



Measuring the Wind



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Lesson Focus

Lesson focuses on how anemometers are engineered to measure the speed of wind, and how designs have changed over time. Student teams design and build a working anemometer out of everyday products and learn about how anemometers are used for feasibility tests on locations considering alternative energy from wind turbines. Student anemometers must be able to sustain the wind generated by a fan or hairdryer at varying speed and students must develop a way to measure and chart rotations at different wind speeds. Students evaluate the effectiveness of their anemometer and those of other teams, and present their findings to the class.

Lesson Synopsis

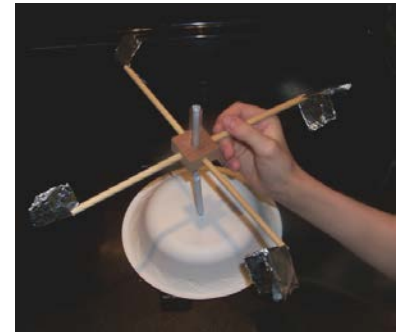
The "Measuring the Wind" activity explores the how anemometers work to record wind speeds and how the equipment has undergone engineering adaptations over time. Students work in teams of "engineers" to design and build their own anemometer out of everyday items. They test their sensors, evaluate their results, and present reflections to the class.

Age Levels

8-18.

Objectives

- ✦ Learn about anemometers.
- ✦ Learn about engineering design.
- ✦ 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:

- ✦ weather sensor equipment
- ✦ interaction of technology and societal issues
- ✦ engineering design
- ✦ teamwork

Lesson Activities

Students explore the impact of how anemometers record the strength of the wind and how this information is used to support society both in terms of weather analysis and also the evaluation of sites for potential wind power projects. Students will work in teams of "engineers" to develop their own anemometer design out of everyday items. They test their sensor, evaluate their own designs and those of other students, and present their findings to the class.

Resources/Materials

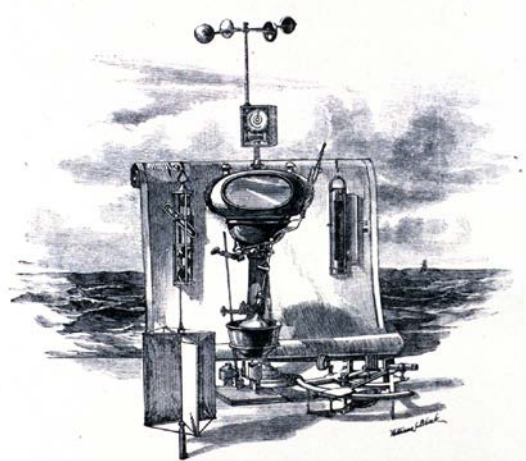
- ✦ Teacher Resource Documents (attached)
- ✦ Student Resource Sheet (attached)
- ✦ Student Worksheet (attached)

Alignment to Curriculum Frameworks

See attached curriculum alignment sheet.

Internet Connections

- ✦ TryEngineering (www.tryengineering.org)
- ✦ National Renewable Energy Laboratory - Wind Research (www.nrel.gov/wind)
- ✦ Institute and Museum of the History of Science, Florence, Italy (<http://brunelleschi.imss.fi.it/museum/esim.asp?c=500005>)
- ✦ Armagh Observatory, Northern Ireland (www.arm.ac.uk/history/instruments/Robinson-cup-anemometer.html)
- ✦ National Science Education Standards (www.nsta.org/publications/nses.aspx)
- ✦ ITEA Standards for Technological Literacy (www.iteaconnect.org/TAA)



ANEMOMETER, THERMOMETER, CURRENT DRAG, SEXTANT, AND CARBONIC ACID APPARATUS.

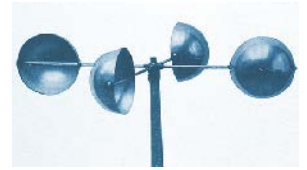
Recommended Reading

- ✦ Wind Energy - The Facts: A Guide to the Technology, Economics and Future of Wind Power by European Wind Energy Association (ISBN: 1844077101)
- ✦ Wind Energy in the Built Environment (ISBN: 0906522358)

Optional Writing Activity

- ✦ Write an essay about why an airport might have several anemometers at different heights to provide information to airport controllers?

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For Teachers: Teacher Resources

◆ Lesson Goal

The "Measuring the Wind" activity explores the how anemometers work to record wind speeds and how the equipment has undergone engineering adaptations over time. Students work in teams of "engineers" to design and build their own anemometer out of everyday items. Student teams test their anemometer, evaluate their results, and present reflections to the class.

◆ Lesson Objectives

- ✦ Learn about anemometers.
- ✦ Learn about engineering design.
- ✦ Learn how engineering can help solve society's challenges.
- ✦ Learn about teamwork and problem solving.

◆ Materials

- ✦ Student Resource Sheets
- ✦ Student Worksheets
- ✦ Hairdryer or fan with multiple speed settings (or if you are in a windy environment, this lesson can be completed outside)
- ✦ One set of materials for each group of students:
 - foil, plastics, paper cups, string, tape, wire, straws, wooden sticks, small wooden spoons, small wooden (balsa) pieces, bendable wire (such as florist or craft wire), paperclips, rubber bands, toothpicks, aluminum foil, glue, paper, cardboard, plastic wrap, or other materials you have available.
 - graph paper for documentation of results.



◆ Procedure

1. Show students the various Student Reference Sheets. These may be read in class, or provided as reading material for the prior night's homework.
2. Divide students into groups of 2-3 students, providing a set of materials per group.
3. Explain that students must develop their own working anemometer from everyday items, and that the team must devise a system for measuring and recording the speed of the wind as indicated by their anemometer.
4. Students meet and develop a plan for their anemometer. They agree on materials they will need, write or draw their plan, and then present their plan to the class.
5. Student teams trade materials with other teams to develop their ideal parts list.
6. Student groups next build their anemometer. They may need to rethink their plan, request other materials, trade with other teams, or start over. They will need to devise a system to count revolutions and chart their results as wind speeds change.
7. Next....teams will test their anemometers with wind (either natural or generated by fan or hairdryer). (Note: you may wish to make the "wind" available during the building phase so they can test their anemometer during the building phase prior to the classroom test.)
8. Teams then complete an evaluation worksheet, and present findings to the class.

◆ Time Needed

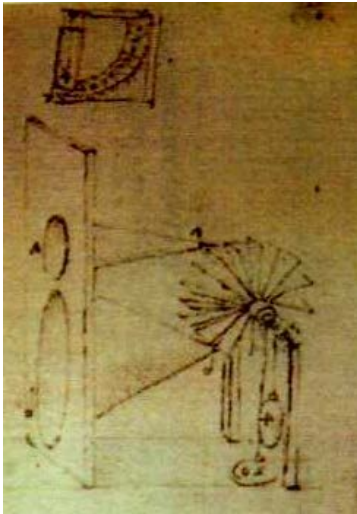
Two to three 45 minute sessions.

◆ Tips

- Students will likely measure the number of revolutions of their anemometer, so you may need to suggest that one of the cups or wind catchers is a different color than the others for easier counting of revolutions.
- The top portion must be able freely move without resistance to spin or turn quickly. Using a straw or pointed object on which the top piece will pivot or spin is essential.
- Students may wish to develop a four cup design, a three cup design, or come up with a new design. Vary this challenge for younger students.

Measuring the Wind

Student Resource: What is an Anemometer?



An anemometer is a device that is used for measuring wind speed, and is one instrument used in a weather station. The term is derived from the Greek word *anemos*, meaning wind. The first anemometer was invented by Leonardo da Vinci. Leonardo actually designed two different types of instruments for measuring wind speed. You can see the drawings for both on the left.

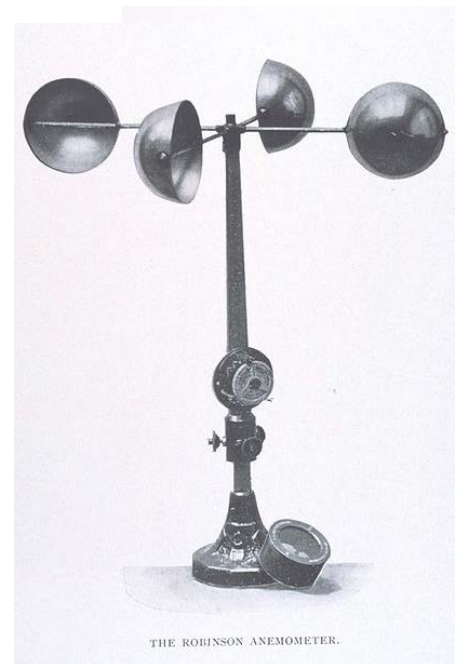
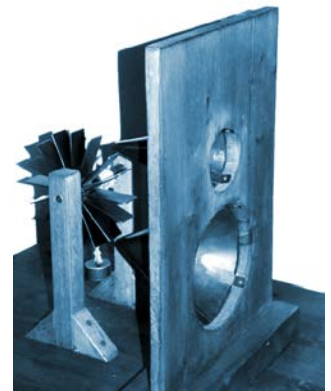
The first one (see right above) is called a "lamellae" or "pennello" anemometer because feathers were once used to gauge wind speed. It was a graduated stick with a thin plate which moved according to the force of the wind.

The other one (right below) is made from cone shaped tubes and was design to check that the wind pressure turning the wheels was proportional to the opening in the cones through which the air passes, given the same wind speed.

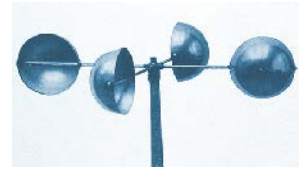
◆ Four Cup Anemometer

A simple type of anemometer is the cup anemometer, invented in 1846 by Dr. John Thomas Romney Robinson. (see right) It included four cups which were mounted on one end of four horizontal arms, which were attached at 90 degree angles to each other on a vertical shaft. Wind blowing horizontally would turn the cups at a speed that was proportional to the wind speed. If you counted the turns of the cups over a specific period of time, you could determine the average wind speed for that location. When Robinson first designed his anemometer, he incorrectly stated that no matter how big the cups were or how long the arms were, the cups always moved at one-third of the speed of the wind. It was later discovered that the actual relationship between the speed of the wind and that of the cups, called the "anemometer factor," actually depended on the dimensions of the cups and arms, and may have a value between two and a little over three.

You can watch a video about anemometers at www.arm.ac.uk/movies/anemometer/anemometer.html.



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Student Resource: What is an Anemometer? (continued)

◆ Three Cup Anemometer

Four cups anemometers were found to experience delays in accuracy when wind speeds changed quickly. So, the three cup anemometer was engineered to improve accuracy and especially in environments where wind might change quickly or unexpectedly. The three cup anemometer was first developed by the Canadian John Patterson in 1926. As is true of many engineered products, they are improved or "re-engineered" over time to enhance performance, reduce costs, or boost safety. In 1935, the three cup anemometer was enhanced by Brevoort & Joiner of the United States. Their work led to a cup-wheel design which was more accurate with an error rate of less than 3% at speeds up to 60 miles per hour (mph). In 1991, the design was changed by the Australian Derek Weston to be able to measure both wind direction and wind speed. Weston added a tag to one cup, which caused the speed to increase and decrease as the tag moved alternately with and against the wind. Three cup anemometers are currently used as the industry standard for wind energy assessment studies.

◆ Using Anemometers to Test Wind Potential

An anemometer is a device that is used for measuring wind speed. Many countries and organizations offer anemometer loan programs, so a company or individual can evaluate the wind at their site to determine if enough wind power would be generated at their location. For these test sites, an anemometer might collect wind-speed data in 10-minute intervals over a long period of time.



◆ Sonic Anemometers

Sonic anemometers (see photo right) were first developed in the 1970s and use ultrasonic sound waves to measure wind speed and direction. They measure wind velocity based on the time of flight of sonic pulses between pairs of transducers. The lack of moving parts makes them appropriate for long term use in exposed automated weather stations and weather buoys where the accuracy and reliability of traditional cup-and-vane anemometers is adversely affected by salty air or large amounts of dust.



◆ Material Selection

The materials selected for designing an anemometer are often based on their intended application. For example, anemometers intended for low wind speed applications, such as air pollution studies, are usually made from lightweight materials. Because of their materials, though, they are not well suited for very windy or icy environments. Materials selection is also important for anticipating the lifespan of the equipment. So, depending on the environment where it will be used, the price someone might be willing to pay, and how long the equipment will be expected to reliably operate, the materials selected for an anemometer design will vary.

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Student Worksheet: Design Your Own Anemometer

You are working as a team of engineers who have been given the challenge to design your own anemometer out of everyday items. You'll be testing your anemometer in several different "wind" speeds generated by a fan or hairdryer in your classroom. You also must devise a system for measuring and recording the speed of the wind as indicated by their anemometer. And, you'll need to chart your wind speeds on a graph, review the designs of other student "engineering" teams, and present your findings to the class.

◆ Planning Stage

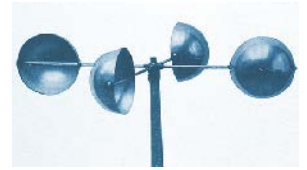
Meet as a team and discuss the problem you need to solve. You'll need to decide if you want to make a four cup or three cup anemometer -- or maybe you'll have a better idea and a new design! Then your team needs to develop and agree on a design for your anemometer. You'll need to determine what materials you want to use -- keep in mind that your design must be strong enough to withstand wind from a fan or



hairdryer and you'll have to be able to generate information about the speed of the wind on a scale you develop -- so there may be some design elements you can engineer into your anemometer to help you keep track of the motion. Draw your design in the box below, and be sure to indicate the description and number of parts you plan to use. Present your design to the class. You may choose to revise your teams' plan after you receive feedback from class.

Materials Needed:

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Student Worksheet (continued):

◆ Construction Phase

Build your anemometer. During construction you may decide you need additional materials or that your design needs to change. This is ok -- just make a new sketch and revise your materials list.

◆ Testing Phase

Each team will test their anemometer at three different "wind" speeds using a classroom fan or hairdryer. Test three times at each speed and determine your average wind speed for each setting of your fan or hairdryer. At each test indicate in the box below what you observe the wind speed to be. Be sure to watch the tests of the other teams and observe how their different designs worked.



Test #	Fan Speed Setting	Wind Speed as Measured by Anemometer	Average Wind Speed at Fan Speed Setting
1	Low		
2	Low		
3	Low		
1	Medium		
2	Medium		
3	Medium		
1	High		
2	High		
3	High		

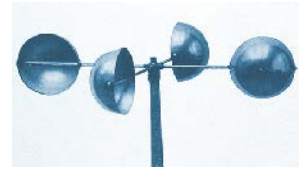
◆ Documentation Phase

Using graph paper, draw a chart that indicates how the wind speed as measured by your anemometer increased as the fan or hairdryer speed setting increased. Use your average wind speeds for the graph.

◆ Evaluation Phase

Evaluate your teams' results, complete the evaluation worksheet, and present your findings to the class.

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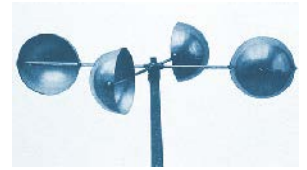


Student Worksheet Evaluation:

Use this worksheet to evaluate your team's results in the "Measuring the Wind" activity.

1. Did you succeed in creating an anemometer that measured the three different "wind" speeds? If not, why did it fail?
2. Did you decide to revise your original design or request additional materials while in the construction phase? Why?
3. Did you find that the readings from one of your tests may have resulted in a major shift in your average reading for that wind speed?
4. If your anemometer was used to test a location to see if it would be a good site to install a wind turbine to harness wind energy, do you think that three tests per speed setting would be enough to generate a reliable average? If not, how many tests do you think would be adequate?
5. If you could have had access to materials that were different than those provided, what would your team have requested? Why?

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Student Worksheet Evaluation: (continued)

6. Do you think that engineers have to adapt their original plans during the construction of systems or products? Why might they?

7. If you had to do it all over again, how would your planned design change? Why?

8. What designs or methods did you see other teams try that you thought worked well?

9. Why do you think the design of anemometers changed so much over time?

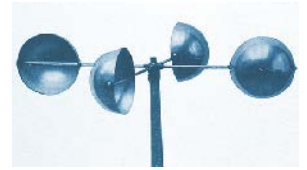
10. List three other pieces of equipment that have been re-engineered over time to improve functionality.

1.

2.

3.

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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)
- 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

- ✦ Position and motion of objects

CONTENT STANDARD D: Earth and Space Science

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

- ✦ Changes in earth and sky

CONTENT STANDARD E: Science and Technology

As a result of activities, all students should develop

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

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 B: Physical Science

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

- ✦ Motions and forces
- ✦ Transfer of energy

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

CONTENT STANDARD F: Science in Personal and Social Perspectives

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

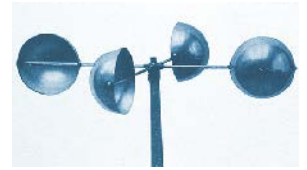
- ✦ Populations, resources, and environments
- ✦ Science and technology in society

CONTENT STANDARD G: History and Nature of Science

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

- ✦ History of science

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For Teachers:

Alignment to Curriculum Frameworks (cont.)

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

CONTENT STANDARD B: Physical Science

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

- ✦ Motions and forces

CONTENT STANDARD D: Earth and Space Science

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

- ✦ Energy in the earth system

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

- ✦ 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

- ✦ Historical perspectives

◆ Next Generation Science Standards Grades 3-5 (Ages 8-11)

Motion and Stability: Forces and Interactions

Students who demonstrate understanding can:

- ✦ 3-PS2-1. Plan and conduct an investigation to provide evidence of the effects of balanced and unbalanced forces on the motion of an object.

Energy

Students who demonstrate understanding can:

- ✦ 4-PS3-1. Use evidence to construct an explanation relating the speed of an object to the energy of that object.

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.

◆ 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.

Measuring the Wind

For Teachers:

Alignment to Curriculum Frameworks (cont.)

◆ Next Generation Science Standards Grades 9-12 (Ages 14-18)

Energy

Students who demonstrate understanding can:

- ✦ HS-PS3-3. Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.

◆ Principles and Standards for School Mathematics

Number and Operations Standard

- ✦ Understand numbers, ways of representing numbers, relationships among numbers, and number systems

Data Analysis and Probability Standards

- ✦ Formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them.

◆ Common Core State Standards for School Mathematics Grades 2-8 (ages 7-10)

Geometry

- Graph points on the coordinate plane to solve real-world and mathematical problems.

- ✦ CCSS.Math.Content.5.G.A.2 Represent real world and mathematical problems by graphing points in the first quadrant of the coordinate plane, and interpret coordinate values of points in the context of the situation.

◆ 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 3: Students will develop an understanding of the relationships among technologies and the connections between technology and other fields of study.

Technology and Society

- ✦ Standard 5: Students will develop an understanding of the effects of technology on the environment.

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.