Wind Energy Part II:

Measuring Wind

The purpose of this lesson is to observe how wind can be measured in order to know where wind is most powerful. Students will learn about and construct a simple anemometer, using it to observe the turning power of wind as it depends on wind speed. Minimal prerequisite knowledge is required for this lesson other than a basic understanding of the effects of wind and the uses of its power in every-day life.

Included in this packet:

California Standards

This lesson addresses or expands on the following California State Science Curriculum Standards for Earth Science and Physical Science:

First Grade

ES3. Weather can be observed, measured, and described. As a basis for understanding this concept:

ES3a. Students know how to use simple tools (e.g., thermometer, wind vane) to measure weather conditions and record changes from day to day and across the seasons.

ES3b. Students know that the weather changes from day to day but that trends in temperature or of rain (or snow) tend to be predictable during a season.

Third Grade

PS1. Energy and matter have multiple forms and can be changed from one form to another. As a basis for understanding this concept:

PS1d. Students know energy can be carried from one place to another by waves, such as water waves and sound waves, by electric current, and by moving objects.

Fourth Grade

ES5. Waves, wind, water, and ice shape and reshape Earth's land surface.

Fifth Grade

ES4. Energy from the Sun heats Earth unevenly, causing air movements that result in changing weather patterns. As a basis for understanding this concept:

ES4a. Students know uneven heating of Earth causes air movements

Sixth Grade

ES4. Many phenomena on Earth's surface are affected by the transfer of energy through radiation and convection currents. As a basis for understanding this concept:

ES4d. Students know convection currents distribute heat in the atmosphere and oceans.

ES4e. Students know differences in pressure, heat, air movement, and humidity result in changes of weather.

Lesson Summary

- *Estimated Time:* 60 minutes

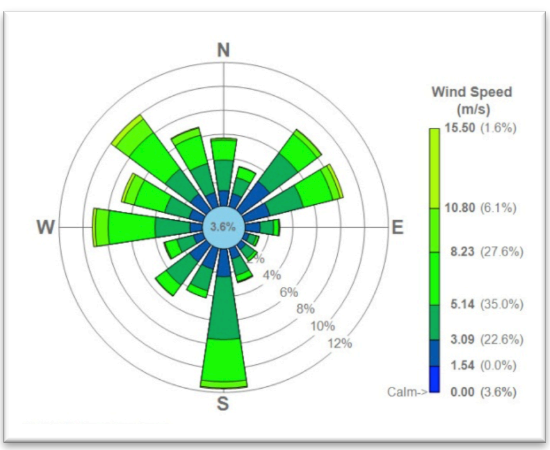
- *Student Prerequisite knowledge*: Wind has speed and direction; wind energy can be converted into rotational energy via a wind turbine, time and distance can be measured to find speed

- *Concepts Learned*: Wind speed is measured using an anemometer, which uses the wind's energy to rotate. By counting the rotations in a given time, wind speed can be calculated and used to determine the viability of a location for generating power from wind.

Background Information for Teachers

Once you find it, wind is simple to capture. However, determining where wind is strongest and therefore most useful requires some research. Scientists and engineers use an **anemometer** to measure wind speed and direction at numerous locations over the surface of the earth, collecting data over a year or more to determine which locations experience the greatest and most consistent wind. They even measure wind over the oceans! You can see these devices everywhere: they are often mounted on radio towers and antennae, or attached to traditional weathervanes.

An anemometer, like a wind vane, can take many shapes. The oldest and most common looks like a horizontal water wheel: three or four cups attached to lateral arms rotate around a common axis, varying their rotational speed with the intensity of the wind. This is the kind students will make during this lesson. Others are shaped like propellers or a common wind turbine, and still more resemble a spinning double-helix (see picture at right). By periodically or continually measuring the rotational velocity of the anemometer, scientists can compare relative wind energy between multiple locations.



Wind direction is measured using a standard wind vane - a flat, vertical tail that is free to rotate laterally around a vertical axis as it is pushed by the wind. The stereotypical wind vane is the arrow and rooster mounted on top of old barns, which always points in the direction of the wind. Wind direction data is plotted on a rose plot, which is a 360-degree graph showing the total amount of time the wind spends blowing in any direction (left).

Using these anemometer tools, utility companies, researchers and engineers can decide where to place wind turbines in order to produce the most electricity. If one wanted to know whether East Palo Alto or downtown Oakland has greater potential for a wind turbine and therefore a renewable source of energy, anemometers would be placed at each location and observed for a year or more. The data could then be compared and the ideal spot chosen.

Materials

Tape and Scissors Provides:

- Small paper cups (5 per group)
- Pencil with full eraser
- Pin
- Plastic straws (2 per group)

You Provide:

- Hole punch
- Permanent marker
- Stapler
- Watch or Clock
- Ruler (for the mathematical extension)
- Window fan (recommended for use inside or in areas where there is little reliable wind)

Preparation

Each of the materials listed above should be present at each desk or workstation. Be sure you have enough instruction sheets and worksheets. *It is recommended that you try the activity once before helping the students.*

The most common problem that students have with their anemometers is that they require too much force to spin or that they spin unevenly. These problems are easily addressed by ensuring that the pin goes through the *centers* of the straws so that each radial arm has exactly the same length. Also check that the pin has not been pushed too far into the eraser so that it is constricting the straws: the straws should have enough space between the pinhead and the eraser to spin freely.

Activity

1. Begin by sitting with the students and having them recall what they know of wind – where it comes from, what it feels like, the effect it has on the environment, homes, the students themselves, etc. Have one or two draw for the class what they imagine "wind" looks like.
2. If available (see the Tape and Scissors website), show relevant pictures and videos of anemometers and other wind-measuring devices.
3. Discuss briefly the goal for the day – to build a working anemometer and use it to measure the relative wind speed between two or more locations. Show and explain the materials that each group will be using. Answer any questions they may have before starting.
4. As students go to their workstations, pass out materials, instructions and vocab lists (if necessary) to each group.
5. If students rely on oral instructions, read aloud from the sheet. Otherwise let the students navigate the instructions together. Walk around and help when they get stuck.
6. After constructing the anemometer, students will answer the questions on the worksheet given. For younger students, have them simply count the number of rotations per minute and take that to be synonymous with the wind speed. If you want to give them an actual converted value for their wind speed, you can use the following equation given their values for rotations per minute and the diameter of their anemometer arm:

   $$\textbf{Wind Speed in mph} = \textbf{(rev/minute)} \times \pi d \times 3.75$$

   where *(rev/minute)* is the number of revolutions per minute that the students counted, and *d* is the diameter of the anemometer arms in centimeters. Π is roughly 3.14 or 22/7, and the constant 3.75 is the conversion from cm/minute to mph.

Anemometer Instructions

A. Collect all materials.

B. Using the hole punch, make four evenly-spaced holes around the side of one of the Dixie cups, about $\frac{1}{2}$" below the brim. Be very careful to ensure that each of the four holes is directly opposite another.

C. Using the pin and pencil, create a central hole in the bottom of the cup wide enough for the pencil to fit through and freely spin.

D. Insert a plastic drinking straw into one of the holes in the side of the cup. Push the straw through the hole on the opposite side of the cup and pull it through until the center of the straw is in the center of the cup with each end sticking out of the cup equally on opposite sides.

E. Repeat the previous step using the other straw and the other two holes so that the straws form a cross in the center of the cup.

F. Find the center of the upright cup where the straws overlap.

G. Make a hole through the overlapping straws with a pushpin. Enlarge the hole with a paperclip or pencil so that the pushpin can rotate freely in the straws. Leave the pushpin in the straws, pointy-end down.

H. Insert the pencil eraser-first up through the hole in the bottom of the cup. Stick the pushpin into the eraser far enough that it is secure, but not far enough that it grips the straws and prevents them from rotating.

I. Find another Dixie cup and staple its brim to the end of one of the straws. The open end of the cup should face sideways.

J. Repeat for three other cups on the ends of each of the other straws. All the cups should face in the same direction, clockwise or counterclockwise around the center cup.

K. Using a marker, color one of the outside cups clearly so that it can be seen while rotating.

L. The anemometer is now complete! Hold it up into the wind or in front of a fan to test it. If it does not rotate freely, adjust the position of the pushpin in the eraser and widen the hole in the straws.

What Do You Think?

Now that you've completed your anemometer, you can use it to measure the speed of the wind. But before we do that, let's try to understand a few things about the anemometer.

1. Why do you think you colored one cup?

2. Would the anemometer spin if it had only 1 cup instead of 4? Why or why not?

3. Most anemometers use 3 cups; why do you think 3 cups might be better than 2 or 4 cups?

4. If the wind changes direction, does the anemometer work? Why or why not?

Measurement and Calculation

1. Test your anemometer in front of a fan or outside in the wind. It should spin freely when the wind is blowing.
2. Have one person watch the clock and another person watch the black cup on the anemometer. When the minute hand on the clock passes 12, say "Go!" and begin watching the black cup. Count the number of times the black cup goes around in one minute. At the end of one minute, stop counting.
3. Write the number of revolutions made by the black cup in the table below. For example, if the black cup went around 72 times in 1 minute, you would write "72" in the first box.
4. Repeat steps 2 and 3 twice more until you have filled in all the boxes.

	Experiment #1	**Experiment #2**	**Experiment #3**
Revolutions per Minute			

5. To find the average speed of your three experiments, take the sum of the numbers in the boxes and divide by 3. Your answer is the *average speed.*
6. The speed you calculated above is the *rotational speed* of the anemometer. To find the wind speed directly, we need to do some calculations. Begin by measuring the *diameter* of the anemometer. You can do this by using a ruler (in centimeters) to measure the distance from one side to the other, or from one cup to the cup on the opposite side.
7. Multiply your answer from question 6 above by □, which is the decimal 3.14 or the fraction 22/7.
8. Now take your answer from question 7 and multiply by your average speed. Your answer is the speed of the wind in *centimeters per minute.*
9. To change your answer to miles per hour (the way we measure speed in cars), multiply your answer by 3.75.

Wrapping Up

As students finish up their lab and questions sheets, help those who are having trouble and encourage others to think about the applications of their anemometers. Those who are finished should compare their results with other groups to see if they measured a similar wind speed. They should also compare anemometers to see which performed best and why.

When every group is finished and has cleaned their workstation, sit again together to review. Welcome anyone who wants to share their answers from the question sheet, and talk about any major differences in data from one group to another. What could cause such differences? How could the anemometers be improved? What is the meaning of "human error?"

If time permits, perform a quick experiment together as a class. Have one student hold the anemometer into the wind or in front of a fan, have another student keep time, and have everyone count the number of rotations the black cup makes in one minute. Then perform the measurements and calculations together to find the wind speed in mph. Discuss the meaning of the unit conversions, including units they may know best, like mph.

Mathematical Extension

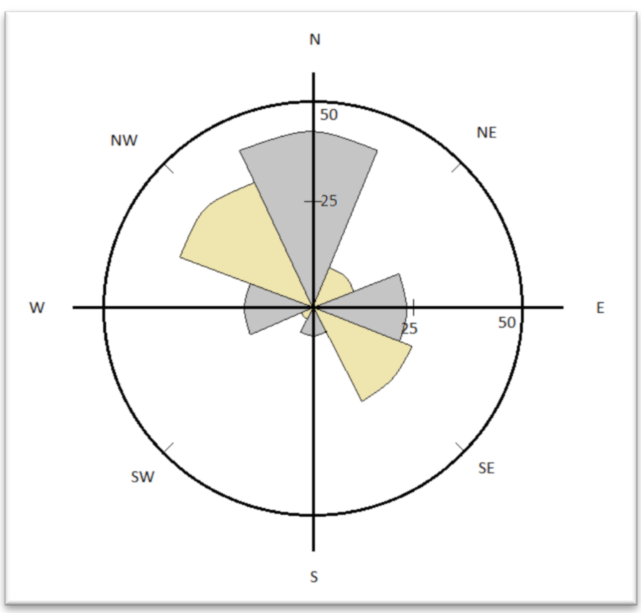
As part of the lab students will measure the diameter of the anemometer and calculate the circumference, or the distance traveled per revolution. They will then count the rotations (by watching the black cup) per minute and calculate the wind speed using the given formula. For extra practice, students can convert the speed to other units.

If time permits or homework can be given, consider expanding the number of trials to five or more in order to see any fluctuations in wind speed (if using a fan you'll have to vary the speed yourself). Students can then graph their data, with speed on the vertical axis and time on the horizontal axis. They can also compare their graphs to check that everyone is measuring the same wind speed fluctuations. Help them understand that these measurements are the ones taken by meteorologists and researchers every day.

Project Extensions

- While the students were able to measure average wind speeds over the course of a few minutes, ideally they could see how wind varies over a much longer time period. After being installed, anemometers typically run for years at a time, taking data over the entire time period and giving scientists a clear picture of wind speed and direction at a specific location.
  As a long-term project, students will choose several locations around the school grounds to test wind speed on a daily basis. If possible, multiple measurements can be done per day as long as the timing is consistent. Each day at the same time(s), each group of students will go to their chosen locations with their anemometers and measure the wind speed and direction (using a simple wind vane and compass) and record it in their project notebook. Data will be collected over the course of a month or school year, depending on preference and practicality, and compiled at the end.
  The wind data can be used to create a rose plot. On the data sheet, separate the data into the eight directions: North, South, East, West, Northwest, Southwest, Northeast, and Southeast. For each of those directions, calculate the average wind speed from all the relevant data and write it next to the corresponding direction.
  On a large piece of paper, draw a large circle with a graph oriented at its center. Around the edge of the circle write the eight directions (N, S, E, W, NE, etc.) in their respective locations. Along the axes of the graph write an even scale of wind speeds starting at zero at the origin and ending at the fastest recorded wind speed where the graph intersects the circle. Using the written data, students can draw a rose plot, where the length of each "petal" along its respective direction axis corresponds to the wind speed, as shown in the example below:

Direction	N	NW	W	SW	S	SE	E	NE
Wind Speed (mph)	42	33	12	2	5	24	21	10



From this plot students can see that the North and Northwest directions receive the most wind on average, but that at some point during the year/month/time frame the wind switches significantly to the East and Southeast directions. Did the students expect this to happen? Do they know what caused the shift, and is it normal?

- Scientists use anemometers to measure wind speeds at various promising locations to gain a better understanding of the wind resources available. If you a energy utility wants to build a wind turbine to augment their electrical grid, they need to know where the most wind can be captured. They then write a proposal showing their data and recommending a location for wind turbine construction.

  Tell students that their job is to recommend to the school principle the ideal placement of a wind turbine on the school grounds. The students will need to take data as explained in the first project above, though a shorter time scale will suffice for the purposes of this project. Students explain their goal, summarize their recommendation, explain their experiment/research steps, present their data both as a graph and a table, explain the results, and conclude with a recommendation.

  The purpose of this project is to practice presenting arguments that are backed by scientific data. Adjust the difficulty and requirements of the project for your class, but make it clear that the students themselves will be determining the outcome of the project, and its success will depend on their scientific ability.

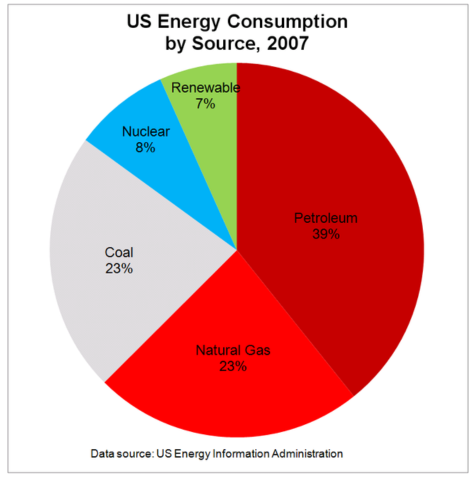
- The first and second projects can be adapted as multi-stage homework, where students use their anemometers to measure wind at home and record the data over a period of time. Parents will need to be notified so that they may help their children remember to take a reading each evening after dinner, or before going to school, etc. Students may then work on their own rose plots individually and have the chance to draw them and present to the class how they took their data and what they found. Emphasis should be given to the process itself as well as the practice with writing and logging data, not as much to the final product.

Information Letter for Parents

(Copy and paste the opening description as well as any relevant section that follows)

Dear Parent or Guardian,

This week in class we will be exploring the power of wind and its practicality as a source of energy. Currently the US relies largely on the burning of fossil fuels (coal, oil, and natural gas) for roughly 85% of its energy needs. Meanwhile, research into renewable forms of energy has shown that wind and solar may be suitable alternatives.



The problem we face is that the extraction and burning of fossil fuels produces an enormous quantity of pollution, and the effect the pollution has had on our atmosphere and ecosystems is becoming increasingly dangerous. So that our students will consider the role that energy plays in our lives, as well as the responsibility we have to use our energy wisely and protect our environment, we will look at the nature of wind and the process of turning its energy into energy we can use. Related science topics include the use of electromagnetism; measurement and calculation of energy and power; and the process of collecting, graphing, interpreting, and presenting data.

Mimicking engineers and researchers, we will build simple anemometers and use them to measure wind speed. These data are what engineers use to decide where to install wind turbines, so we will practice graphing and understanding the data we collect.

As a capstone to the lesson in wind energy we will be doing a class project; it may involve some work for your child at home. Please be sure to ask them about what they're learning about wind and help them find the information they need for their project.

All the best,