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Prototyping a Wind Turbine and Measuring Performance

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> "The stone age did not end because the world ran out of stones, and the oil age will not end because we run out of oil."[1]

Introduction

The Stone Age ended because new technologies were developed, specifically bronze tools, which were less expensive and met the changing needs of people. The Saudis repeat this mantra with an awareness of the availability of cost effective alternative sources of energy generation along with their own investment in alternative energy generation technologies.[2] There is acknowledgement by the Saudis that there are serious economic difficulties ahead.[3]

It is predicted that the worldwide energy consumption in 2035 will be 22.8 TW (terawatts).[4] This is 22.8E12 Watts. Because energy is needed for industrialization and it's a significant part of the world economic base, it is viewed as the number one of the top ten global challenges. For example, energy is first to water, food, environment, poverty, war, disease, education and democracy.[5] If there is energy, water is pumped, fields are irrigated, the environment is remediated, food is transported, war is unnecessary, cures to diseases are found, education is available to everyone and everyone has a voice. To give perspective to the global growth of energy consumption, the year with the energy consumption is listed: 1950 at 3.5 TW, 1970 at 7.3 TW, 2005 at 14.7 TW and projected in 2040 to be 25.6 TW.[6,7]

Solar energy is the fastest growing renewable energy source; however, its study requires a wet laboratory. Therefore, the scope of this unit is to prototype a wind turbine and measure its performance. Because electricity and magnetism are conceptually abstract, integrating these concepts to the creation of energy requires these concepts to be visualized experimentally. For example, radio waves cannot be seen, yet their properties enable a radio to broadcast audio. Similarly, electricity and magnetism cannot be seen by the naked eye. With careful design of renewable energy technologies, energy made from these abstract concepts can be leveraged to operate our industrial societies.

Electricity and magnetic fields are difficult concepts to understand at the high school grade levels 10-11. The approach to this unit is to scaffold the instruction by beginning with experiments that enable the students to see what cannot be seen with the naked eye, a magnetic field. Electricity cannot be seen, but it can be measured as well as quantified using a voltmeter. Then, it is with written instructions that the students will engineer and build a wind turbine to create energy. The energy generated from a wind turbine can be measured directly as current in the units of amps or it can be measured by putting increased demand on the circuit until literally the lights go out. For example lights of increasing intensity can be tested until the demand exceeds generation capacity. Each activity will have an electronic worksheet that will be filled out and submitted in Google Classroom. Each day, the students will do a “Bell Ringer,” which will cover one concept followed by a short class discussion. The Bell Ringer will periodically consist of a series of questions answered in small groups to share peer knowledge. This unit created herein fits into the Energy unit provided by the Project Lead the Way (PLTW) Curriculum. PLTW relates the units to standards.

Demographics

Curie Metropolitan High School has 3000 students in grades 9-12. It is a 1+ school in the Chicago Public School (CPS) District and holds 93.1% of the students below the poverty level. Thus, Curie Metropolitan High School students are eligible and do receive free lunch and breakfast. The school is located on the southwest side of Chicago, a few blocks from Midway Airport. Academic year 2018-2019, the Career Technology and Education Program (CTE) introduced the first year of a 4 year Pre-Engineering major using curriculum from Project Lead the Way (PLTW). The first year, the students take a class called Introduction to Engineering Design (IED) where the students learn how to use the Computer Aided Design Program Autodesk Inventor make drawings and execute the building of half a dozen small projects and a final design project. The second year of the pre-Engineering program is called Principles of Engineering (POE). This course has a section on “Energy Sources and Applications” where this unit will be included. I was hired by CPS to lead and develop the pre-Engineering program. I have completed my first year of teaching High School after making a career change as a contributor in the Pharmaceutical Industry as a Chemical Engineer improving manufacturing processes to reduce costs as well as an Analytical Chemist developing methods for the quantitation of active pharmaceutical ingredients and drug products. At this time, I have 2 POE classes for the 2019-2020 academic year, each with 30 students and 1 IED class. One POE class will be sophomore students and the second junior students. The pre-Engineering major requires the students to stay in the program the entire duration of their high school years. The class meets for 50 minutes every school day. This unit is planned for three weeks with activities first and understanding the principles after each activity.

Content Objectives

There are 4 objectives to this unit. One objective is to understand why we are here at this moment based on historical events. This includes understanding the history of energy usage, globalization, economics of renewables and our changing climate. The second objective is to learn the vocabulary around energy, how it is measured and the abstract concepts surrounding its generation. The third objective is to experiment with magnets and wires to understand fundamental concepts of electricity and magnetism. The fourth objective is to build a prototype wind turbine and measure the energy it produces.

History

The first oil well was drilled in 1859 in Pennsylvania, but it wasn't until the late the 1930s and 1940s when oil began to dominate the US economy.[8] The environmental impact of oil drilling was apparent in Pennsylvania and East Texas during the first explorations. However, it was accepted that this was the price to pay to move from an agrarian economy to one that is industrial. Unfortunately, in the south, the effects on rural poverty and land degradation were ignored by the greed of the wealthy.[9]

In the late 1890s, Arrhenius understood the critical impact of the temperature rise at the Earth Surface with carbon dioxide concentration.[10] Arrhenius calculated an increase in temperature of 8-9 degrees Celsius at the Earth surface in the Arctic region would occur with an increase of carbon dioxide of 2.5-3 times that amount at his time, about 295 ppm.[11] In 1960, Keeling had recognized the need to quantitate the changes in carbon dioxide concentrations by building an experimental station in Hawaii.[12,13] The Intergovernmental Panel on Climate Change (IPCC) was created in 1988 to bring scientists from all United Nations member countries to create a nonjudgmental environment to bring knowledge and create ways to mitigate the impact of climate change.[14] In 2006, our former Vice-President wrote a book to enlighten Americans about the challenges ahead due to global warming.[15] There are still challenges today for Americans to understand the impact of climate change.[16,17] In spite of the resistance to the acceptance carbon dioxide heating our plant, the greatest increase in world energy usage is in renewables (~4x) followed by natural gas (~2.5x) and then petroleum (~2x), while nuclear and coal sources of consumption decrease.[18]

Environmental Impact

Figure 1A illustrates graphically the measurements made of the carbon dioxide concentration in the air and the melting of the Arctic ice in terms of surface area using the data referenced herein.[19,20] NASA shows an average 12.8 percent decline in average September sea ice since the 1990s. Visually, pictures taken from space show one million square miles of the Arctic Ocean ice (the size of California, Indiana and Texas combined) has melted in the last 50 years; the icecap has reduced to half its size.[21] Alaska, Canada and Greenland have experienced a 7 degree Fahrenheit increase in temperature in the last 50 years. Polar bears are becoming extinct and the ecosystem is changing. The frozen tundra is turning into temperate forests. Greenland once a frozen mass is seeing a farming boom of broccoli and potatoes. Countries such as Russia, Canada, and Norway, whose boundaries were defined by land and ice are becoming territories whose borders include open-ocean and the natural resources in these waters are under discussion in the United Nations. The melting of the ice reveals fossil fuels, natural gas, gold, lead, magnesium, and zinc in significant amounts. New sea routes are opening that are as much as 25% shorter than some routes critical to shipping of oil through narrow straits. The climate change observed is large enough to change the economic powers that exist today.[22] The driving force to develop renewable energy is not about running out of fossils fuels; it is about the cost of drilling, securing delivery and saving our planet.[23]

Figure 1B illustrates a proportional increase in world energy consumption with world population graphed using the data referenced herein.[24,25,26] Since 1920, there have been 3 components to global growth. One is the increase in world population.[27,28] Two is an increase in economic growth with an increase in industrialization.[29] Three is an increase in the carbon footprint, the amount of carbon dioxide in the air.[30] With respect to population, the current world population is 7.6 billion.[31] It is predicted by the U.S. Census that China and India will reach a population of 1.43 billion and 1.28 billion people, respectively. The United States is the 3rd most populated country at 323 million people.[32] The U.S. Census projects a maximum world population of 10 billion in 2050, where after it will decline. The population will start to decline in 2030 and 2050 for China and India, respectively. Population changes in Africa, parts of South America and the Philippines are hard to predict.

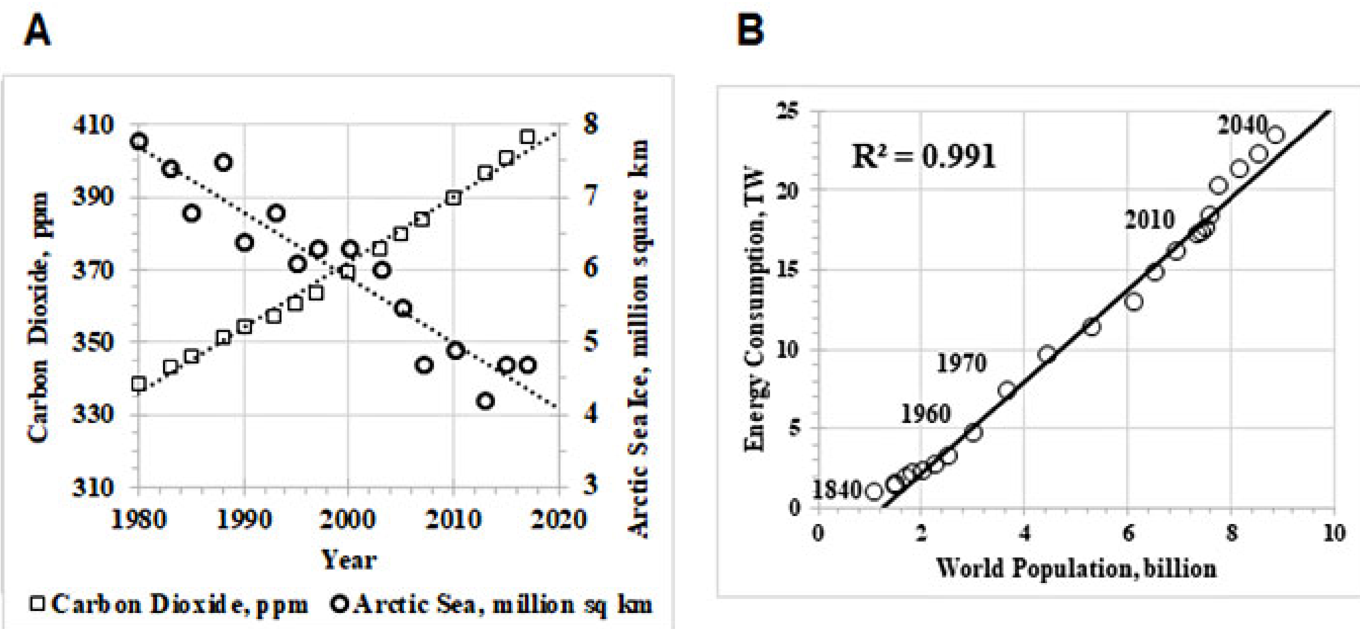

Figure 1. Impact of Industrialization. A) Atmospheric Carbon Dioxide Increasing and Arctic Ice Decreasing in the last 40 years. B) Global Energy Consumption increases Proportionate to World Population.[19,20,24-26]

Economic Stability

It is said that Energy, not the dollar will be the currency of the world.[33] In order to maintain a stable and sustainable, economic global supply of energy, it is critical to reduce the carbon dioxide footprint and secure the supply chain by avoiding civil unrest.[34,35] Safeguarding maritime choke points (e.g. the Strait of Hormuz, Strait of Mandeb, Strait of Malacca, Panama Canal, Suez Canal in order of significance) where 61% of the world's oil trade operates via the sea routes is critical to avoiding a world energy shortage and crisis.[36,37] A summary of the complex international political dynamics are discussed as they show the magnitude of the challenges of oil shipping security.[38,39,40] The political challenges today will undergo a shift and the countries holding economic powers today are likely to change.[41,42,43] The rate of development in countries like China, India and Africa indicate that these countries will be our next world powers.

Figure 2A illustrates the financial investment in renewable energy is significant on a global scale (black columns). China has the largest investment and the greater per cent of the total world investment (dotted columns). This is because China has created policies to use green energy such as solar panels and wind energy in a business to make and sell electric cars. China has been caught in the geopolitics of unstable governments for fossil fuels (e.g. Venezuela) and the limitations set for nuclear energy usage. Thus, China is making a strategic move to be a leader in green energy to develop energy and economic independence.[44] Europe has invested in renewable energy to reduce the impact of political instabilities in the Ukraine. With this investment and growth, the cost of renewable energy is reducing. On a global scale, solar and wind energy are the fastest growing renewable sources of energy and represent 80% of the renewable energy growth. Nuclear energy use is decreasing with safety risks and hazardous waste management demands while hydroelectric energy is holding constant.[45,46,47,48]

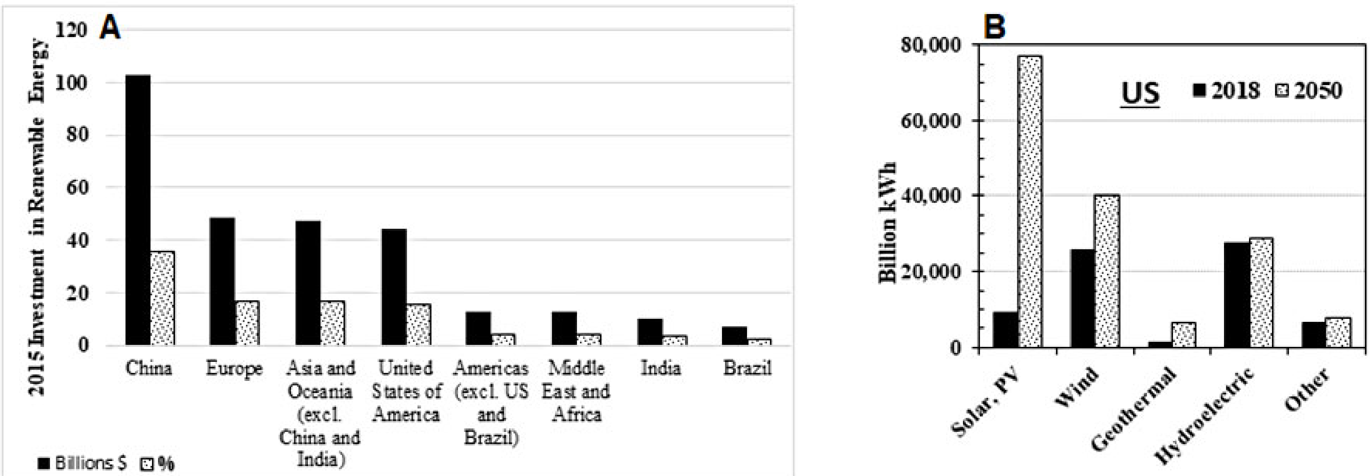

Figure 2. Projection of Renewable Energy Growth A) Investment in Renewable Energy by Country and B) Growth in Energy Consumption by Renewable Energy Source.[44,49]

Figure 2B illustrates the growth in the United States.[49] By 2020, China, U.S. and India will account for 2/3rds of the global renewable energy growth. Integrating the electricity generated from renewable energy in the grid is another challenge. By 2022, Denmark is projected to be the world leader, with 70% of its electricity generation coming from renewable sources next to Ireland (33%), Spain (25%), Germany (25%), England (25%), Italy (15%), Australia (11%), Brazil (10%), U.S.A. (10%), China (8%), India (7%) and Japan (5%).[50]

Investment in education to support technology growth has been quantified. In 2017, in the STEM areas, China and India graduated 4.7 million and 2.6 million students, respectively, the U.S. graduated 568,000.[51] Education is another way to maintain a technology advantage. The number of STEM graduates in 2014 was 1.1 million and 800,000 in China and India, respectively; this shows significant growth of STEM graduates that is explained by the growth in population.[52] In the 2016-2017 academic year, the U.S. imported 128,000 and 105,000 students from China and India, respectively, for programs in science, technology, engineering and mathematics.[53] Now that Europe and Asia has recovered from the World War, the model is shifting from students staying in the U.S. to students returning to their countries.[54]

Cost

In Los Angeles, CA, a solar-battery electricity station is being build providing 7% of the city’s electricity in 2023 with cost estimates of 1.997 cents per kilowatt hour (kWh) for the solar power and 1.3 cents per kWh for the battery storage. This is less expensive than any power generated by fossil fuels.[55] In Lamar, CO, a 161 MW wind farm was built and the wholesale electricity rate was priced at 2.5 cents to 3.5 cents per kWh. The 2005 gas prices have resulted in fuel costs of 5 cents to 6 cents per kWh.[56] In Europe, studies have been done on the cost of combined renewable energy, solar and wind, and compared that with the cost of combined coal and gas power plants. Conventional coal power plants costs are 55 Euro/MWh and 110 Euro/MWh for gas turbine power plants at a carbon footprint cost of 20e/ton. At a carbon cost of 100 Euro/ton, coal power costs 115 Euro/MWh and gas power costs of 155 Euro/MWh. By 2050, it is modelled that the cost of a combined solar/wind power system to give a cost of electricity with low investment costs 80 Euro/MWh and in extreme cases of high investment costs 130 Euro/MWh.[57]

Concept

Energy is difficult to define and has many interpretations. One thing we know is there are 5 ways energy is generated or transformed: electrical, heat, work, light and chemical bonds. In a wind turbine, mechanical energy (work) is turned into electric energy. In the building of a wind turbine, electrical energy is being generated and measured. In this unit, energy is illustrated by the ability to design and build a machine to create electricity or to light a bulb or to move an object. In order to generate electrical energy, it is required to learn about magnets, electrons and copper wire. Specifically, we will be learning about how magnets in the presence of an insulated copper wire move electrons to generate electricity, one form of energy.

Magnetic Fields

One property of a magnet is that it gives off a magnetic field. For example, we cannot see oxygen with our naked eye, but we can do experiments that demonstrate oxygen exists. The same is with a magnetic field. Let's imagine a magnet in the shape of a solid rectangular box. If we gather small iron filings and scatter them about a magnet, the filings will align themselves to show a magnetic field, Figure 3A. The magnetic field is a reflection of the net charge accumulating from the alignment of the electrons. We know that the flow of electricity or the movement of electrons is what creates the poles, the magnetic fields and this unique physical property of polarity in magnets. The next question is, what creates the current in the magnet to give off a magnetic field? Inside a magnet there are atoms and these atoms have negative charges called electrons and positive charges called protons. The protons are held deep in the atom; they cannot move. However, the electrons have freedom to move under certain conditions. The electrons move and create electric currents. The current creates magnetic fields. For most materials, the magnetic fields point in many directions and they don't add up to give a net charge; they neutralize each other. This is not the case for permanent magnets. This is also what happens when an electromagnet is activated.

A magnet is a special type of material. We also know magnetic materials contain a metal and metals contain electrons, some which move readily when a force is applied and other materials where the electron holds tight to the atom. When looking at Figure 3A, let's say where the fields all come to a point, that point is called a pole. Since the direction of the electron movement is opposite one pole is called North (N) and the other South (S). What is a property of a magnetic pole? If we have two magnets and we try to put the North poles together, the two magnets will repel each other. If we put the North and South poles together, the metals will attract and it will take some force to separate the two magnets, Figure 3B.

There are 3 types of magnets: naturally occurring permanent magnets, temporary magnets and electromagnets. The naturally occurring permanent magnets can be made out of iron, actually an iron composite called ferrite. There is an additional magnet called alnico, which is made of aluminum, nickel and cobalt as well as trace amounts of other elements. Another type of permanent magnet is made out of a composite of elements neodymium, iron and boron. This is called a rare earth magnet. These magnets are inexpensive and will be used in our class. Lastly, another natural rare earth magnet that is quite powerful is made out of samarium and cobalt.

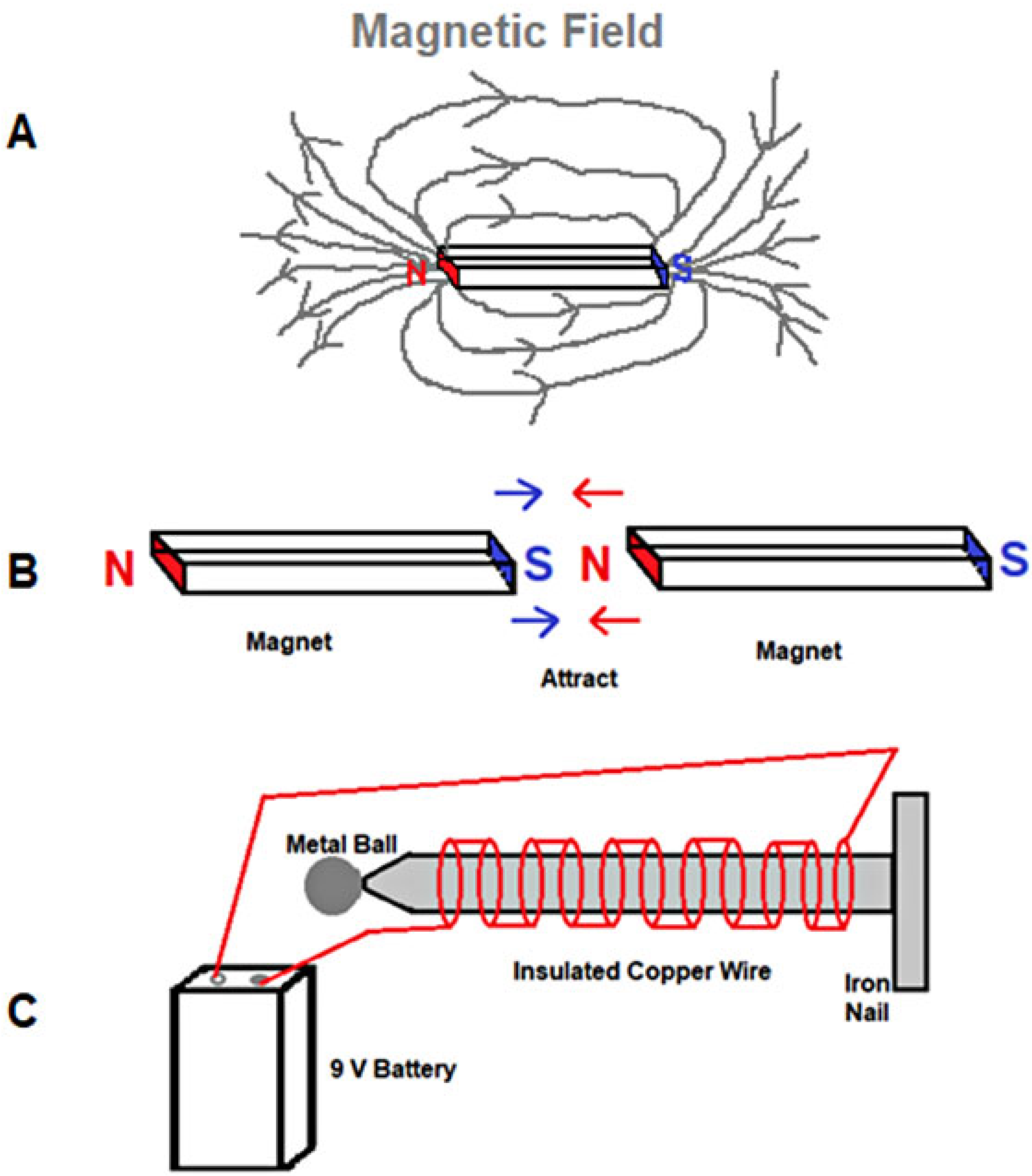

Figure 3. Illustrations of Magnets. A) Magnet illustrating magnetic fields not seeing by the naked eye, B) Attractive force exhibited by 2 magnets C) Illustration of Electromagnet.

Temporary Magnet

A temporary magnet is made, for example, by rubbing a nail or iron with one pole of a permanent magnet. The amount of magnetic force increases with each stroke. With each stroke, the electrons inside the iron are aligning. For a short period of time, the iron will have a North and South Pole. Weak magnets can be made to pick up items like a paperclip.

Electromagnet

An electromagnet is artificially created by using a battery to run current through an insulated wire wrapped tightly around an iron core, such as a nail, Figure 3C. The iron piece will have a North and South Pole and it will pick up metallic objects such as a metal ball or a paperclip. In order to magnetize the nail, the 9 V battery is used to run a current through the copper wire and the flow of electrons (current) in the presence of iron creates the magnetic effect. Once the battery is disconnected, there is no magnetic force and thus no magnet.

Electricity and Energy

The movement of electrons through, for example, copper wire is current and current is used to make electricity. Copper has the unique property that it has an electron that it is ready to give up, allowing an electron to leave the house to run in the magnetic field. In the presence of a magnetic field, the electron in copper that is furthest away of the center of the atom will give off an electron and this electron will move in the direction of the electric field, Figure 4A. The movement of electrons is called current and this it is how electricity is created. The electrons are shown in purple dots, the copper atom is shown in the center and the copper atom that has given up its election is called a copper ion. Figure 4A illustrates copper atoms with electrons rotating in the paths farthest away from the center of the atoms. In the rotation furthest from the center, it is like the electron has nobody to play with, so it bumps into its friends in the magnetic field and as they bump, the energy flows (e.g. like a ripple when a rock is thrown in water). The magnetic field is shown with grey lines. Figure 4B illustrates a fun exercise to do with the students. Here, the negative pole of a battery is set on a round magnet and copper wire (no insulation) is rolled around the battery. The electric and magnetic fields twirl the copper wire. The copper wire is shown in red. By attaching a voltmeter on each end of the copper wire, the current is measured.

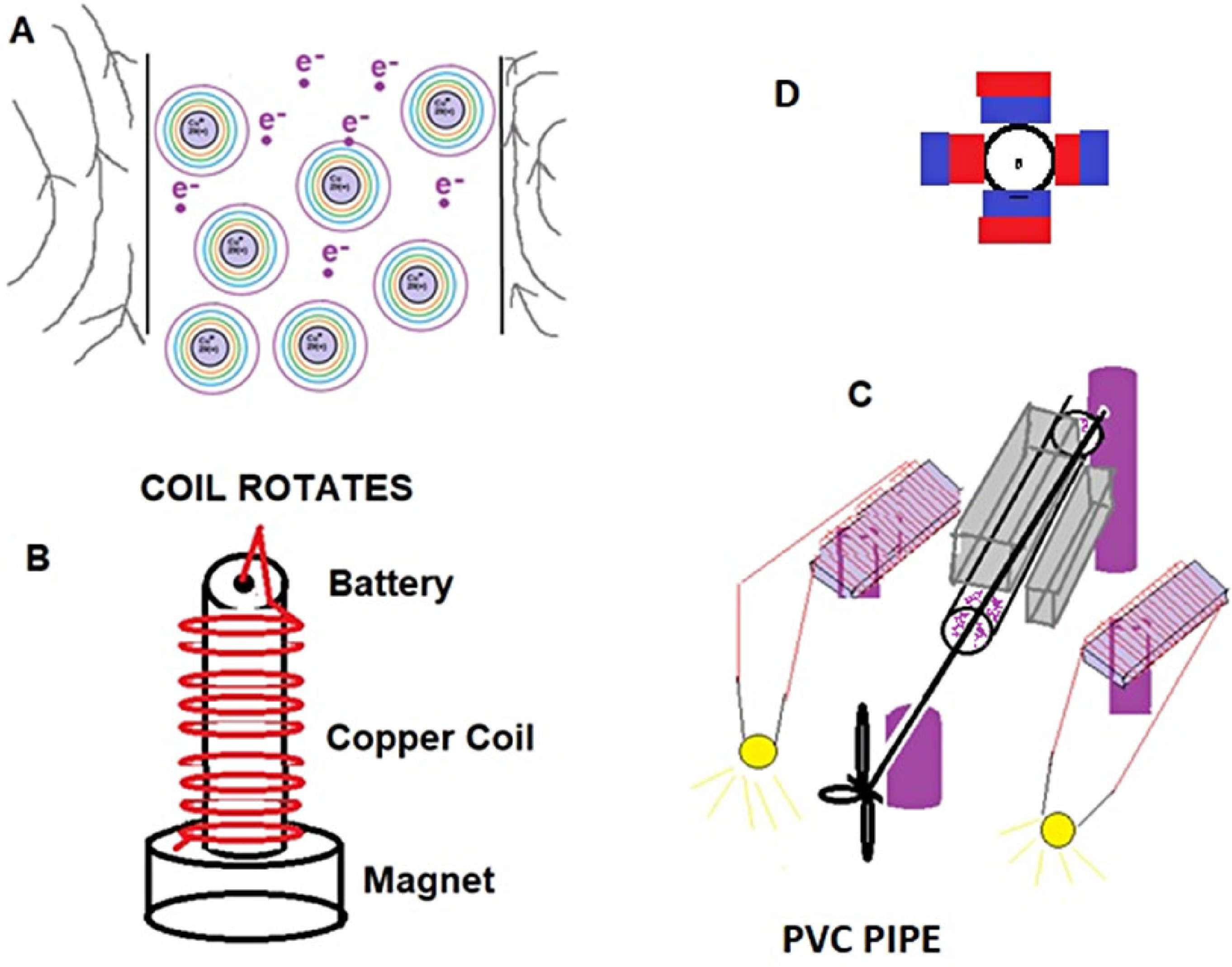

Figure 4. A) Diagram of Copper, Cu+ and free Electrons, B) Diagram for Rotation of Coil, C) Diagram of a Generator Design using PVC Pipe, D) Illustration of the Poles of the magnet direction for 4C.

Figure 4C illustrates a generator made from 1” OD PVC pipe (purple). This has become the preferred design due to the many ways efficiency can be improved and the design can be scaled. First, several tightly bound bundles of copper coated wires (red lines) are coiled on a non-rotating plate called a stator (blue). This stator is made of 2 pieces of 2.5”x3/4” iron strip and folded to give some thickness 1/8-1/4”. The magnets (grey) are attached to each side of the PVC pipe with glue. The magnets must be placed around the PVC with opposite poles adjacent to the pipe as shown in 4D. A nail is held in place in the PVC pipe by wrapping it with tape until it holds by friction and a turbine is attached to the nail. When the turbine turns, so do the magnets. In the presence of the stator windings, a magnetic field is created enabling electrons to light a hobby bulb. This design can be scaled for industrial usage. For example, the number of stator coils can be increased as can the number of magnets. The management of the winding of the coils can enable a significantly greater generation of electricity. Hoover Dam uses this type of design to take water flow and rotate a turbine using a similar generator design.

Fundamentals of Wind Turbines

The familiar term of Windmills is common. A windmill uses mechanical energy to move materials such as water. Wind turbines are used to take mechanical energy and create electrical energy.

Wind turbine blades are shaped similar to an airplane wing. The principles of what make an airplane fly and how the blades turn are the same. On one side of the blade, the blade is curved so a pocket of air is made by the high velocity of the wind passing over it. This provides "lift" and enables the blade to turn. The rotation of the shaft attached to the turbine is passed through a magnetic field created by magnets. The magnetic field moves the electrons inside the copper and mechanical energy is converted to electrical energy; this is called a generator. Our houses run at 110 V and 60 hertz. Depending on the type of generator, the passage of electrons will have to be managed using electrical tools to meet the needs of the grid or our appliances. From here the electricity can be stored in a battery or consumed as it is generated.[58] In the classroom, turbine blades can be made out of 8" diameter of thin PVC piping and cut to make the shape of an airplane wing. Each blade is attached to a flat plate. The flat plate is attached to a shaft. As in Figure 4A, the shaft turns the magnets and the coils produce current that is converted to electricity.

It is likely intuitive that the faster the wind speed, the faster the rotor turns and more electricity is generated. Note, if a rotor turns too fast, the mechanical strength of the blades may be surpassed or the generator may burn out due to too many electrons that are traveling through the wire. On a commercial wind turbine, between the rotor and the generator, a set of gears are put in place between the shaft of the rotor and the shaft of the generator to maintain an electric current that is appropriate for the generator. When the rotor rotates too fast, a break is applied to slow it down. How does the brake "know" when it is to be applied? An anemometer is placed on the casing of the wind turbine, called the nacelle. The anemometer measures wind speed. The anemometer sends a signal to the control box of the brake to keep the blades at a constant speed of rotation.

Another aspect of wind turbines is how high above the ground does the turbine need to be mounted? The wind speed increases the further up from the Earth's surface. Tower heights vary from 100 to 160 feet depending on the length of the shaft and the area the rotor traverses.[59]

Simplifying a Wind Turbine

There are two types of windmills, vertical and horizontal. Due to shorter lifetimes in the field, failed vertical windmills were replaced with horizontal windmills.[60] A windmill takes mechanical movement and converts it into electricity; this is called a generator. This is the opposite of a motor, which takes energy and creates mechanical movement. Many of the components of a motor and a generator are the same. A prototype with main components is illustrated in Figure 5(1). Wind causes the rotor (A+B) to turn. The rotor turns 2 magnets (D) glued to the nail (C) where a spacer of glue (K) and cardboard (E) keeps the magnetic bars parallel to each other. The two magnets are placed across the nail in the direction of attracting each other. Note that the 4 sided cardboard box is not attached to the nail nor to the magnets, thus washers (G) will stabilize the nail. Actually, the box is made first and the nail is pierced into the cardboard. The magnets are attached inside the box. The insulated copper wire (F) is wrapped tightly around the box (E) with one set of windings on one side of the nail and a second set of winding on the other side of the nail. The insulation on the two copper wire ends is removed and attached to the bulb (J) and then a voltmeter (I). It is possible to purchase the generator. The concept of how a generator works and removing the "magic" surrounding how a generator works is fundamental to understanding how a magnetic field generates an electric current in copper wires.[61,62]

The silver magnets (D) are inside the cardboard. Smaller magnets are stacked in this figure. The red insulated copper wire is seen wrapped around the magnet.

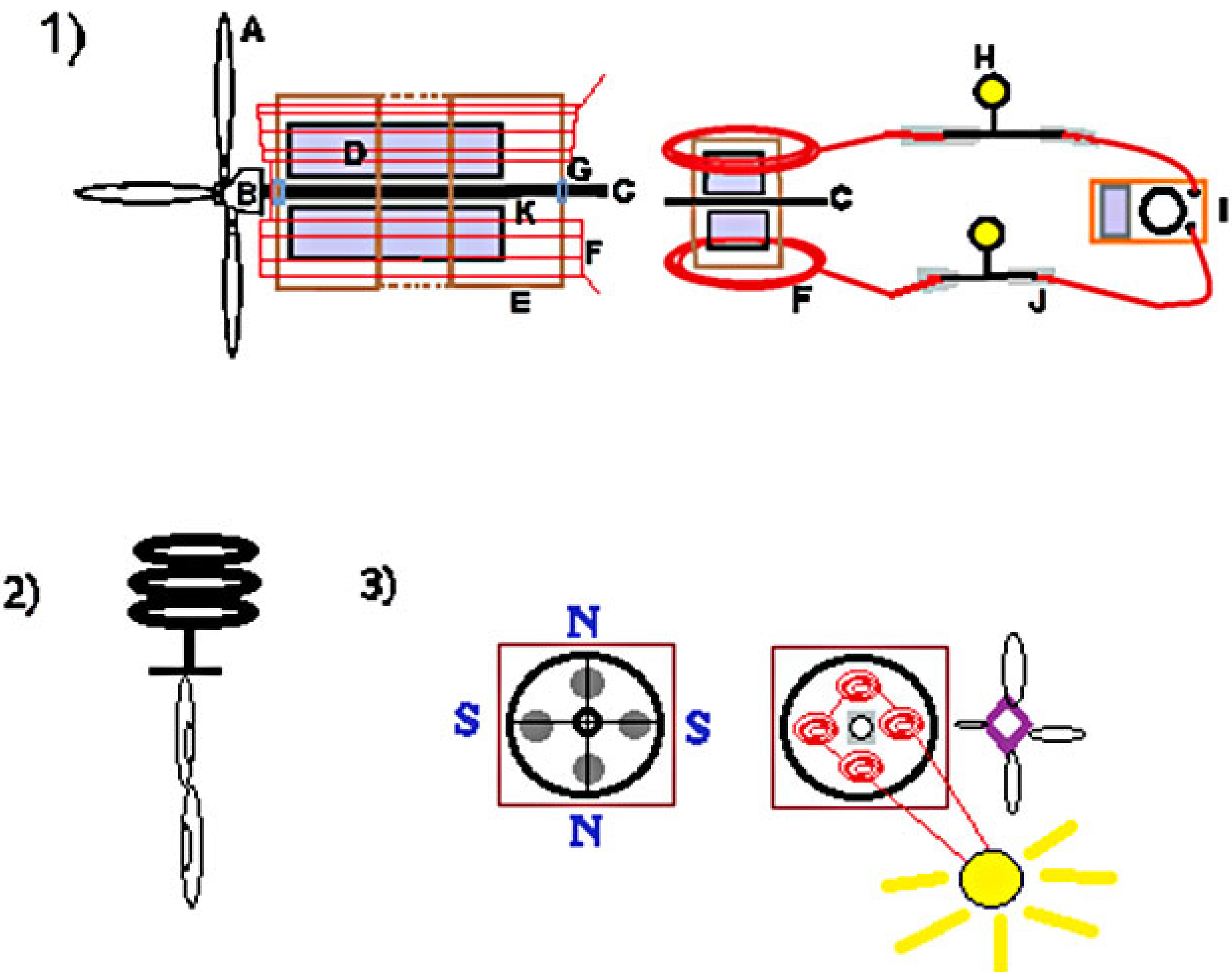

Figure 5. Diagram of Class Prototype Wind Turbine. (1) First Generation Low Cost Wind Turbine Generator, (2) Temporary Magnetism, (3) An Alternative Design to Figure 5(1) and Figure 4(C) for electricity generation in a Wind Turbine.

For demonstration purposes, a handle was put on the generator, instead of turbines. The excluded assemblies from this wind turbine prototype is the gear box, the brake, the anemometer, the yaw (pitch system) and the tower. This prototype was made for the Yale National Initiative summer 2019 meeting; however, the safety hazard of putting the hot glue on the magnets inside the box initiated a redesign.

Figure 5(2) is an illustration of temporary magnetism where 3 circular magnets are attached, temporarily magnetizing a nail and then paper clips. Figure 5(3) is an illustration of another generator design similar to 4C. In this design, 1 or both CDs are glued to a rigid cardboard piece. Then 4 circular neodymium magnets are glued to the CD where the opposite poles of each adjacent magnet face the CD. A washer and a short bolt are glued to the CD. Then a bobbin is used as a set of ball bearings so the top CD turns. Then 4 windings are made each with 250 wraps. These are glued to the CD connected with one wire. A washer is glued to the center of 2nd CD. The second CD in inserted through a bolt and nut with blades attached. Turn the blades and the light will turn on. Instead of a light bulb, a voltmeter can be attached to measure the current.

Teaching Strategies

The concepts that lead to making a Generator follow Next Generation Science Standards provided below.

Performance Standards: 1) Motion, Stability and forces interactions, 2) Matter and its interactions, 3) Energy.

Practices: 1) Plan and Carry out investigations, 2) Developing and using Models, 3) Asking Questions a Defining Problems, 4) Constructing Explanations and Designing Solutions, 5) Analyzing and Interpreting Data.

Disciplinary Core Standards: 1) Forces in Motion, 2) Types of Interactions, 3) Definitions of Energy, 4) Relationship between energy and force, 5) Structure and Properties of Matter, 6) Conservation of Energy and Energy Transfer, 6) Developing Possible Solutions, 7) Wave Properties, 8) Electromagnetic Radiation.

Cross Cutting Concepts: 1) Energy and Matter, 2) Cause and Effect, 3) Patterns, 4) Scale, Proportion and Quantity, 5) Systems and system models, 6) Structure and Function.

The teaching strategies in this unit combine individual learning, collaborative learning, verbalization and hands on learning.

Vocabulary

The concepts for this work involve new vocabulary and knowledge of new concepts. The units for electricity and energy need to be understood clearly. I would like to use a website on the labtops called Kahoot! to practice vocabulary. Kahoot! is a game where the students have a certain amount of time, 10 sec or 20 sec, to answer a question. Each person gets points based on having the correct answer as well as having streaks of answers.

Collaborative Learning

One of the keys to teaching this unit is to create the hands-on activities and increase the difficulty of the activities to master the material as well as troubleshoot student challenges.

Verbal Communication

Each day the students will do a “Bell Ringer.” The Bell Ringer will have a concept question. The students will discuss the concept question. Before the students open the bell ringer, a student at each table will be designated to share out the discussion held at the table. After having 2 minutes to discuss the question, the assigned students will share the discussion.

Project Lead the Way

This is a Unit in Project Lead the Way (PLTW), which also lays out standards.

Activities

Activity 1. Magnetic Fields. Perform a demonstration in front of class using an ELMO type projector of the Magnetic Field given by a rectangular magnet. Place a pile of papers that hold the magnet in place. Place a sheet of paper above the magnet and below the lamp of the projector. Pour the iron filings around the magnet. Observe the magnetic field. The students are to draw the picture of the magnet and the magnetic field in their PLTW notebook. The students will write a paragraph, 5-6 sentences on what they observed and what it means. A worksheet will be provided in Google Classroom with questions on what they saw. The objective is for the students to explain a magnetic field. SAFETY: The iron filings are small, adhere to the skin and “fly” everywhere; thus, this is done as a demonstration.

Activity 2. Properties of Magnets. In pairs, hand out two circular magnets with a hole in the center, 2 circular magnets without a hole in the center, a piece of foam, access to the hot glue gun station, access to station with water, a piece of string, a sharpie and a compass. Put a map of Chicago on the wall. Ask the students to determine North in the classroom. First, have the students will determine the opposing poles by putting the magnets in the fold of a book. Put a dot using the sharpie on the same poles. Use the compass and the magnets to determine north. 1) Put a magnet on a string and determine north and see the side of the magnet facing north. 2) Cut a square piece of foam bigger than the magnet. Glue the edge of the circular magnet to the foam. Put the foam in the water. Identify and label on the foam N, S, E and W. The students will write in their PLTW notebook their observations and challenges. Did the North in the string and water experiment match the north on the compass? In the Bell Ringer on the next day, the students will discuss the next day if they were able to determine the direction north correctly, why and why not.

Activity 3. Fun with Magnets. From the front of the room the students will put in their bucket a battery, AA, a neodymium round magnet and a 10” length of copper. The students will wind the copper around the magnet. Leaving an inch at the top and a ¼ inch at the bottom. The negative pole of the battery will be placed on the neodymium magnet. The copper will be shaped to touch the magnet. The top of the copper wire will be shaped to touch the top of the battery. The wire will spin. This is a fun activity to have electricity and electromagnetism working together to have the wire spin.

Activity 4. Properties of Magnetic fields. Hand out 2 sheets of 12”Wx18”L aluminum foil. Put the sheets over each other and fold them in half to make it 6”W and 18”L. Ensure the aluminum foil is as flat as possible by using a book to press it down. Roll the Aluminum so it is larger than the magnet. Use a dowel rod or pencil to make the roll. Have one person watch the clock second hand. Determine how many seconds it takes the magnet to fall down through the aluminum roll. Repeat this 5 times and write the data in the PLTW notebook. Repeat the timing of the fall of the magnet the same distance, but without the aluminum foil. Write the values in the PLTW notebook. Calculate the average and % residual standard deviation for both experiments. The students will write their conclusion as to what role the aluminum foil had in the experiment. In the Bell Ringer for the next day, the students will do a share out of the role of the aluminum foil on the results. The students will make an Excel® file with a data table of their values, calculations, written conclusions and upload this to Google Classroom for grading.

Activity 5. Make a temporary magnet. Students will work in pairs. The student pair will pick up a nail, 5 paper clips and a magnet. Select three different sides of the magnet to test. For each side add paper clips and let them hang. How many paper clips can be places in series one below the other? A drawing will be made in their PLTW notebooks of the 3 locations on the magnet tested. A table will be made and the number of paper clips that hold in series will be documented. The students will answer the questions: are the paper clips magnets? When connected to a magnet, do the paper clips become magnets? What is a temporary Magnet? In the Bell Ringer for the next morning, there will be a question and a share out on what is a temporary magnet. The students will answer questions in Google Classroom regarding the experiment.

Activity 6. Make an electromagnet. Work in pairs. Collect in your bucket from the teacher 1 nail, 1 battery, a long piece of enamel copper wire, some electrical tape, 10 paper clips, 2 small pieces of flat copper tape and a small piece of sand paper. Make 400 tight windings around the nail. Leave 4 inches of winding at the beginning and at the end of the winding. Use the sand paper to remove half an inch of the red enamel exposing only the copper wire. Check that all the red enamel has been removed on the entire circular cylindrical surface. Put one piece of copper tape on the (+) side of the battery. Place one end of the copper wire on top of the copper tape. Sandwich the copper wire with another piece of copper tape and then insulate by putting electrical tape over the copper tape. Repeat for the (-) side of the battery. Use the nail to pick up as many paper clips as you can. Write in the shared excel document the number of paper clips picked up. See who in the class can pick up the most paper clips. Draw in your PLTW notebook your electromagnet. Write 5-6 sentences to explain the results. Remove the wires from the battery and return the materials. For the Bell Ringer for the next day, the question will be, how can the electromagnet be made stronger? The students will have a few minutes to discuss and then perform a share-out.

Activity 7. Prototype a windmill I [Figure 4(C) and 4(D)]. Students will work in pairs.

First, students will collect buckets to contain their parts from the front of the class and place inside 5 pre-cut 1” OD PVC pipe (1 piece is 1” long, another is 2” long, the next piece is the same length as the magnet and the last 2 pieces are ½” long), 4 square magnets, 1 nail, 2 x 5 inch or 1 x10 inch strip of thin iron metal, a wooden block, a plastic turbine, a small piece of sand paper, 2 LED lights and enamel coated copper wire. The students will have access to glue gun stations. On the PVC pipe, the same length 4 magnet will be glued to each of the side of the PVC pipe. The magnets will need to face the PVC pipe by alternate the North Pole facing the pipe, then the South Pole facing the pipe, the North Pole and then South Pole. The piece is called the rotor. It is critical that adjacent magnet poles oppose each other in facing the pipe. Out of the 1” pipe have the instructor cut out with the soldering iron a slot where the nail will rest. Out of the 2” pipe, have the instructor make a hole a little larger than the size of the nail using the drill press or the soldering iron. Take the nail and put tape around each side of the nail so it sets inside the PVC pipe with a snug fit. Figure out where the 2” long and 1” long PVC pieces fit on the board to that the nail rests on the 1” piece and the nail rotates inside the 2” PVC piece. Glue these pieces onto the block. The magnets glued to the PVC should not touch the bottom of the wood. Set the rotor with the nail going through the hole on one side and on top of the slot on the other side. Turn the nail and the magnets should turn easily. The next step is to make a stator. Take the 5” strip of iron and cut it in half with scissors. Make 5 equal lengths (1” each) of the iron strips. Tape them together tightly so they are touching each other. Repeat this for the other 5” strip of iron. Take the enamel covered copper and make 300 turns around the lead piece. Repeat for the other lead piece. Put one roll of tape around the copper windings to hold them together. Take each of the ½” long PVC pipe and identify where they are to be placed so the windings are close to the magnets, but not touching. Glue the PVC piping in place. Glue the winding to each of the PVC pipes. Glue the turbine to the front of the nail. To each side of the stator there are two wires. Use the sand paper to remove ½” of the enamel from the copper wire for both ends. Repeat for the other stator. For one side, wind the copper around the lead of the LED and repeat for the other LED lead. Repeat for the other side of the stator. Rotate the nail or the turbine and the lights will light. For the Bell Ringer for the next period, we will discuss the purpose of the magnets, their rotation and of the coiling of the wires. The current and voltage will be measured in a shared Google Sheets file to see who generated the most current.

Activity 8. Prototype a windmill II [Figure 5(3)]. Students will work in pairs.

From the front of the class, collect in your containers 2 CDs, 4 round magnets, 1 bobbin, a coil of enamel wire, 2 washers and a turning nub. On one CD draw with a sharpie to lines 90 degrees from each other, meeting in the center. Glue the CD to a piece of cardboard. Mount 4 circular magnets alternating the poles facing the CD. On the second CD, create 4 triangular or circular coils on the back (250 winds per coil). Make the coil of 200 winding around an empty toilet paper roll or around 6-8 pencils and all the windings are made out of one piece of insulated wire. Glue the coils to the 2nd CD and glue the opposite side of the CD to a rigid piece of cardboard. Glue two washers to each CD so that the coils and the magnets face each other. The hole in the washer should be just greater than the dowel rod that will go into the hole. The washer should be large enough to cover the hole of the CD, but small enough to not touch the coils nor the magnets. Glue a stack of washers so the coils and the magnets are close to each other, but do not touch. Glue the stack of washers to the bottom CD. Glue the dowel rod to the top CD (but not to the stack) and let the rest be a shaft to go almost to the bottom of the lower CD to minimize warping as the top CD turns. The top CD should turn freely. Attach with glue the blades to the top CD or make a mechanism that can fix the blades and then be glued to the top CD. Test the system for easy rotation of the top CD. It should rotate freely and without wobble.

Generator used in YNI Demonstration

As Wire, use enamel coated spool copper wire and write down the AWD number that tells the diameter of the copper. Collect 4 block magnets, a nail to be used as your shaft and a sheet of cardboard. Take the sheet of cardboard and cut out a piece that is about 22 cm x 8 cm. Fold the cardboard so there are 2 8x8 cm squares and 2 3x8 cm sides and glue 3rd side glue on to hold the cardboard together. (Scale according to the magnet size). Puncture with the nail a 1/8” hole and ensure nail is loose so it can rotate. Attach each of the 2 block magnets together and put on one side of the nail. Attach the other 2 block magnets on the other side of the nail so they repel each other. Put a spacer on each side of the nail in between the each pair of magnets to hold the 4 magnets together. Wrap the wire around the long side of the wire leaving the other two sides open. Wrap it 400 times with space between wrappings. Ensure that the magnets can rotate freely in the box. Make the blades. Select PVC pipe, plastic or cardboard and mark it so the instructor can cut it to make the blades. Cut a piece of 1/8” dowel rods and attach to each blade using a hot glue gun. Make a hub using a Styrofoam ball. Attach Dowel Rods to Hub. Attach Hub to Shaft. Test your wind turbine by blowing or bring a fan into the classroom. This procedure is not being used because gluing the magnets inside the cardboard housing is difficult to do without touching the hot glue. For reasons of safety, this method is not used.

Appendix

Implementing District Standards

District standards will be met by doing demonstrations on magnetic fields of magnets and the students will draw the results of the demonstrations in their Engineering notebooks. Students will also have to write paragraphs on the meaning of the results. After each experiment, we will do verbal share-outs on critical concepts. Using Google Classroom, students will answer questions on content matter and the results are returned immediately after submission. Students will also do experiments with batteries, enamel wire, copper wire to understand energy in the form of electricity and magnetic fields. This will involve some building and assembly. The students will write their observations, challenges and conclusions informally in their engineering notebook. The last activity is to build a generator that can be mounted to complete the wind turbine. The students will read the maximum current generated and put it in a shared spreadsheet. The students will make a power point presentation and include a frequency histogram of the class results.

Teacher Resources

Simple generator: AC electric generator for science fair https://www.youtube.com/watch?v=k7Sz8oT8ou0 (Last Accessed 12AUG2019)

Multiple Generator

https://www.youtube.com/watch?v=noF5q4-77XI (Last Accessed 12AUG2019)

Unlimited electricity generation with simple tools

https://www.youtube.com/watch?v=ukwHwDyDXJ8&t=3s (Last Accessed 12AUG2019)

Simple Generator, www.etsy.com/shop/lumbernerd

https://www.youtube.com/watch?v=V_FnYANw0Zs (Last Accessed 12AUG2019)

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