Wind Speed and Height: "Why do wind turbines have to be so tall?"

Lesson Overview

In this lesson, students will investigate the relationship between wind speed and height, through both experiments and quantitative analysis. Students will be able to explain why turbines are built at heights of 50-80 m, rather than being taller or shorter.

Grade Level

Grades 9-12 (secondary school)

Time Required

1-2 classes (students can also collect data outside class time for an assignment/science project)

Curriculum Connection (Province/Territory and course)

Atlantic Provinces Education Foundation: General Curriculum Outcomes for Social Studies:
Newfoundland and Labrador - Canadian Geography/World Geography

People, Place and Environment:

- Students will be expected to demonstrate an understanding of the interactions among people, places and the environment.
- Students will use maps, globes, pictures, models and technologies to represent and describe physical and human systems.
- Students will use location, distance, scale, direction, and size to describe where places are and how they are distributed.

Interdependence:

- Students will be expected to demonstrate an understanding of the interdependent relationship among individuals, societies, and the environment and the implications for a sustainable future.
- Identify and describe examples of positive and negative interactions among people, technology and the environment.

Link to the Canadian Atlas Online (CAOL)

www.canadiangeographic.ca/wind

Additional Resources, Materials and Equipment Required:

- Computers
- LCD projector
- Internet access

The following URLs:

- http://www.weatheroffice.gc.ca/canada_e.html
- http://www.windatlas.ca/en/maps.php

Main Objective

This lesson demonstrates the relationship between wind speed and elevation.

Learning Outcomes

By the end of the lesson, students will be able to:

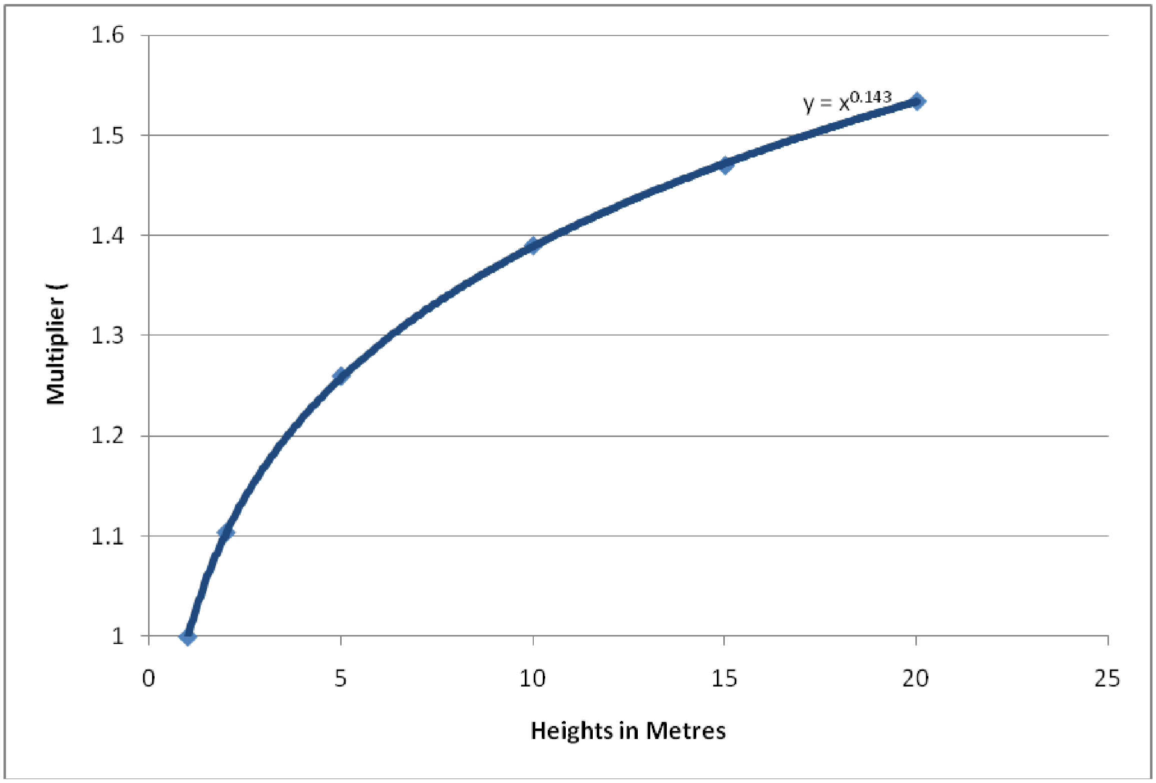
- Understand why turbines are built at heights of 50-80 m, rather than being taller or shorter.
- Understand the relationship between wind speed and height above the ground surface.

The Lesson

	Teacher Activity	Student Activity
Introduction	1. For background preparation, direct students to the information on the Canadian Atlas Online site: www.canadiangeographic.ca/wind 2. Inquire: *"Does it matter where wind turbines are located"?* *"Why is it necessary for the turbines to be mounted so far above the ground?"* *"How much difference does height make?"* ***Note:*** *Wind turbines typically are constructed 50-80 m above the ground surface. Traditional windmills (especially those in The Netherlands) are not so high.*	1. Gather background information from: www.canadiangeographic.ca/wind 2. Discuss in small groups or individual short written responses with suggested responses to these questions. These suggestions will be explored throughout the course of the lesson.
Lesson Development *1. Role of friction*	3. Review the following concepts through guided questioning: a.) Winds are horizontal motions of air produced by pressure differences. b.) **Three** parameters determine speed and direction of wind: ***Coriolis Effect***: movement rotates to the right in the Northern Hemisphere. However, this is only notable over a large region. ***Pressure gradient force***: winds blow from high to low pressure. Larger differences in air pressure produce stronger winds. ***Friction Force:*** interaction with the ground and obstacles. Winds are subject to drag at the surface due to roughness (mountains, trees, buildings). This causes winds to slow down and counters the other effects.	3. Conclude that interaction between ***Coriolis Effect*** and ***Pressure gradient force*** can be seen on weather maps and television weather broadcasts – winds do not move in straight lines from high to low pressure, but rotate counter clockwise around lows, clockwise around highs. (*Observe the regional pattern by watching (recorded) TV weather broadcast; or from downloaded weather maps from Environment Canada website.)* Animations: The Coriolis Effect/Pressure Gradient Force: http://www.classzone.com/books/earth_science/terc/content/visualizations/es1904/es1904page01.cfm?chapter_no=visualization http://ww2010.atmos.uiuc.edu/(Gh)/guides/mtr/fw/crls.rxml Think about consequences: To get out of the wind, get low.

	4. Indicate that in an enclosed space such as a football stadium wind directions can vary with altitude due to the actions of friction and pressure in combination. The wind can blow in a different direction at the top of the stadium (as indicated by the flags) than at field level (as indicated by passes and punts). Ask, "*Have you observed this*? "*Does the height above ground make some difference?"* "*Is the wind direction indicated by flags at your school (or elsewhere in town) always the same as that felt while standing on the ground?"*	4. Respond to example and questions to and conclude that the height above the ground makes some difference. (If it didn't, you could launch a kite at ground level by just letting it go.)
2. Magnitude of Difference: <u>Experimental</u>	5. Use one or more of these techniques to demonstrate: a.) Set an electric fan on the edge of a desk. Estimate the speed of this artificial wind by launching small paper balls from a short distance in front of the fan. (This can provide amusement). See how far the breeze extends below the level of the fan. b.) If you have a tall flagpole available, fly several flags at different heights on the pole and observe the differences. c.) Using either a commercial or homemade anemometer, measure the wind speed at several heights: directly above the ground, at waist height, above your head, from a second story window (if possible and safe). d.) If possible, take measurements from different stories of a taller building (in a safe fashion).	5. In groups or whole class demonstration, explore experiments. ***<u>Note:</u>*** *Hold the anemometer at a 90° angle from the body to ensure that you do not block the wind. To measure directly above the ground, lie down and hold the anemometer upright.* (This could also be done outside of normal class hours or as a project/assignment if time does not permit an exploration of all.)
2. Magnitude of Difference: <u>*Numerical*</u> (Also see graph below)	6. Instruct that through a combination of measurements and physics research, if one knows the speed of the wind at 1 m above the surface, the speed of the wind at greater heights above the ground surface can be estimated. ***<u>Note:</u>*** *The speed of the wind increases proportional to the 1/7 power of the height above the ground. (For heights*	6. For measured wind speeds at each height, calculate the wind speed at 65 m above the ground surface. ***<u>Note:</u>*** *If you measured the wind speed at 2 m above the surface: divide your value by 1.1, to give an estimate of the speed at 1 m above the surface, then use that value in*

	less than approximately 300 m above the ground surface. For greater elevations, this relationship is not valid.) Mathematically: Wind speed at Height z = (Speed at 1 m) x $(z)^{0.143}$ So, if the wind speed at 1 m above the ground is 10 km/h, at 20 m: Speed = $(10)\ (20)^{0.143}$ =(10)(1.534) = 15.3 km/h And at 65 m (the height of a typical turbine), it would be $(10)\ (65)^{0.143}$ = 10 (1.81) = 18.1 km/h At 128 m, speed = $(10)(128)^{0.143}$ = 10 (2) = 20 km/h	*the equation. (Current version used here from:* http://www.windatlas.ca/en/maps.php*)*
3. Wind Speed Map	7. Open the following link to reinforce: http://www.windatlas.ca/en/maps.php Notice that the wind speeds vary with height above the ground surface. Wind speeds are given in m/s 1 m/s = 60 m/minute = 3600 m/h = 3.6 km/h	7. Note that this map allows one to see the differences with height above the ground, as well as from season to season.
4. Reformulation and questions arising.	8. Inquire: a) *"If the wind speed is greater at greater heights, why not build turbines that are 128 m high, instead of 65 m high?"* b) *"Why not build turbines that are only 20 m high?"* c) *"How does the wind speed vary in your area throughout the year?"*	8. Respond to questions: a) *The advantage in increased wind speed does not offset the difficulties in construction or maintenance or the potential risk to low-flying aircraft.* b) *There would be insufficient clearance between the rotor blades and the ground* c) *Study the maps in the online atlas.*
Conclusion	9. Prompt students to synthesize and evaluate their knowledge.	9. Conclude that wind speed is related to height and turbines are constructed at 50-80 m height.



Assessment of Student Learning

In-class discussion, process journal, or short assignment detailing observations or numerical calculations.

Lesson Extension:

<u>Construction of a homemade anemometer</u>

Increased wind speed may indicate approaching storm events. In many areas, winds from one direction may consistently have higher speeds than those from other directions. The instrument used for measuring wind speed is an anemometer.

Commercial mechanical or digital anemometers are available. However, you can construct your own.

Constructing the anemometer requires:

- 5 small paper cups
- 2 straws (or very stiff grass stems or reeds) with the same length
- 1 small nail (a finishing nail) or needle
- 1 small, straight stick, or 1 pencil with eraser
- 1 ruler (to calibrate the anemometer)
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1. Take 1 of the paper cups. Using the small nail, punch four holes in the cup at right angles, approximately 1.5 cm (0.5”) below the rim of the cup. Feed the straws through the holes to make an “X” form.

2. Punch a hole in each of the remaining 4 cups, approximately 1 cm (0.4”) below the rim. Feed each cup onto the end of a straw. Ensure that all of the cups are facing with their openings oriented clockwise.

3. Push the small nail or needle through the centre of the "X" formed by the straws. Push the other end of the nail or needle into the straight stick, or into the eraser of the pencil.

4. Ensure that the anemometer rotates freely. Position it near the wind wave, so that it is exposed to the wind.

5. Calibrating the anemometer requires a ruler. Measure the radius of the circle made by the anemometer as it rotates (the length of one arm, including cup width and straw length to the centre pin). Calculate the circumference of the circle as $C = 2 \pi r$.

Determining Wind Speed

6. When the anemometer is rotating in the wind, measure the number of rotations per minute (RPM).

Multiply the RPM by the circumference to determine the speed of rotation of the anemometer in centimetres per minute.

This value will give you the approximate angular velocity of the anemometer.

The approximately angular velocity value will not be the true wind speed. However, if values are recorded over time, relative changes in the speed of the wind may be determined.

If you have a commercial anemometer available, you can calibrate all your homemade anemometers by mounting them adjacent to the commercial one. Make sure that they are all at the same height above the ground, and in an open area so that there is no interference from structures or trees.

Alternatively, if you have an electric fan, you can mount the anemometers in turn in front of the fan, and calibrate the homemade ones using the commercial anemometer.

Link to Canadian National Standards for Geography

Essential Element#3: **Physical Systems**

- Components of the Earth's physical system
- Global ocean and atmospheric systems
- Spatial graphics (various map types)
- Interpret satellite-produced images to locate and identify physical and human features.

Essential Element #5: **Environment and Society**

- Environmental issues
- Effects of human modification of the physical environment

Geographic Skills #2: **Acquiring Geographic Information**

- Systematically locate and gather geographic information from a variety of sources.

Geographic Skills #5: **Answering Geographic Questions**

- Formulate valid generalizations from the results of various kinds of geographic inquiry