DESIGNING A BRIGHTER FUTURE

UNIT 3:

TURBINES ARE A BREEZE

The popularity of wind energy continues to grow around the world (Canadian Wildlife Federation, 2020) because it is " a key player to lowering our carbon emissions and researchers predict that Canada will increase our power 3.5 fold in the next 15 years (Overall, 2017, para. 2). During this unit, students will have the opportunity to act as engineers and undertake the design process to, as its name suggests, design, build and analyze their own wind turbine.

CURRICULUM CONNECTIONS

This resource is linked to the science and technology curricula at the elementary level, including systems, electricity, forces and the environment, as well as to the arts and mathematics (geometry and trigonometry) curricula. The unit is also associated with the secondary science curricula, particularly in grades 11 and 12, where there is an emphasis on energy, electricity, magnetism and environmental sciences.

LEARNING OUTCOMES

- List the roles and responsibilities of engineers and describe their contributions to society
- Describe different forms of energy
- Explain how a wind turbine works
- Design and build a prototype of a wind turbine
- Test the prototype and assess its effectiveness

SUGGESTED TIME: 2.5 HOURS (ELEMENTARY); 4.5 HOURS (SECONDARY)

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These resources were created through a collaboration between Ingenium and a University of Ottawa doctoral candidate, Janelle Fournier.

INTRODUCTION AND BACKGROUND INFORMATION

For several decades, many countries have used wind energy for electrical purposes. This form of renewable energy has only recently become popular in Canada[1], as the country has utilized other forms of energy, such as hydroelectricity[2].

Wind energy uses the kinetic energy produced by the wind and transforms it into useful forms. There are 4 main uses of wind energy:

1. Ships' sails use wind energy as propulsion;
2. Windmills take the kinetic energy and convert it into mechanical energy to grind grain and pump water;
3. Windmills are also used for sawmilling;
4. More recently, wind energy is used to generate electricity[2].

Almost every province and territory in Canada uses wind power. "By 2018, wind energy will meet about 6% of the country's electricity demand. In some provinces, the percentage is higher: 28% in Prince Edward Island, 12% in Nova Scotia, 8% in Ontario, and 7% in Alberta and New Brunswick" [translation][3].

Although we often see wind turbines that look like the picture to the right, there are actually two categories of wind turbines: vertical axis and horizontal axis. This image represents a horizontal axis wind turbine because the rotating axis of the blades is parallel to the flow of the wind, thus it is horizontal. These wind turbines are the most popular and commonly used commercially because they are most efficient when there is a constant flow of wind. However, if the wind is turbulent, vertical axis turbines (where the main axis of the blades is vertical) should be utilized. They are placed where winds are turbulent, such as shorelines, rooftops and urban landscapes, because their construction allows them to capture wind from all directions[4].

Photo: Johanna Montoya

During this unit, students will have the opportunity to act as engineers to understand, design and test their own horizontal or vertical axis wind turbines. They will have to make design and aesthetic decisions to build efficient turbines.

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[1] Canadian Wind Energy Association, n.d.
[2] Sager, 2016
[3] Canadian Wind Energy Association, n.d., para. 5
[4] Khillar, 2019

RECOMMENDED PROCESS

1. **Brainstorming about engineering**
   - It is suggested that you start the unit by brainstorming about engineering. As the students come up ideas that relate to this profession, try to highlight the engineering disciplines, such as chemical, mechanical, electrical and environmental engineering; the various roles and responsibilities of engineers; and the need for these professionals for the betterment of society.
   - Present the work of a few engineers who work in different fields. Appendix 1 provides examples that can be used to facilitate this discussion.

2. **Explain the design process**
   - If this is the first time you or the students use the design process, Appendix 2 can be a useful tool for you to assist in the introduction of the process to the students.

3. **Setting the scene**
   - Present a situation in which students act as engineers to design wind turbines. For example: you live in a place where all non-renewable resources have been exhausted. You now have the task of ensuring the survival of your community. To do this, you must rely on the wind to design and build a wind turbine.

4. **Working through the steps of the design process**
   - Students, in groups of 3 or 4, begin the steps of the design process. Although this process remains identical for students attending elementary and secondary schools, the extent to which they will undertake the unit differs based on grade levels. The next section provides details based on student grade levels.

GRADE SPECIFIC DETAILS

In this section, there are distinct suggestions for elementary and for secondary teachers. The recommended activity for elementary school students involves designing a wind turbine that can lift an object, while secondary school students will design a wind turbine that can produce electricity.

Grades 4 to 8

Students will have to build a wind turbine that a rope and a container of weights will be attached. The wind turbine is considered effective when it can turn its blades, thus wrapping a piece of string around a wooden dowel, and finally raising a container of weights. The more weight the turbine can lift, the more effective it is.

1. **How wind turbines work**
   - Before designing wind turbines, students should learn how they work. Learn Engineering[5] offers short videos to help with this task. To access their video on wind turbines, please refer to the following site: https://www.youtube.com/watch?v=qSWm_nprfqE.
   - Following the video, you can outline some facts that can help students design an efficient wind turbine.
     - Number of blades: usually between 1 and 8;
     - Blade size: small blades will spin faster than large blades, but large blades have more power;
     - Blade shape: affects the amount of energy produced, because a high blade speed will produce more electricity compared to a low speed;
     - Rotor radius: long arms can support more weight, but small arms rotate faster[6].

2. **Turbine design**
   - Students will have time to brainstorm ideas for their design of a wind turbine that can lift a container with weights. Once they have chosen a model, they should make a list of the materials required and draw a sketch of their turbine.

3. **Building the turbines**
   - Students can bring in materials from home and some items may be provided by teachers. We suggest providing a few items, such as pieces of cardboard, tape, tubes, plastic cups, straws, paper, wooden dowels, etc.[7]. Additionally, we recommend that teachers provide string, a container, and weights, such as washers, to ensure that these items are identical for all student groups.

4. **Analysis of effectiveness**
   - As students build their wind turbines, there should be dialogue between classmates and with teachers. The teacher should ask questions to ensure student understanding. For example, why did you choose this shape and why did you use this number of blades? Why did you choose these materials for construction? How much weight do you think your turbine will be able to lift?

5. **Testing and reconstruction of the prototype**

[5] Learn Engineering, 2015
[6] Northeastern STEM, 2019
[7] Northeastern University Center for STEM Education, n.d.

- Once the wind turbine is built, students should test its effectiveness with a fan. They should note the number of weights that were lifted, as well as the strengths and weaknesses of their prototype. Afterwards, they should have the opportunity to rework their design to improve it.

6. **Presenting the prototype**
   - Ask students to present their final prototype to the class, explaining their design and its effectiveness, successes, failures and areas for improvement.

<u>Grades 9+</u>

The design of a wind turbine at the secondary level differs from the primary level because it will be able to produce electricity. Students will still follow the design process, but are required to seek additional information and complete a few more activities that will help develop their critical thinking.

The Physics of Wind

<u>Kinetic energy formula</u>

$$E_c = 1/2\, mv^2$$

<u>Calculate the power of the wind</u>

$$P = 1/2\, \rho A v^3$$

P = wind power (W)
ρ = air density (kg/m^3)
A = area of the turbine surface (m^2)
v = wind speed (m/s)

1. **Energy forms**
   - Introduce the forms of energy (e.g., kinetic, electrical, sound, etc.), practice energy calculations[8], and explore the concept of energy transformation in order to understand the conversion of kinetic energy into electrical energy.

2. **Operating wind turbines**
   - Have students research how a wind turbine works. We suggest that students refer to the Canadian Wind Energy Association (CanWEA) website.

3. **Exploring turbine types**
   - There are two types of wind turbines – vertical axis and horizontal axis. Students should learn about both types of turbines in order to decide which one would be the most efficient for their prototype. We suggest, completing the next two activities with the students:
     - Provide a history of vertical axis wind turbines focusing on the work of Raj Rangi and Peter South - two Canadians who are recognized for their contribution to wind energy. Details of these engineers can be found in Appendix 3.
     - Conduct an analysis of horizontal wind turbines. To do this, present two wind turbine models that were designed by high school students in a WindEng competition. Provide the fact sheets in Appendix 4 to enable them to analyze the turbines. Ask them which model would be the most efficient for generating energy and to explain their reasoning.

4. **Brainstorm divergent ideas**
   - Once students have a better understanding of wind turbines, student groups should consider the design of their turbine, including the type of turbine. They should also explore wind turbine blades that vary in size and shape. Encourage the use of prior mathematical knowledge such as trigonometry, geometry, circumference, and area[9].

[8] The Royal Academy of Engineering, n.d.
[9] Cunningham et al., 2019

- They will then be asked to sketch the model they wish to build, including the precise dimensions.

5. **Build the wind turbine**
   - After they have chosen the design they want to build, students will have to collect the materials needed for construction.
   - A second option would be to use modelling software such as Google SketchUp or Thingiverse and have the prototype printed on a 3D printer[10].
   - In addition to the materials needed for the blades, a generator is required. Teachers may choose to provide this device or undertake an electromagnetism activity to construct their own small generator.

6. **Test the turbine**
   - Obtain a source of wind, such as a fan, and place the turbine in front of the unit. Ask students to determine the voltage produced by the turbine using a voltmeter. Students will have to adjust the power of the wind source and the distance between the wind source and the turbine. They will need to collect data.

7. **Analyze and modify the turbine**
   - Students will then need to analyze and modify the turbine to ensure its operation, efficiency and aesthetics.

Alternative method – Making the turbine digital

If the tools are available at school, students could use Arduino Uno or micro:bit microcontrollers to measure the capacity of their prototype.

8. **Written report/presentation**
   - Ask students to provide a written report or make an oral presentation to explain their design choices (e.g., type of turbine, number of blades, etc.), efficiency results collected, successes and failures, and areas of improvement.

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- Describe how Newton's laws work on their prototype.
- Draw wind turbine force diagrams to illustrate the forces acting on a turbine.
- Explain how a generator works.
- Explore and describe the social, economic, and environmental impacts of wind energy.

[10] Cunningham et al., 2015

ASSESSMENT

Diagnostic
While the students are brainstorming ideas that pertain to engineering and engineering tasks, teachers can record their prior knowledge of this profession or take a photo of the written/drawn brainstorm session (once completed) for a post-course assessment.

Formative
As students begin the design process, teachers can assess their knowledge of wind turbines, either through questioning or by written documentation. They could ask their students the following questions: Why use a vertical or horizontal axis turbine? Why choose this blade shape? Why these materials? In addition, while they are working (or after they have completed the task) the students could complete a handout for each step of the design process. These documents can be part of the final report or could be useful to ensure student understanding as they work on their prototype.

Summative
Evaluate the final report or oral presentation that describes their design, aesthetics, successes and errors of the turbine, as well as an analysis of the efficiency. Students should also elaborate on how the turbine could be modified or improved.

APPENDIX 1 – ENGINEERS

Engineers use their creativity to design and create machines, structures or processes that can solve societal problems to improve people's quality of life[11,12]. They need to use their knowledge of multiple disciplines, including science and mathematics, to transform abstract ideas into physical objects[11].

Engineers in fields, such as mechanical, civil, electrical, electrical, environmental and chemical, all work to solve problems that affect their discipline. For example, one person might notice the need to connect the city of San Francisco with the Marin County, as did the civil engineer, Joseph Strauss. In response, he designed the Golden Gate Bridge[13].

There are many excellent examples of people trying to make a difference in the world. Discover the work of these passionate engineers!

More details about these engineers can be found at https://womeninstem.ingeniumcanada.org/. We also recommend exploring the posters of: Lynn Conway, Charity Wanjiku, Jill Tarter and Melissa Sariffodeen.

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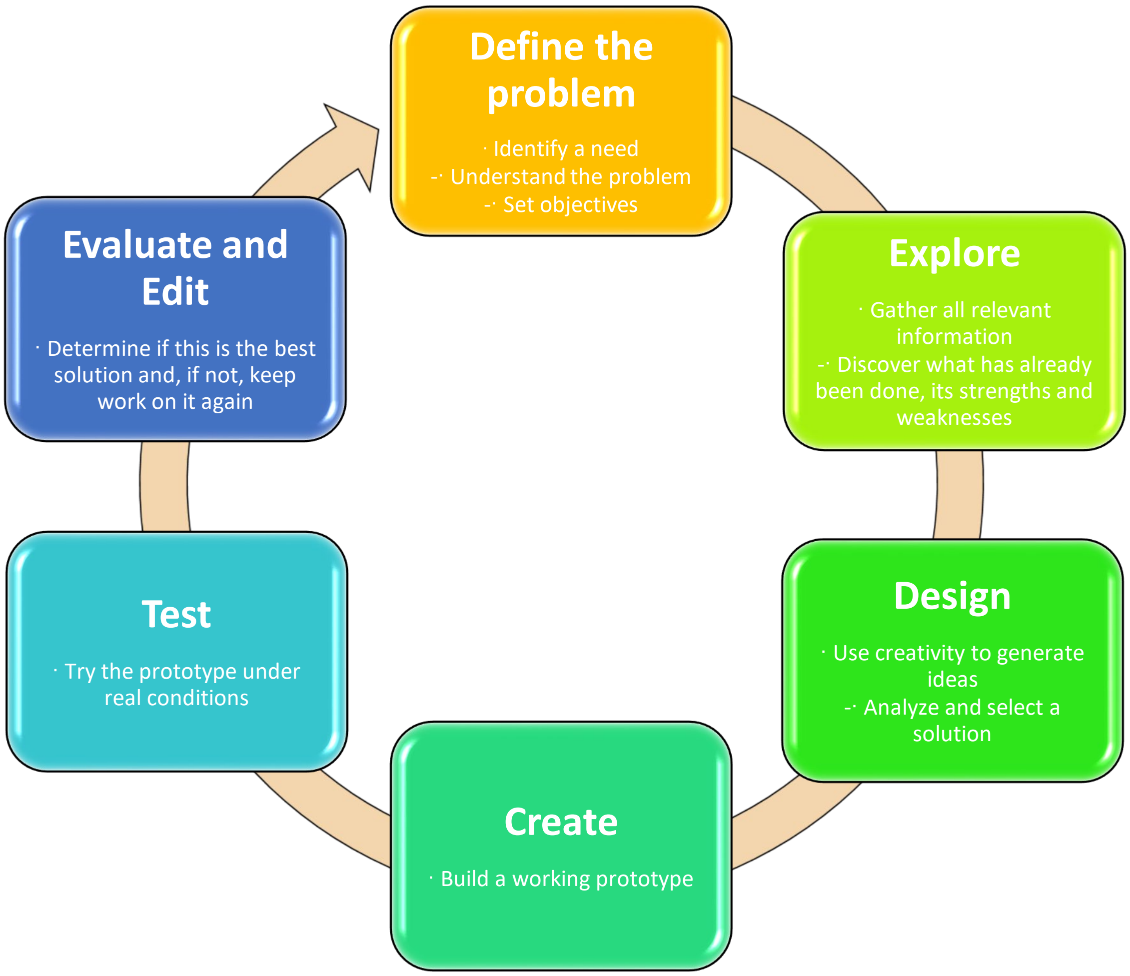
11 Khandani, 2005
12 Lucas, 2014; PBS Kids, 2017; TeachEngineering, n.d.
13 Golden Gate Bridge, Highway and Transportation District, n.d.

APPENDIX 2 –DESIGN PROCESS

The design process, used by engineers, can be used when a someone tries to solve a problem that has multiple solutions. There are six steps to the design process.



Adapted from Khandani (2005); The Works Museum (2016)

APPENDIX 3 – TWO CANADIANS PASSIONATE ABOUT WIND ENERGY

In 1931, Georges Jean Marie Darrieus, an aeronautical engineer from France, obtained the patent for the first vertical axis wind turbine[14,15]. The design had three blades in the shape of an arc, with the tips attached to the top and bottom of the shaft[14]. However, Darrieus did not continue his work on wind power and his contributions had been forgotten[15].

In 1966, when Raj Rangi and Peter South were working for the National Research Council Canada (NRC), they experimented with wind energy. Rangi and South were also working with two- and three-blade arc-shaped models, which allowed the wind to blow in any direction to turn the turbine and thereby generated electricity[16].

Since Darrieus' work had been largely forgotten, the two Canadians did not realize that their models looked very similar to Darrieus'. When they sought a patent for their model of a vertical axis turbine, it was denied. However, some good came out of this, as Rangi and South were credited with the rediscovery and popularization of the Darrieus-type wind turbines[15].

While these Canadian researchers were working on wind energy, they placed a vertical axis wind turbine on the roof of the NRC building (shown in the image below). As you can imagine, this turbine attracted a lot of attention. Subsequently, their work was approved and encouraged by their management[15] and the pair were able to continue working on their passion; wind energy.

Until the late 1980s, the Rangi and South model dominated wind farms in North America[17]. Since then, horizontal axis turbines have gained popularity due to their increased efficiency. Recently, however, there has been a renewed interest in vertical axis turbines in Canada for electrical purposes[18]. So don't be surprised if in the future you see the designs of Raj Rangi and Peter South near you!

Figure 1 - The first vertical axis wind turbine of the Darrieus type developed by Raj Rangi and Peter South. It was mounted on the roof of the National Research Council of Canada building.
(Photo: National Research Council Canada)

[14] Kumar et al., 2019
[15] Tudor, 2010
[16] Ingenium, n.d.
[17] Vertical Axis Wind Turbine Model, n.d.
[18] Sager, 2016

APPENDIX 4 – ANALYSIS OF HORIZONTAL AXIS WIND TURBINES

Fact sheet – turbine A

Artifact number

2010.0092.001

Manufacturer's location

Norwich, Ontario, Canada

Date of manufacture

2010

Context – function

Small scale 3D model of a machine designed to produce electricity from wind.

Technical background

The blades are made of balsa wood, which have been soaked in a mould filled with water. The tower, nose and nacelle are finished, painted and decorated with the school's initials. The blades have red anti-aircraft markings.

Description

The wood-clad model has balsa wood blades; the motor and fittings are made of metal and synthetic material. Model painted white; red markings.

Length

93.0 cm

Width

49.0 cm

Fact sheet – turbine B

Artifact number

2010.0093.001

Manufacturer's location

Toronto, Ontario, Canada

Date of manufacture

2010

Context – function

Small-scale 3D model of a machine designed to produce electricity from wind.

Technical background

After testing several models, the students decided to choose an eight-blade model. The nose and areas of the "pod" were left open for easy access, maintenance and repairs. This would allow students to quickly correct any problems. The turbine produced power for one minute with an average efficiency of 0.707 watts.

Description

Smooth, reflective black synthetic blades attached to an unfinished wooden hub; unfinished wooden frame; black synthetic pole and belt; silver metallic components (some painted white); white moulded synthetic gear.

Length

105.0 cm

Width

59.0 cm

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Vertical Axis Wind Turbine Model, No. 103204.