Session 3

Materials for Design

Engineering Fundamentals

In This Session:

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

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

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

Home Improvement
- Student Handout

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

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

Supplies

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

For Demonstration

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

For Each Small Group

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

Session 3, Materials for Design (continued)

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

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

Materials for Design

Key Concepts: Session 3

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

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

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

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

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

Materials Properties
The definitions for eight material properties are below.

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

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

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

Key Concepts Session 3 (continued)

Material Recycling

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

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

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

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

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

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

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

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

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

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

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

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

Session 3, Activity A

Properties of Materials

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

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

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

Supplies
For Demonstration

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

For Each Small Group

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

3A: Properties of Materials (continued)

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

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

Preparation

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

2. Conduct the properties tests yourself.

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

Procedures
Debrief Home Improvement

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

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

Materials Around Us

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

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

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

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

3A: Properties of Materials (continued)

Why Do Materials Matter?

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

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

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

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

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

Testing Material Properties

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

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

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

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

Density Test
Question: Which materials are denser?

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

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

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

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

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

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

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

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

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

3A: Properties of Materials (continued)

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

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

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

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

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

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

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

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

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

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

3A: Properties of Materials (continued)

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

Strength test

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

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

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

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

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

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

3A: Properties of Materials (continued)

Electrical conductivity test

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

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

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

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

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

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

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

3A: Properties of Materials (continued)

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

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

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

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

2. Rate materials: transparent, translucent, opaque.

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

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

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

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

Properties of Materials

Handout: Session 3, Activity A

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

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

Material Properties Definitions

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

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

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

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

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

3A Handout: Properties of Materials (continued)

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

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

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

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

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

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

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

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

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

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

3A Handout: Properties of Materials (continued)

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

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

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

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

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

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

3A Handout: Properties of Materials (continued)

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

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

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

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

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

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

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

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

3A Handout: Properties of Materials (continued)

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

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

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

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

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

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

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

What Are Things Made Of?

Reading: Session 3, Activity A

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

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

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

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

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

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

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

3A Reading: What Are Things Made Of? (continued)

a well-known application of a polymer.

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

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

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

Session 3, Activity B

Materials Applications

Goal
Evaluate properties of materials for specific applications.

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

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

Supplies
None

Preparation
None

Procedures
Using Materials

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

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

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

4. Have groups present their solutions.

3B: Materials Applications (continued)

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

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

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

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

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

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

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

Materials Applications

Handout: Session 3, Activity B

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

For each problem, determine the following:

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

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

Problems

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

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Meet a Materials Engineer

Reading: Session 3, Activity B

Stephanie Kwolek: Developing a Miracle Fiber

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

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

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

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

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

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

3B Reading: Meet a Materials Engineer (continued)

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

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

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

References

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

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

Session 3, Activity C
Materials Choice

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

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

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

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

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

Procedures
Materials and Cost

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

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

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

3C: Materials Choice (continued)

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

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

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

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

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

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

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

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

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

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

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

3C: Materials Choice (continued)

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

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

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

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

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

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

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

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

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

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

3C: Materials Choice (continued)

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

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

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

Make a Case

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

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

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

Container Design: Extending the Life

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

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

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

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

3C: Materials Choice (continued)

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

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

4. Have groups sketch their ideas.

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

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

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

Materials Choice

Handout: Session 3, Activity C

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

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

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

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

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

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

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

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

3C Handout: Materials Choice (continued)

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

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

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

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

Extending the Life of the Container

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

Meet an Environmental Engineer

Reading: Session 3, Activity C

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

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

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

Laying the Foundation

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

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

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

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

3C Reading: Meet an Environmental Engineer (continued)

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

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

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

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

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

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

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

Materials Scavenger Hunt

Session 3 Home Improvement

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

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

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

Procedures

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

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

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

Materials Scavenger Hunt

Handout: Session 3, Home Improvement

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

What is it?

What does it do?

What properties does it require?

How and why do the materials matter?