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## Lesson Focus

Lesson focuses on how structural engineers have improved the designs of building -- specifically roofing -- over the years to improve the quality of homes and life. Teams of students work together using simple materials to design a roof that will keep the contents of a box dry during a water test. Students determine both the shape of the roof and materials used for construction, test their designs, and present their findings to the class.

## Lesson Synopsis

The "Waterproof that Roof" activity explores how engineers have improved roofing designs and materials in order to protect the contents of buildings. Students explore the hydrophobic effect, and learn about nanotechnology. Then, they work in teams to design a roof structure both in terms of shape and materials to protect a box and its contents from a simulated rainstorm. Teams build, test, and evaluate their designs and those of other student teams.



## Age Levels

8-18.

## Objectives

- ◆ Learn about structural engineering.
- ◆ Learn about materials engineering.
- ◆ Learn how engineering can help solve society's challenges.
- ◆ Learn about teamwork and problem solving.

## Anticipated Learner Outcomes

As a result of this activity, students should develop an understanding of:

- ◆ structural engineering
- ◆ water protection strategies
- ◆ engineering design
- ◆ teamwork

## Lesson Activities

Students learn about structural and materials engineering and work in teams to design, build, and test a roofing system that will keep the contents of a box dry during a classroom "rainstorm."

### Waterproof that Roof!

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## **Resources/Materials**

- ◆ Teacher Resource Documents (attached)
- ◆ Student Resource Sheet (attached)
- ◆ Student Worksheet (attached)

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## **Alignment to Curriculum Frameworks**

See curriculum alignment sheet at end of lesson.

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## **Internet Connections**

- ◆ TryEngineering ([www.tryengineering.org](http://www.tryengineering.org))
- ◆ TryNano ([www.trynano.org](http://www.trynano.org))
- ◆ Thatching ([www.britainexpress.com/History/thatching.htm](http://www.britainexpress.com/History/thatching.htm))

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## **Recommended Reading**

- ◆ Nanotechnology For Dummies (ISBN: 978-0470891919)
- ◆ Nanotechnology: Understanding Small Systems (ISBN: 978-1138072688)
- ◆ Smart Guide: Roofing: Step by Step (ISBN: 978-1580114806)
- ◆ Materials for Architects and Builders (ISBN: 978-0815363385)
- ◆ Knack Treehouses: A Step-by-Step Guide to Designing & Building a Safe & Sound Structure (ISBN: 978-1599217833)

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## **Optional Writing Activity**

- ◆ Write an essay or a paragraph about how technology has improved the reliability and durability of roofs in the past ten years. Or, write an essay about green roofing techniques and their impact on the environment.

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**For Teachers:**  
**Teacher Resource****◆ Lesson Goal**

The "Waterproof that Roof" activity explores how engineers have improved roofing designs and materials in order to protect the contents of buildings. Students explore the hydrophobic effect, and learn about nanotechnology. They work in teams to design a roof structure both in terms of shape and materials to protect a box and its contents from a simulated rainstorm. Teams build, test, and evaluate their designs.

**◆ Lesson Objectives**

- ◆ Learn about structural engineering.
- ◆ Learn how engineering can help solve society's challenges.
- ◆ Learn about teamwork and problem solving.

**◆ Materials**

- ◆ Student Resource Sheets
- ◆ Student Worksheets
- ◆ Large bin or sink for testing roofs, or access to outdoor area for testing; water (1 liter per team), measuring cup (for "rain" water, and measuring any water that goes through the roof into the smaller container "house")
- ◆ Building materials for each team: plastic storage container or planter insert (at least 10 x 25 cm), measuring cup, materials readily available to your classroom for roof, such as leaves, grass, cotton balls, paper towels, string, paper clips, cardboard, tape, newspaper, wooden dowels, branches, shells, nuts, pipe cleaners, non-water proof fabric, wax, oil. You may also provide foil or plastic pieces, but each piece used must not be larger than 4 square centimeters.

**◆ Procedure**

1. Show students the student reference sheets. These may be read in class or provided as reading material for the prior night's homework.
2. To introduce the lesson, ask students to consider the different shapes and materials used in the roofs they see in your community. Discuss how roof shapes need to change to suit different climates, for example, a flat roof is not a good choice for an area that received a great deal of snow as the weight of snow is more likely to collapse the roof structure.
3. Divide your class into teams of 2-3 "engineers." Explain that they need to develop a roofing system for the plastic container (house) that can prevent water from entering the container when 1 liter of water is poured onto it.
4. Teams consider their challenge, develop a drawn plan for both the shape and materials to be used, then present their designs to the class. They may adjust their designs after receiving class feedback.
5. Teams next build their roof structures.
6. Testing is done by the teacher who will pour 1 liter of water over the roof. Testing can be completed with minimal mess by placing each team "house" in a sink or a larger bin, or executed outside.
7. Teams complete a reflection sheet, and share their experiences with the class.

**◆ Time Needed**

Two to three 45 minute sessions.

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## Student Resource: Roofing Materials

The primary job of a roof is to keep water out of a structure. These structures can range from something as simple as a bird house or mailbox to a sports stadium. Of course, roofs also protect against wind, cold, and heat, and also keep unwanted animals and pests out. The pitch (or angle) of a roof is usually proportional to the amount of precipitation the building anticipates. Houses where there is low rainfall may have flatter roofs than areas where large rain or snowfall levels are anticipated. In these areas, steeply pitched roofs with efficient gutter systems are prevalent.

### ◆ History

With the involvement of engineers, much of the innovations and changes in roofing have taken place in the last 200 years, but of course roofs have been important to society for much longer. The Greeks and Romans were believed to be the first to experiment with different roofing styles. The Romans introduced slating and tiling as early as 100 BC. Thatched roofs made of woven grasses were introduced around 735 AD, and have been used extensively in many parts of the world. Thatch is roofing made of plant stalks in overlapping layers. In most of Europe and the United Kingdom, thatch was the preferred roofing material in the countryside -- and also in some villages -- until the late 1800s. Wooden shingles and clay tiles became more popular and spread to mass-production of roofing materials. Concrete tiles are a more recent development. Now, a variety of engineered materials are used to improve water resistance and also increase the lifespan of a roof. Thatched roofs, for example, may require frequent maintenance, while some more recent materials can last up to thirty years without maintenance. But performance isn't the only attribute valued in a roof. Thatch roofs once looked in danger of dying out, and considered a symbol of poverty, but a thatching revival is under way as people look to these designs for their charm in spite of high maintenance.



### ◆ Roofing Materials

The materials used in a roof may be determined by a variety of factors including local laws, material availability, climate, cost, and frequency of required maintenance. Materials can be just about anything, from wheat straw, sea grass, banana leaves, laminated glass, aluminum sheeting, slate, ceramic tile, cedar panels, plastic or rubber sheets, asphalt and asbestos shingles, galvanized steel, and fiberglass sheets, to precast concrete. Newly engineered materials, and advances in solar panels and sun roofs have also had an impact on what roofs look like and how they perform over time.

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## For Students: What is Nanotechnology?

Imagine being able to observe the motion of a red blood cell as it moves through your vein. What would it be like to observe the sodium and chlorine atoms as they get close enough to actually transfer electrons and form a salt crystal or observe the vibration of molecules as the temperature rises in a pan of water? Because of tools or 'scopes' that have been developed and improved over the last few decades we can observe situations like many of the examples at the start of this paragraph. This ability to observe, measure and even manipulate materials at the molecular or atomic scale is called nanotechnology or nanoscience. If we have a nano "something" we have one billionth of that something. Scientists and engineers apply the nano prefix to many "somethings" including meters (length), seconds (time), liters (volume) and grams (mass) to represent what is understandably a very small quantity. Most often nano is applied to the length scale and we measure and talk about nanometers (nm). Individual atoms are smaller than 1 nm in diameter, with it taking about 10 hydrogen atoms in a row to create a line 1 nm in length. Other atoms are larger than hydrogen but still have diameters less than a nanometer. A typical virus is about 100 nm in diameter and a bacterium is about 1000 nm head to tail. The tools that have allowed us to observe the previously invisible world of the nanoscale are the Atomic Force Microscope and the Scanning Electron Microscope.

### ◆ How Big is Small?

It can be hard to visualize how small things are at the nanoscale. The following exercise can help you visualize how big small can be! Consider a bowling ball, a billiard ball, a tennis ball, a golf ball, a marble, and a pea. Think about the relative size of these items.

### ◆ Scanning Electron Microscope

The scanning electron microscope is a special type of electron microscope that creates images of a sample surface by scanning it with a high-energy beam of electrons in a raster scan pattern. In a raster scan, an image is cut up into a sequence of (usually horizontal) strips known as "scan lines." The electrons interact with the atoms that make up the sample and produce signals that provide data about the surface's shape, composition, and even whether it can conduct electricity.

Many images taken with scanning electron microscopes maybe viewed at [www.dartmouth.edu/~emlab/gallery](http://www.dartmouth.edu/~emlab/gallery).



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**For Students:**  
**What is The Hydrophobic Effect?**

Hydrophobic comes from the word hydro (water) and phobos (fear). It can be demonstrated by trying to mix oil and water. And, also is evident if you look at some leaves and flower petals that repel water in droplets after a rain storm. For the leaves, the water repellent can sometimes be a waxy coating on the leaves, or can be the existence of tiny hairlike projections off the surface of the leaf which causes a buffer of air between the hairs -- the air keeps the water away.

◆ **Superhydrophobic Surfaces**

Superhydrophobic surfaces such as the leaves of the lotus plant have surfaces that are highly hydrophobic, or very difficult to wet. The contact angles of a water droplet exceeds  $150^\circ$  and the roll-off angle is less than  $10^\circ$ . This is referred to as the Lotus effect.

◆ **Fabric Applications?**

Scientists and engineers who were aware of the hydrophobic effect decided to apply nanotechnology to the surfaces of fabrics to make them water proof too! The waterproof feature often also helps protect fabrics from staining because liquid cannot easily soak into the fabric fibers. A good example is the work done by a company called Nano-Tex. The company adds nano "whiskers" to cotton fibers in the same way that some leaves have little "hairs" on their surface. Creating the effect for fabric is a little tricky -- a cotton fiber is shaped like a round cylinder, and Nano-Tex adds



tiny nano "whiskers" all around the cylinder so it has a fuzzy surface. The fabric doesn't appear any different or feel any different, but it does repel liquids. And, because liquids do not soak into the fabric, the process also helps the fabric resist staining too. Nano-Tex utilizes nanotechnology to: 1) design molecules with specific performance attributes; 2) engineer the molecules to assemble on the surface of textile fibers with extreme precision, and 3) ensure that they permanently attach to the fibers through patented binding technology. If the molecules were not permanently attached then the fabric might lose its ability to push water away after several machine washings. Over 80 textile mills worldwide are using Nano-Tex treatments in products sold by more than 100 apparel and commercial interior brands. This is just one example of an industry applying nanotechnology to solve problems.

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**Student Worksheet:**

◆ **Engineering Teamwork and Planning**

You are a team of engineers given the challenge of creating a waterproof roof for a small house. You may use any materials provided to you and will have to devise a frame and covering that will prevent water from entering the interior. You can expect a rainstorm containing a liter of water!



◆ **Planning and Design Phase**

Be sure to read the summary sheet about different roofing techniques. Your team has been provided with a set of materials. Review these as a group and draw a structural design in the box below. Please also include a list of materials you think you'll need to build and test your roof.

Materials Required for Building:

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**Student Worksheet:**

◆ **Construction Phase**

Build your roof, and be sure to put your team's name or number on plastic base of your "home" for easy identification during testing. Then, answer the questions below:



1. How similar was your built roof to your written design?

2. If you found you needed to make changes during the construction phase, describe why your team decided to make revisions.

3. Did you find you needed to add additional materials during construction? What did you add, and why?

4. Did you find you had materials left over after construction?

5. What would happen on a real construction job if there were left over materials?

6. Did you test your roof at all during construction? If so, how did your roof work during these pre-tests?

7. Do you think that engineers often change their original plans during the manufacturing or construction process? What do you think this might do to their construction budget?

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**Student Worksheet (continued):**

**◆ Testing Phase**

Your teacher will test each of the roofs in a bin or sink, or outside if space and weather permits. One liter of water will be poured on the roof, and after 10 minutes, the roofs will be removed and your team will measure the amount of any water that leaked into your plastic bin "house."

As you observe other teams' roofs being tested, mark any observations you have about interesting designs, or ideas they came up with in the box below:

**◆ Scoring**

Use the rankings below to score your roof based on the amount of water which leaked into your structure:

Amount of water	No water	3/4 liter of water	1/2 liter of water	3/4 liter of water	1 Liter of water
Score	5	4	3	2	1

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**Student Worksheet (continued):**

◆ **Evaluation**

Complete the evaluation questions below:

1. What aspect of the design of the package that had the best overall score do you think lead to its success?
2. What was the best aspect of your design? Describe one part of your design that you think worked the best.
3. If you had a chance to do this project again, what would your team have done differently?
4. How do you think your roof would have held up to 10 liters of water? How about 100 liters of water?
5. If you could have selected some building materials which were not made available to you, what would you have selected? Why?
6. If your roof design were used on a real building, do you think it would require frequent maintenance? Why?
7. Do you think your roof design might be considered "green?" Why or why not?
8. Do you think this project worked better because you were part of a team, or do you think you could have done a better job working alone?
9. Do you think that engineers work alone, or in a team when they are developing new materials, processes, or products?

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## For Teachers:

### Alignment to Curriculum Frameworks

**Note:** Lesson plans in this series are aligned to one or more of the following sets of standards:

- U.S. Science Education Standards ([http://www.nap.edu/catalog.php?record\\_id=4962](http://www.nap.edu/catalog.php?record_id=4962))
- U.S. Next Generation Science Standards (<http://www.nextgenscience.org/>)
- International Technology Education Association's Standards for Technological Literacy (<http://www.iteea.org/TAA/PDFs/xstnd.pdf>)
- U.S. National Council of Teachers of Mathematics' Principles and Standards for School Mathematics (<http://www.nctm.org/standards/content.aspx?id=16909>)
- U.S. Common Core State Standards for Mathematics (<http://www.corestandards.org/Math>)
- Computer Science Teachers Association K-12 Computer Science Standards (<http://csta.acm.org/Curriculum/sub/K12Standards.html>)

#### ◆ National Science Education Standards Grades K-4 (ages 4-9)

##### **CONTENT STANDARD A: Science as Inquiry**

As a result of activities, all students should develop

- ✦ Abilities necessary to do scientific inquiry
- ✦ Understanding about scientific inquiry

##### **CONTENT STANDARD B: Physical Science**

As a result of the activities, all students should develop an understanding of

- ✦ Properties of objects and materials

##### **CONTENT STANDARD D: Earth and Space Science**

As a result of their activities, all students should develop an understanding of

- ✦ Properties of earth materials

##### **CONTENT STANDARD E: Science and Technology**

As a result of activities, all students should develop

- ✦ Abilities of technological design
- ✦ Understanding about science and technology
- ✦ Abilities to distinguish between natural objects and objects made by humans

##### **CONTENT STANDARD F: Science in Personal and Social Perspectives**

As a result of activities, all students should develop understanding of

- ✦ Science and technology in local challenges

##### **CONTENT STANDARD G: History and Nature of Science**

As a result of activities, all students should develop understanding of

- ✦ Science as a human endeavor

#### ◆ National Science Education Standards Grades 5-8 (ages 10-14)

##### **CONTENT STANDARD A: Science as Inquiry**

As a result of activities, all students should develop

- ✦ Abilities necessary to do scientific inquiry
- ✦ Understandings about scientific inquiry

##### **CONTENT STANDARD B: Physical Science**

As a result of their activities, all students should develop an understanding of

- ✦ Properties and changes of properties in matter

##### **CONTENT STANDARD E: Science and Technology**

As a result of activities in grades 5-8, all students should develop

- ✦ Abilities of technological design
- ✦ Understandings about science and technology

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## For Teachers:

### Alignment to Curriculum Frameworks (cont.)

#### ◆ National Science Education Standards Grades 5-8 (ages 10-14)

##### **CONTENT STANDARD F: Science in Personal and Social Perspectives**

As a result of activities, all students should develop understanding of

- ◆ Populations, resources, and environments
- ◆ Risks and benefits
- ◆ Science and technology in society

#### ◆ National Science Education Standards Grades 9-12 (ages 14-18)

##### **CONTENT STANDARD A: Science as Inquiry**

As a result of activities, all students should develop

- ◆ Abilities necessary to do scientific inquiry
- ◆ Understandings about scientific inquiry

##### **CONTENT STANDARD E: Science and Technology**

As a result of activities, all students should develop

- ◆ Abilities of technological design
- ◆ Understandings about science and technology

##### **CONTENT STANDARD F: Science in Personal and Social Perspectives**

As a result of activities, all students should develop understanding of

- ◆ Personal and community health
- ◆ Science and technology in local, national, and global challenges

##### **CONTENT STANDARD G: History and Nature of Science**

As a result of activities, all students should develop understanding of

- ◆ Science as a human endeavor
- ◆ Nature of scientific knowledge
- ◆ Historical perspectives

#### ◆ Next Generation Science Standards Grades 2-5 (Ages 7-11)

##### **Matter and its Interactions**

Students who demonstrate understanding can:

- ◆ 2-PS1-2. Analyze data obtained from testing different materials to determine which materials have the properties that are best suited for an intended purpose.

##### **Earth and Human Activity**

Students who demonstrate understanding can:

- ◆ 3-ESS3-1. Make a claim about the merit of a design solution that reduces the impacts of a weather-related hazard.

##### **Engineering Design**

Students who demonstrate understanding can:

- ◆ 3-5-ETS1-1. Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.
- ◆ 3-5-ETS1-2. Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.
- ◆ 3-5-ETS1-3. Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.

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## For Teachers:

### Alignment to Curriculum Frameworks (cont.)

#### ◆ Next Generation Science Standards Grades 6-8 (Ages 11-14)

##### Engineering Design

Students who demonstrate understanding can:

- ◆ MS-ETS1-2 Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.
- ◆ MS-ETS1-3. Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.

#### ◆ Standards for Technological Literacy - All Ages

##### The Nature of Technology

- ◆ Standard 1: Students will develop an understanding of the characteristics and scope of technology.
- ◆ Standard 2: Students will develop an understanding of the core concepts of technology.

##### Technology and Society

- ◆ Standard 4: Students will develop an understanding of the cultural, social, economic, and political effects of technology.
- ◆ Standard 5: Students will develop an understanding of the effects of technology on the environment.
- ◆ Standard 6: Students will develop an understanding of the role of society in the development and use of technology.
- ◆ Standard 7: Students will develop an understanding of the influence of technology on history.

##### Design

- ◆ Standard 8: Students will develop an understanding of the attributes of design.
- ◆ Standard 9: Students will develop an understanding of engineering design.
- ◆ Standard 10: Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving.

##### Abilities for a Technological World

- ◆ Standard 11: Students will develop abilities to apply the design process.

##### The Designed World

- ◆ Standard 20: Students will develop an understanding of and be able to select and use construction technologies.

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