I used to think engineering was boring," she admits, "but now I know that it's interesting and also fun."

An Idea Is Born

Brenda's idea for a better alarm clock design came from her own experience. "My older sister and I share a room at home. She works late, and I have to wake up early in the morning to go to school. When my alarm beeps, she hears it, too. She pretty much got mad at that. So that's why I came up with the idea for a clock with two separate alarms."

Brenda had never taken apart electrical devices before, but the *Design and Discovery* curriculum guided her through an understanding of how electronics work. Hands-on activities teach participants about the basics of electricity, such as how to wire a circuit, light up an LED display, and make a buzzer work. Before long, Brenda was busy taking apart alarm clocks and reassembling them to fit her own purposes.

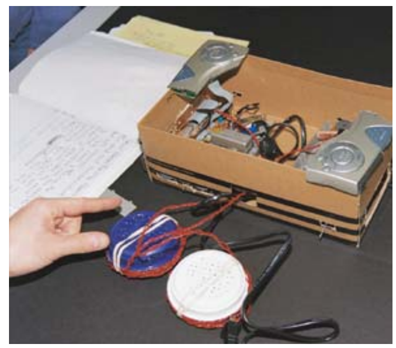
Brenda didn't just rely on her own instincts to create a better clock. She also took consumer surveys, asking her peers "what they hate most about alarm clocks." The survey gave her the idea that people would appreciate a more gentle morning wake-up call. She began to think about possible solutions, taking notes and making sketches in a design notebook. An electrical engineer gave her advice and suggestions as she moved forward with developing her plans. She then proceeded with plans for testing and building prototypes.

Project Examples—Dual Alarm Clock (continued)

Waking to Music

Brenda's redesigned clock features dual alarms, which can be set for separate times. She also has wired up two speakers that can be slipped underneath a pillow. That way, only the person who needs to wake up early hears the alarm. And because Brenda has incorporated a compact disk player, the alarm can be a person's favorite song instead of that pesky buzzing sound.

At this stage in product development, she's using a shoebox as a convenient casing for the alarm clock components. That allows her to access the "innards" of the clock easily when she had ideas for future modifications she wants to test. Her latest brainstorm? "I'm thinking about adding a temperature sensor, so you can wake up and see what the temperature is outside."



The project has taught Brenda one more thing about time: It's easy to lose track of time when you're working on an interesting project. She explains: "When I'm working on this project, I might spend four hours on it without realizing how much time has gone by. It's just so interesting, you know?" Judges at the Northwest Science Expo, an affiliate of the Intel International Science and Engineering Fair (Intel ISEF), awarded Brenda's project an Honorable Mention in Engineering.