Curricular Unit: Creative Engineering Design

Contributed by: Integrated Teaching and Learning Program, College of Engineering, University of Colorado Boulder

Quick Look

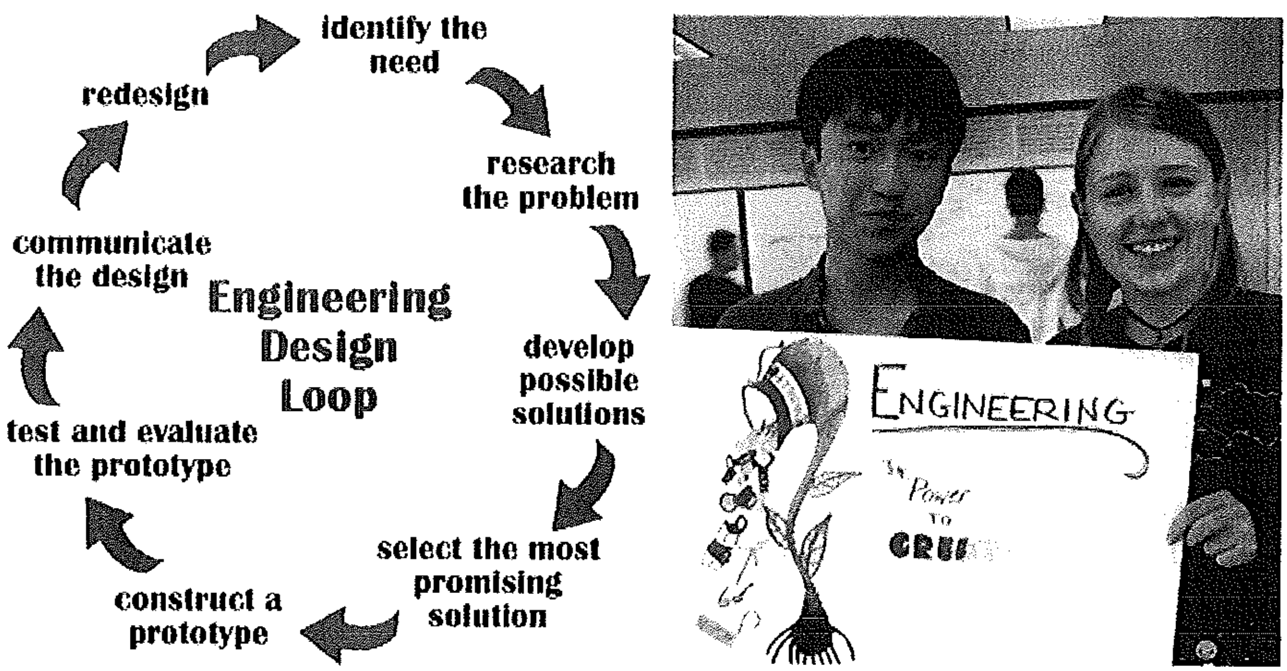
Grade Level: 9 (9-12)
Time Required: 480 minutes

Related Curriculum

Subject Areas: Science and Technology

Activities:
Design Step 1: Identify the Need
Design Step 2: Research the Problem
Design Step 3: Brainstorm Possible Solutions
Design Step 4: Engineering Analysis
Design Step 5: Construct a Prototype

more...



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Summary

Students are introduced to the world of creative engineering product design. Through six activities, teams work through the steps of the engineering design process (or loop) by completing an actual design challenge presented in six steps. The project challenge is left up to the teacher or class to determine; it might be one decided by the teacher, brainstormed with the class, or the example provided (to design a prosthetic arm that can perform a mechanical function). As students begin by defining the problem, they learn to recognize the need, identify a target

population, relate to the project, and identify its requirements and constraints. Then they conduct research, brainstorm alternative solutions, evaluate possible solutions, create and test prototypes, and consider issues for manufacturing. See the Unit Schedule section for a list of example design project topics.

Engineering Connection

The field of engineering is all encompassing in its subject matter and real-world challenges. Yet, engineers of all disciplines have in common certain approaches—teamwork, brainstorming, problem defining with requirements and constraints, the iterative steps of the design process, testing and analysis, prototyping, production and communication. All engineers use some form of the steps of the engineering design process to organize their ideas, and test and refine potential solutions to real-life challenges. Engineers must gain an understanding of all the contextual factors of a particular design challenge—need for the project, relevant social, ethical, environmental and economic conditions of the target population, system integration, and project needs and limitations. Working through all the technical and non-technical issues helps engineers generate useful, appropriate and successful design solutions.

Educational Standards

- Next Generation Science Standards: Science

Unit Overview

Students learn about the cycle of product design through six activities that follow the steps of a simplified engineering design process. Hence, the six activity topics are: 1) identify the need and define the problem; 2) conduct background research, such as an idea web, internet patent search, standards and codes search, reverse engineering, and user interviews; 3) brainstorm and develop ideas and possible solutions; 4) evaluate alternatives and perform design analysis; 5) construct and test prototypes; and 6) perform evaluation and manufacture final products.

Unit Schedule

The structure of this unit has been successfully taught to high school students by various instructors with various design challenge topics. For example, the unit has been scaled as a 13-week high school technical elective, concluding with a Design Expo attended by student families and peers, and as a high school summer camp and a high school/college bridge program, condensed into five days and five weeks, respectively.

Example design project topics taught with this unit structure include:

- house design with elements inspired by nature (biomimicry)
- assistive technology devices
- towers (tested in a university smash lab)
- amusement park rides
- daylighting modifications to existing interior spaces
- interactive table-top educational exhibits
- various solar and water technologies for use by a hypothetical developing community

Assessment

Pre/Post Unit Quiz: To conduct an overall pre/post assessment of the unit (six activities), administer the Engineering Design Quiz to the class before beginning any discussion about engineering design. Then, after completion of activity 6, administer the same quiz to the same students and compare pre- to post- scores to gauge the impact of the curricular unit on students' learning.

Attachments

Engineering Design Quiz (doc)

Engineering Design Quiz (pdf)

Engineering Design Quiz Answers (doc)

Engineering Design Quiz Answers (pdf)

Contributors

See individual activities.

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Supporting Program

Integrated Teaching and Learning Program, College of Engineering, University of Colorado Boulder

Acknowledgements

The contents of these digital library curriculum were developed by the Integrated Teaching and Learning Program in the College of Engineering under National Science Foundation GK-12 grant no. 0338326. However, these contents do not necessarily represent the policies of the National Science Foundation and you should not assume endorsement by the federal government.

Last modified: November 12, 2014

Name: ____ Date: ________________

Engineering Design Quiz

1. **In engineering, the design process begins when…**
    a. information about an existing product is gathered by an engineer
    b. an engineering design team comes up with ideas for a new product
    c. a design engineer recognizes the need for a solution to a problem
2. **Identifying the "target population" or "target audience" occurs during which step of the engineering design loop?**
    a. Identify the Need
    b. Research the Problem
    c. Develop Possible Solutions
3. **Engineers must understand the difference between requirements and constraints. Let's say a team of engineers is asked to design a pair of kids' tennis shoes for less than $20. They determine that the only way to manufacture shoes for this price is to use recycled materials. What is the team's *constraint*?**
    a. The shoes must be designed for kids
    b. The shoes must be made out of recycled materials
    c. The shoes must cost less than $20 to manufacture
4. **During a brainstorming session we want to focus *more* on:**
    a. quantity of ideas rather than quality
    b. quality of ideas rather than quantity
5. **Which step of the engineering design loop distinguishes an engineer from a technician?**
    a. Construct a Prototype
    b. Test and Evaluate a Prototype
    c. Redesign
6. **Although the terms "model" and "prototype" are often used interchangeably, they are not the same thing. A _______ is used to test different aspects of a product before the design is finalized. A ______ is used to demonstrate or explain how a product will look or function.**
    a. model, prototype
    b. prototype, model
7. **When following the engineering design loop, the different stages can occur in which direction?**
    a. clockwise
    b. counter-clockwise
    c. both clockwise and counter-clockwise
    d. in any direction, including shortcuts
8. **The engineering design process is iterative. This allows engineers to…**
    a. become proficient at different engineering software applications
    b. find the most optimal solution to a design problem
    c. incorporate both math and science concepts into a design problem
9. **When finding the solution to an engineering design problem, there is/are usually…**
    a. only one possible correct solution
    b. a very limited number of possible correct solutions
    c. many possible correct solutions

Name: ____ Date: ____________________

Engineering Design Quiz Answers

1. **In engineering, the design process begins when…**
   a. information about an existing product is gathered by an engineer
   b. an engineering design team comes up with ideas for a new product
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   b. a very limited number of possible correct solutions
   c. many possible correct solutions

Curricular Unit: Engineering and Empathy: Teaching the Engineering Design Process through Assistive Devices

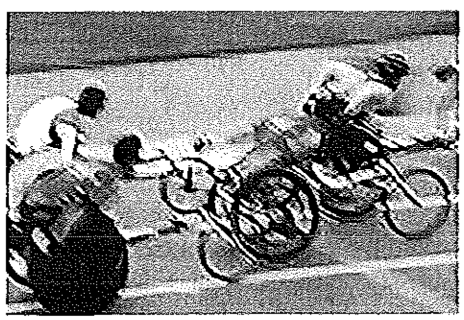
Contributed by: Inquiry-Based Bioengineering Research and Design Experiences for Middle-School Teachers RET Program, Department of Biomedical Engineering, Worcester Polytechnic Institute

Quick Look

Grade Level:	7 (6-8)
Time Required:	1265 minutes (23 x 55-minute class periods)

Related Curriculum

Subject Areas:	Science and Technology
Activities:	Automatic Floor Cleaner Computer Program Challenge Off-Road Wheelchair Challenge Portable Wheelchair Ramp Challenge Super Slinger Engineering Challenge



Engineered assistive devices provide people with disabilities access to formerly inaccessible life activities.

Summary

Students follow the steps of the engineering design process (EDP) while learning about assistive devices and biomedical engineering. They first go through a design-build-test activity to learn the steps of the cyclical engineering design process. Then, during the three main activities (7 x 55 minutes each) student teams are given a fictional client statement and follow the EDP steps to design products—an off-road wheelchair, a portable wheelchair ramp, and an automatic floor sweeper computer program. Students brainstorm ideas, identify suitable materials and demonstrate different methods of representing solutions to their design problems—scale drawings or programming descriptions, and simple models or classroom prototypes.

Engineering Connection

Engineers improve the quality of life for people around the world and they follow the steps of the engineering design process as a widely accepted way of arriving at desirable solutions to identified problems. The activities in this unit guide students through the engineering design process as they apply basic engineering concepts to real-world design problems. Through the development of assistive devices, students are exposed to the humanitarian aspects of engineering. Examples of advanced technology applications abound, for example, cutting edge prostheses such as Dean Kamen's "Luke Arm" or the redesign of traditional prosthesis to improve comfort and user interface.

Educational Standards

- International Technology and Engineering Educators Association: Technology ▸
- Massachusetts: Science ▸
- Next Generation Science Standards: Science ▸

Unit Overview

Students are introduced to the major steps of the engineering design process (EDP) and some of the roles engineers play in our world. After introducing the EDP, students are teamed up with one or two other students. Each student team spends approximately seven days working on each module—an engineering project focused on the humanitarian side of engineering. After the seven days, groups move onto their next engineering design project. This pattern repeats until students have completed all three modules. While each learning module focuses on a different field of engineering, all share the common theme of biomedical engineering through the design of assistive devices.

Unit Schedule

Day 1: Introduce students to the set-up and grading of the class.

Day 2: Start with the five-minute engineer illustration; introduce students to the field of engineering and the engineering design process. Begin Super Slinger Engineering Challenge.

Day 3: Entire-class engineering challenge continued.

Day 4: Test, evaluate and reflect on engineering challenge design solutions. Show students a movie or film that shows people overcoming disabilities through the help of engineered technology; see suggestions in the activity write-up.

Days 5-11: Begin Off-Road Wheelchair Challenge

Day 12: Flex Day

Days 13-19: Begin Portable Wheelchair Ramp Challenge

Day 20: Flex Day

Days 21-28: Begin Automatic Floor Cleaner Computer Program Challenge

Day 29: Flex Day

Day 30: Show students the PBS Frontline episode titled, *Vietnam: Wheels of Change* (10 minutes); available at http://www.pbs.org/frontlineworld/stories/vietnam804/video/video_index.html); conclude with a round table discussion.

Assessment

During this unit, assess students on their abilities to accurately follow the steps of the engineering design process as well as accurately represent their designs using multi-view drawings, scale models and/or prototypes. Use the various formative and summative means of assessment provided.

Contributors

Jared R. Quinn, Kristen Billiar, Terri Camesano

Supporting Program

Inquiry-Based Bioengineering Research and Design Experiences for Middle-School Teachers RET Program, Department of Biomedical Engineering, Worcester Polytechnic Institute

Acknowledgements

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Last modified: November 12, 2014

Hands-on Activity: Super Slinger Engineering Challenge

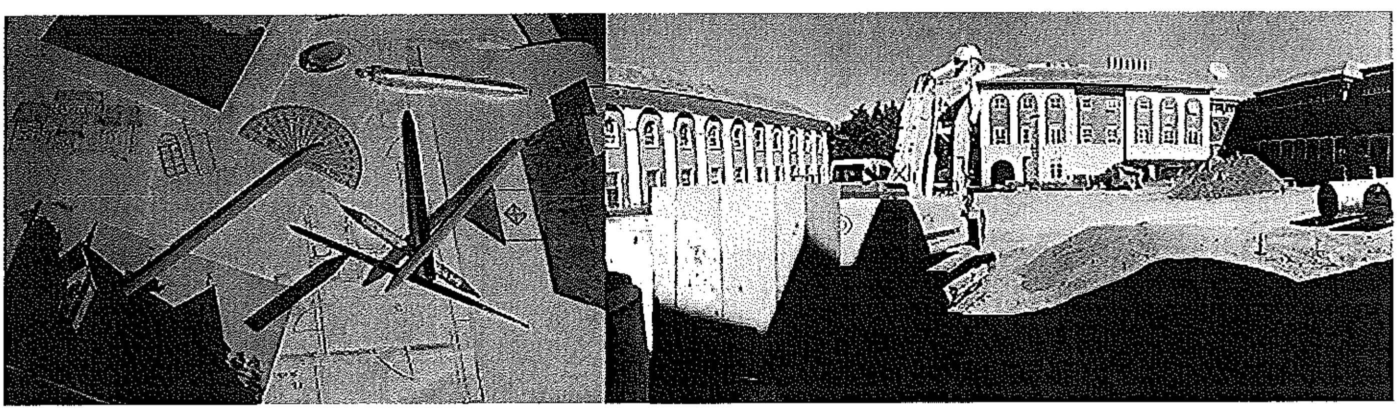
Contributed by: Inquiry-Based Bioengineering Research and Design Experiences for Middle-School Teachers RET Program, Department of Biomedical Engineering, Worcester Polytechnic Institute

Quick Look

Grade Level:	7 (6-8)
Time Required:	110 minutes (15 minutes for engineer illustration and discussion + 20 minutes to define problem + 55 minutes to build + 20 minutes test and debrief = 110 minutes)
Expendable Cost/Grp:	US$ 2
Group Size:	3
Activity Dependency:	None

Related Curriculum

Subject Areas:	Science and Technology
Curricular Units:	Engineering and Empathy: Teaching the Engineering Design Process through Assistive Devices



Like engineers, students in this activity follow the engineering design process to create and build their designs.

Summary

Students are challenged to design, build and test small-scale launchers while they learn and follow the steps of the engineering design process. For the challenge, the "slingers" must be able to aim and launch Ping-Pong balls 20 feet into a goal using ordinary building materials such as tape, string, plastic spoons, film canisters, plastic cups, rubber bands and paper clips. Students first learn about defining the problem and why each step of the process is important. Teams develop solutions and determine which is the best based on design requirements. After making drawings, constructing and testing prototypes, they evaluate the results and make recommendations for potential second-generation prototypes.

Engineering Connection

The engineering design process is a universally accepted method for achieving a desirable solution to an identified problem. This activity walks students through the engineering design process, which is critical to all engineering fields, as they apply basic engineering concepts to a design problem.

Educational Standards

- International Technology and Engineering Educators Association: Technology ▸
- Massachusetts: Science ▸
- Next Generation Science Standards: Science ▸

Learning Objectives

After this activity, students should be able to:

- Identify and describe the parts of the engineering design process.
- Utilize the engineering design process to develop solutions to the assigned problems.
- Explain the reasons for their selected designs and material choices.

Materials List

Each group needs:

- piece of drawing paper, for engineer illustration, one per student
- 1 cardboard box cover (such as the cover from a box that contains 10 reams of copy machine paper)
- Ping-Pong ball
- masking tape
- 10 feet (305 cm) string
- 4 plastic spoons
- 4 film canisters
- 6 pencils
- 4 plastic cups
- 12 rubber bands
- 12 paper clips
- (optional) 1 mouse trap (see Safety Issues section)
- Engineering Design Process Worksheet, one per student
- Engineering Challenge Design Packet, one per student

Introduction/Motivation

What does the phrase "necessity is the mother of invention" mean? (Listen to student ideas.) In general, it means that new designs are created because we need solutions to problems. Engineers are today's problem solvers. By following the steps of the engineering design process, engineers systematically approach and define problems and then arrive at viable solutions. Today we are going to go through the engineering design process and learn just how engineers create effective solutions!

Vocabulary/Definitions

constraint: A limitation or restriction. For engineers, constraints are the limitations that must be considered when designing a workable solution to a problem.
engineering design process: The iterative process through which engineers develop solutions to meet an objective. The steps of the process include: identifying a problem, brainstorming, designing, constructing, testing, analysis and evaluation, redesigning, retesting, and sharing a solution. Science, mathematics and engineering science concepts are applied throughout the process to optimize the solution.
functions: The capabilities or tasks that an engineering solution is able to perform.
objectives: Desired outcomes for an engineering design or product.
problem statement: A sentence or two that describes the identified problem or challenge an engineer or engineering team is working to solve.
prototype: An early functional version (a model, a mock-up) of a design to help move the design process forward by improving the team's understanding of the problem, identifying missing requirements, evaluating design objectives and product features, and getting feedback from others.
requirements:The overall objectives, functions and constraints of a project.

Procedure

Background

The engineering design process is a series of systematic steps that lead to the development of effective and appropriate solutions to identified problems. Engineers use their science and math knowledge to explore all possible options and compare many design ideas. This is called open-ended design because when you start to solve a problem, you don't know what the best solution will be. The process is cyclical and may begin at, and return to, any step.

1. The first step is to **identify a problem** and understand the need to solve it. This includes developing a problem statement and any functions, objectives and constraints required for an ideal solution.
2. Conducting **research** is important for gathering information about the issue at hand and understanding any solutions that have been tried in the past.
3. The next step is to **brainstorm as many solutions as possible.** Creativity and innovation are key in this step.
4. Analysis of possible solutions leads to the **selection of one design**—the team's most promising idea.
5. The next step is to **create a plan**, which often includes making **drawings** and assigning **roles** for everyone on the engineering team for building and constructing a solution **prototype.**
6. After construction, the prototype design is **tested and evaluated.**
7. The end solution is **shared and communicated** in an appropriate way to ensure that the original problem is addressed.
8. In the **redesign** step, improvements are made to the design (or recommended), and revised prototype solutions are tested again. The redesign, retest, analysis cycle is iterated as many times as necessary.

See additional information about the engineering design process at https://www.teachengineering.org/engrdesignprocess.php.

Before the Activity

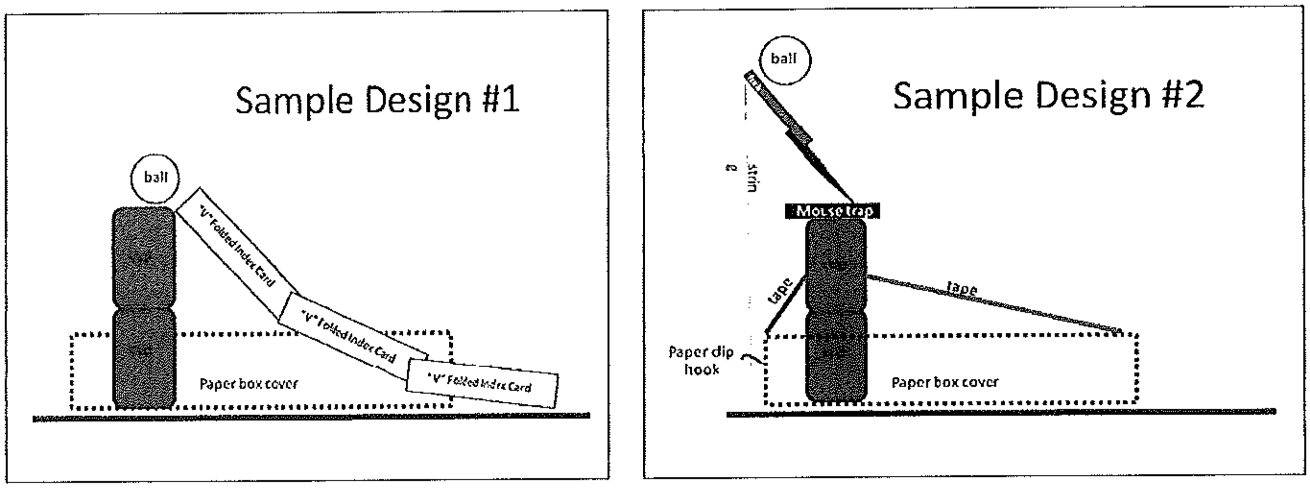
- Gather materials and make copies of the Engineering Design Process Worksheet and the Engineering Design Challenge Packet, one each per student.
- Divide the class into groups of three students each.

With the Students

1. Hand out drawing paper to the students.

- Ask each student to create an illustration/diagram of an engineer.
- Have 4 or 5 students share their illustrations with the class.
- Discuss the preconceived notions the students have regarding engineers. (Point to make: Engineers might look like anyone you know or anyone you see on the street.)

2. Provide students with a brief overview about the challenge. Inform them that this is a "practice" challenge with a focus on learning and following the steps of the engineering design process. As students work through the challenge, make sure they consciously recognize all the steps they must take during the challenge, which step they are working on at any point, and the importance of each step. Once this is established, describe the student challenge for this activity: To design, build and test small-scale launchers while learning and following the steps of the engineering design process.

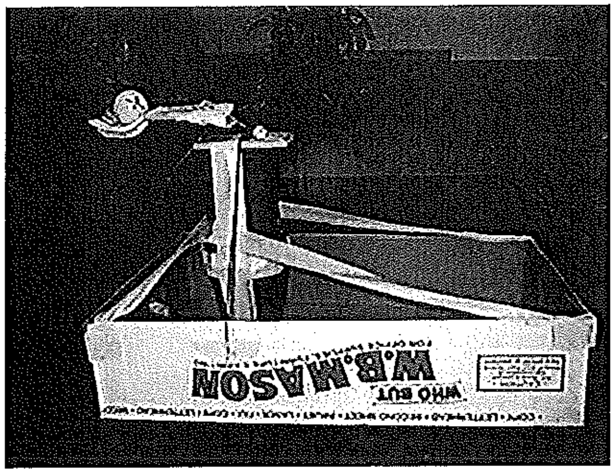


Example innovative engineering launcher designs created by students following the steps of the engineering design process. copyright

3. Hand out the worksheets.

- Complete the engineering design process section (page 2, blank circular diagram) together. As a class, walk students through the steps of the engineering design process, explaining each step and providing clear examples for why each step is important. This could take considerable time, but it is worth the extra effort now so the remainder of the unit runs smoothly. A great reference for clear examples for each step of the engineering design process is the Creative Engineering Design unit, which includes individual activities dedicated to each step of the design process. A quick scan through each activity provides a wealth of useful examples for each step of the engineering design process. As necessary, also refer to the Background section and the vocabulary definitions.
- Then have students complete the first page (vocabulary terms) on their own, either in class or as homework to turn in for grading.

4. Hand out the packets.



As part of the engineering design process, students create and test design prototypes.
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- Introduce students to the materials available to design launcher prototypes.
- Have students use the packet to guide them through the process, composing their own descriptions of the problem statement, function, objective and constraints for this challenge.
- Have each student develop one possible solution to share with his/her group.
- Have groups review each design idea and brainstorm further, weighing the positives and negatives, choosing the most promising design. Help them determine which potential design (or combination) is the "best" based on the design requirements.
- Based on their chosen designs, have groups plan and construct their launchers. During this step, have students accurately represent their designs using multi-view drawings or scale models, as well as construct functional prototypes.
- Once launchers are created, have students test them, collecting and recording test data.
- Then have groups evaluate the effectiveness of their designs by examining the test results. Based on test data and any background research conducted, have them recommend recommend specific suggestions for improvements for their designs (next-generation prototypes).
- Have students complete the packet write-up and turn it in for grading.
- If time permits, have a launcher competition.

5. Debrief with each group to help them understand and reflect upon how what they did was part of the cyclical engineering design process.
6. As time permits, show students a movie or film that shows people overcoming disabilities through the assistance of engineered technology. See suggestions in the Additional Multimedia Support section.

Attachments

Engineering Design Process Worksheet (pdf)

Engineering Design Process Worksheet (docx)

Engineering Design Challenge Packet (pdf)

Engineering Design Challenge Packet (docx)

Safety Issues

Many successful designs have been created without using mousetraps, but if mousetraps are used, attach a piece of wood to each mousetrap base to increase the surface area that can be handled, as a way to prevent potential injury. Do this by using wood glue to adhere a flat, larger piece of wood to the bottom of the mousetrap.

Assessment

Pre-Activity Assessment

Pre/Post Unit Engineer Sketch: First thing (before opening the topic and challenge), give students five minutes to each make a sketch of an engineer. Save and set aside the sketches. Repeat at unit end and compared sketches.

Class Discussion: During the introduction to the topic and the engineering design process, informally evaluate students' prior knowledge about engineering and the design process. Ask the students:

- What is the engineering design process?
- How does the engineering design process work?
- Why use the engineering design process?
- What are the parts of the engineering design process?

Activity Embedded Assessment

Vocabulary: Evaluate students' understanding of the vocabulary words and definitions through observation in group discussions of their comfort and accuracy in using the terms.

EDP Steps: Have students use the attached Engineering Design Process Worksheet to aid them in understanding the steps of the engineering design process as a problem-solving tool. Complete the circular diagram (page 2) together, through class discussion. Then, in class or as homework, have students individually compose definitions to the page 1 vocabulary terms. Evaluate these descriptions to gauge their understanding of key design process components. For answers, refer to the Background and Vocabulary sections.

Drawings and Prototypes: Evaluate students on their ability to accurately represent their launcher design solutions using multi-view drawings, scale models and/or prototypes.

Post-Activity Assessment

Launcher Challenge Steps: Evaluate students' completed Engineering Challenge Packets to gauge their understanding of and ability to follow the engineering design process steps to create their launchers. Make the assessment focus on each student's correct use of the engineering design process, rather than his/her ability to build a successful launcher. Example answers:

- Problem Statement: We need a machine to launch a Ping-Pong ball to hit a target. We must follow the steps of the engineering design process to create a successful launcher.
- Function: Our launcher should be able to aim and launch a Ping-Pong ball.
- Objective: To successfully launch a Ping-Pong ball into the goal area.
- Constraints: Use only using the provided materials and complete the activity in the 110 minutes provided.

Additional Multimedia Support

Show students the one-minute "Let's Build a Filter" scene from the Apollo 13 movie, in which NASA engineers are challenged to construct a carbon dioxide filter using only materials available on the spacecraft; available at YouTube: http://www.youtube.com/watch?v=Z3csfLkMJT4.

Show students a movie or film that shows people overcoming disabilities through the help of engineered technology. Suggestions: *Kiss My Wheels* by Miguel Grunstein and Dale Kruzic (56 minutes), *Not on the Sidelines: Living and Playing with a Disability* by Ben Achtenberg and Karen McMillan (26 minutes), available at Fanlight

Production http://www.fanlight.com/.

Contributors

Jared R. Quinn, Kristen Billiar, Terri Camesano

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Supporting Program

Inquiry-Based Bioengineering Research and Design Experiences for Middle-School Teachers RET Program, Department of Biomedical Engineering, Worcester Polytechnic Institute

Acknowledgements

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Name: ______________________________ Date: ____________ Class: __________

Engineering Design Process

Define the following terms

Engineering design process: ______________________________

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Problem statement: ______________________________

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Function: ______________________________

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Constraint: ______________________________

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Objective: ______________________________

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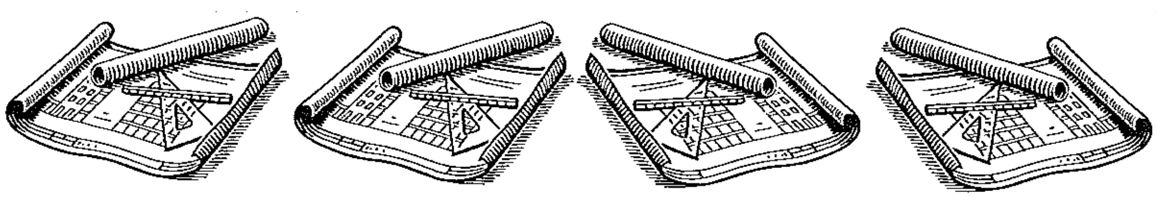
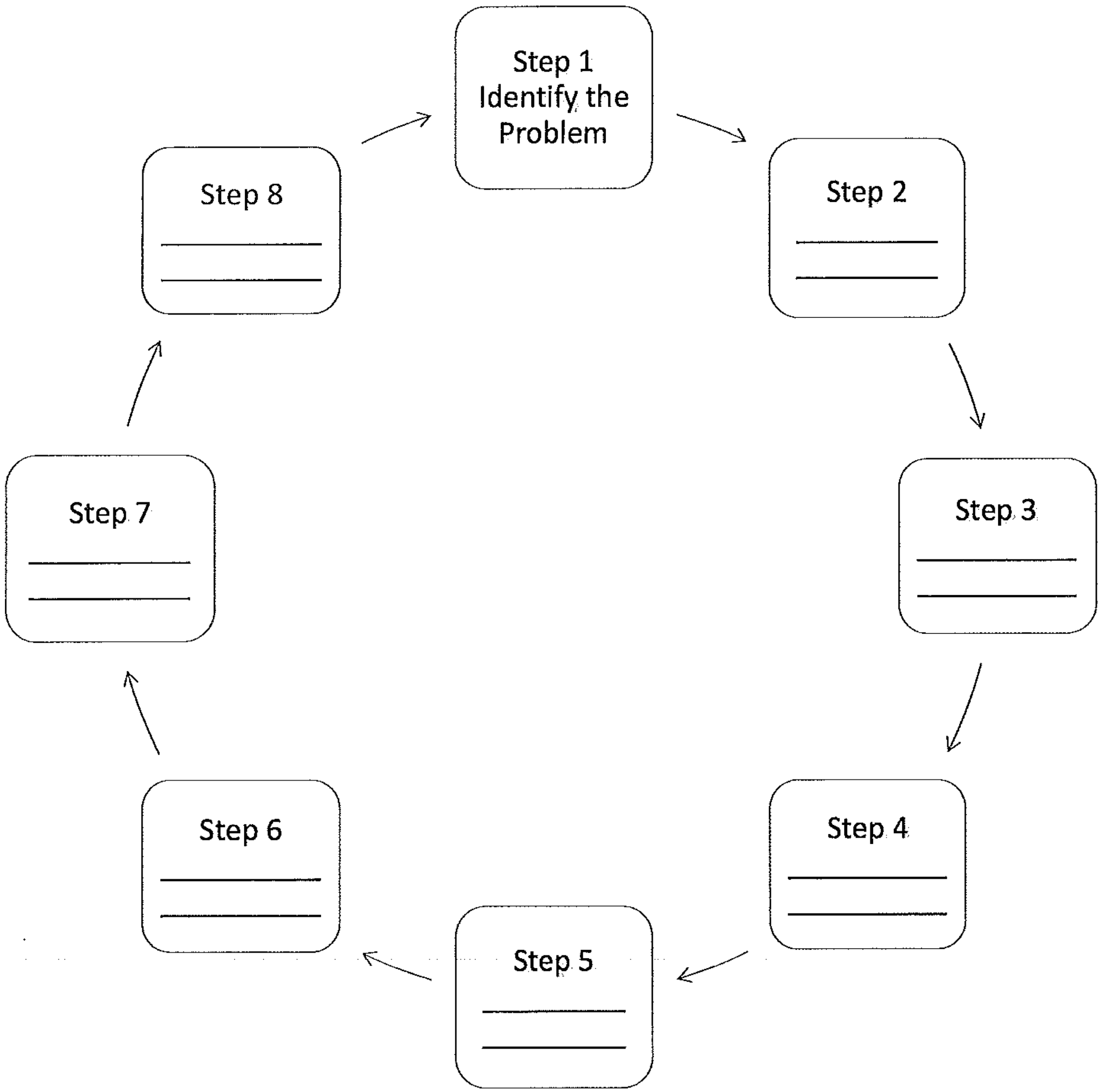
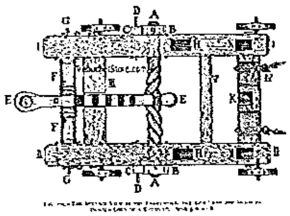


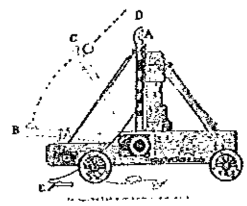
Engineering Design Process



Name: ______________________ Date: ____________ Class: ____________

Engineering Design Challenge Packet





http://www.redstoneprojects.com/trebuchetstore/catapult_2.jpg

Client Statement

Create a "slinger" to be used in an indoor game. The slinger should be made entirely out of the materials provided. The slinger should launch a Ping-Pong ball approximately 20 f into a goal. The slinger should be able to be aimed by the players and be safe for use.

Problem Statement: ____

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Function: ____

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Objective: ____

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Constraints: ____

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Design Solution **(sketch your proposed solution):**

Prototype: ____

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Test Results

Trial	Way Off Target	Off Target	Close	Very Close	Edge of Net	Score
Example		X				
1						
2						
3						
4						
5						
6						
7						

Evaluation of Results ____

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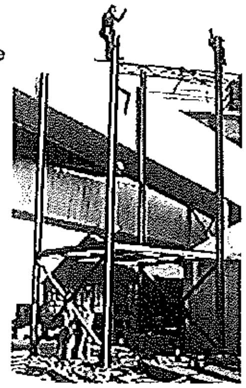
Curricular Unit: Building towards the Future

Contributed by: Techtronics Program, Pratt School of Engineering, Duke University

PARTIAL DESIGN PROCESS

Summary

Students are introduced to some basic civil engineering concepts in an exciting and interactive manner. Bridges and skyscrapers, the two most visible structures designed by civil engineers, are discussed in depth, including the design principles behind them. To help students visualize in three dimensions, one hands-on activity presents three-dimensional coordinate systems and gives students practice finding and describing points in space. After learning about skyscrapers, tower design principles and how materials absorb different types of forces, students compete to build their own newspaper towers to meet specific design criteria.The unit concludes with student groups using balsa wood and glue to design and build tower structures to withstand vertical and lateral forces.


Ironworkers building a tower.
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Engineering Connection

The ability to visualize in three dimensions is imperative to civil engineers. Engineers use a coordinate system whenever they create engineering drawings of structures, usually the Cartesian coordinate system. To build the tallest structures in the world, engineers must understand the importance of adequate foundations and redundancy in design to ensure safety and stability. To meet the challenge, engineers have devised and implemented many other creative designs and material uses so that their structures are able to withstand great forces. Students get a taste of these concepts and then apply what they have learned to create towers to meet specific objectives, as if they were civil engineers.

Quick Look

Grade Level: 7 (6-8)
Time Required: 540 minutes

Related Curriculum

Subject Areas: Geometry, Science and Technology
Lessons: The Next Dimension, Skyscrapers: Engineering Up!
Activities: A Place in Space, Balsa Towers, Newspaper Tower

Summary
Unit Overview
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ENGINEERING... turning ideas into reality

Educational Standards

- Common Core State Standards for Mathematics: Math ▸
- Next Generation Science Standards: Science ▸

Unit Overview

Lesson 1, **The Next Dimension**: Students are introduced to the concept of 3-D coordinate systems and graphing, which are essential to civil engineering work. In an associated activity, **A Place in Space**, students practice finding points in space and describing the location of given points in space.

Lesson 2, **Skyscrapers: Engineering Up!**: Students are presented with a history of skyscrapers and their unnique structural engineering design principles. In an associated activity, **Newspaper Towers**, students compete to build newspaper towers of maximum height and ability to withstand wind forces. In a second associated activity, **Balsa Towers**, student groups use balsa wood and epoxy glue to build structurally sound towers with favorable strength-to-weight ratios.

Unit Schedule

- Day 1: The Next Dimension lesson
- Day 2: A Place in Space activity
- Day 3-4: Skyscrapers: Engineering Up! lesson
- Day 4-5: Newspaper Tower activity
- Day 5-7: Balsa Towers activity

Assessment

After this unit, students should be able to:

- Locate a point in space, given its coordinates and an origin.
- Use coordinates to describe the location of a given point in space relative to some origin.
- Explain why they built their towers the way they did, using the concepts and terms they learned in the history of skyscraper presentation.
- Explain how their towers resisted the wind load (for example, which tower parts supported the bulk of the load, or making the tower really slender so the wind has less area to act on, etc.).

Contributors

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Supporting Program

Techtronics Program, Pratt School of Engineering, Duke University

Acknowledgements

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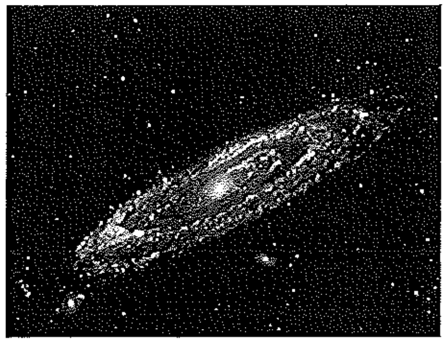
Lesson: The Next Dimension

Contributed by: Techtronics Program, Pratt School of Engineering, Duke University

Summary

The purpose of this lesson is to teach students about the three-dimensional Cartesian coordinate system. Students also gain perspective on the size of our galaxy (the Milky Way) and the distance of a nearby spiral galaxy, the Andromeda galaxy (shown on the right) using a 3D model. 3D graphing is an important tool used by structural engineers to describe locations in space to fellow engineers.



How do we describe a location in space?
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Engineering Connection

Engineers use a coordinate system whenever they create engineering drawings of something, and the Cartesian coordinate system described in this lesson is used most often.

Quick Look

Grade Level:	6 (5-7)
Lessons in this Unit:	1 2
Time Required:	40 minutes Allow for an additional 15-20 minutes if students are asked to build their own sets of axes.
Lesson Dependency:	None

Related Curriculum

Subject Areas:	Geometry Science and Technology
Curricular Units:	Building towards the Future
Activities:	A Place in Space

ENGINEERS help shape the future

Educational Standards

- Common Core State Standards for Mathematics: Math
- International Technology and Engineering Educators Association: Technology
- Next Generation Science Standards: Science
- North Carolina: Math

Pre-Req Knowledge

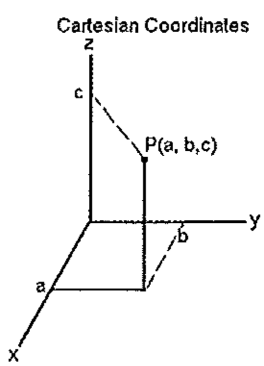
Some experience with the two-dimensional Cartesian coordinate system is helpful, but is not required.

Learning Objectives

At the end of the lesson, students shoud:

- Be able to find a point in space given the X, Y and Z coordinates.
- Have a sense for the dimensions of the Milky Way galaxy, where the Sun is in within it, and the distance to a nearby galaxy.
- Be able to give the X, Y and Z coordinates, given a point in space relative to a specified coordinate system and origin.

Introduction/Motivation



The 3D coordinate system.

Use a flat surface such as a piece of paper, or a table top. Put your finger at a point on the surface, and ask students how they would describe the location of that point. If they have had experience graphing on the XY plane, they will probably figure out that they can give the coordinates of that point relative to a particular corner (over 5 inches, up 9 inches). If they do not get this on their own, ask leading questions to help them. For example, "Well how far away is the point from the side of the paper?" Once students grasp this, move your finger so that it is above the surface you are using. Then ask them again how they would describe the location of that point. They may say something like "above the paper." Ask them to be more specific. The goal is to get them to give a description such as "5 inches over from the left side, 9 inches up, and 6 inches above." Ask them to give you the three coordinates necessary to describe the location of the points.

Next, spend a short time discussing the terms in the vocabulary section.

It is helpful to describe some concrete examples of how the 3D coordinate system is used in everyday life. For example, when you describe the location of an office within a building, you are essentially using coordinates: "Go up 3 floors, do down the hall past four doors and turn right, it's the second room on your left." City blocks are another example of the use of a coordinate system. Directions from one house to another might read, "Go three blocks, then take a right and go four blocks." This is an example of a two-dimensional coordinate system.

Coordinate systems can also help us visualize where we are within our galaxy, as well as how far away a "nearby" galaxy is in space. Have students complete the Galactic Perspectives Worksheet. Students should be placed in teams of 2-3 and each team should be given a ruler.

Lesson Background and Concepts for Teachers

The purpose of this lesson is to familiarize students with 2-D and 3-D graphing and to use these tools to develop a sense of the spatial scales relevant to our galaxy including its spatial dimensions and relative distances between objects within the Milky Way and a neighboring galaxy. Have students complete the Galactic Perspectives student worksheet to achieve this goal.

Students can also learn the basics of graphing in three dimensions. Conduct the A Place in Space associated activity to accomplish this. Its worksheet guides students to first review finding points on the 2D (XY) plane, and then moves on to finding and describing points in a 3D space (X, Y ,Z). In order to get the most out of the activity, groups need their own set of axes. Instructions for how to build these as well as supplies needed are described in the activity's Procedure section.

Vocabulary/Definitions

dimension: A measure of spatial extent. What we see around us is a three-dimensional world, because objects have three dimensions (length, width and height). A line is in one dimension, an area (such as a rectangle drawn on a piece of paper) is in two dimensions, and a box has three dimensions.

axis: In math, a line used as a reference to describe the location of a point. For example, in the Cartesian coordinate system, an axis is a line marked zero at a certain point. An object's location can then be described by measuring how far away (on the line) it is from this origin, and in what direction. In many ways, an axis is like a number line that goes on forever in both directions (positive and negative). An axis is one dimensional.

plane: The set of all points between two intersecting lines. A plane is two dimensional, so it is a flat surface. A flat table top, for example, can be thought of as a plane.

ordered pair: A way to describe the location of a point within a plane, relative to a specified reference point. For example, if the front left corner of your desk is the origin, and you want to find a point given the ordered pair (2, 3) and you know that the unit you are using is inches, you would start at that front left corner of your desk, move two inches to the right, and then 3 inches toward the back of the desk, and you would be at that point.

graph: A visual representation of a mathematical function or set of numbers. In the previous definition for ordered pair, if your desk surface could be thought of as a graph, and you graphed the point (2,3), this means you represented those numbers visually (or graphically).

origin: The specified reference point (0,0,0) in most coordinate systems.

Cartesian coordinate system: The rectangular coordinate system developed by mathematician Descartes. It consists of 2 or 3 axes (X, Y and Z) all at right angles to each other, and all intersecting at a specified origin.

Galactic Center: The center of the Milky Way galaxy

Associated Activities

- A Place in Space - Students practice finding points in space and then describing the locations of given points in space.

Lesson Closure

Coordinate systems can be used for more than mapping objects in space. A coordinate system is used by engineers in all designs. The coordinate system is used to specify dimensions for products. When an engineer designs a part, s/he specifies where each point on the part is located using a Computer Aided Design (CAD) program. Often, parts can be manufactured by sending a CAD drawing file to a machine that is designed to interpret the file and create the part.

- We have learned how to locate a point given an origin, and the X, Y and Z coordinates.
- We can also describe the location of a point by providing this information.
- We have applied this information to construct a 3-D model of our galaxy and a neighboring galaxy, and have gained some insight into galactic distances and related spatial scales.

Attachments

Galactic Perspectives Worksheet (pdf)

Galactic Perspectives Worksheet (docx)

Galactic Perspectives Worksheet Answer Key (pdf)

Galactic Perspectives Worksheet Answer Key (docx)

Assessment

- If students were able to satisfactorily complete the Galactic Perspectives Worksheet with little or no help from teachers or peers then they have demonstrated the ability to use 2-D and 3-D models to explore the spatial scales and dimensions of the Milky Way galaxy and the relative distance to the nearest spiral galaxy (the Andromeda galaxy).
- If students were able to satisfactorily complete the A Place in Space activity worksheet with little or no help from teachers or peers then they have demonstrated a sound understanding of the basics of plotting coordinates in three dimensions.
- Students should be able to locate a point in space, given its coordinates and an origin.
- Students should be able to describe the location of a given point in space relative to some origin using coordinates.

- Should have an enhanced perspective on the dimensions of our galaxy and appreciate the relative distance to other nearby galaxies

Lesson Extension Activities

A practical way to apply what students have learned in this lesson/activity is to have them design basic structures such as bridges or towers using a computer aided design (CAD) program such as the West Point Bridge Builder (http://bridgecontest.usma.edu/). This CAD program is a free bridge designing application used specifically for bridge building contests.

Students could also calculate the scaled-distances to much farther away galaxies, and discover that these galaxies would be quite far away even using the scale model that was applied to the Milky Way.

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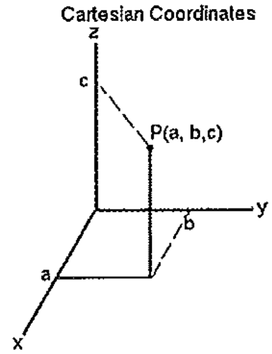
Hands-on Activity: A Place in Space

Contributed by: Techtronics Program, Pratt School of Engineering, Duke University

Summary

Student groups use a "real" 3D coordinate system to plot points in space. Made from balsa wood or wooden dowels, the system has three axes at right angles and a plane (the XY plane) that can slide up and down the Z axis. Students are given several coordinates and asked to find these points in space. Then they find the coordinates of the eight corners of a box/cube with given dimensions.

Cartesian Coordinates



The 3D coordinate system.

Engineering Connection

Engineers use a coordinate system whenever they create engineering drawings of objects and structures, and the Cartesian coordinate system modeled in this activity is used most often.

Quick Look

Grade Level:	6 (6-9)
Time Required:	25 minutes (Plus 15-20 minutes if students build their own set of axes.)
Expendable Cost/Grp:	US$ 3.00
Group Size:	3
Activity Dependency:	The Next Dimension

Related Curriculum

Subject Areas:	Geometry Science and Technology
Curricular Units:	Building towards the Future
Lessons:	The Next Dimension

Educational Standards

- Common Core State Standards for Mathematics: Math
- International Technology and Engineering Educators Association: Technology
- North Carolina: Math

Pre-Req Knowledge

Minimal prior experience graphing in two dimensions is helpful, but not required.

Learning Objectives

After this activity, students shold be able to:

- Locate a point in space, given its coordinates and an origin.
- Describe the location of a given point in space relative to some origin using coordinates.

Materials List

- 3-foot length of ¼ inch x ¼ inch balsa wood or wooden dowel
- a fast adhesive such as a hot glue gun, rubber cement or a golf ball-sized ball of clay
- marker
- ruler
- utility knife or scissors
- 1 inch x 1 inch square of corrugated cardboard, foamcore board or poster board

Introduction/Motivation

The contents of the Introduction/Motivation section of The Next Dimension associated lesson also serve as the introduction to this activity.

Vocabulary/Definitions

dimension: A measure of special extent. What we see around us is a three-dimensional world, because objects have three dimensions: length, width and height. A line is in one dimension, an area (such as a rectangle drawn on a piece of paper) is in two dimensions, and a box (cube) has three dimensions.

axis: In math, a line used as a reference to describe the location of a point. For example, in the Cartesian coordinate system, an axis is a line marked zero at a certain point. An object's location can then be described by measuring how far away (on the line) it is from this origin, and in what direction. In many ways, an axis is like a number line that goes on forever in both directions (positive and negative). An axis is one dimensional.

plane: The set of all points between two intersecting lines. A plane is two dimensional, so it is a flat surface. A flat table top, for example, can be thought of as a plane.

ordered pair: Two numbers used to describe the location of a point within a plane, relative to a specified reference point. For example, if you are told that the front left corner of your desk is the origin, and you want to find a point given the ordered pair (2, 3) and you know that the unit you are using is inches, you start at that front left corner of your desk, move two inches to the right, and then 3 inches toward the back of the desk, and you find that point.

graph : A visual representation of a mathematical function or set of numbers. In the previous definition for ordered pair, if your desk surface is thought of as a graph, you graphed the point (2,3), meaning you represented those numbers visually (or graphically).

origin : The specified reference point [(0,0,0) in most coordinate systems]

Cartesian The rectangular coordinate system developed by the famous mathematician Descartes. It consists of 2 or 3 axes (X, Y *coordinate system*: and Z) all at right angles to each other, and all intersecting at a specified origin.

Procedure

Before the Activity

Gather materials and make copies of the 3D Coordinaes Worksheet.

Follow these steps to build one set of axes for each group. Alternatively, have the groups build the axes themselves.

1. Cut the balsa wood into three segments of 1 foot each. (This will likely take an extra 15-20 minutes.)
2. Use a glue gun (or other adhesive or clay) to glue the three pieces together so that all three are perpendicular to each other, meeting at one point. This forms the three axes.
3. Using a ruler and marker, make marks every inch on each of the three axes, moving away from the origin. Make a total of 10 marks on each axis. If desired, number the markings so that on each axis, "1" is closest to the origin, and "10" is farthest out on the axis.
4. Using a utility knife or scissors, cut the cardboard, foam board or poster board into a 1 foot x 1 foot square. Make a small hole in one corner of the square, about a half inch in from the edges. Make the hole just big enough for the balsa wood axis to fit through.
5. This foam board serves as the XY plane. Slide it over one of the axes (the Z axis) all the way down until it is resting on the other two axes. The hole where the Z axis slides through the XY plane is now at the origin.
6. Use the ruler to draw a 10 inch x 10 inch grid on the plane. Space the grid every inch, so that they match up with the markings on the X and Y axes. Then label the axes on the plane "X" and "Y" and number from 1 to 10 (again counting up as you move away from the origin. These numbers should match up with the numbers on the X and Y balsa wood axes.
7. You have now constructed a 3D coordinate system with a moveable XY plane. To locate a point, first find the desired X and Y coordinates on the XY plane (traditional 2D graphing) and then slide the entire plane up to the specified Z coordinate.

With the Students

1. Divide the class into groups of three students each. Give each group a set of three axes.
2. Hand out the worksheet, which guides students through the 3D activity.

Attachments

3D Coordinates Worksheet (pdf)

Safety Issues

- If students use utility knives to cut the cardboard or foamcore board, closely supervise them and watch for dangerous use of these sharp tools.
- Warn students that the glue guns and the glue get very hot. Also take care with other adhesives and follow their safety instructions

Assessment

Worksheet: If students are able to satisfactorily complete the 3D Coordinates Worksheet with little or no help from the teacher or peers, then they demonstrate a sound understanding of the basics of 3D graphing.

Activity Extensions

Have students find the points to describe shapes that are more complicated than a box.

Try drawing the 3D axes on a piece of paper. Then, try to draw a cube in 3D by locating points on the axes

Change the plane from the XY plane to the XZ or YZ planes by sliding it down a different axis. The points may be located in the same manner, and students will learn that the particular letters and orientation of the planes is arbitrary.

Activity Scaling

- Have less-advanced students do only the 2D part.
- To save time and cost, build just one set of 3D axes and present the activity as a class demonstration, instead of each group having its own set of axes.

Contributors

Ben Burnham

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Last modified: December 26, 2014

Lesson: Skyscrapers: Engineering Up!

Contributed by: Techtronics Program, Pratt School of Engineering, Duke University

PARTIAL DESIGN PROCESS

Summary

Skyscrapers are one of the most glorified products of civil engineering and contain an interesting history of progress and development. Students learn about the history of the world's tallest free standing structures and the basic design principles behind their success. Then, through two associated activities, students are given tower design challenges, as if they were civil engineers. They build their own newspaper skyscrapers with limited materials and time, trying to achieve a maximum height and the ability to withstand a "hurricane wind" force. Then they build their own balsa towers in a competition for height and strength. Discussion focuses on materials, forces that skyscrapers must be able to withstand, basic tower design considerations (foundations), as well as examples unique and inspiring design solutions.

The Citicorp Center in New York City features a unique cantilevered design.
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Engineering Connection

Engineers face many challenges in their quests to build ever-taller skyscrapers. The two associated activities are both engineering design activities providing students the opportunity to act as civil engineers to meet design objectives within limitations.

Quick Look

Grade Level:	7 (6-8)
Lessons in this Unit:	1 2
Time Required:	90 minutes
Lesson Dependency:	None

Related Curriculum

Subject Areas:	Geometry Science and Technology
Curricular Units:	Building towards the Future
Activities:	Balsa Towers Newspaper Tower

ENGINEERS are creative problem solvers

Educational Standards

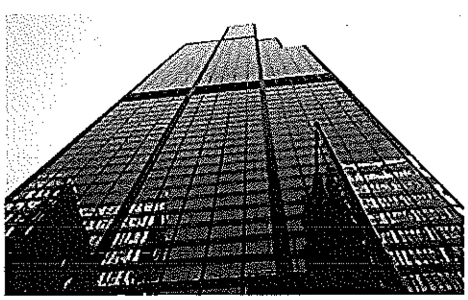
- International Technology and Engineering Educators Association: Technology
- Next Generation Science Standards: Science
- North Carolina: Math
- North Carolina: Science

Learning Objectives

After this lesson, student should be able to:

- Identify several different structural engineering principles relating to skyscrapers.
- Match design principles with famous skyscrapers.
- Explain and appreciate the challenges and difficulties in building tall structures.

Introduction/Motivation



The Willis Tower (formerly the Sears Tower) in Chicago, IL

Ask students to name what they think is the tallest skyscraper (free-standing structure) in the world (and where it is), in the U.S., and in their home towns.

Proceed to tell them the correct answers to these questions and compare their heights to each other and to other lengths the students can relate to (football field lengths, portion of a mile high, etc.) (See Lesson Background information.)

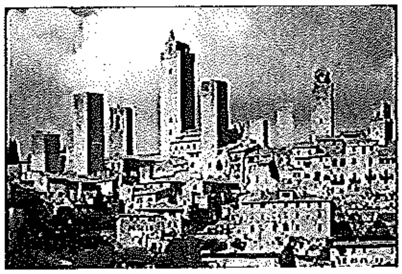
Tallest building in the world – Burj Khalifa located in Dubai, United Arab Emirates, 2,717 feet tall (~9 football fields high) Tallest building in the U.S. – One World Trade Center, located in New York City, 1,776 feet tall (~6 football fields high)

Proceed to conduct the Newspaper Towers activity so that students can discover, through trial and error, which structural designs work better than others.

Lesson Background and Concepts for Teachers

After students have completed the newspaper tower activity, present them with the following history of skyscrapers and the photographs provided throughout this lesson.

Skyscraper Presentation



The San Gimignano Towers in Italy.

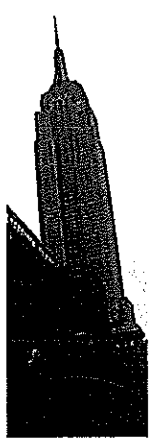
For the beginning of the presentation, read the "Skyscraper Basics" portion of PBS's Building Big website. The information about the San Gimignano Towers, gothic cathedrals, steel and iron, and elevators provide a brief but informative early history of skyscrapers.

Foundations are a critical design element that enable skyscrapers to stand on the ground beneath them. Skyscrapers themselves would exert too great a force over too small an area for the soil to support them. Thus, tall towers require foundations to help spread that force over a larger area. If the soil is still too soft even with a large foundation, sometimes geotechnical engineers direct construction crews to dig down to reach bedrock to as an anchor to better support a building. However, sometimes, like in San Francisco, and many other coastal areas, the bedrock lies deep underground. In those cases, MANY concrete piles (long rods of concrete) are driven into the ground with a large diesel hammer until they hit the bedrock. Then, the foundation and skyscraper sits on those piles.

The Home Insurance Building.

The Empire State Building was completed in 1931 in New York City. It remained the tallest structure in the world for more than 40 years! PBS's Building Big website provides background information and interesting facts about the Empire State Building.

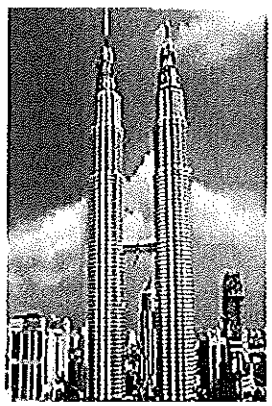
In discussing the Empire State Building, point out that its 3-D grid of columns evenly spaced throughout the entire structure prevented having large open spaces, it was noted for its fast construction, and its more-than-necessary amount of columns (redundancy) enabled the building to withstand the impact of a B-25 bomber.



The Empire State Building was the tallest building in the world from 1931-1972.

The Citicorp Center in New York City solved an interesting engineering design problem. Although it was never the tallest building in the world, it still is a very impressive civil engineering feat. PBS's Building Big website provides information and interesting facts about the Citicorp Building and obstacles its designers had to overcome.

In discussing the Citicorp Center, point out its cantilevered structure that allowed the nearby church to remain in place. Also, an interesting fact is that when Hurricane Ella was approaching the city and the Citicorp Center, the city was only hours away from evacuating the area, concerned that the tower would not withstand the gale wind forces. Briefly discuss its tuned-mass-damper, an advanced engineering accomplishment.



The Petronas Towers in Malaysia.

Point out to the students the bundled tube structure of the Willis Tower (formerly known as the Sears Tower) and how it works to withstand both lateral and vertical loads. In addition, describe how this tower sits on a large number of piles driven down to the bedrock.

The Petronas Towers in Kuala Lumpur, Malaysia, were featured in the movie Entrapment, and were until 2004 the tallest building in the world, and the first tallest skyscraper not located in the U.S. PBS's Building Big website provides information and interesting facts about the Petronas Towers.

When discussing the Petronas Towers, point out the near-cylindrical design of the towers and how this enables the towers to experience a lower wind force than if they were rectangular in nature. Also, mention the double-decker elevators, which are a fairly new-development that permit more stories and higher towers to be built.

When completed, the Taipei 101 in Taipei, Taiwan, was the tallest structure in the world standing 509 m high (1671 ft). This skyscraper is built in a highly active earthquake zone and thus features a tuned mass damper system to increase its ability to withstand tremors. This tower also has double-decker elevators, similar to those in the Petronas Towers.

The Burj Khalifa, designed by the same Chicago-based architectural firm that designed the Sears Tower and One World Trade Center, is now the tallest building in the world. Located in Dubai, United Arab Emirates, the Burj Khalifa's structure tapers as it rises. The building's designers created a new structural system – called a buttressed core – to support its massive weight. This system uses a hexagonal core with reinforcement from three supporting members that form a Y shape, helping to keep the building from twisting. To further reduce stress on the building, its design was rotated so that it faces less of the area's prevailing winds.

Vocabulary/Definitions

cantilever: A projecting structure supported only at one end, like a shelf or a diving board.
redundancy: The structural design principle of placing more columns and beams in a structure than is necessary. That way, if one or many beams or columns fail or break the building will still be able to support its own weight.
tuned mass damper: Typically a large block of concrete that sits on a structure's top floors to counteract the wind and earthquake forces. When an earthquake or high winds force the structure one way, the block slides the other way, dampening the affect.
lateral force: A force that impacts a structure horizontally, such as winds and earthquakes.
deflection: The amount a structure bends or moves from its "at rest" position.
civil engineering: A field of engineering pertaining to non-moving structures such as roads, sewers, towers, buildings and bridges.
member: A beam or column of a structure.
foundation: A large, deep and wide concrete base that a tower sits on, always much wider than the tower itself. Sometimes foundations rest upon soil, other times, soil is removed so the foundation can rest on or attach to bedrock below. When the bedrock is too deep, concrete or steel piles are used.

Associated Activities

- Newspaper Towers - Students build their own newspaper towers in a competition for height, while also being able to withstand a simulated "hurricane" wind force.
- Balsa Towers - Students build their own balsa towers in a competition for height and strength.

Assessment

Concluding Discussion: Ask students the following questions and discuss as a class:

- Which newspaper tower designs worked and which did not work? Why?
- Compare successful towers to skyscrapers discussed in the lesson introduction. What are successful design approaches? (Examples: Wide bases, deep and anchored foundations, using the triangle as the strongest shape, the bundled tube shown in the Sears Tower diagram, etc.)
- Why might limiting the amount of materials be realistic and sometimes beneficial? (Answer: Economic factors and limited budgets are a fact of life, non-renewable resources such as steel, less labor-intensive construction, etc.)
- Why did you build your towers the way you did? Explain. (Encourage them to use the concepts and terms they learned in the history of skyscrapers presentation.)
- How did your tower resist the wind load? What was your design approach? (Example answers: Certain parts of the tower supported the bulk of the load/force, or really slender towers so that the wind had less area to act upon.)

Lesson Extension Activities

Assign students to look at buildings in their town or simple structures in their neighborhoods and comment on aspects of the structures that help them support their own weight, or some active force impacting them.

Additional Multimedia Support

The Skyscrapers page at the PBS Building Big website provides a wealth of information on skyscraper basics and many examples for presentation to students. See http://www.pbs.org/wgbh/buildingbig/skyscraper/index.html

References

Building Big. PBS. Accessed June 25, 2004. (source of lesson background information) http://www.pbs.org/wgbh/buildingbig/

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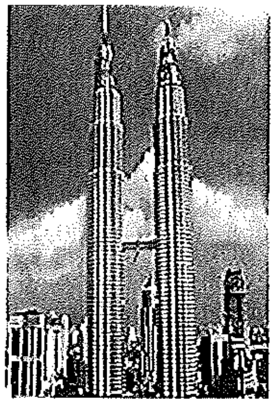
Hands-on Activity: Newspaper Tower

Contributed by: Techtronics Program, Pratt School of Engineering, Duke University

PARTIAL DESIGN PROCESS

Summary

Student groups are challenged to design and construct model towers out of newspaper. They are given limited supplies including newspaper, tape and scissors, paralleling the real-world limitations faced by engineers, such as economic restrictions as to how much material can be used in a structure. Students aim to build their towers for height and stability, as well as the strength to withstand a simulated lateral "wind" load.


The Petronas Towers.

Engineering Connection

Students act as civil engineers as they design and build newspaper towers. They must pay particular attention to designing the tower to withstand the forces of high winds, a problem that students may not have considered in the construction of tall buildings.

Quick Look

Grade Level:	7 (6-8)
Time Required:	50 minutes
Expendable Cost/Grp:	US$ 1.00
Group Size:	3
Activity Dependency:	Skyscrapers: Engineering Up!

Related Curriculum

Subject Areas:	Geometry Science and Technology
Curricular Units:	Building towards the Future
Lessons:	Skyscrapers: Engineering Up!

ENGINEERS help shape the future

Educational Standards

- International Technology and Engineering Educators Association: Technology ▸
- Next Generation Science Standards: Science ▸
- North Carolina: Math ▸
- North Carolina: Science ▸

Learning Objectives

After this activity, students should be able to:

- Identify which designs can and cannot withstand the self-weight of the newspaper tower as well as a lateral wind load.
- Explain how their towers worked to withstand the lateral wind load using terms learned in other lessons within this curricular unit if applicable or general engineering terms.

Materials List

- newspaper
- office tape
- scissors
- meter stick

Introduction/Motivation

Today, your engineering design challenge is to design and construct a model tower using only newspaper and tape and scissors. Your team will be given limited supplies and a time limit. The tower must be as tall as you can make it, but also stable enough to stand up to a wind load since it will be built in a hurricane-prone region.

Your task mirrors the challenges that engineers are given in the real world—with objectives, requirements and constraints such as budgets, material limitations and deadlines. An engineering team that can design a structure to meet the objectives with the fewest materials (hence, less cost), is favored over other companies that cannot utilize the given materials as effectively.

When you are brainstorming about your design approach in your teams, think about the real skyscrapers you have seen as inspiration, including the tallest buildings and towers in your home town. What are their shapes? What are their foundations like?

(Move on to provide students with details provided in the Procedure section so that they understand how much material they may use and how much time they have.)

Vocabulary/Definitions

buckling: When a column fails by bending at some point in the height of the column, usually towards the midpoint caused by a vertical force.

lateral force: A force that impacts a structure horizontally (that is, wind and earthquakes).

deflection : The amount a structure bends or moves from its "at rest" position.

civil engineering : The field of engineering pertaining to non-moving structures such as roads, sewers, towers, buildings and bridges.

bundled The design principle that the Sears Tower is built on. The building is basically a collected bunch of tubes, with all the *tube*: supporting columns of each "tube" located on the perimeter of the tube. This structure is very good at resisting wind loads.

tube-style support: Implemented on building such as the World Trade Center, Sears Tower, and many newer structures. The majority of the supporting columns are mover to the perimeter of the tower instead of spread throughout. This allows open expanses of floor space on every floor.

Procedure

Background

Several solutions to this design challenge are more obvious that others, although students can definitely surprise you with unexpected designs that work quite well.

- Rolling several small tubes to attach to the bottom or a central tube of newspaper is a good design. The cylinder acts to allow the tower to have the wind go around the building. The more narrow and slender the tower is at height the better it is able to withstand the "wind" because less surface exists for the wind to act upon.
- Another solution is a tripod type design. While the majority of the newspaper is used to build up, toward the bottom, three tightly wound newspaper rolls extend down from the tower to the table at an angle. This gives the tower more resistance against toppling in the wind load.
- Another solution involves having a very wide base for the tower to sit on, like a foundation.

With the Students

- Divide the class into groups of three students each.
- Distribute scissors around the classroom for students to share. Give each group 12 inches (30 cm) of tape and three full sheets of newspaper.
- Give teams 20 minutes to test different designs.
- After 20 minutes, students are allowed to return all their materials to the teacher in exchange for another 12 inches (30 cm) of tape and three more sheets of newspaper.
- Give students an additional 25 minutes of construction time.
- TESTING: Measure and record the height of the final tower. Then step away from the tower so it is at arm's length and blow out a full breath to simulate a hurricane. A successful tower will not topple over. Make sure the tower is not secured to a table, the floor or any other piece of furniture or wall.

Safety Issues

Watch that students are careful with the scissors.

Troubleshooting Tips

If students are struggling, consider allowing more time or providing more materials.

If students are struggling for design ideas, suggest they think about tall buildings they may have seen in cities or in their own towns that have cylindrical shapes or large foundations or triangular trusses for support. If necessary, suggest more specifics, such as the idea of rolling the paper for strength and/or using a triangular or wider base.

Assessment

Concluding Analysis: Have students explain how their towers work to resist the "wind" load, using engineering terms learned from earlier in the lesson, or from other lessons within the curricular unit if applicable.

Results Debriefing: Have students discuss as a class what designs did and did not work and why that was so. Examples of successful design approaches included: triangular base, wide base, small tower surface area, tubes, etc. Examples of unsuccessful design approaches include: large flat surfaces for tower sides, small bases, etc.

Activity Extensions

Have students try building newspaper towers for height only or to support an object. Have them then compare the differences in design between towers designed to hold vertical vs. lateral loads, and between towers that are not designed to hold any weight but their own.

Activity Scaling

- For younger kids, allow more time and materials, and suggest some design ideas.
- For high school students, allow less time and fewer materials, or have them use only one sheet of letter-sized paper but more time.

References

Building Big. PBS. Accessed June 25, 2004. http://www.pbs.org/wgbh/buildingbig/

Contributors

Kelly Devereaux and Benjamin Burnham

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Supporting Program

Techtronics Program, Pratt School of Engineering, Duke University

Acknowledgements

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Last modified: December 26, 2014

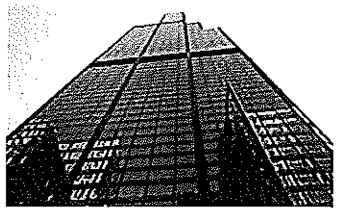
Hands-on Activity: Balsa Towers

Contributed by: Techtronics Program, Pratt School of Engineering, Duke University

PARTIAL DESIGN PROCESS

Summary

Students groups use balsa wood and glue to build their own towers using some of the techniques they learned from the associated lesson. While general guidelines are provided, give students freedom with their designs and encourage them to implement what they have learned about structural engineering. The winning team design is the tower with the highest strength-to-weight ratio.



The Sears Tower, Chicago, IL

Engineering Connection

Students act as if they are civil engineers, and make balsa wood towers to meet a design requirement. They brainstorm, design, test and redesign their model towers.

Educational Standards ❶

- Common Core State Standards for Mathematics: Math ▸
- International Technology and Engineering Educators Association: Technology ▸
- Next Generation Science Standards: Science ▸
- North Carolina: Math ▸
- North Carolina: Science ▸

Learning Objectives

- Students will be able to draw structurally sound 2D designs on paper.
- Students will be able to construct 3D structures from 2D designs.

Materials List

- markers
- large sheets of paper, such as butcher paper
- quick drying epoxy glue (90-second or 5-minute)
- 1/4 x 1/4 inch balsa wood strips
- 1/8 inch balsa wood sheets
- (optional) dremel tool
- measuring rulers
- utility knives (for students, if possible, otherwise one for the teacher)
- newspaper, to protect table tops from glue
- scrapwood, to cut on (and protect the table tops)
- goggles, one per person
- scale, to weigh towers
- flat board, to set on top of a tower and on which to place weight for testing
- weights or many identical books, to use as mass/weight to test tower strength
- Structural Strength Testing Handout, one per student

Source for balsa wood and glue: http://www.specializedbalsa.com/

Introduction/Motivation

Your engineering design challenge today is to build a structurally sound tower with a favorable strength-to-weight ratio. Working in teams, you will experiment with various designs and come up with what you believe is the best one.

Who can tell me what we mean by "strength-to-weight ratio"? (Listen to student explanations. Correct and amend as necessary.) That's right, it is the ratio of the amount of weight a structure can hold to the mass of the structure itself.

Which team will succeed in building a tower with the highest strength-to-weight ratio? Let's get started!

Vocabulary/Definitions

buckling:	When a column fails by bending at some point in the height of the column, usually towards the midpoint and caused by a vertical force.
lateral force:	A force that impacts a structure horizontally, such as winds and earthquakes.
deflection :	The amount a structure bends or moves from its "at rest" position.
civil engineering:	The field of engineering pertaining to non-moving structures such as roads, sewers, towers, buildings and bridges.
strength-to-weight	A ratio of the amount of weight a structure can hold to the mass of the structure itself.

Quick Look

Grade Level:	7 (6-8)
Time Required:	120 minutes
Expendable Cost/Grp ❶:	US$ 10
Group Size:	4
Activity Dependency ❶:	Skyscrapers: Engineering Up!

Related Curriculum ❶

Subject Areas:	Geometry Science and Technology
Curricular Units:	Building towards the Future
Lessons:	Skyscrapers: Engineering Up!

ENGINEERING... because dreams need doing *ratio:*

Procedure

1. Gather materials and make copies of the Structural Strength Testing Handout, one per student.
2. Divide the class into groups of three or four students each. Hand out the large-sized paper and writing implements.
3. Direct the teams to brainstorm and then sketch their tower ideas and designs on the large-sized paper. One possible tower-building technique is to build each side (either 3 or 4) and then attach each side together. Or, take a ground-up approach and build all of the sides of the tower at the same time. Expect students to discover what shapes are the strongest in the design of a physical structure.
4. Distribute the building materials.
5. Explain safety techniques that pertain to the utility knives, epoxy glue and dremmel tool. See the Safety Issues section.
6. Demonstrate for students on how to safely cut and glue together two pieces of balsa wood. Note that epoxy glue has two components: resin, and hardener. To use it, apply a small amount of the resin to the area to be glued, and then apply the hardener, which makes it dry practically instantly.
7. Give the teams time to build the towers on their own.
8. If some groups finish early, suggest that they decorate their towers, keeping in mind the strength-to-weight ratio objective.
9. Hand out the worksheets for students to record their testing data and the data from other groups.
10. Test each tower to see how much it weighs, and how heavy a load it can support. In order to test a tower's strength, place a flat board on the top of the tower. Then, carefully apply masses (such as a book at a time) to simulate a load. Remind students to record the results (tower weight and load weight at failure) for every team's tower test.
11. Have students calculate strength-to-weight ratios and graph the class results on the worksheets.
12. Lead a class discussion: Compare results. Which team design was the most successful? Why?
13. After the initial testing, expect that students have learned a lot about what worked and what did not work. Point out that the engineering design process is "iterative," meaning it is a cycle that is repeated over and over so that improvements can be made from what is learned in testing, until a successful design is achieved. Do they have ideas to improve the strength-to-weight ratio of their towers? Give groups time to redesign and reinforce their towers, and test again.

Attachments

Structural Strength Testing Handout (pdf)

Structural Strength Testing Handout (docx)

Safety Issues

- Several safety issues must be taken into account when building the towers. Require students to wear safety goggles when cutting with utility knives, using epoxy glue and using the dremel tool. Also, since utility knives are very sharp, supervise their use at all times and direct students to always cut down and away from themselves and other people. Epoxy glue is very strong and dries very fast so students should be careful not to get any on their skin.
- If not enough adults are available to adequately supervise students using utility knives, use 1/8 inch square balsa wood strips because they can be cut with scissors.

Troubleshooting Tips

If a team's tower is weak or unstable, have students examine each region of the tower and think about how they can reinforce it.

If epoxy glue is not practical or students have trouble with it, super glue works as an alternative.

Investigating Questions

- Which shapes/structures seem to be the strongest while using the least material?
- If you were going to tell someone how to build a strong and light tower, what instructions and advice would you give?

Assessment

- Did all group members participate in the design, construction and testing of the tower?
- How well did the towers perform, compared to expectations?
- What would students do differently next time (did they learn from their mistakes)?

Activity Extensions

Lead a class brainstorming session in which you ask students what they would tell someone who wanted to build a strong tower and had no idea how.

Contributors

Kelly Devereaux, Benjamin Burnham

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Supporting Program

Techtronics Program, Pratt School of Engineering, Duke University

Acknowledgements

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Last modified: December 26, 2014

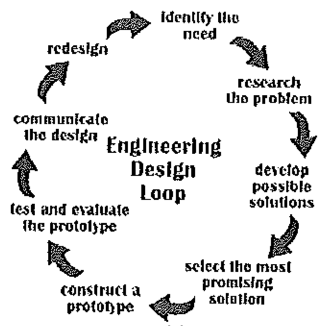
Hands-on Activity: Design Step 1: Identify the Need

Contributed by: Integrated Teaching and Learning Program, College of Engineering, University of Colorado Boulder

FULL DESIGN PROCESS

Summary

Students practice the initial steps involved in an engineering design challenge. They begin by reviewing the steps of the engineering design loop and discussing the client need for the project. Next, they identify a relevant context, define the problem within their design teams, and examine the project's requirements and constraints. (Note: Conduct this activity in the context of a design project that students are working on, which could be a challenge determined by the teacher, brainstormed with the class, or the example project challenge provided [to design a prosthetic arm that can perform a mechanical function].)



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Engineering Connection

The engineering design process is a specific set of steps engineers use to organize their ideas and refine potential solutions to engineering challenges. Embarking an engineering design project is much more than simply describing the project; engineers must gain an understanding of all the issues surrounding a particular design challenge. These issues might include the need for the project, relevant social and economic conditions of the target population, and project constraints and requirements. Working through these non-technical contextual factors helps engineers generate useful, appropriate and successful design solutions.

Quick Look

Grade Level:	9 (9-12)
Time Required:	60 minutes
Expendable Cost/Grp:	US$ 0.50
Group Size:	4
Activity Dependency:	None

Related Curriculum

Subject Areas:	Science and Technology
Curricular Units:	Creative Engineering Design

ENGINEERS are creative problem solvers

Educational Standards

- International Technology and Engineering Educators Association: Technology ▸
- Next Generation Science Standards: Science ▸

Pre-Req Knowledge

A basic understanding of the steps of the engineering design loop. While these steps are not covered in this activity, a visual aid is provided for review.

Learning Objectives

After this activity, students should be able to:

- Identify the need for a specific engineering design project.
- Describe the design project context.
- Identify and differentiate the design project constraints and requirements.

Materials List

Each group needs:

- Design Challenge Project Description (This document is created in advance by the teacher or brainstormed/written as a class to describe the class design challenge, patterned after the attached Example Design Challenge Project Description; or else use the example challenge description.)
- Defining the Problem Worksheet
- 5 index cards (any size) or 1-2 sheets of cardstock
- 1 pair of scissors

For the entire class to share:

- overhead projection of the Engineering Design Loop Visual Aid, or copies for handouts
- props to help explain the specific project topic; perhaps a PowerPoint with pictures and drawings

Introduction/Motivation

(Have an overhead transparency of the Engineering Design Loop Visual Aid ready to display in a prominent place in the classroom, or else make copies of the same graphic to use as handouts.)

Today we are beginning an engineering design project! Similar to real-world engineering, our project requires strong teamwork, research, design, building, testing and communication. You will have a chance to get creative and work hands-on with a variety of materials. However, before we can dive into the design/build/test stages, let's take a start at the beginning and gather some information about the project.

(Show the design loop graphic by overhead projection or handout.) First, let's review the engineering design loop. Remember, the engineering design process is a specific set of steps that engineers use to organize their ideas and refine potential solutions to engineering challenges. Who remembers all of the steps? The steps include: identify the need, research the problem, develop possible solutions, select the most promising solution, construct a prototype, test and evaluate the prototype, communicate the design, and redesign.

Following this process, we start out by identifying the *need* for our engineering project. Instead of asking "what do we want to design?" we ask "*why* do we want to design that?" and "what problem and or need will our design ultimately be solving?"

Next, we want to identify our target population, which is the group of people who will benefit from our project. Is the target population ultimately one individual, a group of individuals, a specific community, or a larger, identifiable population? Is the target population from a specific location (country, region, town), demographic (age or gender), or other identifying characteristics (health condition or employment)? How is our target population connected?

After we understand our project need and our target population, we will identify our project's requirements and constraints. A *requirement* is a need or a necessity; it's what a particular product or service should do. A *constraint* is a restriction on the degree of freedom you have in providing a solution to a need or problem. For example, you may be required by your parents to receive good grades. At the same time, you may be constrained by other activities such as work, sports, sleep, spending time with friends, and so on. Although worthwhile, these time constraints may impinge on the amount of time you have to study. So, your challenge would be to find out how to meet the requirement of receiving good grades under the given time constraints.

Back to our engineering project — our final step today is to develop a project definition within each of our design teams. This includes relating the project's problem or need to some aspect of our personal lives. Ultimately, we want to design something that would help us if we were experiencing the same problem or need as our target population.

(Note: After conclusion of this activity, proceed to the next activity in the series, Design Step 2: Research the Problem.)

Vocabulary/Definitions

constraint: A restriction on the degree of freedom one has in providing a solution to problem or challenge.

engineering design loop: A specific and iterative set of steps that engineers use to evaluate and refine potential solutions to problems or challenges. The steps: identify the need, research the problem, develop possible solutions, select the most promising solution, construct a prototype, test and evaluate the prototype, communicate the design, and redesign. Also called the engineering design process.

iterative: Characterized by or involving repetition. The steps of the design loop are iterative (not rigid or linear). During the process, you may go back and forth among the steps and may not always follow them in order. For example, you may skip ahead to test a proof of concept or go backwards to learn more about the essential problem.

prosthetic: A device (external or implanted) that substitutes for or assists a missing or defective body part.

requirement: What a particular product or service should do. It is a statement that identifies a necessary attribute, capability, characteristic or quality. In engineering, sets of requirements are inputs into the design stages of product development.

target population: An identified population, clients or subjects intended to be served by a particular program.

Procedure

Background

Creating a Project Description: Before beginning this set of six activities (starting with this activity), determine a topic for the class design challenge and create a one-page Design Challenge Project Description patterned after the attached Example Design Challenge Project Description. Alternatively, engage the class to brainstorm a design challenge, or use the attached example. For the example description, as well as the ongoing activity write-up (all six activities), the project challenge is to design a prosthetic arm that can perform a mechanical function. Topics for project challenges are limitless; other successful ideas used in the past with high school students include: house design with elements inspired by nature (biomimicry); assistive technology devices; towers (tested in a university smash lab); amusement park rides; daylighting modifications to existing interior spaces; interactive table-top educational exhibits, and different solar and water technologies for use by a hypothetical developing community.

If you write a project description or brainstorm a topic with the class, clearly outline the design challenge objectives and your project expectations. Provide a relevant context to help the students:

- recognize the need for the project and identify a target audience,
- relate the project to some aspect of their lives, and
- identify and differentiate requirements and constraints.

Recognizing the Need: Often, the success of an engineering innovation depends on the satisfaction of the end user(s). For instance, an engineering team designing a water filter might begin by asking themselves "What is the *real* need for this project? Is it designing a water filter or, more generally, designing a means to purify water?" By doing this, the team may discover that starting the design process with the intent to meet this more general need "frees" them to generate solutions that extend beyond a water filter.

Identifying a Target Population: A target population is an identified group of people intended to be served by a particular program or project. We might describe a target population by its geographical location (country, region, town, etc.) as well as by its age group, gender, or condition (for example, a health condition). Identifying a target population helps engineers more accurately define the problem and recognize requirements and constraints.

Relating to the Project: As an example, a project description to design an electricity-generating waterwheel might begin with a discussion about a community that lacks electricity. Students could discuss how a rural electrification project could **meet the need** for community residents who want to boil water, read at night, and so on. To help students relate to the project, ask them to discuss how their own lives would be impacted if they did not have access to electricity.

Requirements and Constraints: Write the project description so that students can identify and differentiate requirements and constraints. A requirement is a need for what a particular product or service should do. It is a statement that identifies a necessary attribute, capability, characteristic or quality. A constraint is a restriction on the degree of freedom you have in providing a solution. Constraints might be economic, political, technical, environmental, and/or pertain to your project resources, schedule, target environment, or to the product itself.

For example, a design challenge might ask students to build a pair of recyclable tennis shoes for less than $20. The **requirement** that the tennis shoes be recyclable and cost less than $20 will likely **constrain** the design to inexpensive materials that students can find in recycling bins.

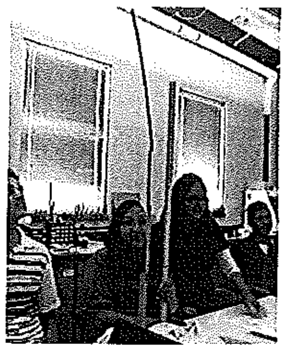
Sometimes we call this process "design under constraint." Real-world limits such as these often boost creativity as engineers (and students!) are challenged to make more with less.

Engineering Design Loop: The steps of the design process include: identify the need, research the problem, develop possible solutions, select the most promising solution, construct a prototype, test and evaluate the prototype, communicate the design, and redesign. See the Engineering Design Loop Visual Aid. This activity focuses on the first step, identify the need.

Before the Activity (Teacher Prep)

- Write-up a Design Challenge Project Description (or brainstorm one with the class, or use the attached example.)
- For the Introduction, have an overhead transparency of the Engineering Design Loop Visual Aid ready to display in a prominent place in the classroom, or else make copies of the same graphic to use as handouts.
- Make copies of the Design Challenge Project Description, Engineering Design Loop Visual Aid (optional), and Defining the Problem Worksheet, one each per team.
- Collect props and/or create a presentation to help explain your specific design challenge.

With the Students



In the warm-up design challenge, students aim to build the tallest tower using only a given supply of paper and

a pair of scissors, while following the steps of the engineering design loop.
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1. Divide the class into groups that will keep the same team members throughout the design project (all six activities). The optimal group size is 3 to 5 students each.

2. Review the engineering design loop by conducting the pre-activity assessment described in the Assessment section. This asks the teams to engage in a 10-minute design challenge and record their efforts to complete each step in the process. As a class, discuss any questions that arise about the design loop.

3. Introduce the design challenge. As a class, review the Design Challenge Project Description (as previously written by the teacher or brainstormed/written by the class, or attached to this activity).

4. Use the Investigating Questions to lead a class discussion about how to recognize the need and identify a target audience for a hypothetical engineering project.

5. Give each team a copy of the Defining the Problem Worksheet. So students thoroughly define their projects, make sure they consider each worksheet question. Help them complete this worksheet as questions arise.

6. When worksheets are completed, lead a class discussion to explore students' responses to the worksheet questions. Ask each team to present their answers to one section of the worksheet.

7. To conclude, conduct the post-activity assessment described in the Assessment section to help students relate the project to some aspect of their own lives. This role-reversal exercise asks students to imagine they are members of the target population and develop three questions that they would ask the project engineers. Share some of these as a class.

Attachments

Engineering Design Loop Visual Aid (doc)

Engineering Design Loop Visual Aid (pdf)

Example Design Challenge Project Description (doc)

Example Design Challenge Project Description (pdf)

Defining the Problem Worksheet (doc)

Defining the Problem Worksheet (pdf)

Troubleshooting Tips

If you have trouble coming up with a design challenge, it helps to brainstorm with the students. Choose a topic (for example, prosthetics), and make a list on the board of potential design/build projects that relate to the topic. See the Teacher Background section for other topic ideas.

Investigating Questions

Use the following discussion questions to help students gain understanding of two important aspects of engineering problem solving: **recognizing a need and identifying a target audience.**

- **What are some problems and/or needs in our world today?** (Possible answers may relate to: failing schools, energy shortages, famine, war, natural disasters.)
- Let's pick one of these problems. **Who specifically experiences this problem?** (For example, famine. Famine is widespread food shortage that is typically related to overpopulation and poverty. We could say that, generally, poor people living in overpopulated regions experience famine.)
- Let's call the group of people experiencing this problem our "target population." **Is our target population concentrated in one geographic area? If not, how are they connected? Do they share a similar condition or socio-economic status?** (For example, today many Africans suffer from famine due to rapid population growth, soil erosion, and governments that do not adequately support agriculture. Famine has also occurred in regions in the Middle East due to political conflict. So, we can say that famine is a problem that affects a target population characterized by overpopulation and poverty. Our target population is connected by geography and also by social and economic factors.)

Assessment

Pre-Activity Assessment

Warm-Up Design Challenge: Lead students through a quick and simple design challenge to help them review the steps of the engineering design loop and begin to work with their teammates. Their team challenge is to construct the tallest tower possible in 10 minutes using only the given (3 to 5) index cards and a pair of scissors. No external support (such as textbooks) or adhesives are allowed. Alternative materials: Provide 1 or 2 sheets of cardstock instead of index cards. Additional requirement idea: The tower must stand on its own for at least 10 seconds.

To start the challenge, project the Engineering Design Loop Visual Aid in front of the class (or provide as a handout) and direct the teams to follow these steps as they design the towers. Designate one person to be each team's reporter to record their progression through the process as they solve the tower challenge. As an example, recorders may write something like the following:

- **Identify the Need & Define the Problem** – The problem to solve is to construct the tallest tower possible using only the materials provided.
- **Research the Problem** – Everyone on the team provided input about the best shape for a tall tower based on what we have seen and learned about.
- **Develop Possible Solutions** – We each created a sketch of how we think the tower should be designed.
- **Evaluate the Alternatives & Select Most Promising Solution** – We selected and combined design ideas from the best sketches.
- **Construct a Prototype** – We constructed the prototype tower based on our design.
- **Test and Evaluate the Prototype** – We tested the tower by finding the position in which the tower stood straight up. It only stood by itself for 10 seconds. We will have to design a wider base so it stands for more than 10 seconds.
- **Communicate the Design** – We gave a short demonstration of our tower in front of the class. We talked about what worked and what did not work when we tested our tower.
- **Redesign** – We were able to rebuild our tower with a wider base and test it again. It stood by itself for 32 seconds. It worked better this time!

Example student notes describing what they did at each step of the engineering design loop in the 10-minute warm-up design challenge.

After 10 minutes, bring together the class to compare team notes about the engineering design loop and discuss the process. Some questions to ask the students:

- How did it go? (Expected answers: Not always smoothly; sometimes struggles and snags.)
- Did you follow the steps of the engineering design loop in the order presented?
- Did you skip or combine steps? (Explain how the process is "iterative.")
- Was it helpful to use the engineering design loop for this simple design challenge?
- Can you imagine how the engineering design process would be helpful for much bigger engineering projects?

Activity-Embedded Assessment

Worksheet: Give each team a copy of the Defining the Problem Worksheet. Teams should thoughtfully complete this worksheet either in class or as a team homework assignment. Once the teams have compiled their answers, lead a class discussion and ask each team to present their answers to one section of the worksheet.

Post-Activity Assessment

Relating to the Project – Role Reversal: Have students imagine that they are members of the target population experiencing the problem and/or need outlined in the design challenge. From the point-of-view of a member of the target population, have each team develop three questions that they would ask the project engineers about the challenge. Share some of these as a class. If time permits, ask each student to write a short letter to a (hypothetical) engineer explaining how his or her life is impacted by the problem and/or need. How would his or her life, family and community be different if this need or problem were resolved?

Activity Extensions

Case Studies: Have each team research an engineering design product that is related to their assigned design challenge and present the research as a case study to the class. Require that information provided in the case study identify the need for the project, target population, requirements and constraints, as well as provide a description of the engineering solution and an assessment of whether or not the solution met the target population need.

Additional Multimedia Support

For a description of the engineering design process, see https://www.teachengineering.org/engrdesignprocess.php

References

Target Population (definition). Program Evaluation Glossary. US Environmental Protection Agency. Accessed January 8, 2010. http://ofmpub.epa.gov/sor_internet/registry/termreg/searchandretrieve/glossariesandkeywordlists/search.do;jsessionid=mJCLP7qhS3htvXDpvyMf7ZlqpnVNMCPtGDCFTHL81hnT30TML4X7l-3432! details=

Yowell, J.L. and Carlson, D.W., Eds., Introductory Engineering Design: A Projects-Based Approach, Third Edition, Textbook for GEEN 1400: First-Year Engineering Projects, Integrated Program, College of Engineering and Applied Science, University of Colorado at Boulder, Fall 2000. Accessed April 8, 2010. http://itll.colorado.edu/index.php/courses_workshops/geen_1400/resources/textbook/

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Hands-on Activity: Design Step 2: Research the Problem

Contributed by: Integrated Teaching and Learning Program, College of Engineering, University of Colorado Boulder

Summary

Through Internet research, patent research, standards and codes research, user interviews (if possible) and other techniques (idea web, reverse engineering), students further develop the context for their design challenge. In subsequent activities, the design teams use this body of knowledge about the problem to generate product design ideas. (Note: Conduct this activity in the context of a design project that students are working on, which could be a challenge determined by the teacher, brainstormed with the class, or the example project challenge provided [to design a prosthetic arm that can perform a mechanical function]. This activity is Step 2 in a series of six that guide students through the engineering design loop.)


Background research is an important step of the engineering design process.

Engineering Connection

Developing a thorough knowledge base of existing products related to a need or problem is important for all engineering design projects. This step helps the engineering team determine if a similar product already exists or whether any regulatory and standards issues (such as intellectual property, safety or environmental issues) must be considered in the product design. Engineers often design modifications or incremental improvements to existing products, so one way to learn more about a product is to purchase and take apart similar, competing products.

Quick Look

Grade Level:	9 (9-12)
Time Required:	60 minutes The time required to complete this design process step is adjustable to as little or as long as the teacher deems appropriate. We suggest a minimum of 60 minutes and a maximum of three class periods.
Expendable Cost/Grp ❶:	US$ 0
Group Size:	4
Activity Dependency ❶:	Design Step 1: Identify the Need

Related Curriculum ❶

Subject Areas:	Science and Technology
Curricular Units:	Creative Engineering Design

Educational Standards ❶

- International Technology and Engineering Educators Association: Technology ▸
- Next Generation Science Standards: Science ▸

Learning Objectives

After this activity, students should be able to:

- Gather and organize background information related to a design challenge.
- Conduct an information search to find existing solutions or products related to a problem.

Materials List

Each group needs:

- Design Challenge Project Description (created in Activity 1), or use the attached Example Design Challenge Project Description
- blank paper and pencils
- Idea Web Example
- 2 worksheets of the following four, for each team's selected two types of background research: Patent Search Worksheet, Standards and Codes Search Worksheet, Reverse Engineering Worksheet and User Interview Worksheet

For the entire class to share:

- computers with internet access
- (optional) small video or audio recorders for user interviews

Introduction/Motivation

Today we are continuing to work on our engineering design project for this class. Similar to real-world engineers, we must develop a thorough knowledge base of the information related to our design to determine if a similar product already exists or if any regulatory and standards issues (such as intellectual property issues, safety or environmental issues) exist that must be considered in the design of the product. We do this by conducting a variety of information searches and compiling all the information in a useful way. Can anyone think of a way to get useful information about our project?

Sometimes it is hard to know what information we need to find before we have a product design. One way to identify what information we should be looking for is to break down our problem statement or "need" into an idea web. An idea web starts with the main need or problem in the middle of a piece of paper. Then the team draws branches from the main problem to represent different parts of the problem, such as audience, requirements, constraints, and questions. Each engineer on the team may choose to or be assigned to focus on addressing one particular part of the problem or the team may work together to establish the knowledge base. Often, new questions arise, requiring the team to do additional background research in order to answer them

A patent search is another way to find existing information about a related product. This type of search is often done by engineers in the beginning stages of product design and is really helpful for avoiding designs that infringe on an idea that has legal protection. Many websites offer information on existing patents, including the US patent and Trademark Office (http://www.uspto.gov) and Google patent search (http://www.google.com/patents).

Standards and codes developed by industry or federal, state or local governments are also important to know for product design. Standards are any agreed-upon common criteria, item or process that helps to ensure the safety and interchangeability of a product. For example, having standard bolt sizes helps designers communicate to manufacturers located elsewhere exactly which bolt to use in making a product. A code is a collection of standards that are mandatory for use in the development of a particular item. For example, building codes specify the height and area limitations for certain types of buildings in a city. Can anyone think of why we would need to know the standards and codes related to our product design? Some other examples might include the chemical properties of the materials used in a product or process, the environmental impacts of the product, and the safety of the user interfaces.

Reverse engineering an existing product is another way to learn about technologies that relate to the design of a new product. When possible, engineers test competitor's products to determine how to make their new design even better. They take products apart to figure out how they work, and then they often reassemble them to see how the parts interact. Reverse engineering requires careful observation, disassembly, documentation, analysis and reporting.

Lastly, user interviews can give us valuable insight into a product design. We have already indentified our target population, and, when possible, interviewing members of that population about our product can be extremely helpful. Since the customer ultimately determines whether a product is a success or failure, it is important to communicate often with the user during the design process. It is useful to use props during the interviews to watch how a user interacts with a product. Sometimes how the user uses the product is more telling than what they say about it. Gathering initial data from the user helps the engineering team identify which aspects of the problem are the most important to address for its audience.

Back to our engineering project—today we will focus on conducting as much background research as possible on our problem in order to generate a common knowledge base for our team as we begin to brainstorm possible engineering solutions.

(Note: After conclusion of this activity, proceed to the next activity in the series, Design Step 3: Brainstorm Possible Solutions.)

Vocabulary/Definitions

code: A set of mandatory minimum standards or rules. For example, a building code, a safety code, a fire code, the UL code, etc.

engineering design loop: A specific and iterative set of steps that engineers use to evaluate and refine potential solutions to problems or challenges. The steps: identify the need, research the problem, develop possible solutions, select the most promising solution, construct a prototype, test and evaluate the prototype, communicate the design, and redesign. Also called the engineering design process.

patent: An official document given by a state or government that allows exclusive right or privilege to an inventor for a specified period of time.

standard: Something set up and established as a rule for the measure of quantity, weight, extent, value, or quality. For example, standardized bolt sizes. See http://standards.gov/standards_gov/standards.cfm.

target population: The population, clients, or subjects intended to be identified and served by a particular program.

Procedure

Before the Activity (Teacher Prep)

- Base this activity off of an existing project with a Design Challenge Project Description (See the first activity of this unit, Design Step 1: Identify the Need). This can be a challenge determined by the teacher, brainstormed with the class, or the Example Design Challenge Project Description attached to this activity.
- Make copies of the attached Idea Web Example, one per team.
- Make copies of the Patent Search Worksheet, Standards and Codes Search Worksheet, Reverse Engineering Worksheet, and User Interview Worksheet. Teams are asked to complete *at least two* of these four knowledge-base handouts.
- Student teams should continue with the same 3-5 members each, as determined in the first activity of this unit, Design Step 1: Identify the Need.

With the Students

1. Review the steps of the engineering design loop as described in the pre-activity assessment. Discuss any questions as a class.
2. Review the Design Challenge Project Description as class.
3. Use the Investigating Questions to lead a class discussion about the role of background research in engineering problem solving.
4. Give each team a blank sheet of paper. Review an example idea web with the students to illustrate how to start thinking about what background research they need to conduct. Have student teams each create an idea web of the design challenge.
5. Have students choose at least two of the following methods for developing their knowledge base: patent research, standards and codes research, reverse engineering, and user interview. Have student teams complete their worksheets in sub-group pairs. Provide assistance as questions arise. Conduct the activity-embedded assessment (as described in the Assessment section) to discuss students' responses to the worksheet.
6. Conduct the post-activity assessment to help students share their new knowledge base within their team and their class. This assessment asks them to create a list of the main points that they discovered and plan to use to inform their design. Then, the students reflect on the research process and ask if any questions are still unanswered.

Attachments

Example Design Challenge Project Description (doc)

Example Design Challenge Project Description (pdf)

Idea Web Example (doc)

Idea Web Example (pdf)
Patent Search Worksheet (doc)
Patent Search Worksheet (pdf)
Standards and Codes Search Worksheet (doc)
Standards and Codes Search Worksheet (pdf)
Reverse Engineering Worksheet (doc)
Reverse Engineering Worksheet (pdf)
User Interview Worksheet (doc)
User Interview Worksheet (pdf)

Investigating Questions

Use the following discussion questions to help students gain understanding of an important aspect of engineering problem solving: **background research.**

- **Why do engineers conduct background research before they design a new product?** (Possible discussion points: To find out if similar products already exist, to discover any regulatory and standards issues, such as intellectual property issues, safety or environmental issues, that are pertinent to the new product design.)
- Many types of background research can be conducted. **What are some examples of background research?** (Possible discussion points: Basic search for existing similar products, talking to the target audience(s), patent searches, codes and standards searches.)

Assessment

Pre-Activity Assessment

Engineering Design Loop Review: The engineering design loop is a specific set of steps engineers use to organize their ideas and refine potential solutions to engineering challenges. Ask for student volunteers to identify and define each step of the design process. (Note: The steps of the design loop include identify the need, **research the problem**, develop possible solutions, select the most promising solution, construct a prototype, test and evaluate the prototype, communicate the design, and redesign.)

Activity-Embedded Assessment

Worksheets: Using the attached four worksheets, have each team complete two of the following methods for developing their knowledge base: patent research, standards and codes research, reverse engineering, and user interview. Review and discuss the worksheet answers with the entire class. Use the answers to gauge students' mastery of the subject.

Post-Activity Assessment

A Common Knowledge: Have students work with their team to develop common, shared background knowledge related to their design problem. Have each team develop a priority list of the main points they plan to consider as they begin to generate ideas for their product design. Lastly, ask each team to share two or three of their research findings with the entire class.

Reflecting on the Process: Have the teams work together to reflect on the background research that they conducted. Have the teams consider:

- Have we researched the most important information related to our project?
- What do we know now that we did not know before?
- Do we have any unanswered questions that surfaced as a result of our research?
- Do we need to do any follow-up research to answer those questions?

Activity Extensions

Patent Searches: Give students one of the following products (or generate your own list) and have them complete a sample patent search. Require students to make a list of patents they find that are associated to the product. This extension activity demonstrates the wide variety of patents that relate to a single "common" product. Possible items: shower head, headphones, skateboard, backpack.

"Standard" Communication: Have students explain in their own words why common standards exist for the measure of quantity, weight, extent, value, or quality of an item. Have them research a real situation or describe a fictional scenario in which standards are not used. Ask students to share their explanations with the class.

Additional Multimedia Support

Direct students to the helpful "Be a Patent Detective!" page to learn different ways (by patent number, by inventor last name, by keywords) to look for inventions on the US Patent and Trademark Office's website; see: http://www.uspto.gov/web/offices/ac/ahrpa/opa/kids/kidsearch.html

For a complete description of the engineering design process, see https://www.teachengineering.org/engrdesignprocess.php

References

Yowell, J.L. and Carlson, D.W., Eds., Introductory Engineering Design: A Projects-Based Approach, Third Edition, Textbook for GEEN 1400: First-Year Engineering Projects, Integrated Program, College of Engineering and Applied Science, University of Colorado at Boulder, Fall 2000. http://itll.colorado.edu/index.php/courses_workshops/geen_1400/resources/textbook/ Accessed April 8, 2010.

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Hands-on Activity: Design Step 3: Brainstorm Possible Solutions

Contributed by: Integrated Teaching and Learning Program, College of Engineering, University of Colorado Boulder

Summary

Brainstorming is a team creativity activity that helps generate a large number of potential solutions to a problem. In this activity, students participate in a group brainstorming activity to generate possible solutions to their engineering design challenge. Students learn brainstorming guidelines and practice within their teams to create a poster of ideas. The posters are used in a large group critiquing activity that ultimately helps student teams create a design project outline. (Note: Conduct this activity in the context of a design project that students are working on; this activity is Step 3 in a series of six that guide students through the engineering design loop.)

Students reflect upon the ideas generated during their team's brainstorming session. copyright

Quick Look

Grade Level:	9 (9-12)
Time Required:	60 minutes Although the time required to complete this design loop step is flexible, realize that students often get caught up in the brainstorming/idea generating process and never move to actual idea selection if not monitored by the teacher.
Expendable Cost/Grp:	US$ 1
Group Size:	4
Activity Dependency:	Design Step 2: Background Research

Related Curriculum

Subject Areas:	Science and Technology
Curricular Units:	Creative Engineering Design

Engineering Connection

Brainstorming is a helpful technique for group projects, especially for teams needing to break out of the same pattern of thinking and develop a new way of viewing something. Engineering teams are usually composed of a diverse mix of individuals, including engineers with expertise in different disciplines, as well as other professionals. Brainstorming allows teams to tap into all the expertise in the group to develop the most successful solution to a design challenge. Some engineering companies specialize in brainstorming unique solutions to design challenges.

Educational Standards

- International Technology and Engineering Educators Association: Technology ▸
- Next Generation Science Standards: Science ▸

Learning Objectives

After this activity, students should be able to:

- Describe and apply the "rules" of brainstorming.
- Use brainstorming as a technique to generate a large number of ideas.

Materials List

Each group needs:

- 1 large sheet of butcher paper or white paper, ~ 4 x 4 ft (~1 x 1 m) in size
- a few different colored markers
- Brainstorming Guidelines Handout

For the whole class to share:

- magnets or strong tape to hang the large sheets of paper in the classroom
- 2-3 pads of sticky notes, in two different colors
- Overhead projection of Brainstorming Guidelines Handout

Introduction/Motivation

(Have an overhead transparency of the Brainstorming Guidelines Handout ready to display in a prominent place in the classroom, or else make copies of the guidelines to use as handouts.)

By this point, you should have a good understanding of your design challenge. You and your team have worked to define the problem, identify the project's constraints and requirements, and complete some background research.

Now, let's begin the process of thinking about solutions to the design challenge. To do this, engineers often use a technique called "brainstorming." Brainstorming is a team creativity activity that helps you generate a large number of potential solutions to a problem or challenge. It can be helpful when you need to break out of the same pattern of thinking and develop a new way of looking at something.

When we are working to first come up with ideas, we want to keep open minds and encourage all ideas — even if they don't seem realistic. We want to withhold criticism of our ideas and those from our team members. Also, when we brainstorm, we are striving for quantity of ideas, not quality. Think of it like you are dragging a big net through the ocean in hopes of catching a king salmon. While a big net scoops up many little fish in the process, it also improves your chances that you will find your main prize!

Brainstorming is meant to encourage creative thinking; however, some basic ground rules make it more successful. Let's take a look at these before we divide into our groups for some team brainstorming. (Show the brainstorming guidelines by overhead projection or handout.)

Who has heard the expression "focus on quality — not quantity"? Most of the time you do want to focus more on the quality of your work and less on how fast you can complete it. Brainstorming, in contrast, asks you to focus on quantity, not quality. The purpose is to collect as many ideas as possible, even if they seem ridiculous. We do this because often, wild ideas lead to the most innovative designs. Later in the design challenge you will have time to focus on the quality and practicality of your design.

Remember to record all of your ideas; you do not want to forget an idea that could become useful later. Also, build on the ideas of others. It is good to work together as a team to develop a possible solution, instead of selecting one person's idea. In engineering, the best ideas are generally a team effort. Sometimes, this can start a snowball effect of additional ideas, so remember to stay focused on the design problem you are working on right now; you will have time to explore other ideas once you have finished working on this one.

Most importantly, when you are brainstorming, remember to withhold criticism of any ideas, including your own. Don't worry about saying something that seems silly or unrealistic. Silly ideas can lead to excellent creative design solutions!

(Note: After conclusion of this activity, proceed to the next activity in the series, Design Step 4: Engineering Analysis.)

Vocabulary/Definitions

*brainstorming:*A team creativity activity with the purpose to generate a large number of potential solutions to a design challenge.

Procedure

Background

Brainstorming is a group creativity technique used to generate a large number of ideas for the solution to a problem. The process itself can boost morale, enhance work enjoyment, and improve team dynamics. Suggested **brainstorming guidelines** include:

1. **Focus on quantity:** The first ground rule is to focus on quantity. You want to capture as many ideas as you can -- even if they seem silly.
2. **Withhold criticism:** Not only should you refrain from criticizing the ideas of others, you should make sure not to criticize your own ideas as they emerge during the brainstorming process.
3. **Encourage wild ideas:** We know from experience that (with a bit of reworking and refinement) wild ideas usually lead to the most innovative designs.
4. **Record all ideas:** During a brainstorming session it is helpful to designate a person on your team to write down each idea as it is thrown out. Sentence structure, spelling and grammar do not matter for this list, so wait until later to review or edit anything you write down. Just make sure to capture all the ideas.
5. **Combine and improve ideas:** In the midst of brainstorming, try to build upon the ideas of others. Think of your brainstorming session as a snowball rolling down a "mountain of ideas." Initially, the snowball is small, but it quickly grows and gains momentum as it travels down the hill. The best ideas in engineering are generally a team effort.
6. **Stay focused on topic:** Although brainstorming is meant to be creative and free flowing, make sure you focus your ideas on the topic at hand. This helps you later when you are organizing all the ideas generated in the brainstorming session.

Teams in which students are unfamiliar with each other may show apprehension toward sharing ideas and "letting loose" in a brainstorming session. Remind students that brainstorming is a time to be creative, and even silly! Use the questions suggested in the **Investigating Questions** section to help groups break the ice and make sure the brainstorming ground rules are followed.

Before the Activity (Teacher Prep)

1. Cut several large sheets of paper, one sheet per team.
2. Gather markers, sticky notes, and magnets or tape.
3. Use the attached Brainstorming Guidelines Handout to make an overhead transparency and/or copies to use as handouts for each team.
4. Student teams should continue with the same 3-5 members each, as determined in the first activity of this unit, Design Step 1: Identify the Need.

With the Students: Introduction & Set-Up

1. Introduce the concept of brainstorming by leading the Introduction/Motivation section.

2. Use the Brainstorming Guidelines Handout to review the brainstorming ground rules.

3. Lead the pre-activity assessment (as described in the Assessment section) to help students capture the design challenge in a specific question. This exercise asks students to reflect on their design project and develop one question that captures the essence or basics of the design challenge.

With the Students: Team Brainstorming

4. Give each team a big piece of paper and a few markers.

5. Ask teams to write their specific design challenge question from Step 3 (above) across the top of their papers.

6. Initiate the brainstorming process by reviewing the brainstorming techniques presented in the overhead transparency or handout (and the Procedure-Background section).

7. Invite teams to begin brainstorming with words or quick sketches using their poster-sized paper and markers.

8. Direct students to write and draw legibly and large enough so their sketches and annotations will be able to be seen by the rest of the class from the front of the room.

9. Give the teams ~20 to 30 minutes to brainstorm. Encourage them to cover the paper with ideas.

10. If teams become stuck, ask them to jot down opposites or jot down things that are only slightly related. Just keep them moving and associating.

11. When time is up, ask teams to cluster their ideas by circling terms that seem related and drawing lines between the terms.

12. Have teams continue the clustering process until they have created associations among most terms. Some terms may be left un-circled, but might still be useful.

13. Ask teams to use magnets or tape to hang their brainstorming posters on a classroom wall or the chalkboard.

With the Students: Class Brainstorming

14. Give each person several sticky notes in two colors. For example, if the class is composed of six teams, give each student five blue sticky notes and five pink sticky notes.

15. Indicate that the blue sticky notes are to be "ideas I like," and the pink sticky notes are to be "questions or suggestions for improvement."

16. Ask each team to come to the front of the room and explain their brainstorming posters to the rest of the class.

17. After each team has presented, ask students to "roam the room" and look at each others' posters to find ideas they like and identify a question or suggestion for improvement.

18. Ask students to write these comments on the sticky notes and post them on the other teams' brainstorming papers *at the spot where the idea or concept is written.*

19. Once everyone has finished posting their sticky notes, have each team reflect on the feedback they received via the sticky notes, as described in the activity embedded assessment (see the Assessment section).

20. Have students save their brainstorming posters with comments so they may refer to them as the project progresses.

21. Lead the post-activity assessment (as described in the Assessment section) with the students. In this activity wrap up, students prepare outlines that incorporate the brainstorming data into larger ideas. These ideas may also be recorded in paragraphs to begin a first draft of a design description.

Attachments

Brainstorming Guidelines Handout (doc)

Brainstorming Guidelines Handout (pdf)

Troubleshooting Tips

Be alert for team problems with brainstorming, such as distraction and evaluation apprehension. Discourage criticism of ideas. Remind students that in brainstorming, no idea or suggestion is "silly." All ideas should be respectfully heard. This is the time to be uncritical and build on each others' ideas.

When creativity begins to taper during a brainstorming session, a teacher or facilitator can stimulate creativity by asking the group questions such as: "What if you combine these ideas?" and "Can you rank these ideas from silliest to most serious?"

Students often get caught up in the brainstorming/idea generating step of the engineering design loop and never move to actual selection of one idea, so monitor their progress and keep them moving towards this goal.

Investigating Questions

Use these questions as a "warm up session" or to break the ice with unfamiliar team members and make sure the **brainstorming** ground rules are understood.

- If your team were asked to design the perfect cell phone, **what would it be like?** (Possible discussion points: How would it look? What size would it be? What would be its features? Would these vary, depending on the target audience?)
- Imagine the school has just been awarded a large amount of money to build something new or to create a new program. **What facilities or program would benefit students most?** (Possible discussion points: Is there anything that this school is currently missing? Do any existing facilities or programs need major improvement? How many students would be impacted by the suggested ideas? How would you determine what would benefit the students most? How could you get input from the entire student body in deciding the new facility or program?)

Assessment

Pre-Activity Assessment

Capture the Challenge: It helps facilitate the brainstorming activity if the class, as a whole, first arrives at a common understanding of the design challenge. Ask teams to spend a few minutes defining the design challenge in their own words. Write each team's response on the board and then work with the students to combine ideas to come up with **one question** that captures the essence or basics of the design challenge. For example, our example project on designing prosthetics might ask:

- How can we design a prosthetic hand to perform one mechanical function using simple materials (such as wood, plastic tubing, bendable metals and various adhesives)?

Activity-Embedded Assessment

Team Reflection: Once teams are finished giving each other feedback using the sticky notes, ask them to write answers to the following questions on the backs of their brainstorming posters.

1. Where are most of the "ideas I like" sticky notes concentrated on your brainstorming poster? The ideas and concepts that other students liked are _________.
2. Where are most of the "questions or suggestions for improvement" sticky notes concentrated? The ideas and concepts that need further development are _________.

Post-Activity Assessment

After the Storm: Ask teams to start filling in the gaps between the ideas they have just brainstormed. Have students prepare an outline that incorporates as much of the brainstorming data that seems logical. Have them also start to write out some larger groups of sentences or full paragraphs to expand upon the smaller clusters and phrases. Suggest they quickly sketch some descriptions if that better illustrates their ideas. From this, they can start to write larger sections of first draft descriptions of their designs. Remind students that they do not have to start at the "beginning" of their brainstorming sequence. Encourage them to focus on the section that comes together most easily.

Activity Extensions

Practice, Practice! It is always good (and fun!) to have students practice brainstorming ideas in teams. For a quick warm-up activity or to fill extra time at the end of a class period, give student teams a hypothetical design challenge to brainstorm for 10 minutes. Then, have them share some of their solution ideas with the class. Some example challenges include a bedroom security system, a new desk organizer, an improved backpack, etc.

Additional Multimedia Support

IDEO is a worldwide engineering design and innovation consulting firm, known for digging deep and creatively to find unique solutions to design challenges. See more at http://www.ideo.com/. Show students the motivating eight-minute NBC Nightline segment on IDEO's innovation process (see brainstorming and use of sticky notes around minute 4) as they redesign a shopping cart at: http://www.youtube.com/watch?v=M66ZU2PCIcM

References

Yowell, J.L. and Carlson, D.W., Eds., Introductory Engineering Design: A Projects-Based Approach, Third Edition, Textbook for GEEN 1400: First-Year Engineering Projects, Integrated Program, College of Engineering and Applied Science, University of Colorado at Boulder, Fall 2000. Accessed April 8, 2010.
http://itll.colorado.edu/index.php/courses_workshops/geen_1400/resources/textbook/

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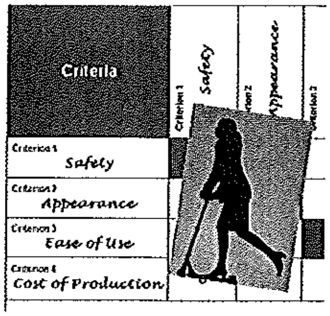
Hands-on Activity: Design Step 4: Engineering Analysis

Contributed by: Integrated Teaching and Learning Program, College of Engineering, University of Colorado Boulder

FULL DESIGN PROCESS

Summary

Engineering analysis distinguishes true engineering design from "tinkering." In this activity, students are guided through an example engineering analysis scenario for a scooter. Then they perform a similar analysis on the design solutions they brainstormed in the previous activity in this unit. At activity conclusion, students should be able to defend one most-promising possible solution to their design challenge. (Note: Conduct this activity in the context of a design project that students are working on; this activity is Step 4 in a series of six that guide students through the engineering design loop.)



Various types of engineering analysis guide the development of product design.

Engineering Connection

Engineering analysis is the internal guidance of a project. It can be described as the breaking down of an object, system, problem or issue into its basic elements to get at its essential features and their relationships to each other and to external elements. It is an important part of the engineering design loop that occurs many times during the completion of real-life engineering product or system design. Often, a thorough and varied analysis of a design prior to implementation leads to increased safety and efficiency in using the product.

Quick Look

Grade Level:	9 (9-12)
Time Required:	60 minutes
Expendable Cost/Grp:	US$ 0
Group Size:	4
Activity Dependency:	Design Step 3: Brainstorm Possible Solutions

Related Curriculum

Subject Areas:	Science and Technology
Curricular Units:	Creative Engineering Design

Educational Standards

- Common Core State Standards for Mathematics: Math
- International Technology and Engineering Educators Association: Technology
- Next Generation Science Standards: Science

Learning Objectives

After this activity, students should be able to:

- Describe the role of analysis in engineering.
- Evaluate alternatives using an interaction matrix analysis.
- Compare and contrast design alternatives to select the most promising idea.

Materials List

Each group needs

- Famous Failures Case Studies, one per student or pair of students
- Example Evaluating Alternatives Rubric
- Evaluating Alternatives Rubric

Introduction/Motivation

Analysis is the essence of being an engineer; it is what distinguishes an engineer from a technician. Engineering analysis helps us make decisions and guide the design process. A design project without analysis is like a softball team without a coach, a ship without a sail, or a class without a teacher — imagine that! So what is engineering analysis, exactly? Basically, it is the breaking down of an object, system or problem, into its fundamental parts to understand their relationships to each other and to outside elements.

For example, let's say you are a part of a team of engineers working to reduce the number of car accidents that occur during rush-hour traffic. You might start by generating a set of design alternatives to this problem: *Expand the roads and highways? Build more bike routes? Design a new subway system?* Let's say your team determines the best alternative is the expansion of roads and highways. Now another design analysis is needed: *How many new stoplights should be constructed? How many lanes do we need? How much money will it cost to maintain these new roads? Will many trees need to be cut down? If so, will this displace birds and other wildlife?*

Do you see how the engineering analysis includes much more than the object or system being designed? Even in the case of building a new road, engineers must analyze the impacts of the new road on the city budget and the surrounding environment and impacted wildlife.

Our history has many examples of engineering projects that either succeeded or failed because of the type of engineering analysis used to evaluate the design. One "success story" in engineering is the development of modern aircraft. A century ago, the first flying machines were very unsafe. Their designs were based more on bird flight than on fundamental engineering concepts. The designers of these flying machines often tested them by jumping off great heights — sometimes meeting their death in the process.

Fortunately, over many years, engineers have developed a much better approach to engineering analysis for airplanes. Today, engineers use computer programs to design and build models of airplanes and see how the models respond to elements and forces such as weather patterns and wind shear.

Now, can anyone think of an engineering "failure?" It's hard to call an unsuccessful engineering project entirely a "failure" because we usually learn the most from failed attempts. In any case, let's take a look at some "famous failures" in engineering and see how the role of analysis played a part in the project. (Hand out the Famous Failures Case Studies to students, one per student or pair of students.)

It's important to understand that the types of engineering analysis are many and different throughout the course of every design loop, and through the course of our project development. Right now, because we are more or less in the conceptual phase of our own design challenge, we will use the engineering analysis process to help us evaluate the best design alternative from our brainstorming results. We will do this by using an "interaction matrix" in which we generate criteria for our design (attributes we think are important) and then rank each of our design alternatives according to these criteria. It may sound complicated, but it is quite useful to help guide your team's decision making process.

(Note: After conclusion of this activity, proceed to the next activity in the series, Design Step 5: Construct a Prototype.)

Vocabulary/Definitions

computer-aided design: The use of computer technology for the design of objects; CAD design can also include symbolic information such as materials, processes, dimensions and tolerances.
dynamic analysis: An analysis of an object that accounts for interactions and uncertainties in the environment.

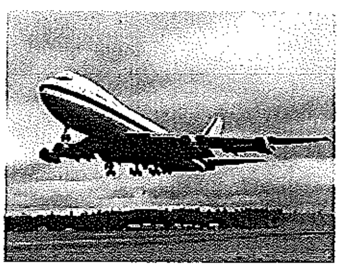
engineering analysis: The breaking down of an object, system or problem, into its basic parts to understand its essential features and their relationships to each other and to outside elements.
rubric: A scoring tool that lists the criteria against which to evaluate a design.
static analysis: An analysis of an object as if it was not moving.

Procedure

Background

What differentiates engineering design from simple "tinkering until you get it right" is the role of analysis in the design. Engineering analysis is the internal guidance of a project. It can be described as the breaking down of an object, system, problem or issue into its basic elements to get at its essential features and their relationships to each other and to external elements. The process of analysis is different at various stages of the design process. Toward the beginning of a project, engineers might perform an analysis to select the best design alternative. Once the best design alternative has been agreed upon, the team might perform design analyses that focus on the technical details of the design.

We can learn about the role of analysis in engineering by examining case studies of engineering projects that succeeded — and failed — due largely to the analysis used in the design. First, let's consider the development of airplanes during the past century. Many early flight pioneers died while testing their inventions. These early flying machines were based more on birds and other airborne creatures and less on fundamental engineering equations. However, these early attempts gave birth to the modern field of aeronautics and the fundamental engineering equations used to design modern airplanes.



The design of modern airplanes, such as this Boeing 747, depends on sophisticated engineering analysis techniques.
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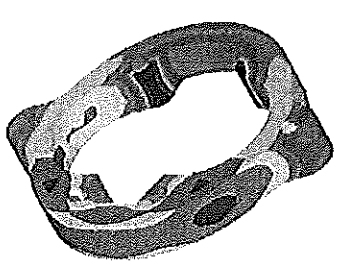
Another major progression that has helped the aeronautic industry is the development of computer-aided design (CAD) programs. Engineers use these programs to build computer simulations of airplanes and analyze the effects of different materials, forces, weather patterns, and so on. This method of analysis is generally more accurate, cost effective, and safe than testing full-scale physical models.

Computer-aided design analysis is not confined to the aeronautic industry; many automobiles, buildings, and prosthetic devices are designed using advanced computer software.



Computer-aided analysis applied to the design

of an automobile gearbox.
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Now, let's look at a famous engineering "failure" of our time. Some past engineering failures have been attributed to following a methodology that seemed to work. However, when scale models or forces were expanded and the designs subjected to external elements, the results were catastrophic.

The Titanic is one example. Although the Titanic was thought to be the most robust and elaborate ship of its time (in the early 1900s), it sank when its starboard side was punctured by an iceberg, causing the starboard side of the hull to fill with water and tip the giant ship. Unfortunately, the engineering analysis of the ship had been a purely static one, meaning that engineers had analyzed the ship as if it were not moving. This static analysis accounted for the weight of the passengers, cargo and wind forces, while a dynamic analysis would have taken into account external forces such as the unbalancing movement of a collision with an iceberg.

The Titanic – the most elaborate ship of the early 1900s – shown in a sea trial. Thorough engineering analysis is crucial to ensure human safety.
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Many advanced analytical tools are needed to perform thorough engineering analyses; hence, it is often difficult for beginning design students to carry out adequate analysis. A good point to make with students is that in the "real world," engineers are continually called upon to learn and apply new engineering concepts in analysis. It is truly a lifelong learning process.

Before the Activity (Teacher Prep)

- Read and review the four attachments (case studies and answer, example rubric, blank rubric).
- Make copies of the Famous Failures Case Studies handout (one per student or pair of students), Example Evaluating Alternatives Rubric (one per team), and Evaluating Alternatives Rubric (one per team).
- Student teams should continue with the same 3-5 members each, as determined in the first activity of this unit, Design Step 1: Identify the Need.

With the Students

1. To introduce the concept of engineering analysis and provide relevant examples, lead the Introduction/Motivation section with the students.
2. (optional) Use the Investigating Questions to discuss the role of analysis in engineering problem solving.
3. Conduct the pre-activity assessment (described in the Assessment section) to help students understand the role of analysis in engineering. This asks students to read the two Famous Failures Case Studies and answer the discussion question at the end, "What factor(s) did the engineers of both the Titanic and the Tacoma Narrows Bridge fail to include in their engineering analysis?"
4. Start the main activity with the students by giving each design team a copy of the Evaluating Alternatives Rubric. (Note: This would be a good time for teams to take out the design challenge project work they have completed in previous activities [defining the problem, background research and brainstorming ideas].)
5. Review the rubric instructions with the students. This is called interaction matrix analysis. It may be helpful to show and refer to the example rubric.
6. Have teams begin their rubric by making lists of all the criteria they can think of to help rank their design alternatives.
7. Next, have teams assess the relative importance of each criterion relative to all the other criteria.
8. Have teams normalize the values by calculating each value as a proportion of a total that equals 1.
9. Teams can now analyze alternative designs according to how well each design satisfies each of the identified design criteria.
10. Lastly, have the teams analyze their results. The design alternative with the highest value is the "best" idea—meaning that it best meets the criteria.

Attachments

Famous Failures Case Studies (doc)
Famous Failures Case Studies (pdf)
Famous Failures Case Studies Answer (doc)
Famous Failures Case Studies Answer (pdf)
Example Evaluating Alternatives Rubric (doc)
Example Evaluating Alternatives Rubric (pdf)
Evaluating Alternatives Rubric (doc)
Evaluating Alternatives Rubric (pdf)

Troubleshooting Tips

The rubric can be tricky at first. Make sure to review the process of using this matrix (and the example rubric) before asking students to complete the matrix.

Investigating Questions

Use the following discussion questions to help students gain understanding of an important aspect of engineering problem solving: **analysis.**

- **What is a major difference between a technician and an engineer?** (A possible answer would explain how engineers provide analysis in their design work. Engineers figure it out with careful testing, calculations and data analysis to evaluate their design.)
- **What are some types of analysis that an engineer could use to test a design?** (Possible answers may relate to: mathematical calculations; testing of stress, loads or function; or computer-aided analysis.)

Assessment

Pre-Activity Assessment

Famous Failures: Give each student (or pair of students) a copy of the Famous Failures Case Studies. Ask them to read the two case studies and answer the discussion question at the end: "What factor(s) did the engineers of the Titanic and the Tacoma Narrows Bridge fail to include in their engineering analysis?" See possible answers in the Famous Failures Case Studies Answers.

Activity-Embedded Assessment

Stepping through the Analysis Process: To make sure that students understand the process outlined in the Evaluating Alternatives Rubric, go through the scenario presented in the example rubric. This step-by-step example shows how a student team used the analysis process to evaluate alternatives for a scooter design.

Post-Activity Assessment

Tell It in Two Minutes: Give each team two minutes to summarize the results of the evaluating alternatives process:

1. What were the team's design alternatives?
2. What criteria did the team use to evaluate these alternatives?
3. What was the outcome of the rubric? (In other words, which alternative received the highest score?)
4. Defend why the most promising idea from the analysis is the one that should move forward in the design process.

Activity Extensions

Real-Life Project Analysis: As part of the teams' background research (completed in the Design Step 2: Background Research activity), students were asked to find examples of 'real-life: engineering projects similar to their own design challenge.' Now, ask students to look more closely at the analysis process used by the engineers for these projects. Did the engineers use computer simulations, build physical models, or perform another type of engineering analysis?

Additional Multimedia Support

Show students a four-minute video about the failed Tacoma Narrows Bridge including footage of the 1940 collapse, at: http://www.youtube.com/watch?v=3mclp9QmCGs

References

Famous Failures of Complex Engineering Systems. December 1-5, 1997. Theoretical Foundations of Virtual Engineering and Complex Systems, AFOSR/Caltech Workshop, Control and Dynamical Systems, California Institute of Technology. Accessed January 26, 2010. (Brief recaps of Titanic sinking, Estonia ferry sinking, Tacoma Narrows Bridge collapse, Denver airport baggage handling system.)

History of Flight around the World. American Institute of Aeronautics and Astronautics. Accessed January 26, 2010. (Profiled by country and by pioneers.) https://www.aiaa.org/Secondary.aspx?id=2910

Huston, Dryver R. and Harold R. Bosch. Aerodynamic Design of Highway Structures. Winter 1996. Public Roads Magazine, Vol. 59, No. 3. Turner-Fairbank Highway Research Center, Federal Highway Administration, US Department of Transportation. Accessed January 26, 2010. http://www.tfhrc.gov/pubrds/winter96/p96w46.htm

Super Bridge: Suspension Bridges. Updated October 2000. NOVA Online, Southern Oregon Public Television. (Links to videos of Tacoma Narrows Bridge oscillation and collapse.) Accessed January 26, 2010. http://www.pbs.org/wgbh/nova/bridge/meetsusp.html

Yowell, J.L. and Carlson, D.W., Eds., Introductory Engineering Design: A Projects-Based Approach, Third Edition, Textbook for GEEN 1400: First-Year Engineering Projects, Integrated Program, College of Engineering and Applied Science, University of Colorado at Boulder, Fall 2000. Accessed April 8, 2010. http://itll.colorado.edu/index.php/courses_workshops/geen_1400/resources/textbook/

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Supporting Program

Integrated Teaching and Learning Program, College of Engineering, University of Colorado Boulder

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Last modified: December 26, 2014

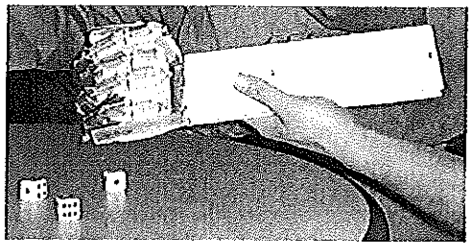
Hands-on Activity: Design Step 5: Construct a Prototype

Contributed by: Integrated Teaching and Learning Program, College of Engineering, University of Colorado Boulder

FULL DESIGN PROCESS

Summary

Students learn about the manufacturing phase of the engineering design process. They start by building prototypes, which is a special type of model used to test new design ideas. Students gain experience using a variety of simple building materials, such as foam core board, balsa wood, cardstock and hot glue. They present their prototypes to the class for user testing and create prototype iterations based on feedback. (Note: Conduct this activity in the context of a design project that students are working on; this activity is Step 5 in a series of six that guide students through the engineering design loop.)



The purpose of creating prototypes is to test out new design ideas. In this case, can this student-made prosthetic roll dice? copyright

Engineering Connection

Prototypes are routinely used as part of the product design process to give engineers and designers the ability to explore design alternatives, test theories and confirm performance prior to starting production of a new product. Almost every engineering discipline uses prototypes in some way, including aerospace, computer, mechanical, civil, environmental and electrical engineering.

Educational Standards

- International Technology and Engineering Educators Association: Technology ▸
- Next Generation Science Standards: Science ▸

Learning Objectives

After this activity, students should be able to:

- Explore design alternatives through the creation of prototypes.
- Explain the difference between prototypes and models.
- Compare and contrast the use of different construction materials in the development of prototypes.

Materials List

Prototyping materials and tools for the entire class to share may vary, depending on the project. Some suggested items include:

- foam core board
- balsa wood
- cardstock
- wooden or metal dowels
- craft utility knives
- rulers (if using utility knives, metal-edged rulers work best)
- cutting surface, such as a plastic board, kitchen cutting board or back of a newsprint pad
- hot glue and hot glue gun
- scrap materials (have students scavenge or ask for donations)
- Foam Core Tips Handout, one per team (if using foam core)

Introduction/Motivation

How does a typical engineering design loop begin? (Take suggestions from the students.) That's right. The engineering design process begins by defining the engineering challenge, performing background research, brainstorming potential solutions, and evaluating several alternatives. And what is next? (Listen to suggestions from the students.) Next, an engineering team synthesizes this information to begin the product manufacturing process. Many times, something that works on paper proves to be very difficult to build. To help engineering teams assess the "buildability" of their project concept, they often create prototypes.

A prototype is a working model of a product that is used for testing before it is manufactured. Prototypes help designers learn about the manufacturing process of a product, how people will use the product, and how the product could fail or break. A prototype is not the same thing as a model. A model is used to demonstrate or explain how a product will look or function. A prototype is used to test different working aspects of a product before the design is finalized.

For example, a team of engineers designing a new cell phone might produce several cardboard and paper models to illustrate how the final product would look and feel. They may survey the general public to gain feedback about how the cell phone could look. The team might build a sturdier plastic prototype to test how easily the cell phone could break when dropped. If the prototype does not meet the team's design requirements, then they may complete an "iteration." Iteration is when engineers try again and re-design, re-build and re-test. Engineers often iterate many times before determining the final solution to a problem.

Quick Look

Grade Level:	9 (9-12)
Time Required:	120 minutes The time required to complete this design process step is adjustable to as little or as long as the teacher desires. We suggest a minimum 120 minutes and a maximum dependant on the design difficulty and number of iterations.
Expendable Cost/Grp:	US$ 5 Cost is variable, depending on the materials required by teams to build their prototypes. Some example materials are suggested.
Group Size:	4
Activity Dependency:	Design Step 4: Engineering Analysis

Related Curriculum

Subject Areas:	Science and Technology
Curricular Units:	Creative Engineering Design

ENGINEERS help shape the future

Once a successful prototype has been developed, the engineering team can use it as a mock-up for full-scale manufacturing.

Your team will follow a similar process. By building a prototype, you should be able to determine if your chosen design solution is feasible and which aspects of your design needs special materials or further refinement. You will also ask other people to test your prototype to help you identify any problems a user might encounter. You may even have time to complete a few iterations, or modifications, to your prototype.

(Note: After conclusion of this activity, proceed to the next activity in the series, Design Step 6: Evaluate/Manufacture a Final Product.)

Vocabulary/Definitions

balsa wood: One of the lightest varieties of wood available with remarkable strength. Because it can be carved easily and bent into a number of shapes, balsa wood is often used to build models and prototypes.

foam core board: A lightweight and rigid material commonly used to produce architectural models, prototype small objects and produce patterns for casting. It consists of three layers—an inner foam layer (Styrofoam, polystyrene, etc.) with outer facings of slick, smooth paper in various colors.

iteration: Repeating a series of steps to get closer to a desired outcome (that is, re-design, re-test, re-build to get nearer to an optimal engineering solution to a specific problem). Also: A version of the final product or solution. For example: Our third iteration passed the strength test.

manufacturing: The use of machines, tools and labor to make things for use or sale. On a large scale, the transformation of raw materials into finished goods.

model: A plan, representation (often in miniature), or description designed to show the main object or workings of a product concept.

prototype: A model of a product that is used for testing before it is manufactured. Prototypes help designers learn about the manufacturing process of a product, how people might use it, and its durability.

rapid prototyping: The automatic construction of physical parts and prototypes using additive manufacturing technology directed by computer-aided design modeling software. In additive manufacturing, a material is laid down in layers to create an object.

Procedure

Background

New designs often have unexpected problems, and it is often difficult to determine whether a new design or product will perform as intended. Prior to large-scale manufacturing of a product, engineers often build prototypes. A prototype is a model of a product used to explore design alternatives, test theories, confirm performance and ensure the product is safe and user-friendly. Engineers use prototypes to figure out specific unknowns still present in the design.

For example, a student team designing a prosthetic hand that rolls dice could build a prototype using simple materials such as wood, rubber bands and string to test that the prosthetic hand performs the desired function of rolling and picking up dice. In most cases, an iterative series of prototypes is designed, constructed and tested as the final design emerges, is refined and becomes ready for production.

A philosophy often repeated and credited to Tom Kelley of IDEO, a successful worldwide engineering design and innovation consulting firm, is, "**Fail often to succeed sooner.**" It might be helpful for students in the midst of prototyping iterations to see the value of this approach as expressed by professional designers. We learn more from failures than successes.

Rapid prototype machines can literally bring computer-aided engineering designs to life! Some examples of objects, tools and parts manufactured using a rapid prototype machine and CAD software.

Often, the term prototype is interchanged with the term "model," which can cause confusion. While several types of prototypes exist, for the purpose of this activity, we will make the following distinction: Whereas a model is used to demonstrate or explain how a product will look or function, a prototype is used to work out the kinks in a design or to try new ideas. Keep in mind that prototypes are unrefined versions of a future product. Most companies do not show prototypes to the general public to ensure that the public's opinion is based on the final product.

In some cases, engineers "rapid prototype" a part. Rapid prototyping is the automatic construction of physical objects using additive manufacturing technology and computer-aided design (CAD) software.

Basically, a virtual design from CAD software is "read" by a rapid prototyping machine that divides the design into thin horizontal slices. The machine then lays down successive horizontal layers of liquid or powder (such as ABS plastic material) and adhesive in the shape of the virtual design. The primary advantage of rapid prototyping is the ability to create almost any shape or feature, including assemblies with moving parts.

Before the Activity (Teacher Prep)

- Collect various materials and tools that students can use to construct prototypes.
- If using foam core board as a primary building material, review the tips outlined in the attached Foam Core Tips Handout,

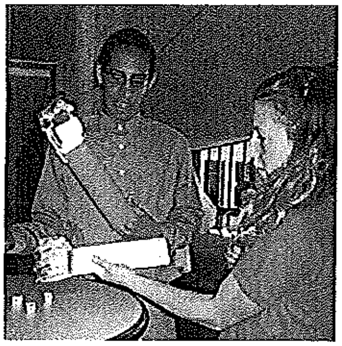
and make copies, one per team.

- Student teams should continue with the same 3-5 members each, as determined in the first activity of this unit, Design Step 1: Identify the Need.

With the Students

1. Explain to students the purpose of building prototypes. Mention that several types of prototypes exist, but we will focus on creating prototypes for the purpose of testing different working aspects of a product before the design is finalized.

2. (optional) Ask students the Investigating Questions about creating and testing prototypes.



Students perform user testing to see if their prototypes function as intended.

3. Show students the available building materials (or allow them to bring in their own if this was established in advance).

4. Review the Foam Core Tips Handout (if applies), or any other information on material use or tool safety.

5. Lead the pre-activity assessment (as described in the Assessment section) to give students a chance to sketch their ideas before constructing prototypes. Students are asked to complete a more detailed sketch of their design than in previous activities. Have them label materials and specify dimensions.

6. Give students "free time" to experiment with the materials and begin construction. Answer questions as they arise.

7. Early in the construction process, briefly stop the class to lead a mini design review as described in the Assessment section (activity embedded assessment). Have each team show the class their initial prototype, explain its purpose, and describe any challenges they have encountered during the build process. Follow with a class discussion to collaborate in figuring out possible solutions.

8. Once teams have finished the build process, have them swap prototypes and engage in the user testing as described in the Assessment section (post-activity assessment).

9. Give teams enough time to create at least one iteration of their prototypes. Have students add modifications to their sketches (made in Step 4), modify or re-build their prototypes, and proceed through another round of user testing for each iteration.

Attachments

Foam Core Tips Handout (doc)

Foam Core Tips Handout (pdf)

Safety Issues

- This is the first point in the design cycle in which safety issues are important. Remind students to be careful when using hot glue, utility knives, and construction materials and tools.

Troubleshooting Tips

If students become frustrated with the way their initial prototypes look, remind them that prototypes are used to test out new ideas and are not meant to look perfect!

Investigating Questions

Use the following discussion questions to help students gain understanding of an important aspect of engineering problem solving: **creating and testing prototypes.**

- **What is an advantage of building a prototype prior to full-scale manufacturing?** (Possible answer: Exploring design alternatives with a prototype saves resources [time, money and materials] required to manufacture a final product.)
- **Why might most engineering companies refrain from releasing a prototype to the general public?** (Possible answer: Because they want the public's opinions to be based on the final product, not on early versions and rudimentary prototypes.)

Assessment

Pre-Activity Assessment

Sketch It! Have students use their initial sketches or outlines created in the Design Step 3 activity to generate more detailed sketches of their envisioned prototypes, labeling them with dimensions and materials. Now that they have seen the available materials, they should have a sense for the degree of the complexity achievable in this first prototype. Review the sketches with the students to check that they are designing prototypes, not models. If time allows, have them draw the prototype sketches to scale.

Activity-Embedded Assessment

Design Review: Briefly stop the prototype construction process to bring the class together as a group. Ask each team to show its initial prototype, explain its purpose (what the team is attempting to test) and describe any challenges encountered during the build process. Write these challenges on the board and lead a class brainstorming session so students may offer solutions to other teams' challenges. (Note: Alternative options for performing design reviews include: asking the team to present to a small "client focus group" that includes the teacher and a few others, having students rotate around the room and review for one other team, or asking another class to come in to listen and provide feedback to initial design descriptions.)

Post-Activity Assessment

User Testing: To simulate user testing, have each team swap prototypes with another team. Ask teams to give each other feedback:

- Is the prototype functional? What works? What does not work?
- Is the prototype used to explore several design alternatives?
- What improvements could be made?

Reflection: After user testing, ask the design teams to reflect on the feedback received. Have them write short documents for the teacher summarizing the feedback and what changes they intend to make in the next iteration of their designs.

Activity Extensions

Limitations to Prototypes: Have student teams brainstorm the limitations of prototypes and generate lists of ideas. Engage the class in a discussion of these limitations and expand the discussion to talk about what can be done to accurately determine these factors for final production. For example, limitations might include evaluating costs, time to build, material function and actual environmental impact.

References

Prototype. Last updated January 1, 2010. Wikipedia, The Free Encyclopedia. Accessed January 27, 2010. http://en.wikipedia.org/wiki/Prototype

Rapid prototyping. Last updated January 13, 2010. Wikipedia, The Free Encyclopedia. Accessed January 27, 2010. http://en.wikipedia.org/wiki/rapid_prototyping

Sloane, Paul. Failure is the Mother of Invention. Published October 13, 2004. Innovation Tools. Accessed February 9, 2009. http://www.innovationtools.com/Articles/EnterpriseDetails.asp?a=158

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Last modified: December 26, 2014

Hands-on Activity: Off-Road Wheelchair Challenge

Contributed by: Inquiry-Based Bioengineering Research and Design Experiences for Middle-School Teachers RET Program, Department of Biomedical Engineering, Worcester Polytechnic Institute

Quick Look

Grade Level:	7 (6-8)
Time Required:	385 minutes (7 x 55-minute class periods)
Expendable Cost/Grp ❶:	US$ 2
Group Size:	3
Activity Dependency ❶:	None

Related Curriculum ❶

Subject Areas:	Science and Technology
Curricular Units:	Engineering and Empathy: Teaching the Engineering Design Process through Assistive Devices

Engineering solutions can help people with physical disabilities to take on physical challenges.
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Summary

Students further their understanding of the engineering design process (EDP) while being introduced to assistive technology devices and biomedical engineering. They are given a fictional client statement and are tasked to follow the steps of the EDP to design and build small-scale, off-road wheelchair prototypes. As part of the EDP, students identify appropriate materials and demonstrate two methods of representing solutions to their design problem (scale drawings and simple scale models). They test the scale model off-road wheelchairs using spring scales to pull the prototypes across three different simulated off-road surfaces.

Engineering Connection

Engineers follow the engineering design process as they create solutions that improve the lives of many people through the development of assistive technology devices. For example, advancements in wheelchairs, prosthetics, and hearing and visual aid devices illustrate the humanitarian aspect of engineering.

Educational Standards

- Common Core State Standards for Mathematics: Math ▸
- International Technology and Engineering Educators Association: Technology ▸
- Massachusetts: Science ▸
- Next Generation Science Standards: Science ▸

Pre-Req Knowledge

A familiarity with the engineering design process and recognition that the process works in a cyclical fashion rather than a linear process with a beginning and an end.

Learning Objectives

After this activity, students should be able to:

- Identify and describe the steps of the engineering design process.
- Describe how to use the engineering design process to develop solutions to problems.
- Explain the reasons for their selected designs and material choices.

Materials List

Each group needs:

- cardstock strips
- cardboard strips
- plastic drinking straws
- plastic coffee stirrers
- hot glue gun with hot glue sticks
- scissors
- 3 rulers, one per student
- measuring tape
- graph paper and pencils
- client model, such as a doll or an action figure (or any object to represent a person that students can measure to gain dimensions for the wheelchair prototype and that could ride in the wheelchair during testing)
- Off-Road Wheelchair Packet, one per student
- computers, for internet research

To share with the entire class (for testing):

- simulated grassy field surface made from a cardboard box cover base (12 x 19 in [~30 x 50 cm) lined with a piece of high-pile carpet
- simulated sandy beach surface made from a cardboard box cover base (12 x 19 in [~30 x 50 cm) lined with

sand and fish tank gravel

- simulated wooded trail surface made from a cardboard box cover base (12 x 19 in [~30 x 50 cm) lined with randomly placed straw and cardboard scraps
- 3 spring scales

Introduction/Motivation

Engineers who design assistive technology offer people with physical disabilities more in life than a reserved parking spot.
copyright

(optional; If time permits, show students a movie or film that shows people overcoming disabilities through the help of engineered technology. See suggestions in the Additional Multimedia Support section.)

People with physical disabilities are faced with many challenges. Not only must they overcome the physical challenges presented by their disabilities, but they also must deal with the perception of "being different." The engineering community has developed many assistive devices to help people with disabilities live a life that is as independent and as "normal" as possible.

What is an assistive technology device? (Listen to student ideas.) An assistive device is a device that is designed (or sometimes a device that is adapted) to assist a person with a disability to carry out a task. Can you think of some examples? (Listen to student ideas. Possible answers: Canes, crutches, wheelchairs, walkers, eye glasses, prosthetics, and replacement body parts.) Whether the assistive device is very advanced, such as a prosthetic foot for running, or very basic, such as a grab-bar in the shower, does not matter. All these devices were designed by engineers to help all members of our community feel as capable and independent as possible.

Vocabulary/Definitions

assistive device:	A device designed and constructed to assist people in carrying out tasks. Also called assistive technology devices.
bioengineering:	A field of engineering that solves problems related to life sciences by the application of physics, chemistry and mathematics concepts, as well as the engineering design process.
biomedical engineering:	A field of engineering that collaborates with doctors, surgeons and other medical professionals to produce technology to promote the lives of patients.
engineering design process:	The iterative process through which engineers develop solutions to meet an objective. The steps of the process include: identifying a problem, brainstorming, designing, constructing, testing, analysis and evaluation, redesigning, retesting, and sharing a solution. Science, mathematics and engineering science concepts are applied throughout the process to optimize the solution.
mechanical engineering:	A field of engineering based on designing and constructing mechanical systems through the application of physics, mathematics and material science concepts, as well as the engineering design process.

Procedure

Background

Our society's technological knowledge base is increasing at an astonishing rate. With this increase in knowledge comes an increase in the quality, design and access to assistive devices. As the number of injured soldiers has increased, the government has invested more resources into the development of assistive devices designed to help them. For example, Dean Kamen, who is known for the development of the Segway, was funded by the U.S. government to create a new prosthetic arm to people who have lost arms. Kamen's *Luke Arm* is leaps and bounds ahead of its predecessors. (As time permits, shows students videos on this topic; see suggestions in the Additional Multimedia Support section.)

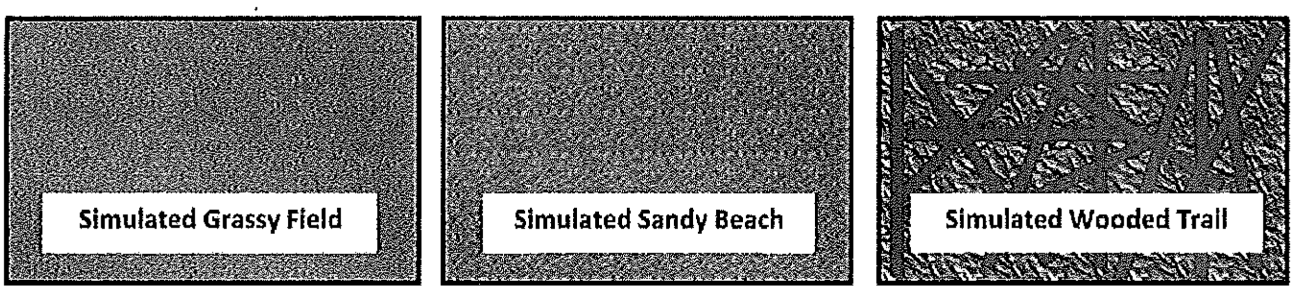
Even with the recent advancements in assistive device technology, low-tech solutions continue to meet the needs of end-users. For example, the Rough Rider wheelchair, by Whirlwind International, combines many existing technologies, such as mountain bike tires for the main wheels and shopping cart wheels for the front wheels, to produce an inexpensive wheelchair that is capable of handling the everyday surfaces encountered by people with disabilities. It is especially designed to handle rugged terrain easily and has been proven in more than 25 countries with thousands of riders in the worst of conditions.

Day	Activity
1	Introduce the project Students define the problem
2	Student teams... - brainstorm solutions - discuss pros and cons for each solution - choose best solution
3	Create scale drawings for selected design
4-6	Construct, test, redesign scale model prototype
7	Final prototype testing Complete Off-Road Wheelchair Packet Present prototypes to the class

Suggested seven-day project schedule for the activity.

Before the Activity

- Gather and prepare supplies for the student groups.
- Make copies of the Off-Road Wheelchair Packet.
- Prepare three simulated off-road surfaces for prototype testing. See the Materials Lists for materials to line or fill the bases of three cardboard box covers.



Test student prototypes on three types of surfaces to represent a grassy field (plush carpeting), sandy beach (sand and fish tank gravel), and wooded trail (straw and cardboard scraps).

With the Students

1. As a class, discuss the idea of a physical disability and assistive devices.

- Have students describe in detail their favorite physical activities.
- Ask: How would you feel if you could no longer physically do those activities?
- Ask: What if technology could help you to continue to do your favorite activities?

2. Introduce students to the off-road wheelchair challenge project.

- Describe a fictitious 18-year-old competitive mountain biker who was injured and is now confined to a wheelchair. This athlete is the end-user (client) for the design project.
- Hand out the packets to students.
- Read aloud the project introduction and client statement from the packet.

3. Divide the class into groups of three students each.
4. Direct the groups to follow the steps of the engineering design process to design and build a scale model prototype of an off-road wheelchair for the client. Use the model client for measurements. Have them complete the packet as they go along, and use it as a guide for each step of the process.
5. As students move through the process, have them conference with the teacher at the following points before moving ahead.

- Identify the need (problem statement, function, constraint, objective)
- Research
- Develop possible solutions (minimum of three)
- Select the best solution
- Blueprint and prototype
- Test and evaluate
- Communicate solutions
- Redesign (future recommendations)

6. Have groups begin by completing the definitions for mechanical engineering, bioengineering and biomedical engineering on page 1 of the packet. If they are unsure of any definition, have them use the internet to research that field.
7. **Identify the need:** Have students write problem statements, considering information provided in the introduction and the client statement in the packet. Have them write paragraphs for each of the following:

- How the wheelchair functions (what it does)
- The objectives for the wheelchair (what it is)
- The constraints (include materials, timeframe, etc.)

8. **Research:** Have students use the internet to research past and present wheelchair designs, off-road bikes and mountain bikes, as well as why people need wheelchairs. Have them keep records of all relevant information found, as well as website sources.
9. **Develop possible solutions:** Require each group to develop at least three possible designs for their off-road wheelchairs, documenting them in the packet. Suggest group brainstorming to come up with designs together and/or have students individually draw their own ideas to share with the group.
10. **Select the best solution:** Together as a group, discuss the pros and cons of each design and decide which of the possible designs (or a combination of more than one design) is the most promising design

solution to meet the objectives and constraints. Remind students to be prepared to explain to the teacher the reasons for their decisions.

11. **Blueprint and prototype:** Have students complete final design drawings that include labeled dimensions and materials. Make the drawings clear enough that another person could readily learn what is needed and how to create the prototypes. Once the final design is complete, use the provided materials to construct the prototype.
12. **Test and evaluate:** Once student groups have finished building their wheelchair prototypes, have them test them on the three simulated off-road surfaces. Do this by attaching a spring scale to the prototype wheelchair and pulling it across the length of the surface. Direct students to notice on the spring scale how much force is being applied to pull the wheelchair and record the maximum force. Complete three trials on each surface and record data in the table in the packet. Also describe each trial in words below the table, as well an evaluation that explains whether the design was effective, and provide reasons.
13. **Communicate Solutions:** When groups are ready, have students present their prototypes to the class. Include in the presentation descriptions of how they developed the designs, how the tests went, and prototype evaluations. Have the rest of the class ask questions and offer comments.
14. **Redesign (future recommendations):** Have students finish their packets by writing recommendations on ideas for further research, and what they would improve in a redesign.
15. Have students turn in their completed packets for grading.
16. As time permits, lead a class discussion to compare results and conclusions.

Attachments

Off-Road Wheelchair Packet (pdf)

Off-Road Wheelchair Packet (docx)

Assessment

Pre-Activity Assessment

Class Discussion: Informally evaluate students' prior knowledge about engineering and the engineering design process, assistive technologies and disabilities.

Activity Embedded Assessment

As We Work: During the course of the activity, students work on the Off-Road Wheelchair Packet, which serves as formative assessment of their abilities to follow the engineering design process while creating and testing off-road wheelchair prototypes.

Design Drawing and Prototype: Examine students' drawings and prototypes to gauge their abilities to demonstrate methods of representing solutions to design problems.

Post-Activity Assessment

Final Documentation: Evaluate students' completed Off-Road Wheelchair Packets as summative assessment of their abilities to accurately use the engineering design process to create and test wheelchair design prototypes. Evaluate their vocabulary word definitions and answers to other questions to gauge their comprehension of the process and project components. Example answers:

- Problem Statement: An 18-year old competitive mountain biker is injured and now confined to a wheelchair. To remain active and enjoy traveling across terrain that is inaccessible by a conventional wheelchair, this athlete needs an all-terrain wheelchair to improve his/her quality of life. We will approach solving this problem by creating a small-scale prototype for the all-terrain wheelchair.

- Function: The all-terrain wheelchair should allow the client to access and travel across terrain that is inaccessible by a conventional wheelchair.
- Objective: The all-terrain wheelchair prototype should be able to roll across the three simulated surfaces: a grassy field, a sandy beach, and a wooded trail. We also aim for our prototype to use minimal force to roll across these surfaces.
- Constraints: Construct the all-terrain wheelchair prototype with the provided materials and within the seven class periods provided.

Final Prototype: Examine students' completed drawings and wheelchair design prototypes to gauge their abilities to demonstrate methods of representing solutions to design problems.

Graphing the Results: Using the data from the test results, graph the amount of force applied for the three types of surfaces. Students can find the average of the force amongst the three trials and use that as the maximum force applied for each surface. Discuss final results and determine which surface resulted in the highest force.

Additional Multimedia Support

Show students a movie or film that shows people overcoming disabilities through the help of engineered technology. Suggestions: *Kiss My Wheels* by Miguel Grunstein and Dale Kruzic (56 minutes), *Not on the Sidelines: Living and Playing with a Disability* by Ben Achtenberg and Karen McMillan (Fanlight Production, http://www.fanlght.com; 26 minutes).

Watch Dean Kamen's Prosthetic "Luke Arm" Be Awesome at the Grocery Store (Gizmodo; 1:25 minutes): http://gizmodo.com/5670842/watch-dean-kamens-prosthetic-luke-arm-be-awesome-at-the-grocery-store

Dean Kamen: The Emotion behind Invention (TED talk; 19:33 minutes): http://www.ted.com/talks/dean_kamen_the_emotion_behind_invention.html

Wheel chair back-flip (YouTube; 3:36 minutes): http://www.youtube.com/watch?v=7NJvgT60-mk

Off- road chair for yard work, hunting and fishing (YouTube; 8:23 minute): http://www.youtube.com/watch?v=sPSf517GVd0

Katie bot III, extreme mobility wheelchair (YouTube; 1:58 minutes): http://www.youtube.com/watch?v=yr8d9QAc5RQ

Four-wheel drive wheelchair on different surfaces (YouTube; 3:05 minutes): http://www.youtube.com/watch?v=wThIlpmvCPg

Track drive wheelchair goes to the beach (YouTube; 4:05 minutes): http://www.youtube.com/watch?v=7I0ThOC3VAA

References

Adee, Sarah. "Dean Kamen's 'Luke Arm' Prosthesis Readies for Clinical Trials." *IEEE Spectrum.* February 2008. Accessed November 28, 2012. http://spectrum.ieee.org/biomedical/bionics/dean-kamens-luke-arm-prosthesis-readies-for-clinical-trials

Assistive Device (definition). 1998. MedicineNet.com, MedicineNet, Inc. Accessed July 19, 2010. http://www.medterms.com/script/main/art.asp?articlekey=2372

Bellis, Mary. *Inventors: History of the Wheelchair: The first dedicated wheelchair was made for Phillip II of Spain*. About.com, New York Times Company. Accessed November 28, 2012. http://inventors.about.com/od/wstartinventions/a/wheelchair.htm

Kaye, H. Stephen, Kang, Taewoon, and LaPlante, Mitchell. *Wheelchair Use in the United States*, Disability Statistics Center, Abstract 23. May 2002. University of California-San Francisco. Accessed November 28, 2012. http://dsc.ucsf.edu/publication.php

Magar, Prashant. *History of Assistive Technology*. Buzzle.com. Accessed July 21, 2010. http://www.buzzle.com/articles/history-of-assistive-technology.html

Reinhart, Kevin A. *The History of Assistive Technology*. 2010. eHow-Health, Demand Media Inc. Accessed March 29, 2011. http://www.ehow.com/about_6802248_history-assistive-technology.html

What Is Assistive Technology? The National Center on Accessible Information Technology in Education. University of Washington. Accessed July 22, 2010. http://www.washington.edu/accessit/articles?109

Whirlwind Wheelchair (description and photos). 2012. Whirlwind International. Accessed November 28, 2012. http://www.whirlwindwheelchair.org/roughrider/

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Last modified: November 12, 2014

Name: ______________________ Date: ____________ Class: ____________

Off-Road Wheelchair Packet

Define the following terms

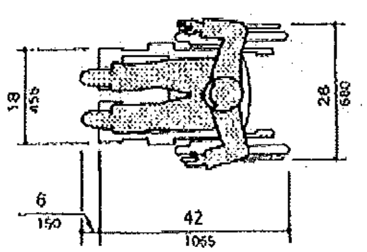
Mechanical engineering:

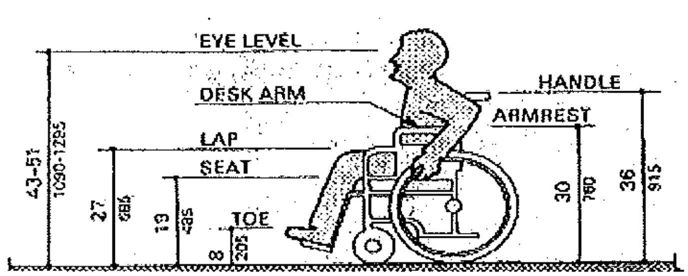
Bioengineering:

Biomedical engineering:

Introduction

You work for an engineering company that specializes in making outdoor sporting equipment. The company has recognized that many people who are confined to wheelchairs enjoy outdoor activities such as light hiking or even mountain biking. Your role is to develop an off-road wheelchair design that enables this end user to access to formerly inaccessible outdoor activities.





ncbi.nlm.nih.gov

Client Statement

Create an off-road wheelchair for recreational purposes. The wheelchair should be easy to transport and operate, and be effective in traversing off-road terrain, such as trails, fields and beaches.

Problem Statement (Define the problem in detail)

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Revised Problem Statement: (Definition of the problem in detail including client modifications)

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Functions (what the product does)

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Objectives (What the product is)

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Constraints (The product must or must not)

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Background Research

As homework, use the internet to research past and present wheelchair designs, off-road and mountain bikes, why people need wheelchairs, and other related topics. Keep a record of relevant material and source websites.

Design Solutions (Sketch and describe 3 possible solutions)

Design #1

Design #2

Design #3

Prototype Creation (describe why you chose the design you did)

____

____

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____

____

Test Design

1. Attach the scale model wheelchair prototype design to the spring scale.
2. Pull your prototype wheelchair across the three simulated off-road surfaces.
3. Record the highest amount of force needed to move your prototype at any point during each movement simulation.
4. Record your data in the table.

Test Results (Complete the table and record the test results in detail)

(Force Measured In Newtons)	Trial 1	Trial 2	Trial 3
Beach			
Light Hike			
Field			

(Description of results) ____

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Evaluation of Results (Was your design effective? How do you know?)

Future Recommendations (What you would recommend for future research)

Hands-on Activity: Portable Wheelchair Ramp Challenge

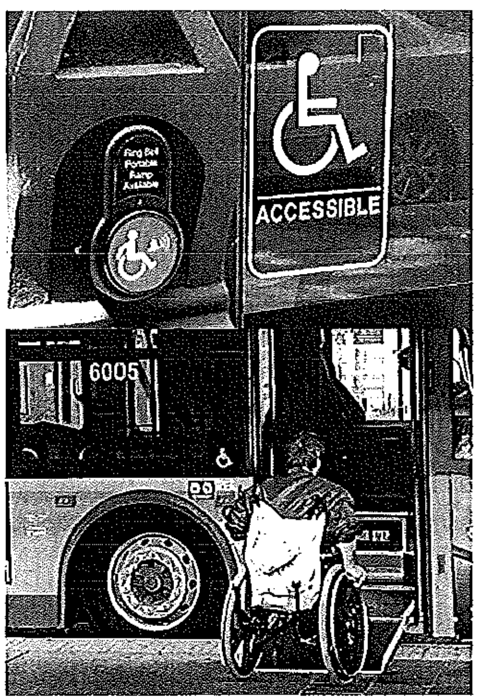
Contributed by: Inquiry-Based Bioengineering Research and Design Experiences for Middle-School Teachers RET Program, Department of Biomedical Engineering, Worcester Polytechnic Institute

Quick Look

Grade Level:	7 (6-8)
Time Required:	385 minutes (7 x 55-minute class periods)
Expendable Cost/Grp:	US$ 2
Group Size:	3
Activity Dependency:	None

Related Curriculum

Subject Areas:	Science and Technology
Curricular Units:	Engineering and Empathy: Teaching the Engineering Design Process through Assistive Devices



Engineering designs, such as portable or retractable ramps help people in wheelchairs access structures that are not handicap accessible.

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Summary

Students follow the steps of the engineering design process while learning more about assistive devices and biomedical engineering applied to basic structural engineering concepts. Their engineering challenge is to design, build and test small-scale portable wheelchair ramp prototypes for fictional clients. They identify suitable materials and demonstrate two methods of representing design solutions (scale drawings and simple models or classroom prototypes). Students test the ramp prototypes using a weighted bucket; successful prototypes meet all the student-generated design requirements, including support of a predetermined weight.

Engineering Connection

The engineering design process is a widely accepted way of arriving at desirable solutions to identified problems. This activity guides students through the engineering design process steps as they apply basic engineering concepts to real-world design problems. Through the development of assistive devices, students are exposed to the humanitarian nature of engineering.

Educational Standards

- Common Core State Standards for Mathematics: Math ▸
- International Technology and Engineering Educators Association: Technology ▸
- Massachusetts: Science ▸
- Next Generation Science Standards: Science ▸

Pre-Req Knowledge

Familiarity with the engineering design process and recognition that the process works in a circular fashion rather than a linear process with a beginning and an end.

Learning Objectives

After this activity, students should be able to:

- Identify and describe the steps of the engineering design process.
- Describe how to use the engineering design process to develop solutions to problems.
- Explain the reasons for their selected designs and material choices.

Materials List

Each group needs:

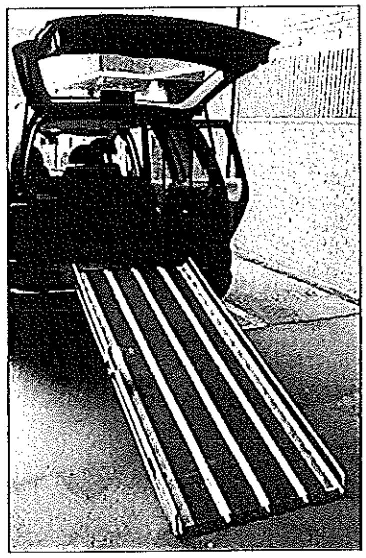
- cardstock strips
- cardboard strips
- cardstock sheets
- plastic drinking straws
- plastic coffee stirrers
- hot glue gun with hot glue sticks
- scissors
- 3 rulers, one per student
- measuring tape
- graph paper and pencils

- Portable Wheelchair Ramp Packet, one per student
- model all-terrain wheelchair prototype created in Off-Road Wheelchair Challenge, for sizing prototype ramp

To share with the entire class (for testing):

- 1 bucket, to hold weights
- 2 7-lb (~3 kg) weights

Introduction/Motivation



An example portable wheelchair ramp, engineered to enable people with disabilities to access many different locations. This ramp is wide and folds longitudinally.
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In our last activity, we developed an off-road wheelchair so that our 18-year old client who was once a competitive mountain biker and now confined to a wheelchair, can travel on rough terrain that would otherwise be inaccessible to him/her.

Will our off-road wheelchairs enable our client access to everywhere? (Listen to student responses.) No, other everyday obstacles will stop the wheelchair. One example is stairs.

How do people restricted to wheelchairs usually overcome the problem of stairs? (Answer: They use ramps or take an elevator.) That's right!

In today's activity, we will again use the engineering design process to help us develop a wheelchair ramp for our client. Since we want our client to be able to access as many places as possible, our goal is to design, create and test designs for portable wheelchair ramps.

Vocabulary/Definitions

assistive device:	A device designed and constructed to assist people in carrying out tasks. Also called assistive technology devices.
bioengineering:	A field of engineering that solves problems related to life sciences by the application of physics, chemistry and mathematics concepts, as well as the engineering design process.
biomedical engineering:	A field of engineering that collaborates with doctors, surgeons and other medical professionals to produce technology to promote the lives of patients.

constraint:	A limitation or restriction. For engineers, constraints are the limitations that must be considered when designing a workable solution to a problem.
engineering design process:	The iterative process through which engineers develop solutions to meet an objective. The steps of the process include: identifying a problem, brainstorming, designing, constructing, testing, analysis and evaluation, redesigning, retesting, and sharing a solution. Science, mathematics and engineering science concepts are applied throughout the process to optimize the solution.
functions:	The capabilities or tasks that an engineering solution is able to perform.
objectives:	Desired outcomes for an engineering design or product.
problem statement:	A sentence or two that describes the identified problem or challenge an engineer or engineering team is working to solve.
prototype:	An early functional version (a model, a mock-up) of a design to help move the design process forward by improving the team's understanding of the problem, identifying missing requirements, evaluating design objectives and product features, and getting feedback from others.
requirements:	The overall objectives, functions and constraints of a project.
structural engineering:	A field of engineering that focuses on the design of structures through using physics and mathematics principles, as well as the engineering design process with the intent to make sure structures are built adequately to support or resist loads, including environmental conditions.
universal design:	The concept of designing buildings, products and technologies so that they are accessible to all people regardless of age, physical abilities or status. Universal design takes into account assistive technology considerations as well as aesthetic aspects of design.

Procedure

Background

Throughout history, people developed devices to help people with disabilities. These devices have become a benefit to us all. For example, the first typewriter was built in 1808 by Pellegrino Turri with the purpose to help a blind friend write more legibly, and in 1920, Harvey Fletcher developed the first hearing aids, which eventually led to today's public address systems.

Today's assistive devices are as varied as the people who use them. Can you think of any examples of assistive devices? (Possible answers: Wheelchairs, canes, handicap-accessible elevators and ramps, hearing devices, eyeglasses, etc.) Great! Other examples include technology that helps people use computers and other technologies. For example, engineers have designed keyboards with large keys and special mice for people with limited fine motor skills. Software has been designed to read computer screen text in an audible computer-generated voice so that blind people have the same access to information as everyone else. Other devices help people with speech impairments by speaking for them out loud when text is entered on a keyboard. These are just a few examples of the assistive technology that is available today.

Some of the most important assistive devices can be as simple as a ramp. The ADA (Americans with Disabilities Act) provides accessibility guidelines for the construction of ramps in public places, such as a maximum slope of 1:12. Unfortunately, most homes have steps, but no ramps, which can drastically limit a person with a physical disability. A simple web search reveals many companies that have developed portable wheelchair ramps, but they are often heavy and difficult to transport. (As time permits, shows students videos on this topic; see suggestions in the Additional Multimedia Support section.) As our understanding of material science continues to grow, we are able to develop stronger and lighter ways to achieve our goals, even if they are as simple as a portable wheelchair ramp. We are going to design and develop a wheelchair ramp that meets all the needs of our "client." Let's begin!

Day	Activity
1	Introduce the project Students define the problem
2	Student teams... - brainstorm solutions - discuss pros and cons for each solution - choose best solution
3	Create scale drawings for the selected design
4-6	Construct, test, redesign scale model prototype
7	Final prototype testing Complete Portable Wheelchair Ramp Packet Present prototypes to the class

Suggested seven-day project schedule for this activity.

Before the Activity

- Gather and prepare supplies for the student groups.
- Make copies of the Portable Wheelchair Ramp Packet.
- As pre-activity homework, have students sketch and measure the entrances to their homes with as many details as possible, as described in the Assessment section.

With the Students

1. As a class, discuss the idea of a physical disability and assistive devices.

- Have students share some of their home (or school) entrance measurements and details. How would someone with a cane, a walker or a wheelchair navigate each entry (steps, doorways, landings, railings, etc.)?
- Ask: How would you feel if a good friend could no longer visit your home because of the physical layout of its entrance?
- Ask: What if technology could enable your friend to continue to visit your home, and other friends' homes, too?

2. Introduce students to the portable wheelchair ramp challenge project.

- Have students describe examples of good friends who visit their homes regularly and the activities that they do when they visit. Have students next imagine that this friend has been injured and no longer can use his/her legs. This friend is the end-user for the design project.
- Hand out the packets to students.
- Read aloud the project introduction and client statement from packet.

3. Divide the class into groups of three students each.
4. Direct groups to follow the steps of the engineering design process to design and build a small-scale prototype of a portable ramp that can make buildings temporarily handicap accessible. Have them complete the packet as they go along, and use it as a guide for each step of the process.
5. As students move through the process, have them conference with the teacher at the following points before moving ahead.

- Identify the need (problem statement, function, constraint, objective)

- Research
- Develop possible solutions (minimum of three)
- Select the best solution
- Blueprint and prototype
- Test and evaluate
- Communicate solutions
- Redesign (future recommendations)

6. Have groups begin by completing the definitions for structural engineering, universal design and assistive device on page 1 of the packet. If they are unsure of any definitions, have them use the internet to research those items.
7. **Identify the need:** Have students write problem statements, considering the information provided in the introduction and the client statement in the packet. Have them write paragraphs for each of the following:

- How the wheelchair ramp functions (what it does)
- The objectives for the wheelchair ramp (what it is)
- The constraints (include materials, timeframe, etc.)

8. **Research:** Have students use the internet to research past and present ramp designs, ramp standards and materials, and any other relevant topics. Have them keep records of all relevant information found, as well as website sources.
9. **Develop possible solutions:** Require each group to develop at least three possible designs for their portable wheelchair ramps, documenting them in the packet. Suggest group brainstorming to come up with designs together and/or have students individually draw their own ideas to share with the group.
10. **Select the best solution:** Together as a group, discuss the pros and cons of each design and decide which of the possible three (or more) designs (or a combination of more than one design) is the most promising design solution to meet the objectives and constraints. Remind students to be prepared to explain to the teacher the reasons for their decisions.
11. **Blueprint and prototype:** Have students complete final design drawings that include labeled dimensions and materials. Make the drawings clear enough that another person could readily learn what is needed and how to create the prototypes. Once the final design is complete, use the provided materials to construct the prototype.
12. **Test and evaluate:** Once student groups have finished building their wheelchair ramp prototypes, have them test how the ramps work. Do this by placing a ramp prototype between two desks. Then have students use the load applicator to apply increasing weights to the prototype. Apply increasing amounts of weight to the middle of the ramp until it holds the minimum required weight (based on the problem statement). Have groups write in their packets paragraphs describing the test and results, as well as evaluations of the results that explain whether the designs were effective and provide reasons.
13. **Communicate solutions:** When groups are ready, have students present their prototypes to the class. Include in the presentation descriptions of how they developed the designs, how the tests went, and prototype evaluations. Have the rest of the class ask questions and offer comments.
14. **Redesign (future recommendations):** Have students finish their packets by writing recommendations on ideas for further research, and what they would improve in a redesign.
15. Have students turn in their completed packets for grading.
16. As time permits, lead a class discussion to compare results and conclusions.

Attachments

Portable Wheelchair Ramp Packet (pdf)

Portable Wheelchair Ramp Packet (docx)

Assessment

Pre-Activity Assessment

Real-Life Details: As pre-activity homework, have students sketch the entrances to their homes with as many details as possible. Measure the height of the stairs and doorway openings and the length of the stairs and any landings, and document the dimensions on their drawings. Alternatively, do the same for various entrances to the school.

Class Discussion: Informally evaluate students' prior knowledge about engineering and the engineering design process, assistive technologies and disabilities.

Activity Embedded Assessment

As We Work: During the course of the activity, students work on the Portable Wheelchair Ramp Packet, which serves as formative assessment of their abilities to follow the engineering design process while creating and testing their portable wheelchair ramp prototypes.

Design Drawing and Prototype: Ask students to draw a picture of the ramp that they have chosen to design. The sketch should include dimensions (i.e., length of the ramps). You might want them to include both the real-life dimensions (as if it were to be built at full scale) and the dimensions of the scaled prototype. Examine students' drawings and prototypes to gauge their abilities to demonstrate methods of representing solutions to design problems.

Post-Activity Assessment

Final Documentation: Evaluate students' completed Portable Wheelchair Ramp Packets as summative assessment of their abilities to accurately use the engineering design process to create and test portable wheelchair ramp design prototypes. Evaluate their vocabulary word definitions and answers to other questions to gauge their comprehension of the process and project components. Example answers:

- Problem Statement: The problem our group is working with is that our good friend is confined to a wheelchair and cannot visit our homes, as well as many other places that do not have wheelchair ramps. We aim to solve this problem by creating a portable wheelchair ramp. First we will create a small-scale prototype that should support 25 pounds of weight.
- Function: Our wheelchair ramp should support the weight of our friend and his/her wheelchair, as well as fold up and fit in the trunk of a car. Our small-scale prototype should function as a small-scale version, able to support 25 pounds of weight.
- Objective: Our objective is to design a prototype for a portable wheelchair ramp that can support at least 25 pounds of weight when placed across a space between two desks.
- Constraints: We can use only provided materials and must complete the entire engineering design process for our protytpe in the seven class periods provided.

Final Prototype: Examine students' completed drawings and portable ramp design prototypes to gauge their abilities to demonstrate methods of representing solutions to design problems.

Additional Multimedia Support

Ramps evaluated by wheelchair users; design considerations (YouTube; 5:21 minutes):

http://www.youtube.com/watch?v=w9asMwsjKjM

Portable Wheelchair Ramps (YouTube; 7:55 minutes): http://www.youtube.com/watch?v=BNm2zFZreil

Roll a Ramp System for Wheel Chairs, Scooters & Power Chairs (YouTube; 6:17 minutes): http://www.youtube.com/watch?v=ojzq0SpdsyA

For more videos, search YouTube for "portable ramp" or "rolling portable ramp."

References

ADA Wheelchair Ramp Specs. 2012. Mobility-Advisor.com. Accessed November 28, 2012. http://www.mobility-advisor.com/wheelchair-ramp-specs.html

Kaye, H. Stephen, Kang, Taewoon, and LaPlante, Mitchell. Wheelchair Use in the United States, Disability Statistics Center, Abstract 23. May 2002. University of California-San Francisco. Accessed November 28, 2012. http://dsc.ucsf.edu/publication.php

Reinhart, Kevin A. *The History of Assistive Technology.* 2010. eHow-Health, Demand Media Inc. Accessed March 29, 2011. http://www.ehow.com/about_6802248_history-assistive-technology.html

Storr, Tim, et al. Design Features of Portable Wheelchair Ramps and their Implications for Curb and Vehicle Access. May/June 2004. *Journal of Rehabilitation Research & Development*. Volume 41, No. 3B, pp. 443-452. Accessed November 28, 2012. (Evaluation of 12 different portable ramps and their different product features; includes photos) http://www.rehab.research.va.gov/jour/04/41/3b/storr.html

Contributors

Jared R. Quinn, Kristen Billiar, Terri Camesano

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Supporting Program

Inquiry-Based Bioengineering Research and Design Experiences for Middle-School Teachers RET Program, Department of Biomedical Engineering, Worcester Polytechnic Institute

Acknowledgements

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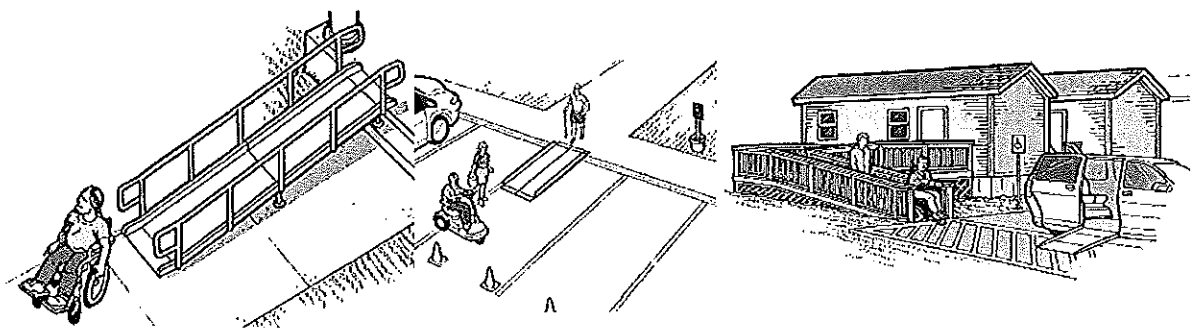
Last modified: November 12, 2014

Name: ______________________________ Date: ____________ Class: ____________

Portable Wheelchair Ramp Packet



http://www.ada.gov/votingchecklist.htm; http://www.ada.gov/emergencyprepguide.htm

Define the following terms

Structural engineering: ____

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Universal design: ____

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Assistive device: ____

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Introduction

Your best friend has recently lost the ability to use his/her legs and now relies on a wheelchair for mobility. Her/his parents have added ramps to their house to make access easier, but it is very difficult for your friend to visit your home and the homes of other friends where ramps are not permanently installed.

Client Statement

Create a portable ramp that can make typical houses and other buildings temporarily handicap accessible. The ramp should be light, easy to transport, easy to operate, safe and versatile.

Problem Statement (Define the problem in detail)

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Revised Problem Statement (Definition of the problem in detail including client modifications)

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Functions (what the product <u>does</u>)

Objectives (What the product <u>is</u>)

Constraints (The product <u>must</u> or <u>must not</u>)

Background Research

As homework, use the internet to research current wheelchair ramp designs, wheelchair ramp standards, ramp materials, and other related topics. Record relevant material and the source websites.

Design Solutions (Sketch and describe 3 possible solutions)

Design #1

Design #2

Design #3

Prototype Creation (describe why you chose the design you did)

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Test Design

1. Place the ramp prototype between two desks.
2. Use the load applicator to apply increasing weights to your ramp.
3. Apply weight to the middle of the ramp until the device holds the minimum required weight based on the problem statement.

Test Results

(Description of test results) ____

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Evaluation of Results (Was your design effective? How do you know?)

Future Recommendations (What you would recommend for future research)

Hands-on Activity: Automatic Floor Cleaner Computer Program Challenge

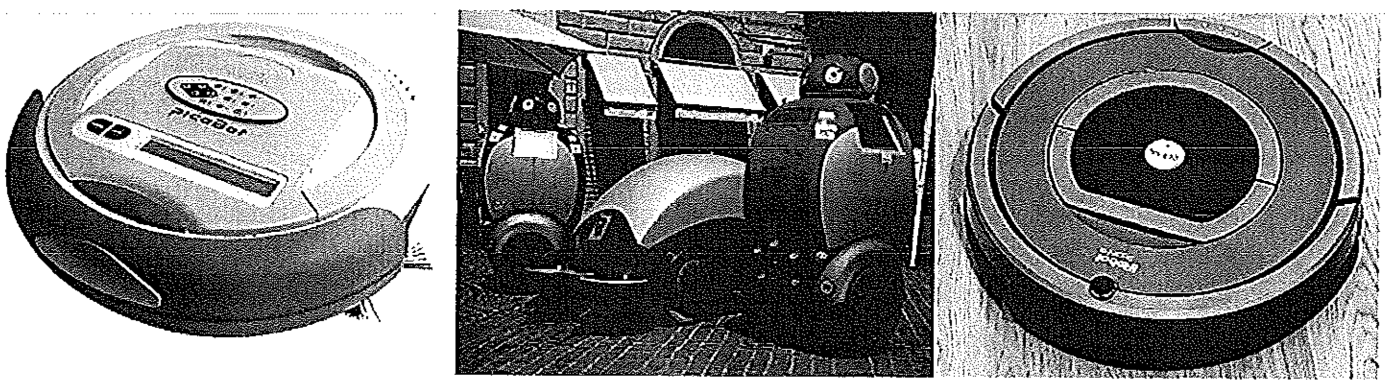
Contributed by: Inquiry-Based Bioengineering Research and Design Experiences for Middle-School Teachers RET Program, Department of Biomedical Engineering, Worcester Polytechnic Institute

Quick Look

Grade Level:	7 (6-8)
Time Required:	385 minutes (7 x 55-minute class periods)
Expendable Cost/Grp ❶:	US$ 0 This activity requires use of non-expendable (re-usable) LEGO MINDSTORMS® NXT robot kits and software; see the Materials List for details.
Group Size:	3
Activity Dependency ❶:	None

Related Curriculum ❶

Subject Areas:	Science and Technology
Curricular Units:	Engineering and Empathy: Teaching the Engineering Design Process through Assistive Devices



Through engineering design, automated robots, such as these vacuum robots, assist people in the routine chore of cleaning a home, something that can be too challenging for people with disabilities or many elderly people.
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Summary

Students learn more about assistive devices, specifically biomedical engineering applied to computer engineering concepts, with an engineering challenge to create an automatic floor cleaner computer program. Following the steps of the design process, they design computer programs and test them by programming a simulated robot vacuum cleaner (a LEGO® robot) to move in designated patterns. Successful programs meet all the design requirements.

Engineering Connection

The engineering design process is a widely accepted way of arriving at a desirable solution to an identified problem. This activity guides students through the engineering design process as they apply basic engineering concepts to real-world design problems. Through the development of assistive devices, students see the helpful and humanitarian nature of engineering. Assistive devices, such as smart prosthetics, are designed by engineering teams applying their understanding of robotics, electrical engineering, and biomedical engineering, to help improve peoples' lives.

Educational Standards

- International Technology and Engineering Educators Association: Technology ▸
- Massachusetts: Science ▸
- Next Generation Science Standards: Science ▸

Pre-Req Knowledge

Familiarity with the engineering design process and recognition that the process works in a cyclical fashion rather than a linear process with a beginning and an end. It is helpful if the teacher is familiar with the LEGO MINDSTORMS NXT robot and performs the activity prior conducting it with students.

Learning Objectives

After this activity, students should be able to:

- Identify and describe the steps of the engineering design process.
- Describe how to use the engineering design process to develop solutions to problems.
- Explain the reasons for their selected designs.
- Design a program so that a LEGO robot moves according to certain requirements.

Materials List

Each group needs:

- LEGO MINDSTORMS NXT robot and software, such as the LEGO MINDSTORMS Education NXT Base Set and Software Pack (5003404) available for $376 at https://shop.education.lego.com/legoed/education/NXT/NXT+Base+Set+and+Software+Pk/5003404&isSimpleSearch=false
- computer, loaded with NXT 2.1 software
- Automatic Floor Cleaner Computer Program Packet, one per student
- piece of drawing paper, for engineer illustration, one per student

To share with the entire class (for robot challenge):

- masking tape for floor markings (one set per five groups): 2 ft (61 cm) straight line, 2 ft x 2 ft (61cm x 61 cm) square, and an irregular line (made with straight lines and 90° angles); see Figure 1 for a visual

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Introduction/Motivation

Engineering teams working with robotics have developed many beneficial assistive devices, such as those that help people walk, rehabilitate motor skills and control technology devices.
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So far in this unit, we have developed prototypes for an off-road wheelchair and a portable wheelchair ramp, following the steps of the engineering design process. Both devices help improve the lives of disabled people. These challenges are both related to helping people get around to different places, which is important, but many more challenges exist for people with disabilities, even within their own homes!

Even if you do not have a disability—think of what a chore it can be to clean a house! So, what might it be like if you had disabilities that restricted your motion? Or for elderly persons lacking sufficient strength and agility? How would you wash windows, clean counters or vacuum carpeting? It would be much more challenging!

In our final activity of this unit, we will use the engineering design process to develop a robotic vacuum cleaner that is able to clean a room on its own. Through engineering, this type of an assistive device is readily available to help people, and we will go through the process of developing it!

Vocabulary/Definitions

assistive device:	A device designed and constructed to assist people in carrying out tasks. Also called assistive technology devices.
bioengineering:	A field of engineering that solves problems related to life sciences by the application of physics, chemistry and mathematics concepts, as well as the engineering design process.
biomedical engineering:	A field of engineering that collaborates with doctors, surgeons and other medical professionals to produce technology to promote the lives of patients.
computer engineering:	A field of engineering based on developing computer systems and applying electrical engineering and computer science concepts, as well as the engineering design process.
constraint:	A limitation or restriction. For engineers, constraints are the limitations that must be considered when designing a workable solution to a problem.

engineering design process: The iterative process through which engineers develop solutions to meet an objective. The steps of the process include: identifying a problem, brainstorming, designing, constructing, testing, analysis and evaluation, redesigning, retesting, and sharing a solution. Science, mathematics and engineering science concepts are applied throughout the process to optimize the solution.

functions: The capabilities or tasks that an engineering solution is able to perform.

objectives: Desired outcomes for an engineering design or product.

problem statement: A sentence or two that describes the identified problem or challenge an engineer or engineering team is working to solve.

robot: A machine or mechanical device that performs tasks on command with human-like skill.

robotics: The science, engineering and/or technology of designing, building and using computer-controlled robots to perform tasks.

Procedure

Background

Tools for helping people with physical challenges have been around for as long as society has recognized people who need help. When renowned anthropologist Margaret Mead was asked about which discovery signifies the development of civilization, she did not refer to arrowheads or tools. For her, what illustrated the development of civilization was the discovery of a human femur bone that had been broken and then healed. This was powerful discovery because, based on the laws of nature, an animal with a broken femur bone is sure to die. The fact that the broken bone healed, shows that other humans took care of the injured person, which showed compassion. This same compassion for other people led humans to create the first eyeglasses, the ear trumpet, and the wheelchair. Through the use of cutting-edge technology, engineers have been able to make the daily lives of people with disabilities less dependent on others.

Remember how Rosie the robot from the *Meet the Jetsons* cartoon enabled the family to go about their business while the housework was completed by a robot. Today, companies such as *IRobot* have brought this idea to many homes across the country. The *Roomba* vacuum cleaner is a small robot vacuum cleaner that continuously cleans the floors and automatically returns to a charging base when the battery runs low. The simple chore of keeping the floors clean, proven to be difficult for the elderly is now effortlessly accomplished by a robot. With this assistance, many elderly people are able to stay in their homes. Companies such as *Lawnbott* have expended this idea to include robotic lawnmowers. The application of robotics to solving bioengineering problems makes sense. As technology evolves, its costs reduce, making it more attainable for the average person to have assistive devices that help them live their lives as they define them, rather than the way they might be defined by physically limiting disabilities.

Day	Activity
1	Introduce the project Students define the problem
2	Student teams... - brainstorm solutions - discuss pros and cons for each solution - choose best solutions
3	Write programming descriptions for selected designs
4-6	Program, test, redesign prototype robotic floor cleaner
7	Final prototype testing Complete Automatic Floor Cleaner Computer Program Packet Present prototypes to the class

Suggested seven-day project schedule for this activity.

Before the Activity

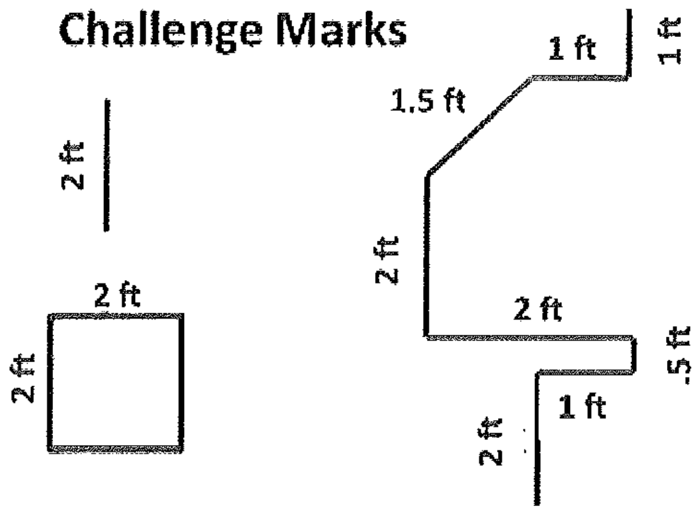

Figure 1. Use masking tape to create challenge marks on the floor.

- Gather supplies and make copies of the Automatic Floor Cleaner Computer Program Packet.
- Use masking tape to create challenge marks on the classroom floor, as shown in Figure 1.

With the Students

1. As a class, discuss the idea of a physical disability and assistive devices for the elderly.

- Have students discuss ways that robots can help people with disabilities or physical limitations.
- Ask: How would you feel if your grandparent had to leave his/her home because s/he could not vacuum the floor anymore.
- Ask: What if technology could help your grandparent to remain in his/her own home?

2. Divide the class into groups of three students each.
3. Introduce students to the LEGO MINDSTORMS NXT kit.

- Have students construct the "basic car" using the instructions booklet in the kit.
- Show students the basic method of programming the NXT module using the LEGO MINDSTORMS Education NXT software.

4. Hand out the packet to students. Introduce them to the challenge by having a few students read aloud the project introduction and client statement from the packet:

Introduction: Imagine that you work on a team for a robotics and computer engineering company. Your job is to create the computer program to control the movements of their new assistive floor cleaner. You will use the LEGO "basic car" robot to test and demonstrate your program.

Client statement: Many people develop vision problems as they age. With diminished eyesight a number of problems arise, such as the cleanliness of the home. We have developed a small, self-contained floor cleaner. Our goal is to have the "robot cleaner" be able to move around the room in a random pattern while using sensors to avoid running into furniture, pets and other obstacles in the room. This random pattern enables the robot to clean the entire floor if given enough time.

5. Provide additional clarification of the objectives: To do this, you will use the LEGO software to design programs that move the LEGO "basic car" robot in the following patterns across the floor:

- Move in a straight line for 2 feet.
- Move in a straight line for 2 feet, turn around and return.
- Travel the 2 foot by 2 foot square marked on the floor.
- Follow the irregular line on the floor that is composed of straight lines as well as 45° and 90° angles (see Figure 1 example).
- Travel in a smooth circle or a "figure 8" shape (+10 bonus points)

6. Direct groups to follow the steps of the engineering design process to complete the project. Have them complete the packet as they go along, and use it as a guide for each step of the process.
7. As students move through the process, have them conference with the teacher at the following points before moving ahead. Each of the steps below are explained in further detail in later steps.

- Identify the need (problem statement, function, constraint, objective)
- Research
- Develop possible solutions (minimum of three)
- Select the best solution
- Blueprint and prototype
- Test and evaluate
- Communicate solutions
- Redesign (future recommendations)

8. Have groups begin by completing the definitions for robot, robotics and computer engineering on page 1 of the packet. If they are unsure of any definitions, use the internet to research those items.
9. **Identify the need:** Have students write problem statements, considering the information provided in the introduction and the client statement in the packet. Have them also write paragraphs for each of the following:

- How the robot should function (what it does)
- The objectives for the robot (what it is)
- The constraints (include materials, timeframe, etc.)

10. **Research:** Have students use the internet to research robotics, computer programs, existing robotic assistive devices, computer programs that control robot movement, robotic automation and other related topics. Remind them to keep records of all relevant information found, as well as website sources.
11. **Develop possible solutions:** Require each group to develop at least three possible designs for programming the LEGO robot, documenting them in the packet. Suggest that groups brainstorm, work together and consider all different possibilities. In this case, groups may develop more than three possible designs for their programs.
12. **Select the best solution:** Together as a group, discuss the pros and cons of each program design for each of the five robot challenges. Decide which is the most promising design solution to meet the objectives and constraints. Choose one of each as the best for testing.
13. **Blueprint and prototype:** Have students write up detailed descriptions of how to program the robot for each challenge in the Creation of Prototype section of the packet. Make the description (written design) clear enough that another person could read it and know exactly what to do to program the robot. Once programmed, refer to the robot as the "prototype."
14. **Test and evaluate:** Have groups program and test their robots for each challenge. Remind them to describe how they are testing in the Test Design section of the packet. Ideally, the robot is able to

successfully follow the challenge marks on the floor, but have students keep track of how often during the tests the robot bumps into objects, becomes stuck or detours from the marked path. Document the results of each test and evaluations of the results in the packets. Have groups write in their packets paragraphs describing the test and results, as well as evaluations of the results that explain whether the designs were effective and provide reasons.

15. **Communicate solutions:** When group are ready, have students present their prototypes to the class. Include in the presentations descriptions of how they developed the designs, how the tests went, and prototype evaluations. Have the rest of the class ask questions and offer comments.
16. **Redesign (future recommendations):** Have students finish their packets by writing recommendations on ideas for further research, and what they would improve in a redesign.
17. Have students turn in their completed packets for grading.
18. As time permits, lead a class discussion to compare results and conclusions. Which team had the most successful product?
19. As time permits, show students the 10-minute PBS Frontline episode titled, *Vietnam: Wheels of Change* (10 minutes). See online location in the Additional Multimedia Support section.
20. Conclude by handing out drawing paper to students and giving them five minutes to each make a sketch of an engineer. Share the finished drawings with the class.

Attachments

Automatic Floor Cleaner Computer Program Packet (pdf)

Automatic Floor Cleaner Computer Program Packet (docx)

Assessment

Pre-Activity Assessment

Class Discussion: Informally evaluate students' prior knowledge about engineering and the engineering design process, assistive technologies and disabilities.

Activity Embedded Assessment

As We Work: During the course of the activity, students work on the Automatic Floor Cleaner Program Packet, which serves as formative assessment of their abilities to follow the steps of the engineering design process while creating their robot cleaners.

Post-Activity Assessment

Final Product: Examine students' completed Automatic Floor Cleaner Program Packets as summative assessment of their abilities to accurately use the engineering design process to create their robot cleaners. Evaluate their vocabulary word definitions and answers to other questions to gauge their comprehension of the process and project components. Example answers:

- Problem Statement: Our grandparents are having difficulty remaining their own homes. All the members of our group would like to see our grandparents remain in their own homes instead of moving into nursing homes or assisted living facilities. One challenge they struggle with is cleaning their homes. We would like to help our grandparents by creating a robot that can vacuum their floors.
- Function: Our robot cleaner should move around a room in a random pattern, avoiding obstacles using a sensor. The robot cleaner should also be capable of vacuuming the floor. We will construct a prototype robot and a program for the robot so that it moves as we desire, although this prototype will not actually vacuum the floor.

- Objective: Our robot cleaner should successfully follow the challenge marks along the floor based on a program that we design and apply to the robot.
- Constraints: Our constraints include using only the provided materials and completing the challenge in the seven class periods provided.

Pre/Post Unit Engineer Sketch: To conclude the unit, give students five minutes to each make a sketch of an engineer. Compare to the sketches made at the beginning of the unit (in the first activity).

Additional Multimedia Support

Show students the PBS Frontline episode titled, *Vietnam: Wheels of Change* (10 minutes), available at http://www.pbs.org/frontlineworld/stories/vietnam804/video/video_index.html

References

Kaye, H. Stephen, Kang, Taewoon, and LaPlante, Mitchell. Wheelchair Use in the United States, Disability Statistics Center, Abstract 23. May 2002. University of California-San Francisco. Accessed November 28, 2012. http://dsc.ucsf.edu/publication.php

Reinhart, Kevin A. *The History of Assistive Technology*. 2010. eHow-Health, Demand Media Inc. Accessed March 29, 2011. http://www.ehow.com/about_6802248_history-assistive-technology.html

Rosmanitz, Klaus. Braille – A Language for Blind People. English Online. Accessed July 21, 2010. http://www.english-online.at/society/braille/braille-language-for-blind-people.htm

Sachikonye, Thembe. "Local Drummer: The Lessons of the Healed Femur." Published online July 29, 2011. Africa Heritage Society. Accessed November 29, 2012. http://www.africaheritage.com/news.php?id=488

What is Assistive Technology? The National Center on Accessible Information Technology in Education. University of Washington. Accessed July 22, 2010. http://www.washington.edu/accessit/articles?109

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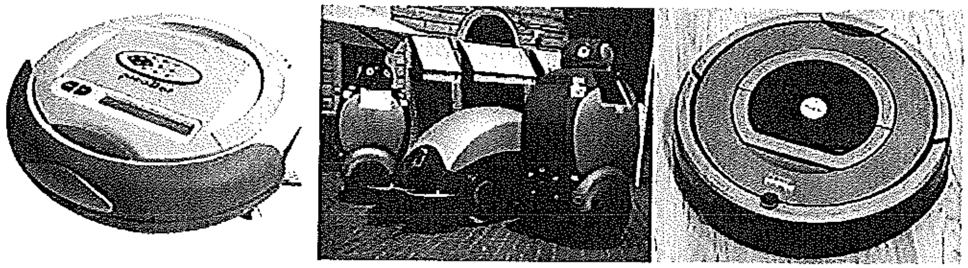
Last modified: November 12, 2014

Name: ______________________________ Date: ____________ Class: __________

Automatic Floor Cleaner Computer Program Packet



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Define the following terms

Robot: ______________________________

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Robotics: ______________________________

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Computer engineering: ______________________________

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Construction

Use the NXT directions to build the "basic car" robot.

Programming

Use the LEGO software to create a program for each of the following tasks. Make sure each program has a clear title including your initials, such as: JQ SQUARE, JQ LINE, JQ CIRCLE.

1. Drive in a straight line for 2 feet.
2. Drive in a straight line for two feet, turn around and return.
3. Trace the square marked on the floor.
4. Follow the irregular line on the floor.
5. Drive in a smooth circle. (+10 bonus)

Introduction

You work as an engineering consultant for a major robotics and computer engineering company. Your newest job is to create the computer program to control the movements of their new assistive floor cleaner. Use the LEGO MINDSTORMS NXT "basic car" robot to test and demonstrate your program.

Client Statement

Many people develop vision problems as they age. With diminished eyesight, a number of problems can arise, such as keeping one's home clean. We have developed a small, self-contained floor cleaner. Our goal is to have the "robot cleaner" be able to move around the room in a random pattern, while using sensors to avoid running into furniture, pets and other obstacles in the room. This random pattern enables the robot to clean the entire floor if given enough time.

Problem Statement (Define the problem in detail)

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Revised Problem Statement (Definition of the problem in detail including client modifications)

Functions (what the product does)

Objectives (What the product is)

Constraints (The product <u>must</u> or <u>must not</u>)

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Background Research

As homework, use the internet to research robotics, computer programs, existing products that carry out similar functions, computer programs that control robot movements, robotic automation, and other related topics. Keep a record of relevant material and the source websites.

Design Solutions (describe/sketch 3 possible design solutions)

Design #1

Design #2

Autor

Design #3

Automal

Prototype Creation (Describe each part of the program in detail)

Test Design (How you will test your program design)

Test Results (describe the test results in detail)

***Evaluation* of Results** (Based on the results; what worked, what did not work)

Future Recommendations (What you would recommend for future designs)