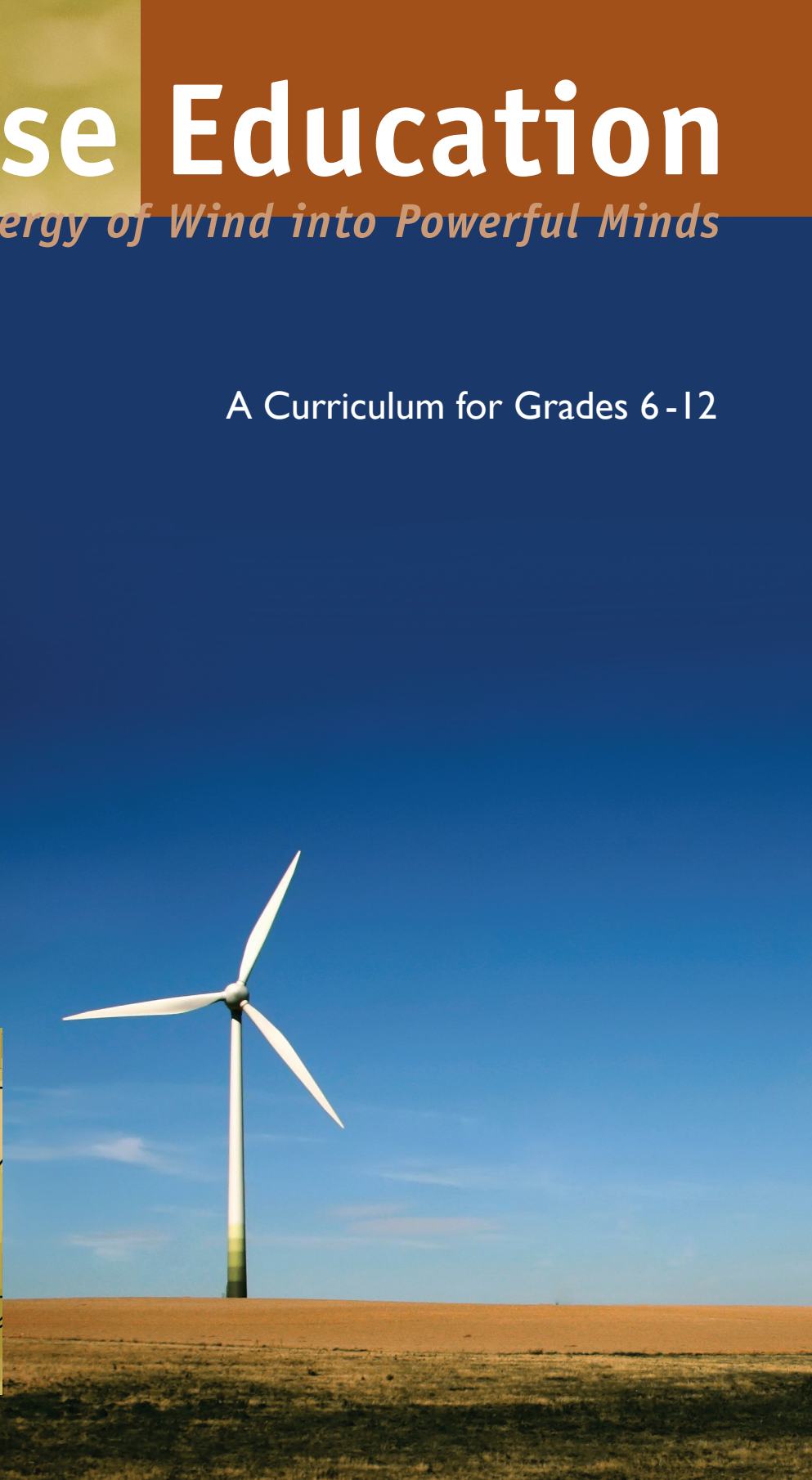
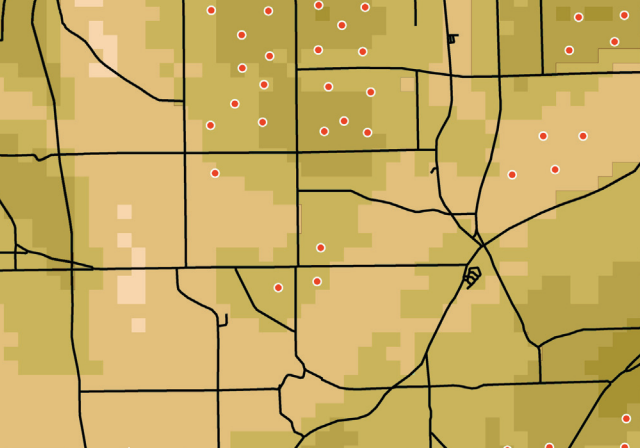
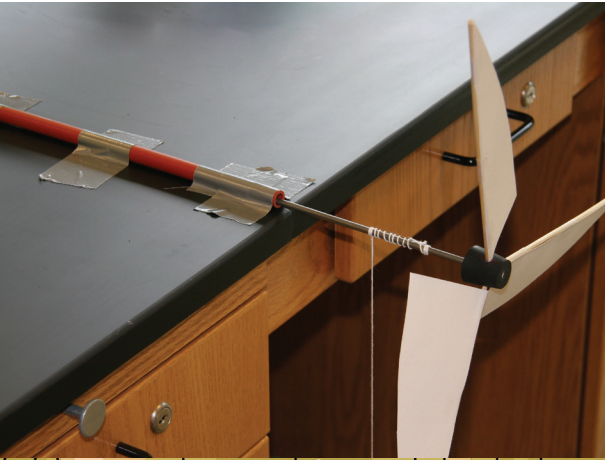


# WindWise Education

*Transforming the Energy of Wind into Powerful Minds*

A Curriculum for Grades 6-12





WindWise Education was developed with funding from the New York State Energy Research & Development Authority.

# HOW CAN I DESIGN BETTER BLADES?

LESSON

9

## KEY CONCEPT

Students will learn how to design and construct different turbine blades to maximize the power output of a wind turbine.

## TIME REQUIRED

1 – 2 class periods

## GRADES

6 – 8

9 – 12

## SUBJECTS

Physical Science

Technology/Engineering

Mathematics

## BACKGROUND

Blade design and engineering is one of the more complicated and important aspects of current wind turbine technology. Today engineers strive to design blades that extract as much energy from the wind as possible in a variety of wind speeds, while remaining durable, quiet and affordable. This engineering process requires a great deal of scientific experimentation, modeling, and testing.

## OBJECTIVES

At the end of the lesson, students will

- Be able to participate in the engineering design process
- Understand how blade design variables affect power output
- Know how to improve and optimize wind turbine blades

## METHOD

Students will use a variety of materials to design blades that optimize the power output of a model wind turbine.

## 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 or multimeter box
- 1 box fan
- Ruler
- Pictures of wind turbine blades (see the Blade Design PowerPoint show in Additional Resources)
- Student Worksheets\*

Blade building materials

- Balsa wood, corrugated plastic, cardstock, paper plates, plastic cups, index cards, etc.
- ¼" dowels
- Duct tape and/or hot glue
- Scissors, Exacto knives
- Protractor for measuring blade pitch



### 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.

### GETTING READY

- Students should have completed the “Which Blades Are Best?” lesson.
- It is useful to have some blades, turbines, and hubs ready so you can demonstrate how to safely use the tools and turbines.
- Set up turbine testing stations:
  - Place all of the materials in one central location where students can select items and you can monitor their use to make sure that students are using them safely.
  - Having the same fans at each station would be ideal, but sometimes it is not possible. Therefore, make sure that students use the same fan and at the same speed when testing the blades.
- Factor in that there can be a wait at the testing stations. While students only need a few minutes to test and then change their blades, having a few stations set up reduces the wait time.
- Consider having students begin the design process at home in order to save some classroom time, as the construction and revision of the blades can be time consuming.

### ACTIVITY

#### Step 1: Beginning Questions for Students

Recap the results from the “Which Blades are Best?” lesson. Discuss which variables had the most impact.

#### Step 2: Blade Design and Construction

Have all students analyze the data on their own and come up with their own individual designs. Have students create a design plan (may include drawings and/or descriptions) and approve it before construction.

##### Design Constraints

- Can use any materials found in the classroom resource area
- Do not use any metal
- Cannot use any manufactured blades or propellers
- Blades cannot be more than 20” long
- Must have no sharp points

Have students use their data sheets to keep track of the materials they use.

If students are constructing their blades in the classroom, set limits on how long they can work on them. You can also limit supplies or attach costs to supplies they must purchase with a set budget. This cuts down on waste and requires students to put more thought into selecting materials.

Have students test their blades at low and high speeds. To simulate low speed, turn the fan down or move the wind turbine back 2 meters. Students should test their blades at least once and optimally twice before presentation time (once with the initial design and a second time after any design revisions have been made).

As the designs progress, encourage students to experiment with advanced ideas, such as using the **airfoil** shape and/or making blades with **twisted pitch**.

### Step 3: Competition

Students' blades can be evaluated in three ways (you may pick one or use all three). Evaluating in all three ways gives students with different skills a chance to succeed.

- Quality of construction
- Level of innovation
- Power output at low and high wind speeds

Quality of construction and innovation can be evaluated by the whole class using the voting sheets on the worksheet. This allows students to compare power output to other characteristics that are important. Students can display their blades with a name label and spend 10 minutes walking around and evaluating each of the blades. Students can also predict which blade designs will be the best and why. Tally the votes using this scale: 1<sup>st</sup> = 3 points, 2<sup>nd</sup> = 2 points, 3<sup>rd</sup> = 1 point. The student with the most points wins that category.

Power output can be evaluated by testing the blades at low and high wind speeds. Use students as recorders, timers, and multimeter experts. Let each student mount and set their own blades. Ask each student to describe the main features of their blades (length, materials, number of blades, etc.) to the class. Place the turbine at about 1 meter away and let it run at high speed for 30 seconds. Record the highest voltage number you see in 30 seconds. Have students record these data on their worksheets. Do the same in low speed conditions. To simulate low speed, turn the fan down or move the wind turbine back 2 meters. If after a few seconds students want to adjust the blades, allow them to do it only once to limit the amount of time on each blade set. After measuring voltage and current, calculate power using the equation:  $P=VI$ .

### Step 4: Wrap Up

Wrap up the lesson with some of the following questions

- Which type of blades worked best at low speeds? High speeds?
- Why do you think these blades performed the best?
- What problems did you encounter?
- Which features did you incorporate from modern turbine designs?

### EXTENSION

Measure the power output and efficiency of different blade configurations. See "Which Blades Are Best?" for more information about measuring power output and efficiency.



### VOCABULARY

**Airfoil** – “Teardrop” cross-section used for wind turbine blades. The airfoil shape is most efficient because it creates lift while minimizing air turbulence.

**Rotor Solidity** – Measurement of how “solid” the rotor is. A high solidity does not have a lot of space between blades. Low solidity (like most modern turbines) has fewer blades and more empty space in the rotor.

**Twisted Pitch** – Blades of real wind turbines have higher pitch near the root and less pitch at the tip. This greatly reduces drag at the blade tips to increase performance.

### RELATED ACTIVITIES

- Lesson 6: How Does a Windmill Work?
- Lesson 8: Which Blades Are Best?

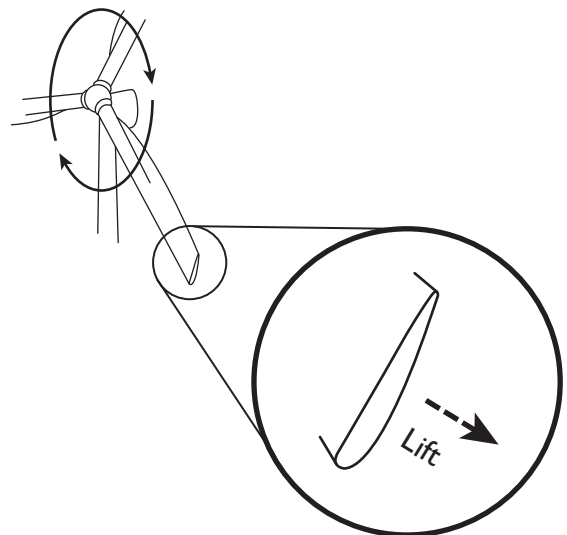
### ADDITIONAL RESOURCES

**KIDWIND, WIND TURBINE BLADE DESIGN**—<http://www.kidwind.org/lessons/SFBladeDesign.html> —Detailed information on designing your own wind turbine blades for model turbines. This page also has helpful information and resources about real wind turbine blades.

**DANISH WINDPOWER ASSOCIATION: BLADE TESTS**—<http://www.talentfactory.dk/en/tour/manu/bladtest.htm> —Shows how blades are tested on commercial wind turbines. This site also includes a variety of useful wind energy information.

**DANISH WINDPOWER ASSOCIATION: BLADE DESIGN**—<http://www.talentfactory.dk/en/tour/wtrb/blades.htm> —Information about turbine blade design.

**LM GLASFIBER**—<http://www.lmglasfiber.com> —Has a picture archive and information on the testing and development of the latest blade technology. The world’s largest test bed for rotor blades is located at LM Glasfiber in Lunderskov, Denmark. It can test blades of up to 80 meters in length using state-of-the-art testing methods.



The airfoil shape of wind turbine blades creates lift while minimizing turbulence.

## 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 intended methods, provide new insights into phenomena.

### Engineering Design

#### Key Idea 1:

Engineering design is an iterative process involving modeling and optimization; this process is used to develop technological solutions to problems within given constraints.

### Intermediate Level Science–Standard 6: Interconnectedness & Common Themes

Models

#### Key Idea 2:

Models are simplified representations of objects, structures, or systems used in analysis, explanation, interpretation, or design.

### Magnitude & Scale

#### Key Idea 3:

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.

### Optimization

#### Key Idea 6:

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 Performance Indicator 4.1b

Fossil fuels contain stored solar energy and are considered nonrenewable resources. Solar energy, wind, moving water, and biomass are some examples of renewable energy resources.



### *Major Understandings:*

4.1d Different forms of energy include heat, light, electrical, mechanical, sound, nuclear, and chemical. Energy is transformed in many ways.

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

### **Physical Setting–Physics: Standard 1–Analysis, Inquiry, and Design (High School)**

Students will use mathematical analysis, scientific inquiry, and engineering design, as appropriate, to pose questions, seek answers, and develop solutions.

#### **Key Idea 3:**

The grouping of magnitude 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.

#### **Engineering Design**

##### **Key Idea 1:**

Engineering design is an iterative process involving modeling and optimization; this process is used to develop technological solutions to problems within given constraints.

### **Physical Setting–Physics: Standard 6–Analysis, Inquiry, and Design (High School)**

#### **Key Idea 2:**

Models are simplified representations of objects, structures, or systems used in analysis, explanation, interpretation, or design.

#### **Key Idea 3:**

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:**

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





Name \_\_\_\_\_

Date \_\_\_\_\_

Class \_\_\_\_\_

**DESIGN YOUR OWN BLADES**

**Design**

1. Sketch and describe the design of your blades (length, shape, number, materials, etc).
2. Explain why you designed your blades this way. Use data from Lesson 8 to support your initial design (if completed).

**Test Run #1**

Test your blades for 30 seconds and record your data below.

**Power=Voltage x Amps**

	<b>VOLTAGE</b>	<b>AMPERAGE</b>	<b>POWER OUTPUT</b>
<i>High Wind Speed</i>			
<i>Low Wind Speed</i>			

**Modifications**

3. What modifications could you make to your blade set to increase the power output?
4. Why do you think these blades would work better?

**Test Run #2**

Test your modified blades for 30 seconds and record your data below.

	<b>VOLTAGE</b>	<b>AMPERAGE</b>	<b>POWER OUTPUT</b>
<i>High Wind Speed</i>			
<i>Low Wind Speed</i>			

Competition

<b>NAME</b>	<b>NUMBER OF BLADES</b>	<b>MATERIALS</b>	<b>LENGTH (CM)</b>	<b>ADDITIONAL DESIGN FEATURES</b>	<b>HIGH POWER</b>	<b>LOW POWER</b>	<b>AVERAGE</b>



Name\_\_\_\_\_

Date\_\_\_\_\_

Class\_\_\_\_\_

**Questions**

1. Describe the blades that seemed to perform the best. What characteristics did they have?

2. Why do you think they performed so well?



Name \_\_\_\_\_

Date \_\_\_\_\_

Class \_\_\_\_\_

**Voting Form**

Use these forms to vote on other students' blade designs.

QUALITY OF CONSTRUCTION	
1 <sup>ST</sup>	
2 <sup>ND</sup>	
3 <sup>RD</sup>	
INNOVATION	
1 <sup>ST</sup>	
2 <sup>ND</sup>	
3 <sup>RD</sup>	

QUALITY OF CONSTRUCTION	
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2 <sup>ND</sup>	
3 <sup>RD</sup>	

### DESIGN YOUR OWN BLADES

**Design**

1. Sketch and describe the design of your blades (length, shape, number, materials, etc).  
*Student observations.*
2. Explain why you designed your blades this way. Use data from Lesson 8 to support your initial design (if completed).  
*Student observation, but it is a good idea for students to keep their data from Lesson 8 so that they have ideas to base their designs on.*

**Test Run #1**

Test your blades for 30 seconds and record your data below.

**Power=Voltage x Amps**

	VOLTAGE	AMPERAGE	POWER OUTPUT
<i>High Wind Speed</i>			
<i>Low Wind Speed</i>			

**Modifications**

3. What modifications could you make to your blade set to increase the power output?  
*Student observations.*
4. Why do you think these blades would work better?  
*Student observations. Look for changes to their blades based on the analysis of Test #1 performance and data from Lesson 8.*

**Test Run #2**

Test your modified blades for 30 seconds and record your data below.

	VOLTAGE	AMPERAGE	POWER OUTPUT
<i>High Wind Speed</i>			
<i>Low Wind Speed</i>			

**Questions**

1. Describe the blades that seemed to perform the best. What characteristics did they have?

*Student observations.*

*Some common themes (these will depend on type of turbine used: direct drive vs. geared vs. weightlifting device):*

- *Blades match fan size*
- *Blades are smooth*
- *Blades go all the way to base of hub*
- *2-4 blades in total*
- *Wider at the root than at the tip*
- *Might have a twist along length of blade (20 degree pitch at base, 0 degree pitch at tip)*
- *Blade angle low, around 5-10 degrees*
- *Airfoil shape to increase rotational lift and increase blade velocity*

2. Why do you think they performed so well?

*Student observations. Can relate better performance to the observations above. Great blades capture the energy of the wind without causing too much drag and slowing themselves down.*