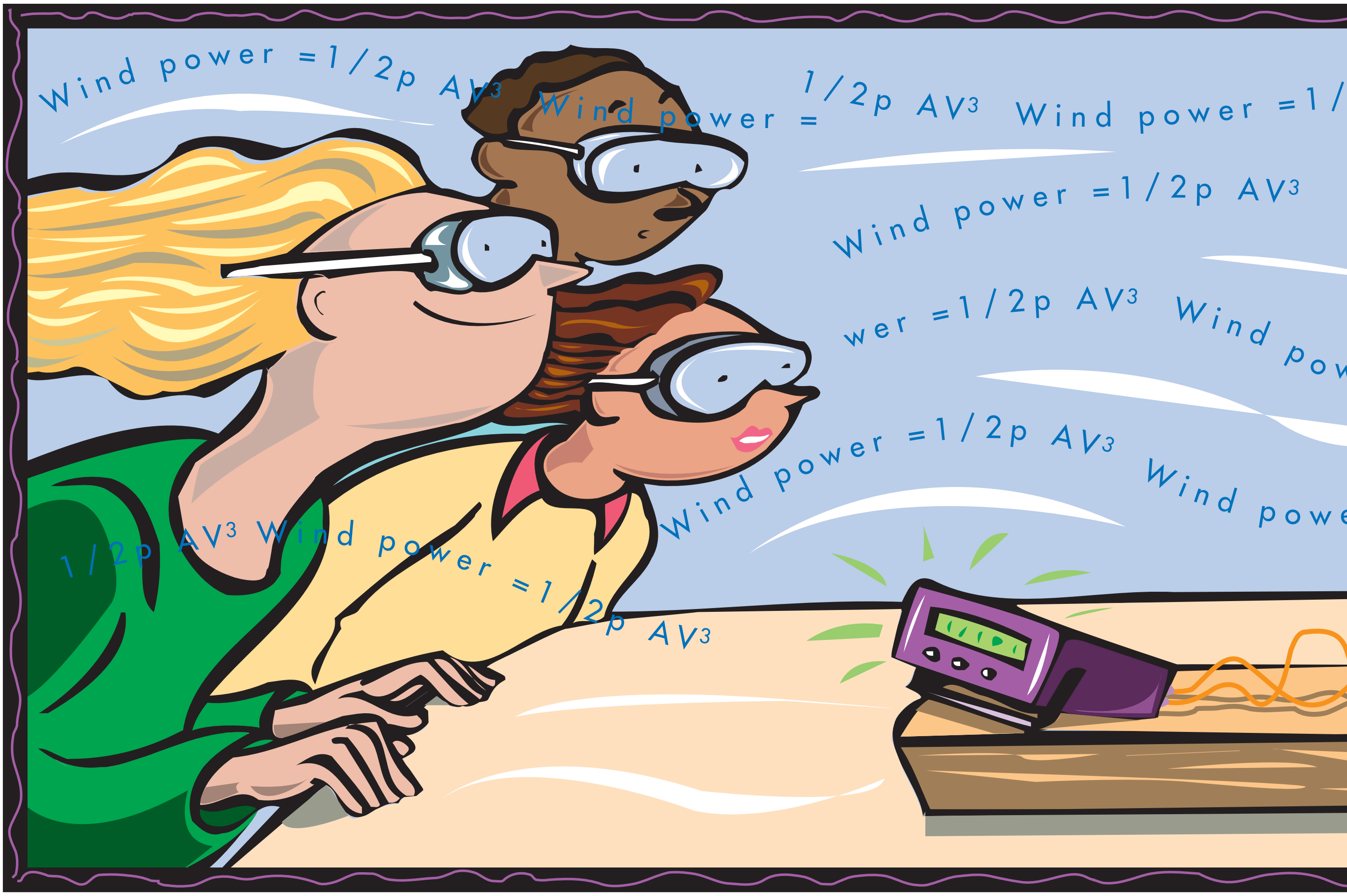
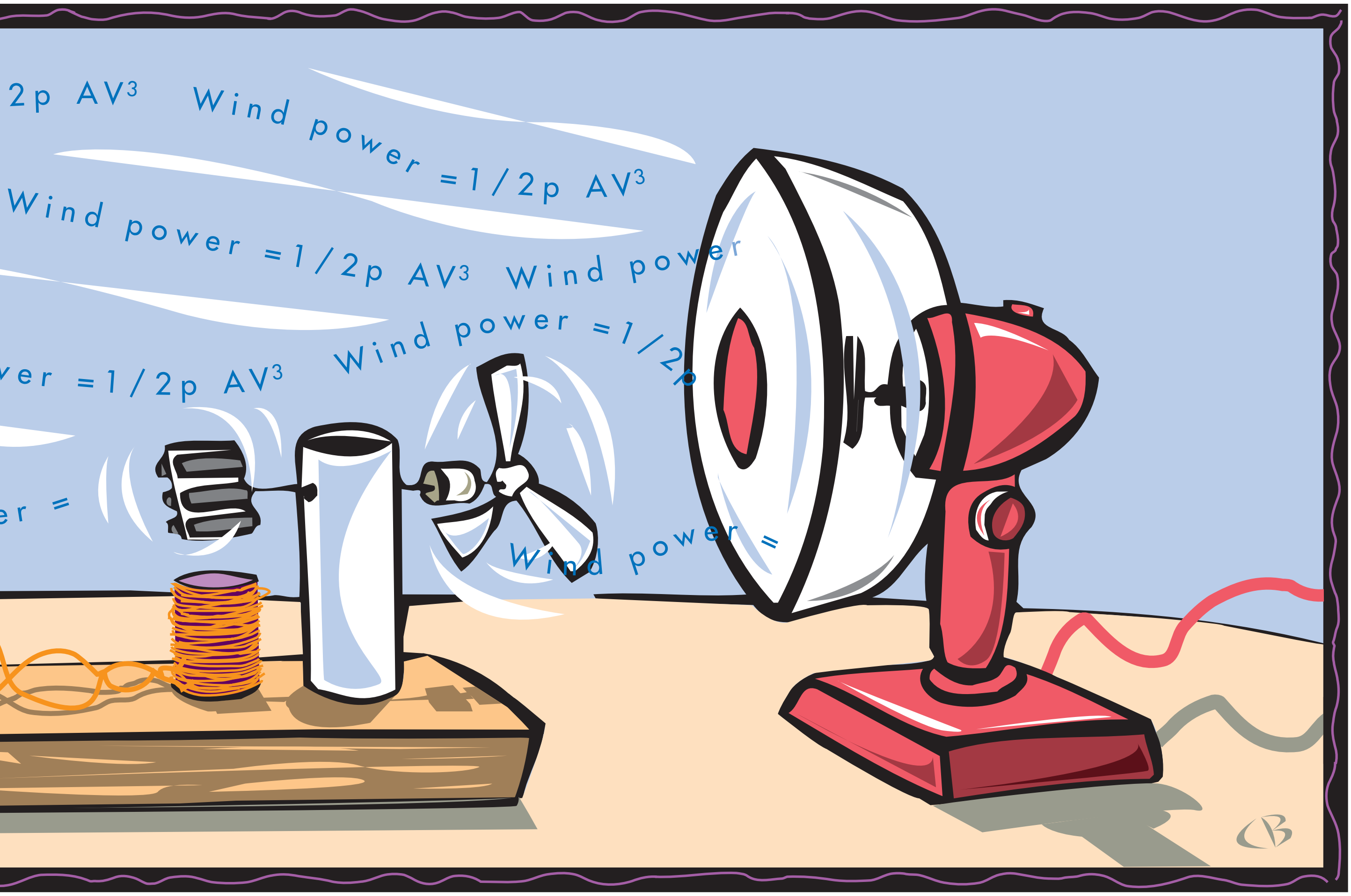


ART BY CHARLES BEYL

Capture the Wind

Students get a charge from wind energy



HARNESSING THE POWER OF WIND TO generate electricity is a challenge faced by modern energy scientists interested in nonpolluting, renewable sources of energy. Solving the problem of how to most efficiently transform the kinetic energy of wind into usable forms of mechanical and electrical energy requires an understanding of the relationships between wind turbine design (blades, tower, and generator), wind speed, turbine location, and electrical output.

We developed this investigation to teach middle and high school students the abstract energy concepts, design features, and problems involved in harnessing wind energy. Efficient harvesting of energy from wind depends on interdisciplinary exploration. Like energy scientists, students must use teamwork and draw on ideas and knowledge from the disciplines of Earth science, physics, math, and engineering, as well as social and environmental science.

This investigation uses an open inquiry approach with substantive, cooperative work as students explore in small design teams. Using simple materials, they are challenged with the question, “How can one harness the energy of wind to create electricity?” This investigation has been successfully used both as an introductory hook to set the stage for further exploration of energy topics and as a culminating project that allows students to apply what they have learned about energy concepts.

CAROL SNETSINGER, CAROL BREWER, AND FLETCHER BROWN

HARNESSING WIND ENERGY

Kinetic wind energy originates as solar energy because uneven heating of the Earth’s surface by the Sun creates high and low pressure systems on local and global scales. Differential heating, movement of air between high and low pressure systems, and the rotation of the planet create wind. The challenge for wind engineers is to convert the kinetic energy of wind into usable forms of mechanical and electrical energy.

People have used wind energy for thousands of years. For example, ancient Egyptians used wind power to sail ships on the Nile River. The earliest windmills of Europe and Asia looked like giant paddle wheels. These windmills converted wind energy into mechanical energy that turned wheels for grinding grain. Centuries later in Holland, improved windmills with propeller-type blades were used to pump water to create arable lands.

During the early 1900s, rural areas in North America without access to electric service often were powered by

Current research in wind energy focuses on improving design features and turbine location to make electrical production by windmills economically efficient (Gipe, 1995).

windmills, but when power lines were strung across the rural United States in the 1930s, the use of windmills to generate electricity declined. Since the oil crisis of the 1970s, wind has once again been looked upon favorably as a renewable source of nonpolluting energy. Current research in wind energy focuses on improving design features and turbine location to make electrical production by windmills economically efficient (Gipe, 1995). Modern wind energy engineers base the design of windmills on the relationships between blade design, wind speed, and electrical output using the following formula:

$$\text{wind power} = 1/2p\ AV^3$$

where p = air density (1.29 kg/m^3 at standard atmospheric pressure and temperature); A = area swept by blades (calculated as πr^2 in square meters); V = wind velocity (in m/s); and wind power (in joules/s or watts) = volts x amps. If students are told that a wind machine with 3-meter-long blades is in a wind with a velocity of 10 m/s, then they can calculate the power as follows. The area swept by the blades would be $A = \pi\ (3m)^2 = 28.27\ m^2$. Wind power in this example can then be calculated as:

$$\begin{aligned}\text{wind power} &= 1/2\ (1.29\ kg/m^3)(28.27m^2)\ (10\ m/s)^3\\ &= 1/2\ (1.29\ kg/m^3)(28.27m^2)(1000m^3/s^3)\\ &= 18\ 234\ \text{joules/s} = 18\ 234\ \text{watts}\\ &= 18.23\ \text{kilowatts}\end{aligned}$$

DESIGNING A WIND MACHINE

For this investigation, students need a basic concept of how electricity is generated. Simply understanding that a magnetic field passing through a coil of wire creates an electrical charge is sufficient. Applying this concept to a larger scale, generating electricity involves rotating coils of wire between opposing poles of magnets. Simple explorations with an electromagnet made from a D-cell and wire coiled around a nail can solidify students' understanding of the relationship between magnetism and electricity and set the stage for them to design a wind machine that generates electricity (Strongin, 1991).

Design teams were formed with three to five students, and each team was presented with a kit of materials to construct a machine that generates electricity from wind (Figure 1). Teams were challenged to design a system to harness wind energy with maximum electrical generation. Initially, teams designed a wind-driven system that created electricity. Later, they methodically tested and refined their designs using a household fan as a source of wind. Prior to beginning construction, students were briefed on the safe use of the tools and materials provided.

Successfully generating electricity from wind was done in two parts. First, students designed a simple wind-driven device or turbine that could turn the shaft of a motor to create electricity. In the second part, students developed a generator, which gave them an understanding of how rotating mechanical energy can be used to generate electricity. These parts can be worked on during the same inquiry or separated into individual investigations. If students are asked to tackle both parts of the problem, they may be more successful if they create the wind-driven device first and then work on the design of the electrical

FIGURE 1.

Materials used to build wind machines. (English units are used for common construction materials.)

Kit materials:
- 2" x 4" block of wood
- 2 or 3 16-penny nails
- 20 meters #22 or #24 gauge magnet wire
- 15 cm piece of 2" PVC pipe or stiff cardboard tube (pre-drill holes at various levels to fit axis of wind turbine)
- 4 to 6 bar- or disk-shaped magnets
- coat hanger or stiff wire
- corks
- Styrofoam balls of various sizes
- wooden beads or empty thread spools
- 2 L plastic soda bottle
- scrap of thin sheet metal
- aluminum soda can
- corrugated cardboard and posterboard
- 0.5 m^2 scrap of cloth
- 1 sheet balsa wood (approximately 0.3 m x 0.3 m)
- scissors
- low-voltage hobby motor (optional)
- protractors (optional)
- low-voltage flashlight bulb (optional)

Classroom materials:
- hot-melt glue gun and glue sticks
- duct tape
- small knives
- wire cutter or tin snips
- hammers
- variable-speed household fans
- sandpaper
- voltmeter (sensitive to 0.1 volt)
- drill with small bits

generator. Students can use a low-voltage hobby motor in place of the generator if the focus of the inquiry is limited to designing the wind turbine.

Once their wind machines were generating electricity, students conducted controlled experiments to determine the relationship between wind velocity, blade size or angle, and electrical output.

WINDING UP

Our student teams needed as little as 1 hour to develop a working model of a wind turbine using a hobby motor to test their design. At least 3 hours were needed to design a wind turbine and generator system from scratch. We guided brainstorm sessions to design a wind turbine, and students described objects and ideas they thought could help capture wind. As they brainstormed and planned the mechanics of their designs, teams were encouraged to think about how they could use glue guns and duct tape to attach objects in their kits. For example, a Styrofoam ball or cork provided an excellent base for attaching blades made out of various materials. The ball or cork could be pierced and glued onto the end of coat hanger wire that served as an axle, or it could be glued directly to the shaft of a hobby motor for testing the design with a fan (Figure 2).

FIGURE 2.

Wind turbine design attached to a hobby motor.

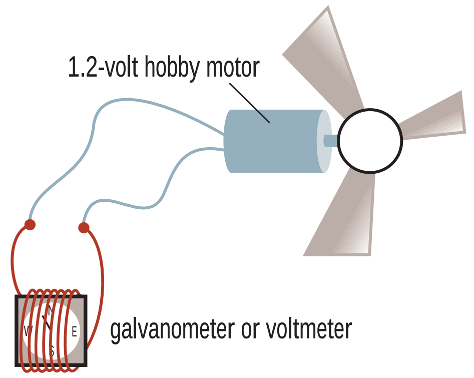
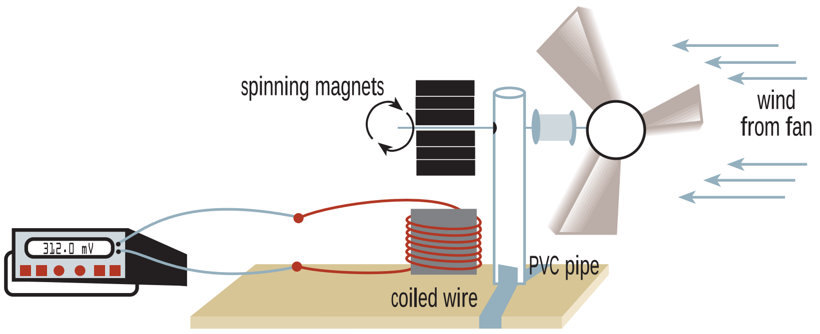


FIGURE 3.

Example of a student-designed generator.



Designing the electrical generating system required a basic understanding of electricity. Although most motors have several coils of wire spinning past magnets, it was easiest to build a simple model in which a spinning magnet exposed opposite poles to one stationary, perpendicular coil of wire (Figure 3). Magnets were easily attached with hot glue onto a coat hanger wire. (Magnet wire often has an enamel coating that has to be sanded off before electrical contact can be made.)

After teams developed a working model of the wind turbine and generator, they tested their designs using a strong fan as a wind source. The electrical output of hobby motors and the student-designed generators were measured with voltmeters sensitive to 0.1 volt. In the absence of a voltmeter, the presence of an electrical charge was determined using a crude galvanometer made from wire wrapped around a compass. Electricity flowing through the wrapped wire creates a magnetic field that deflects the compass needle (Benrey and Shultz, 1986).

TESTING THE DESIGN

Once their wind machines were generating electricity, student groups refined their designs by manipulating one variable at a time. In this phase of the inquiry, they conducted controlled experiments to determine the relationship between wind velocity, blade size or angle, and electrical output.

Based on their experience in wind turbine design, students created a list of factors that influence the amount of electricity they could generate with their wind machines. For example, they listed blade length, blade width, blade angle, wind speed, and blade material. Depending on the class level, students chose a single variable or multiple variables. Then student teams were ready to make a prediction and design an experiment to test how their selected variable would affect the electrical output of their system. Students conducted their experiments, summarized their results in tables or graphs, compared the results to their initial predictions, and drew conclusions based on the evidence. Finally, each team presented its experimental design, wind energy system, and findings to the class.

FOLLOW-UP AND ASSESSMENT

In follow-up discussions, key concepts and terms were applied to the wind systems. For example, at a basic level, the hobby motor could be called an electrical generator, while the blade system was called a turbine. In more advanced classes, parts of the electrical generator design were compared using proper terms for bearing and shaft features.

Students made presentations to the class at the end of both the design and testing phases to share their designs and give us opportunities to assess student understanding of the inquiry. During these presentations, students demonstrated the electrical output of their systems, described their design process, shared key discoveries, and discussed factors they thought influenced their success (or lack thereof). Students were assessed on their ability to design an experiment and methodically test design features to determine the relationships between those features. Advanced students compared known relationships between blade size, wind speed, and electrical output (wind power = $1/2pAV^3$) with their own findings. We facilitated the discussions by asking how each team came up with their design, which designs seemed the most efficient, and which criteria each team used to make design decisions.

> *This investigation allows for a high degree of flexibility for teachers. The inquiry can include one or two phases, and the level of guidance (in both the design and testing phases) can be varied.*

Written assignments can be effectively integrated with this inquiry to set the stage for the investigation or to assess individual understanding after the investigation is completed. For example, prior to the investigations students can describe what they know about wind energy or what they think are the greatest obstacles to designing a wind-driven electrical generator. Afterward, individual students can discuss how their groups approached these problems and the obstacles they overcame as they designed their system. Written assignments also are ideal for exploring the environmental and economic costs of harnessing energy from wind versus other traditional and alternative energy sources.

A POWERFUL PROJECT

Students from both middle and high schools were highly enthusiastic about this inquiry. They found it challenging, and many spent hours after school tinkering with their designs and bringing "junk" from home to incorporate into their designs. Because there was no preconceived "correct" design, teachers using this investigation in their classes reported that lower-achieving students and those with behavioral challenges were surprisingly active participants in the inquiry and were often among the students who remained after school to perfect their wind systems.

This investigation allows for a high degree of flexibility for teachers. The inquiry can include one or two phases, and the level of guidance (in both the design and testing phases) can be varied to fit teaching styles, student backgrounds, and the timing of the inquiry within a unit. Teachers can emphasize different aspects of math and science, varying their expectations of students during the two phases of the investigation.

Developing efficient designs for harnessing wind energy is currently an active area of research (for an example, check the National Renewable Energy Laboratory at *www.nrel.gov*) and wind "farms" and windmills are common in many locations around the country. Consulting with local wind energy engineers, taking trips to a research facility or wind farm, and collaborating with experts on the Internet helped our students connect their investigations to actual research. Thus students, as wind energy researchers, integrated information from diverse sources and experiences and applied their knowledge to realistic challenges. ✧

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