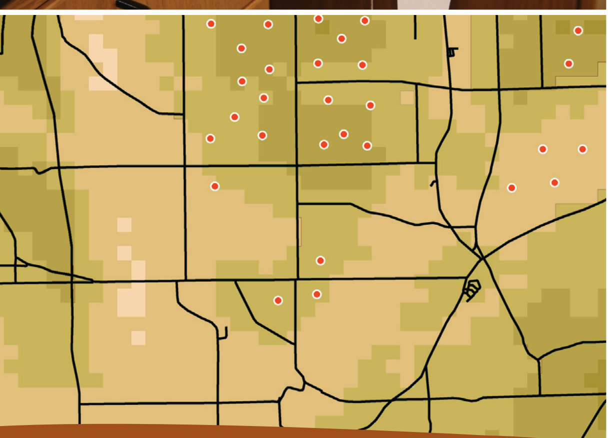
WindWise Education

Transforming the Energy of Wind into Powerful Minds

A Curriculum for Grades 6-12



www.WindWiseEducation.org

NYSERDA

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V1.0

WHICH BLADES ARE BEST?

LESSON 8

KEY CONCEPT

Students will learn through experimentation how different blade designs are more efficient at harnessing the energy of the wind.

TIME REQUIRED

1 – 2 class periods

GRADES

6 – 8
9 – 12

SUBJECTS

Physics
Technology/Engineering
Mathematics

windwise education

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BACKGROUND

The blades of a wind turbine have the most important job of any wind turbine component—they must capture the wind and convert it into usable mechanical energy. Over time, engineers have experimented with many different shapes, designs, materials, and numbers of blades to find which work best. This lesson explores how engineers determine the optimal blade design.

OBJECTIVES

At the end of the lesson, students will

- Know the process of scientific inquiry to test blade design variables
- Be able to collect, evaluate, and present data to determine which blade design is best
- Understand the engineering design process
- Understand how wind energy is converted to electricity

METHOD

Students will use wind turbine kits to test different variables in blade design and measure the power output of each. Each group of students will isolate one variable of wind turbine blade design, then collect and present data for that variable. If time allows, students can use their collected data to design an optimal set of wind turbine blades using the next lesson, "How Can I Design a Better Blade?"

MATERIALS

You will need one set of the following materials for each group:

- ❑ 1 model turbine that can quickly interchange blades
- ❑ 1 multimeter or voltage/current data logger
- ❑ 1 box fan
- ❑ Milk cartons, PVC pipe, or paper towel rolls (optional)
- ❑ Ruler
- ❑ Pictures of wind turbine blades (see the Blade Design PowerPoint show in Additional Resources)
- ❑ Sample blades of varying sizes, shapes, and materials
- ❑ Balsa wood, corrugated plastic, cardstock, paper plates, etc.
- ❑ ¼" dowels
- ❑ Duct tape and/or hot glue
- ❑ Scissors
- ❑ Protractor for measuring blade pitch
- ❑ Safety glasses
- ❑ Poster-size graph paper (optional)
- ❑ Student Worksheets

GETTING READY

- Students should already have a basic understanding of wind energy, including the following concepts
    - What a wind turbine is
    - The fundamental parts of a wind turbine
    - How wind turbines transform energy from the wind
    - Some basic variables that impact turbine performance
- Most of this background was covered in the lesson “How Does a Windmill Work?” The additional resources listed at the end of this lesson also provide helpful information.
- The Blade Design PowerPoint found in the Additional Resources section will also be helpful for this lesson. This slideshow features descriptions of different blade designs and close-up pictures of wind turbine blades.
- Set up a safe testing area. Clear this area of debris and materials. Make sure the center of the fan matches up with the center of the wind turbine. If working with multiple turbines, set them up so students will not be standing in the plane of rotation of a nearby turbine.
- Prepare 3-4 simple blade sets as samples for students to begin to see several variables and figure out how to build blades. Make sure the sample blade sets display different blade variables, such as length, material, and number of blades.
- Make copies of worksheets.

ACTIVITY

Step 1: Beginning Questions for Students

- What do you think makes one turbine work better than another?
- What variables affect the amount of power a turbine can generate?
- Do some variables matter more than others? (For example, is turbine height more important than the number of blades?)
- What do the blades of modern wind turbines look like? Is this similar to older windmills? Why?
- How many blades do most wind turbines have? What do you think would happen with more or fewer blades?

Step 2: Brainstorm Blade Variables

Provide students with photos of different turbine designs using the Blade Design PowerPoint or other photos found in the Additional Resources. While looking at the photos, have students brainstorm some of the variables that affect how much energy the blades can capture.

Example variables may include

- Length
- Number
- Weight
- Pitch/Angle
- Shape
- Blade material
- Twist

Step 3: Determining Variables
Break students into small groups (optimal is 4 students per group) and give each student a worksheet. Have each group select one variable that they are going to test. Length, number, pitch/angle, and shape are easy variables to test, but students can come up with additional variables as well. Before constructing blades, groups should determine what needs to be held constant in order to effectively test their variables.

If you are conducting this exercise as a demonstration, ask students which variable will perform better and why before testing it. Students will complete their worksheets while the teacher tests each variable. Students can take turns attaching blades or reading the multimeter.

Step 4: Building Blades
Depending on the variable being tested, some groups will have to build multiple sets of blades, while other groups will only build one set. For example, the group testing blade material will have to build one set of identical blades with each material being tested. The group testing pitch/angle, however, will only build one set of blades and then test the angle of these blades on the turbine. Groups should collect their blade materials, then work together to construct blades.

Step 5: Testing Blades
The group will attach each set of blades to the turbine and test it at both high and low wind speeds. Change wind speed by moving the turbine away from the fan or turning the fan lower. Wind coming from a fan is very turbulent and does not accurately represent the wind a turbine would experience outside. To clean up this turbulent wind, students can make a wind tunnel by building a honeycomb in front of the fan using milk cartons, PVC pipe, or paper towel rolls. This will slow the wind coming off the fan, but it will also straighten it out.

Be sure students understand what blade pitch (angle) is and how they will measure it or keep it constant. This concept was introduced in “How Does a Windmill Work?”

Make sure that students keep pitch constant while testing other variables or the results can be problematic.

Students will measure the voltage with a multimeter and record their data on the worksheet. If time permits, have students do three replications of each variable and average their results.

Step 6: Analysis
Once students have collected their data, have them answer the questions on the worksheet and make a graph of their data to present to the class. If poster-size graph paper is available for students, ask them to replicate the graph on this paper for their presentations.

BLADE PITCH

Blade pitch is the angle of the blades with respect to the plane of rotation. The pitch of the blades dramatically affects the amount of drag experienced by the blades. Efficient blades will provide maximum torque with minimum drag. Measure pitch with a protractor.

CAUTION!

- Wear safety glasses.
- Stand in back of or in front of the wind turbine during testing. Do not stand in the plane of rotation as you could be hit if your blade flies off during testing.
- The hubs on many homemade wind turbines are not industrial scale. At high RPMs, the blades may come off. If this continues to happen, you can use tape to secure them.
- The voltage and current produced by your turbine is not enough to cause injury, but it is always a good idea to treat electricity with care and caution.

Step 7: Presentation
Each group will have 5 minutes to present their data to the class. Students should discuss their variables, how they designed the blades, and the results. Have students record the results from each group on their worksheets so they have all of the class results.

Step 8: Wrap Up
Wrap up the lesson with some of the following questions:

- What variable has the greatest impact on power output?
- What type of blades worked best at low speeds? High speeds?
- What number of blades worked best?
- What shapes worked best?
- What length worked best?
- What problems did you encounter?
- Did longer blades bend backward in the wind? Was this a problem?
- What happened when the diameter of the turbine rotor was bigger than the diameter of the fan?

Have students analyze the class data and describe an optimal blade design. If time permits, this can be used as a starting point for the extension lesson: "How Can I Design a Better Blade?"

EXTENSION

The following extension may be made for grades 9-12

- Have students also collect amperage data and calculate power. Discuss voltage, amperage, and power and how they relate to one another.
- Have students determine the efficiency of their turbines. The efficiency of a turbine is a comparison between the theoretical power available in the wind and the actual power output of the turbine. To calculate the theoretical power in the wind, students can use this equation:

$P = 1/2\ \varrho\ (\pi\ r^2)V^3$
P = Total power available in the wind
ϱ = Air density (1.23 kg/m^3 at sea level)
π = pi (3.14)
r = rotor radius (length of one blade)
V = velocity of the wind

Turbine efficiency is equal to the total power output of the turbine divided by the theoretical power available. Do not be surprised if your efficiency is under 5%. The maximum theoretical efficiency of a wind generator is 59%. Research Betz Limit to learn more about this.

VOCABULARY

Amperage – A measure of the flow rate of electrical current that is available. Amps = Watts/Volts.

Blade Pitch – Angle of the blades with respect to the plane of rotation. (Blades perpendicular to the oncoming wind would be 0 degrees. Blades parallel to the wind would be 90 degrees).

Drag – In a wind turbine also called wind resistance. Friction of the blades against air molecules as they rotate. Drag works against the rotation of the blades causing them to slow down.

Lift – A force experienced by the blades that is perpendicular to the oncoming flow of air. Lift is a force working to speed up the rotation of the blades.

Multimeter – An electronic instrument that can measure voltage, current, and resistance.

Power – The rate at which energy changes form from one form to another, or the rate at which work is done

Voltage – The electrical pressure that drives electric current. Voltage is a convenient way of measuring the ability to do electrical work. Volts = Watts/ Amps

Wattage – A unit of measure for power, or how fast energy is used. One watt of power is equal to one ampere (a measure of electric current) moving at one volt (a measure of electrical force). One watt is equivalent to one joule of electrical energy per second. Watts = Volts x Amps.

RELATED ACTIVITIES

- Lesson 6: How Does a Windmill Work?
- Lesson 9: How Can I Design a Better Blade?

ADDITIONAL RESOURCES

WIND TURBINE BLADE DESIGN POWERPOINT SLIDE SHOW—http://www.kidwind.org/Presentations/WindTurbineBladeDesign..March.08.ppt

KIDWIND, CLASSROOM WIND TURBINES—http://www.kidwind.org/lessons/SFBuildingSFintro.html —KidWind has compiled a list of ideas for building your own wind turbine. This site also includes complete kits, instructions on how to build model turbines, and more ideas for classroom activities.

KIDWIND, WIND TURBINE VARIABLES—http://www.kidwind.org/lessons/SFvariables.html —Explains the different wind turbine variables.

WIND WITH MILLER—http://www.talentfactory.dk/en/kids/index.htm —This is a good introduction to wind energy and wind turbines. Great for grades 6-8.

DANISH WIND ENERGY ASSOCIATION—Guided Tour—How does it Work?, http://www.talentfactory.dk/en/tour/wtrb/comp/index.htm

More advanced explanations of wind turbine science, better for grades 9-12.
NATIONAL RENEWABLE ENERGY LABORATORY— http://www.nrel.gov/data/pix —Search for wind turbines and blades; you will also find a wide range of wind energy images.

NY STATE STANDARDS

Intermediate Level Science–Standard 1: Analysis, Inquiry, and Design
Scientific Inquiry

Key Idea 1:
The central purpose of scientific inquiry is to develop explanations of natural phenomena in a continuing, creative process.

Key Idea 3:
The observations made while testing proposed explanations, when analyzed using conventional and invented methods, provide new insights into phenomena.

Engineering Design

Key Idea 1:
Engineering design is an iterative process involving modeling and optimization (finding the best solution within given constraints); this process is used to develop technological solutions to problems within given constraints.

Intermediate Level–Science Standard 6: Interconnectedness: Common Themes
Key Idea 2:
Models: Models are simplified representations of objects, structures, or systems used in analysis, explanation, interpretation, or design.

Key Idea 3:
Magnitude and Scale: The grouping of magnitudes of size, time, frequency, and pressures or other units of measurement into a series of relative order provides a useful way to deal with the immense range and the changes in scale that affect the behavior and design of systems.

Key Idea 6:
Optimization: In order to arrive at the best solution that meets criteria within constraints, it is often necessary to make trade-offs.

Intermediate Level Science–Standard 4: The Physical Setting
Key Idea 4:
Energy exists in many forms and when these forms change energy is conserved.

Major Understandings:
4.1b Energy may be converted among mechanical, electromagnetic, nuclear, and thermal forms

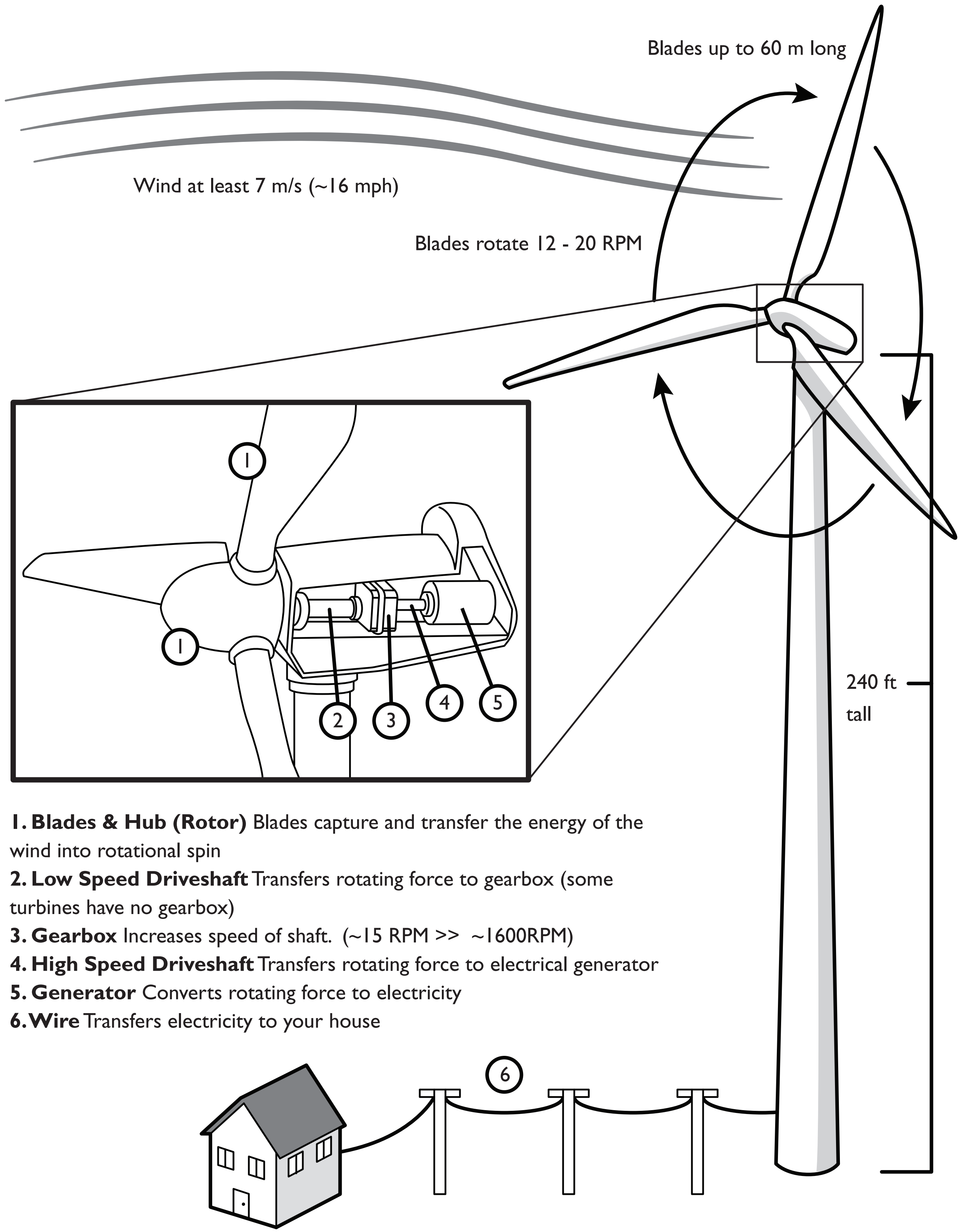
4.1d Kinetic energy is the energy an object possess by virtue of its motion.

4.1p Electrical power and energy can be determined for electric circuits

Key Idea 5:
Energy and matter interact through forces that result in changes in motion

5.2e A machine can be made more efficient by reducing friction. Some common ways of reducing friction include lubricating or waxing surfaces.

ENERGY TRANSFERS AND CONVERSIONS IN A WIND TURBINE



1. Blades & Hub (Rotor) Blades capture and transfer the energy of the wind into rotational spin
2. Low Speed Driveshaft Transfers rotating force to gearbox (some turbines have no gearbox)
3. Gearbox Increases speed of shaft. (~15 RPM >> ~1600RPM)
4. High Speed Driveshaft Transfers rotating force to electrical generator
5. Generator Converts rotating force to electricity
6. Wire Transfers electricity to your house

Name______________________________ Date____________ Class_______

Variable

What variable will you test for your experiment? ______________________________

Constants

What variables do you have to keep the same (constant) as you perform this experiment?

Experimental Design

Describe how you will perform this experiment.

1. What materials will you use?

2. How many times will you test your variable?

3. How long will you run the test?

4. How will you change your variable?

5. How will you record output?

Hypothesis

1. What do you think will happen?

2. Why do you think this will happen?

Data Tally Sheet – Grades 6-8

	LOW SPEED	HIGH SPEED
Variable *(e.g., length, # cm long)*	Voltage (mV or V)	Voltage (mV or V)

Graph Your Data

Voltage Output

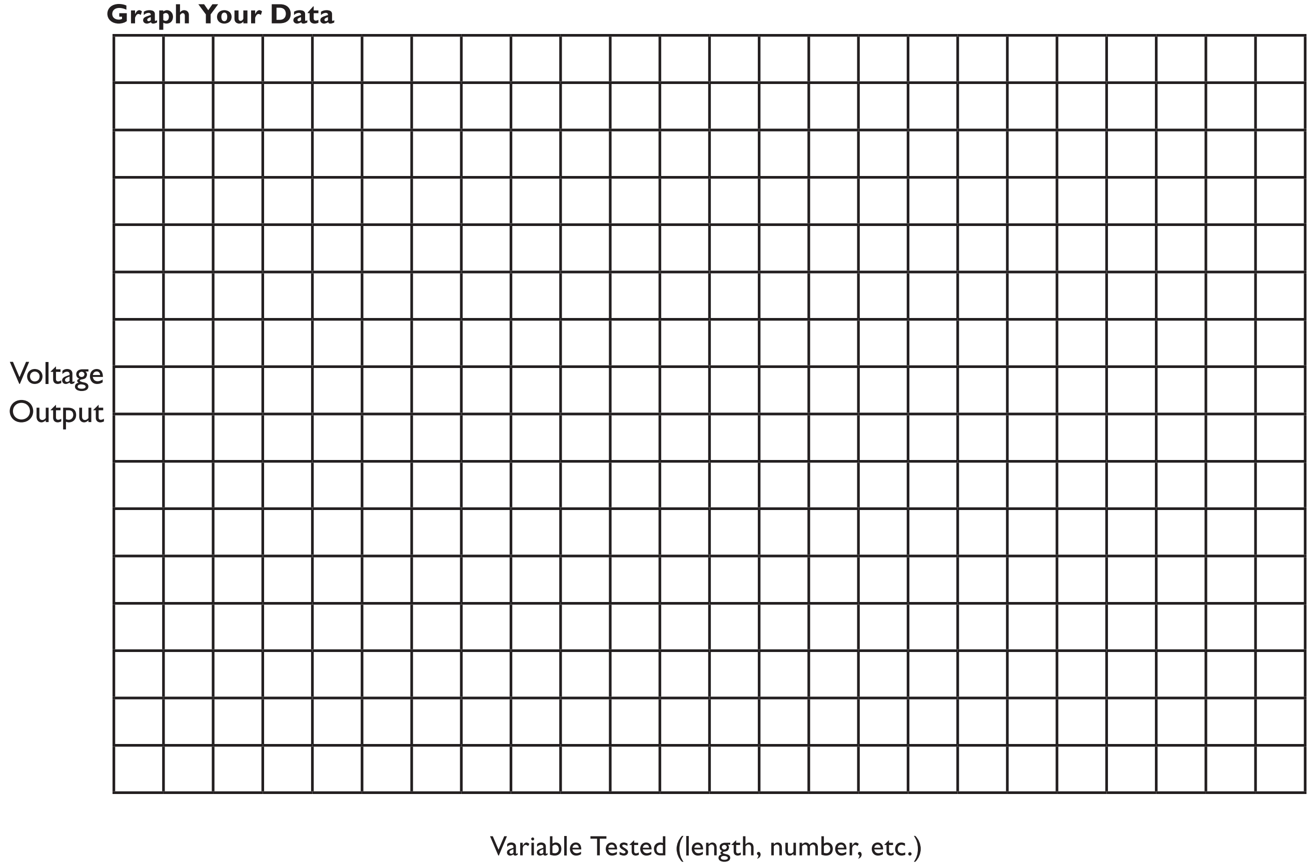
Variable Tested (length, number, etc.)

Data Tally Sheet – Grades 9-12

LOW SPEED			
Variable *(e.g., length, # cm long)*	Voltage (mV or V)	Amperage (mA or A)	(V x A) = Power (mW or W)

Variable *(e.g., length, # cm long)*	Voltage (mV or V)	Amperage (mA or A)	(V x A) = Power (mW or W)

Graph Your Data



Name______________________________ Date______________ Class________

What Happened?

1. How did the voltage change as a result of manipulating your variable?

2. What was the optimal setting for the variable that you tested?

3. Do you think that your variable has a large or small effect on how much power the turbine can make?

4. What problems did you encounter as you performed your experiments? How could you fix these problems?

Class Results

Record the results from the class experiments in the table below.

Power = Voltage (V) X Current (A)

Make sure you are recording volts and amps (not milliamps). 1 A=1,000 mA

VARIABLE	VOLTAGE (V)	AMPERAGE	POWER OUTPUT
(e.g. length cm)		(extension) (mA or A)	(optional) (mW or W)
15 cm	1.7	100 mA	0.17 W

1. If you were a lead design engineer, what would you recommend your company do to their turbine blades based on the class results? Why?

Variable

What variable will you test for your experiment?

Answers will vary. Example variables: Blade pitch, blade shape/size, material of blades, number of blades, etc.

Constants

What variables do you have to keep the same (constant) as you perform this experiment?

Answers will vary. Example variables: Blade pitch, blade shape/size, material of blades, number of blades, etc.

Experimental Design

Describe how you will perform this experiment.

1. What materials will you use?
   Answers will vary. Balsa, corrugated plastic, paper plates, cardboard, etc.

2. How many times will you test your variable?
   Variables should be tested at least 2 times.

3. How long will you run the test?
   Answers will vary. Trials should last at least 20 seconds.

4. How will you change your variable?
   Answers will vary.

5. How will you record output?
   Output should be recorded using a multimeter or other quantitative measurement.

Hypothesis

1. What do you think will happen?
   Students should hypothesize how changing their chosen variable will affect the power output of the wind turbine.

2. Why do you think this will happen?
   Students should explain why they think changing the variable will affect power in this way.

What Happened?

1. How did the voltage change as a result of manipulating your variable?
   Changing the variable should cause the voltage to increase or decrease.

2. What was the optimal setting for the variable that you tested?
   Which trial yielded the most voltage? For example, if the test variable is "blade pitch," students may answer "Blades pitched at 20 degrees produced the most voltage."

3. Do you think that your variable has a large or small effect on how much power the turbine can make?
   Answers will vary.

4. What problems did you encounter as you performed your experiments? How could you fix these problems?

   Answers will vary. One common problem is that it is hard to keep all other variables constant while testing one specific variable.

Class Results

Record the results from the class experiments in the table below.

Power = Voltage (V) X Current (A)

1. If you were a lead design engineer, what would you recommend your company do to their turbine blades based on the class results? Why?

   Students should describe the optimal blade design based on class results. This answer should discuss at least three variables—e.g., length of blades, number of blades, blade pitch, blade material, etc.