Solar Radiation Big Data Analysis for Strategic Positioning of Solar Panels

NSF I-READ RET Summer 2024 Program

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Abstract:

The primary goal of this project is to learn the use of big data available on the National Renewable Energy Laboratory (NREL) solar position and intensity (SOLPOS) calculator and use Microsoft Excel to analyze the data for strategic positioning of solar panels. The team collected data from SOLPOS to study the changes in solar irradiance (ETR) in latitude and longitudinal locations North, East and West of Corpus Christi, Texas. The irradiance was found to differ significantly between North and South locations, however little difference can be found between cities from West to East. In addition to analyzing the solar radiation data obtained from SOLPOS, the team gathered experimental data from Bishop, Texas and Corpus Christ, Texas to compare with the SOLPOS data. The variation between the measured ETR and SOLPOS data showed dependence on the location and weather condition. Temperature difference between the front and back of the solar panel showed dependence on the panel materials, and location and positioning of the panel.

Introduction:

Renewable energy is becoming a more desirable option than environmentally harmful energy production. As research and development in the field of renewable energy continues to expand, the option to utilize some form of renewable energy in our daily energy consumption is becoming a popular option [1].

In particular, solar energy technology is continuing to develop and becoming more and more efficient over time. With new developments and innovation, solar energy technology has an exciting future. Currently, the solar energy technology for home consumption most commonly utilizes roof mount solar panels. Some commercial solar energy farms utilize field mount solar panel systems.

Solar energy utilizes the light energy from the sun called “photons”. The photons are absorbed into the solar panel which causes the electrons to vibrate within the solar panels. As the electrons move, energy is generated and passed to the output using a conductive wire. The electricity is then connected to an inverter and transferred into the building/structure/system etc. [2].

There are 4 primary types of solar panels [3]:

1) Monocrystalline: Also known as single-crystal panels, these are made from a single pure silicon crystal that is cut into several wafers. Since they are made from pure silicon, they can be readily identified by their dark black color. The use of pure silicon also makes monocrystalline panels the most space-efficient and longest-lasting among different solar panel types.

2) Polycrystalline: As the name implies, these come from different silicon crystals instead of one. The silicon fragments are melted and poured into a square mold. This makes polycrystalline cells much more affordable since there is hardly any wastage and gives them that characteristic square shape. However, this also makes them less efficient in terms of energy conversion and space, since their silicon purity and construction are lower than monocrystalline panels.

3) Passivated Emitter and Rear Cell (PERC): These panels are an improvement of the traditional monocrystalline cell. This relatively new technology adds a passivation layer in the rear surface of the cell that enhances efficiency in several ways. It reflects light back into the cell, increasing the amount of solar radiation that gets absorbed. It reduces the natural tendency of electrons to recombine and inhibit the flow of electrons in the system. It allows greater wavelengths of light to be reflected. Light waves over 1,180nm can’t be absorbed by silicon wafers and simply pass through, so they end up heating the cell’s metal back sheet and reduce its efficiency. The passivation layer reflects these higher wavelengths and stops them from heating up the back sheet.

4) Thin-film panels: These panels are characterized by very fine layers that are thin enough to be flexible. Each panel does not require a frame backing, making them lighter and easier to install. Unlike crystalline silicon panels that come in standardized sizes of 60, 72, and 96-cell counts, thin-film panels can come in different sizes to suit specific needs. However, they are less efficient than typical silicon solar panels.

The National Renewable Energy Laboratory (NREL) solar position and intensity (SOLPOS) website can be useful to analyze the extraterrestrial solar irradiance (ETR) information to determine optimal positioning of solar panels in addition to optimal angle inflection. ETR is the amount of solar radiation that would reach a location on Earth's surface measured in W/m^2. The high and low periods of solar irradiation can also be determined depending on location. Although the SOLPOS solar data generation can be useful for study and design, the actual data may vary to some degree. The actual solar radiation may be less than predicted with the SOLPOS solar simulation.

Our team developed three research questions:

1) Using the Big Data available on the NREL SOLPOS website, obtain the solar energy yield throughout each day of the year at different locations and for a variety of tilt to find the best location and tilt.

2) Compare the solar irradiance obtained from SOLPOS with experimental observation at various locations to understand the reliability of SOLPOS. Is there a significant difference between simulation data from SOLPOS and experimental data?

3) Measure the temperature on front and back of the solar panels throughout the daytime hours to determine if there is a significant difference that can cause damage to the panel.

Research Methodology:

The NREL SOLPOS website was used to compute the amount of solar irradiation (ETR) at various locations across the US and Canada [4]. The required input values such as the start and end dates were easy to understand and input.

Entering the output time intervals on SLOPOS was important to understanding how detailed the information could be. It was decided to collect the data at every 30 minutes interval from SOLPOS.

Entering the information for the site location on SLOPOS required the use of a computer to locate GPS coordinates for each of the cities north of Corpus Christi, Texas and east and west of Corpus Christi, Texas. The locations were selected by using a map and the cities that have similar latitude or longitude compared to Corpus Christi, Texas, were selected.

By trial and error method, it was discovered that the surface pressure and ambient dry-bulb temperature on SLOPOS had little to no effect on the solar irradiation values (ETR). Optional values that may need to be input were the azimuth of the panel. NREL data for SOLPOS set their panels to be aligned south to north on a 180-degree angle. The angle of 0-degrees was aligned with north pointing – so the angle 180-degrees has the panel facing south with the back side of the panel facing north. The degrees tilt from the horizontal of the panel was the direction it was elevated with respect to the ground [5].

The solar constant is a globally accepted value. It has been computed by using the temperature of the sun. These rays travel to the Earth and then that energy being distributed across 1 square meter of land. Its value is 1.361 kW/m^2 [6].

Understanding the optional input values on SLOPOS such as shadow-band width (cm), shadow-band radius (cm) and shadow-band sky factor, the glossary and terms tool kit found in the Solar Position and Intensity Grid Modernization Data and tools was necessary. These were explained as a subroutine; and the requirement of inputting a value for the interval measurement period explained that if 0 was selected that this was a null reading [7].

After configuring the SOLPOS input / output data, the Extraterrestrial Global Irradiance on a tilted surface (ETR, W/m^2) was recorded. Extraterrestrial meaning outside or above the earth. Irradiance is the solar energy being transferred to the planet by way of sun rays being released to the Earth. It is the measure of the power of all the forms of energy (radio to gamma rays) in the entire EM spectrum. As an example, Figure 1 shows the irradiance map of the US. According to the map, southern Texas, where both Corpus Christi and Bishop are located, has the ability to collect between 5.50 and 5.75 kWh/m^2 per day [8].

After collecting the ETR values for various cities at different tilt angles of the solar panel from SOLPOS, the information was transferred into a Microsoft Excel spreadsheet to visualize and analyze the data.

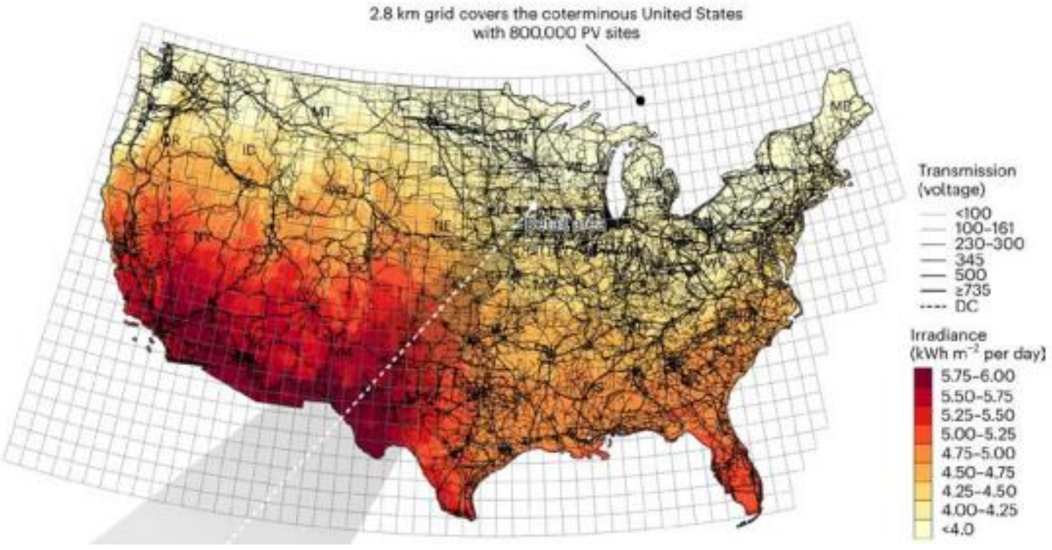

Figure 1: Irradiance map of the US [8].

For experimental observation, two different solar panel sites were chosen, Bishop and Corpus Christi, Texas. In Bishop, the ETR was measured on a small rural ground-mounted photovoltaic solar power farm (see Figure 2). This solar farm has 48 panels at a 74° angle North. The tilt of these solar panels with respect to the horizon is 18.9° angle. The panel design is a monocrystalline panel to provide maximum collection. In Corpus Christi, Segway 100W solar panel (see Figure 3) was used to experimentally obtain the ETR at various tilt angles. The panel is a monocrystalline panel with 23.7% efficiency [9]. Fluke IRR1 Solar Irradiance Meter (see Figure 4) was used to measure the solar irradiance and temperatures on the front and back of the solar panels. The Segway Solar Panel was adjusted to 0°, 15°, 30°, and 45° during each hour and the ETR was measured using the Fluke IRR1-SOL meter. Additionally, the tilt angle for the Segway Solar Panel was measured using the Fluke IRR1-SOL meter. After 10 minutes past the hour, the Fluke IRR1-SOL meter was used to measure the temperature on the front and back of the Segway Solar Panel. All measurements were recorded throughout the day.

Figure 2: Solar farm located in Bishop, Texas.

Figure 3: Segway solar panel in Corpus Christi, Texas.

Figure 4: Fluke IRR1 Solar Irradiance Meter showing a sample reading for ETR and temperature.

Results and Discussion:

Figure 5 shows the 3D plots of average yearly ETR variation with time for 0°, 15°, 30°, and 45° tilt for Corpus Christi, TX, Kansas City, MO, and Winnipeg, Canada, and corresponding 2D plots. These cities have similar longitude but different latitude. As can be seen in the figure, the ETR varies significantly between these cities, showing that the ETR may depend on the latitude.

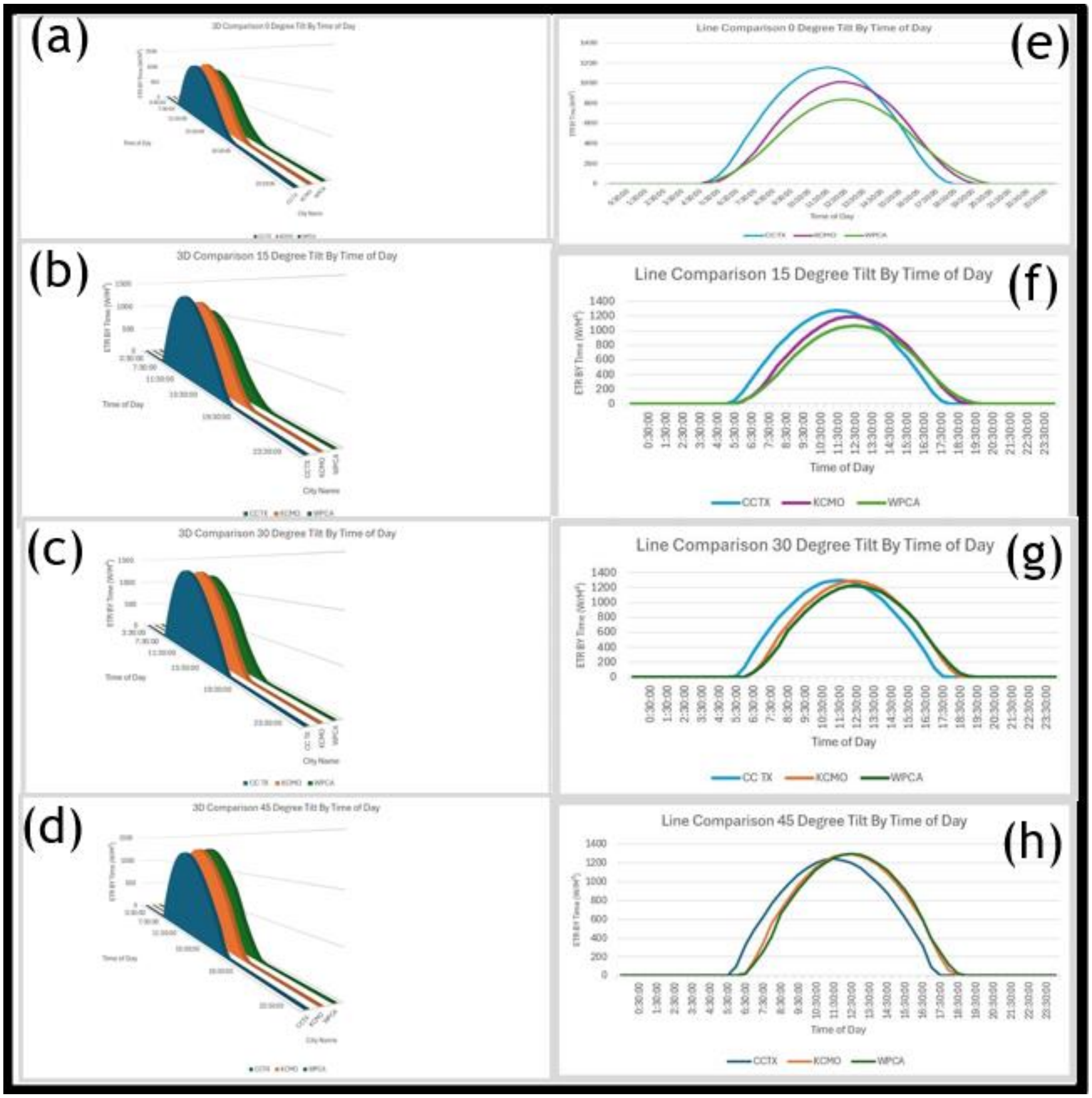

Figure 5: Comparison of average yearly ETR value for Corpus Christi, TX, Kansas City, MO, and Winnipeg, Canada - (a) 3D plot for 0° tilt, (b) 3D plot for 15° tilt, (c) 3D plot for 30° tilt, (d) 3D plot for 45° tilt, (e) 2D plot for 0° tilt, (f) 2D plot for 15° tilt, (g) 2D plot for 30° tilt, and (h) 2D plot for 45° tilt.

Figure 6 shows the 3D plots of average yearly ETR variation with time for 0°, 15°, 30°, and 45° tilt for Dallas, TX, Tucson, AZ, and San Diego, CA, and corresponding 2D plots. These cities have similar latitude but different longitude. As can be seen in the figure, the ETR does not vary significantly between these cities, showing again that the ETR may depend on the latitude.

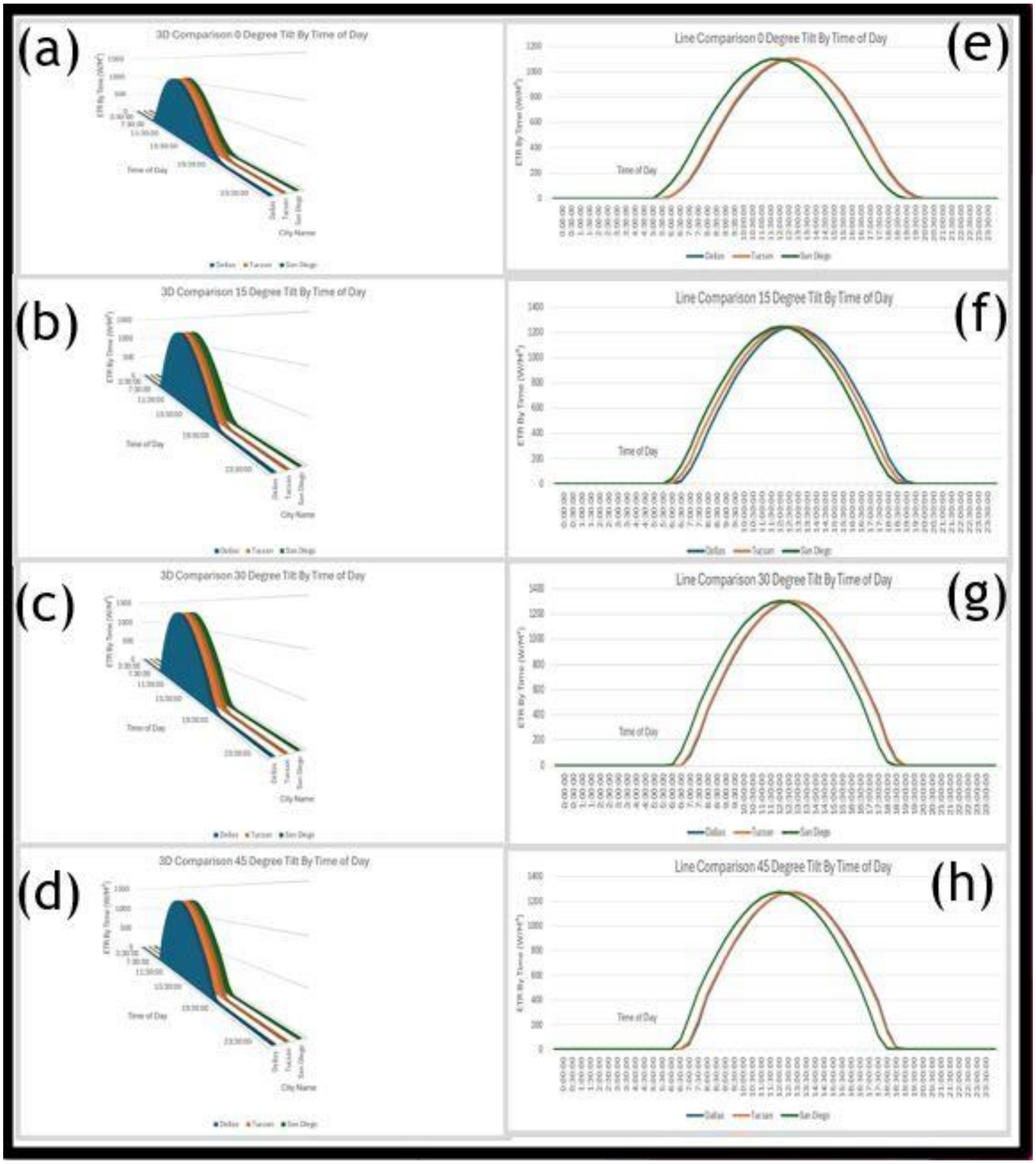

Figure 6: Comparison of average yearly ETR value for Dallas, TX, Tucson, AZ, and San Diego, CA - (a) 3D plot for 0° tilt, (b) 3D plot for 15° tilt, (c) 3D plot for 30° tilt, (d) 3D plot for 45° tilt, (e) 2D plot for 0° tilt, (f) 2D plot for 15° tilt, (g) 2D plot for 30° tilt, and (h) 2D plot for 45° tilt.

Figures 7 and 8 show the comparison of ETR values obtained from SOLPOS with the values measured experimentally in Corpus Christi and Bishop, TX, respectively. For Corpus Christi, various tilt of the solar panel is compared, however, for the Bishop site, the solar panel is fixed, so the comparison is made for a fixed tilt. For Corpus Christi, the simulation data from SOLPOS is significantly greater than the measured data for all the tilts. This variation may be due to cloud cover and weather conditions, interference by trees or buildings, and human error. However, for the Bishop site, the measured ETR data matches well with the SOLPOS data. Table 1 shows the measured data obtained from Bishop, Texas.

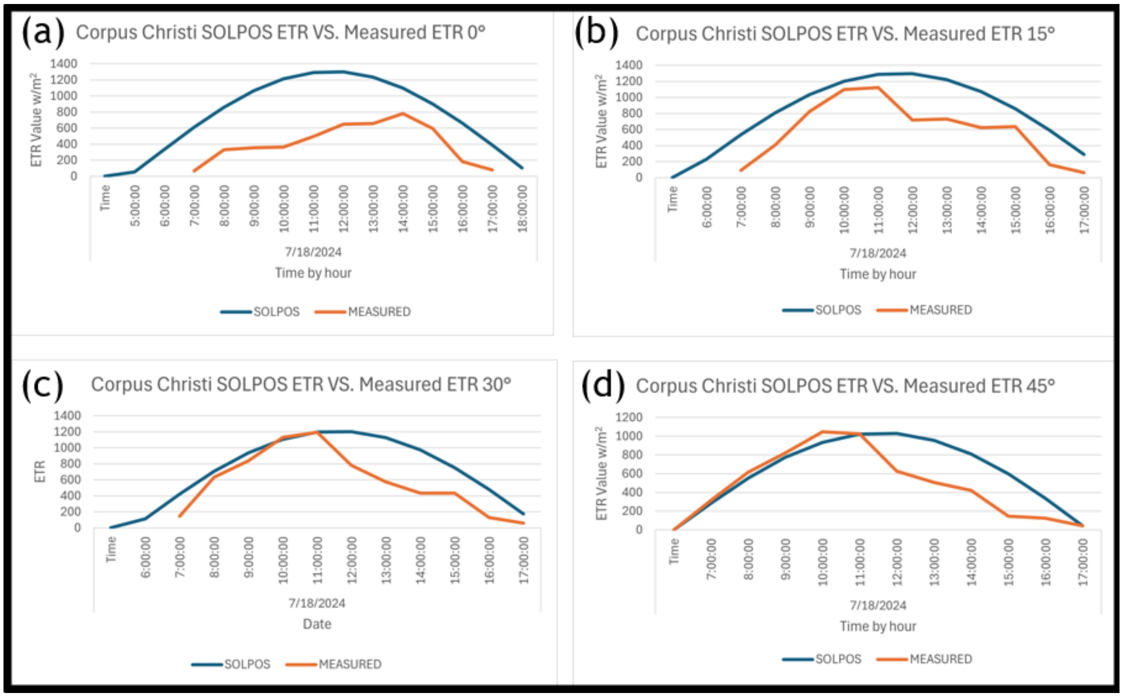

Figure 7: Comparison of ETR values obtained from SOLPOS with the measured value in Corpus Christi, Texas for (a) 0° tilt, (b) 15° tilt, (c) 30° tilt, and (d) 45° tilt.

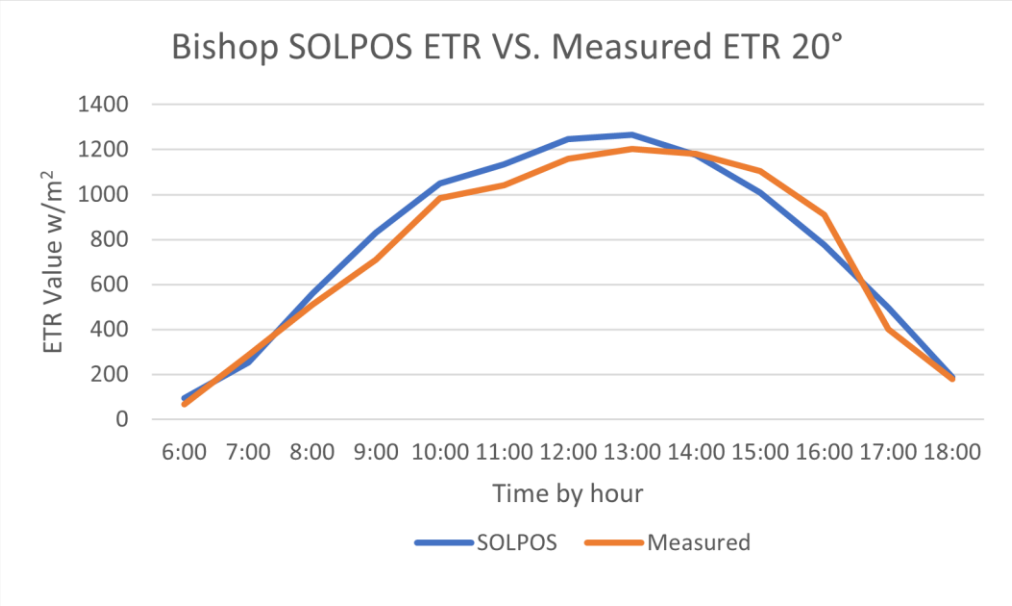

Figure 8: Comparison of ETR values obtained from SOLPOS with the measured value in Bishop, Texas on July 20, 2024, for a constant tilt.

Table 1: Measured data from Bishop, Texas solar farm

Date	Time	Outside temp. (°C)	PV meter reading (kWhr)	Number of panels	Watts generated	Front of panel (°C)	Back of panel (°C)	ETR value from meter
7/18/2024	6:00	25	66	48	1.375	25	25	**66**
	7:00	26.1	1010	48	21.042	25.6	26.1	**285**
	8:00	29.4	5254	48	109.458	28.3	28.9	**511**
	9:00	32.2	99668	48	2,76.4	31.7	32.2	**711**
	10:00	33.3	217394	48	4529	32.8	33.9	**985**
	11:00	33.9	217393	48	4529	38.6	35	**1040**
	12:00	34.4	217394	48	4529	37.3	35	**1160**
	13:00	36.7	217394	48	4529	38.9	35.6	**1203**

	14:00	33.9	217394	48	4529	37.2	36.1	**1180**
	15:00	32.8	216299	48	4529	35	33.9	**1105**
	16:00	31.7	195230	48	4067	33.3	32.8	**910**
	17:00	30.6	99876	48	2080.75	31.1	30	**400**
	18:00	29.4	1054	48	21.96	30	28.3	**180**
7/19/2024	6:00	25.6	64	48	1.33	25.6	25.6	**62**
	7:00	25	1200	48	25	25.6	25	**282**
	8:00	25.6	5602	48	116.7	26.1	25.6	**506**
	9:00	27.8	99873	48	2080.7	27.8	27.2	**764**
	10:00	28.3	217393	48	4529	29.8	28.3	**987**
	11:00	33.3	217393	48	4529	37.1	30	**996**
	12:00	35	217390	48	4529	45.3	35.3	**1040**
	13:00	37.8	217394	48	4529	43.9	38.9	**1200**
	14:00	37.8	217393	48	4529	44.3	37.2	**1169**
	15:00	36.1	217391	48	4529	37.7	35	**1108**
	16:00	33.9	205617	48	4284	36.7	34.9	**920**
	17:00	33.3	10568	48	220.2	35.8	33.7	**375**
	18:00	32.8	568	48	11.83	33.2	31.5	**114**
7/20/2024	6:00	25	58	48	0.52	25	25	**56**
	7:00	25.6	1080	48	22.5	25	25.6	**277**
	8:00	27.2	5602	48	116.7	26.1	26.7	**499**
	9:00	28.3	98799	48	2058	26.7	27.8	**722**

	10:00	30	217389	48	4529	30.6	29.4	**987**
	11:00	31.7	217388	48	4529	35.8	34.4	**1050**
	12:00	32.8	217393	48	4529	43.1	37.1	**1135**
	13:00	33.9	217394	48	4529	43.1	38.7	**1201**
	14:00	36.1	217396	48	4529	46.1	39.7	**1180**
	15:00	35	217201	48	4525	46.2	37.8	**980**
	16:00	33.9	9987	48	208	33.3	35	**805**
	17:00	32.8	5423	48	113	32.2	33.3	**353**
	18:00	31.7	140	48	2.92	31.1	32.8	**111**

This farm should be generating 13,680 kW every hour if the panels were at maximum efficiency. That is to say, each 48 panels (285 kW/hr) working together would generate 13,680 kW each hour. The max that is generated is 4,529. The solar power rating is the (theoretical value - actual value) divided by the theoretical value.

(13680 - 4529)/13680 = 0.669 or 67%.

Figures 9 and 10 show the comparison of ambient temperature and the front and back of the solar panel for the similar comparable time frame for Bishop and Corpus Christi, Texas, respectively. As can be seen in Figure 9 (Bishop, Texas), the temperature variation between the ambient, front and back of the panel is negligible. However, as shown in Figure 10 (Corpus Christi, Texas), temperature in the front of the panel is significantly higher than the back of the panel and ambient, especially in the later part of the day. The materials for the two solar panels are different with different thermal conductivity. It is likely that the difference in the material for each solar panel contributed heavily to the differentiation of panel temperature compared to the ambient temperature. Nonetheless, the temperature variation in the solar panel in Corpus Christi, Texas indicates that the solar panel material should be chosen very carefully when installing a solar panel.

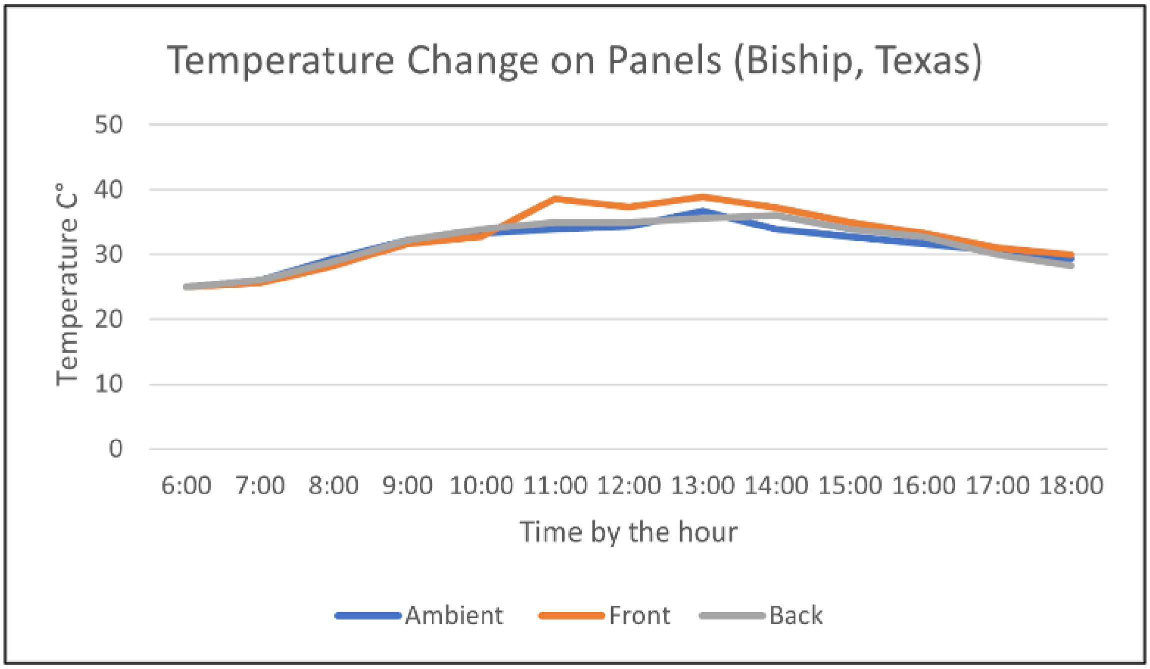

Figure 9: Ambient temperature compared to front and back panel temperature in Bishop, Texas.

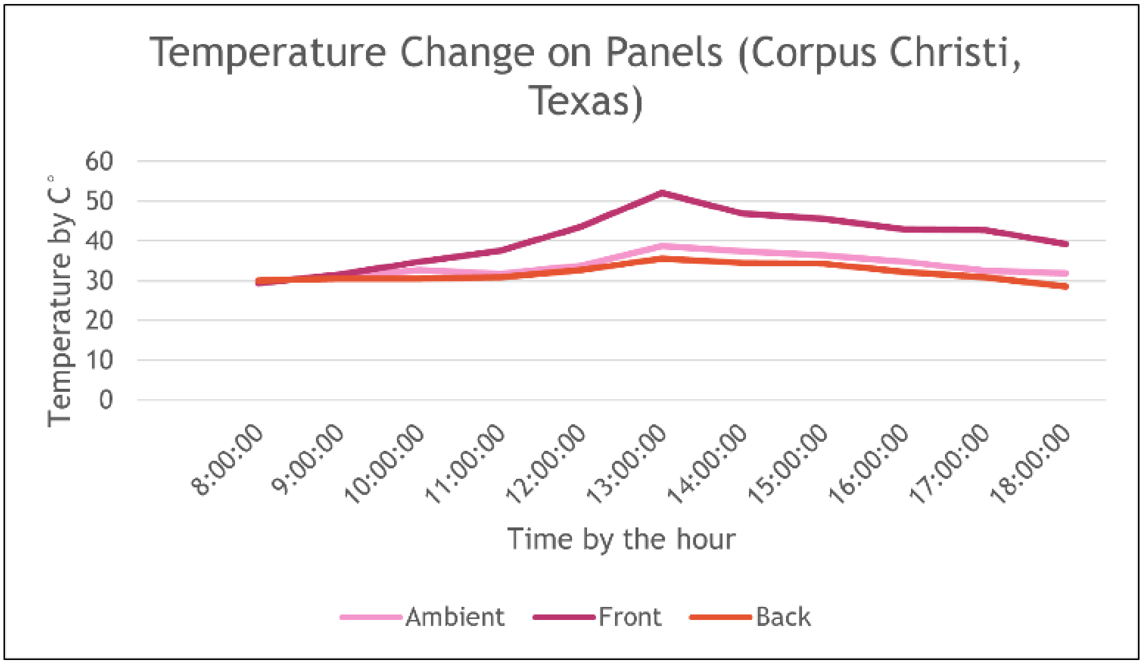

Figure 10: Ambient temperature compared to front and back panel temperature in Corpus Christi, Texas.

Research Summary and Conclusions:

This research focuses on analyzing the solar radiation big data available on NREL SOLPOS website for strategic positioning of solar panels as well as experimental observation of solar irradiation and temperatures on the solar panel. According to the analysis of big data available on SOLPOS, the ETR varies greatly between cities with different latitude while cities of similar latitude differed slightly. Thus, solar irradiation may depend more on latitude rather than longitude.

The measured solar irradiance for Corpus Christi, Texas is found to be consistently lower than the SOLPOS data. However, for Bishop, Texas, experimental data matches well with the SOLPOS. There are some explanations for the differences observed in Corpus Christi. For example, some irradiation measurement differences may be due to cloud cover or obstructions such as trees and/or buildings. Human error may also be a contributing factor to the difference. On the other hand, Bishop, Texas has high quality solar panels with no obstructions as they are located on open field without any obstructions nearby.

According to the experimental work, temperature variation between the ambient, front and back of the solar panel in Bishop, Texas, is negligible. However, for Corpus Christi, Texas, temperature in the front of the panel is significantly higher than the back of the panel and ambient. This variation may be due to the difference in solar panel materials, which shows significance of solar panel material in the context of overheating that can potentially damage the panel. Learning modules were developed based on the research experiences and findings, as discussed later.

Acknowledgements:

This material is based upon work supported by the National Science Foundation under Award No. 2206864. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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Course Modules Developed During I-READ Summer Program

Course Modules Developed: **Module 1 – Appendix A**

Module 1: Module 1 is a 5 Day lesson developed for a Pre-Calculus lab which applies a variety of necessary skills as described in the TEKS – P.1(A)-(G) P.2(A)-(D). Students will use the SOLPOS website to obtain data which is then analyzed with Microsoft Excel to obtain various graphs and calculations. Students will then conduct collection of data experimentally which will be utilized to compare against the SOLPOS data. Students will provide a conclusive report and PowerPoint presentation.

Course Modules Developed: **Module 2 – Appendix B**

Module 2: Module 2 is a 5 Day lesson developed for a Physics class which applies a variety of necessary skills as described in the TEKS –1 A - F, 2 B - C, 3 C and 4 A. Students will work with and practice on Significant digits on Day 1, percent error on Day 2, graphing on Day 3 and Day 4, and on Standard Deviation during Day 5.

Course Modules Developed: **Module 3 – Appendix C**

Module 3: 5 Day lesson developed for a Physics research and design class using TEKS – 5(A) & 8(D). Students will conduct a 5 day experiment where they test different types of interference with solar panel collection of irradiation. The students will explore different materials which may impede or increase the irradiation collected by the solar panel. Students will report their findings in a written report and also in a presentation.

APPENDIX A

Module 1: Lesson Plans – Graphing Sin and Cos Trigonometric Functions & Solar Data Collection Lab

Applicable TEKS - TEKS – P.1(A)-(G) P.2(A)-(D)

Knowledge & Skill Statement - P.1: The student uses mathematical processes to acquire and demonstrate mathematical understanding. The student is expected to:

- Student Expectation - P.1A: Apply mathematics to problems arising in everyday life, society, and the workplace.
- Student Expectation - P.1B: Use a problem-solving model that incorporates analyzing given information, formulating a plan or strategy, determining a solution, justifying the solution, and evaluating the problem-solving process and the reasonableness of the solution.
- Student Expectation - P.1C: Select tools, including real objects, manipulatives, paper and pencil, and technology as appropriate, and techniques, including mental math, estimation, and number sense as appropriate, to solve problems.
- Student Expectation - P.1D: Communicate mathematical ideas, reasoning, and their implications using multiple representations, including symbols, diagrams, graphs, and language as appropriate.
- Student Expectation - P.1E: Create and use representations to organize, record, and communicate mathematical ideas.
- Student Expectation - P.1F: Analyze mathematical relationships to connect and communicate mathematical ideas.
- Student Expectation - P.1G: Display, explain, and justify mathematical ideas and arguments using precise mathematical language in written or oral communication.

Knowledge & Skill Statement - P.2: The student uses process standards in mathematics to explore, describe, and analyze the attributes of functions. The student makes connections between multiple representations of functions and algebraically constructs new functions. The student analyzes and uses functions to model real-world problems.

- Student Expectation - P.2A: Use the composition of two functions to model and solve real-world problems.
- Student Expectation - P.2B: Demonstrate that function composition is not always commutative.
- Student Expectation - P.2C: Represent a given function as a composite function of two or more functions.
- Student Expectation - P.2D: Describe symmetry of graphs of even and odd functions.

Material List: 1 Fluke IRR1 Solar Irradiance Meter, 4 Portable Solar Pannels, 2 Giant Post It Notepads, 6 Packs of Markers, 6 Yard Sticks, 1 Presenter (clicker for presentation on findings).

Summary: The student will learn to use Excel and the TI-Nspire to graph real world data and draw conclusions from the data. This lesson is expected to last the duration of 5 school Days. Students will work collaboratively in small groups for a majority of this lab. Teacher will observe and monitor as students work.

Objective: Students will graph, interpret, and analyze data on solar panels to determine the *best graph for the data and decide the optimal angle placement of solar panels in Corpus Christi in addition to the students' city of choice in Table 1.1.*

Day 1: Whole group instruction which reviews the process to graph Sin and Cos in Excel and generate trigonometric graphs from the data using Worksheet "Graphing Lab A". Students may reference the video and instructional guide located in the Canvas module for additional instructions.

Students will prepare a ticket out the door to submit on Canvas during the last 5 minutes of class. The ticket out the door will be a short list of the steps necessary to enter data and create a sin or cos graph from that data using Excel and/or Ti-Nspire.

Day 2: Students will be given "Graphing Lab B" to work on individually (with shoulder and or table partners if assistance is necessary). Students will utilize SOLPOS to gather data for a chosen city and use Microsoft Excel to manipulate and graph the data. Once students have completed "Graphing Lab B", students will compare their solutions with the other students at their table.

Students will compare their solutions with the posted solutions for "Graphing Lab A" and "Graphing Lab B" and complete a google questionnaire located on canvas about their results as a ticket out the door.

Day 3: Students will be instructed on the use of the Fluke IRR1 Solar Irradiance Meter and the Solar Panel operation and use. Students will collect and record experimental data for Table 2.2 throughout the day.

Day 4 & Day 5: Students will work in small groups and use as work days to finalize their reports / PowerPoint presentations. Students will compile their data and create a Lab report using the "Analysis and Data Report" as a guide to thoroughly describe the solar data exploration activities, computations, and data findings. Student groups will present their findings on Day 5.

NAME ______________________________ DATE ____________________ PERIOD __________

Graphing Lab (A)

Graphing Sine and Cosine Functions

Transformations of Sine and Cosine Functions A sinusoid is a transformation of the graph of the sine function. The general form of the sinusoidal functions sine and cosine are $y = a \sin(bx + c) + d$ or $y = a \cos(bx + c) + d$. The graphs of $y = a \sin(bx + c) + d$ and $y = a \cos(bx + c) + d$ have the following characteristics.

Amplitude = $|a|$ Period = $\frac{2\pi}{|b|}$ Frequency = $\frac{|b|}{2\pi}$ or $\frac{1}{\text{period}}$

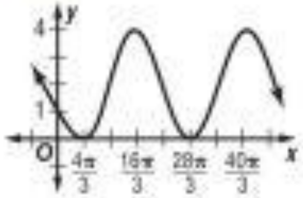
Phase Shift = $-\frac{c}{|b|}$ Vertical Shift = d Midline $y = d$

Example: State the amplitude, period, frequency, phase shift, and vertical shift of $y = -2 \cos\left(\frac{x}{4} - \frac{\pi}{3}\right) + 2$.

Then graph two periods of the function.

Amplitude $= |a| = |-2| = 2$

Period $= \frac{2\pi}{|b|} = \frac{2\pi}{\left|\frac{1}{4}\right|}$ or 8π



Frequency $= \frac{|b|}{2\pi} = \frac{\left|\frac{1}{4}\right|}{2\pi}$ or $\frac{1}{8\pi}$

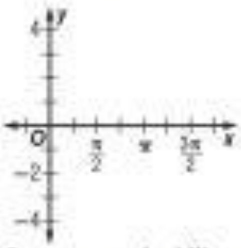
Phase Shift $= -\frac{c}{|b|} = \frac{-\left(-\frac{\pi}{3}\right)}{\left|\frac{1}{4}\right|}$ or $\frac{4\pi}{3}$

Vertical Shift = d or 2

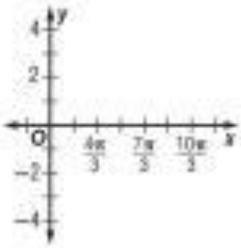
Exercises

State the amplitude, period, frequency, phase shift, and vertical shift of each function. Then graph two periods of the function.

1. $y = 3 \sin(2x + \pi)$



2. $y = \cos\left(x - \frac{\pi}{3}\right) + 2$



State the frequency and midline of each function.

3. $y = 3 \sin\left(\frac{1}{2}x + \frac{4\pi}{3}\right) + 1$

4. $y = \cos(3x) - 2$

Write a sine function with the given characteristics.

5. amplitude = 2, period = 4, phase shift = $\frac{1}{2}$, vertical shift = 4

TEKS – P.1(A)-(G) P.2(A)-(D)

NAME ______________________________ DATE ____________________ PERIOD __________

Graphing Lab (B)

Graphing Sine and Cosine Functions

Applications of Sinusoidal Functions You can use sinusoidal functions to solve certain application problems.

Example: The table shows the average monthly ETR (Solar Radiation), in Corpus Christi, Texas.

The data can be modeled by a sinusoidal function of the form $y = a \sin(bx + c) + d$. Find the maximum M and minimum m values of the data, and use these values to find a, b, c, and d.

Month	ETR
Jan	326.43
Feb	360.23
Mar	387.67
Apr	426.89
May	436.56
June	450.56
July	435.67
Aug	423.54
Sept	416.32
Oct	395.87
Nov	364.23
Dec	322.87

Table 1.1

Exercise

1. **Choose any city in the United States (other than Corpus Christi) and use excel to find the monthly average ETR using the SOLPOS website and record in Table 1.2 below.**

City Chosen: ______________________ **Longitude** ___________, **Latitude**______________

Table 1.2

Month	ETR
Jan	
Feb	
Mar	
Apr	
May	
June	
July	
Aug	
Sept	
Oct	
Nov	
Dec	

a. Use Excel / Ti-Nspire to compute average monthly ETR.

b. Use Excel / Ti-Nspire to graph a trigonometric function that models the monthly attendance at the chosen city location for the complete year.

c. According to your model, what is the Maximum, Minimum, and Range of the ETR measurements?

TEKS – P.1(A)-(G) P.2(A)-(D)

NAME ______________________ DATE ______________ PERIOD ________

Solar Data Collection Lab Computations

Instructions:

a) **Students will utilize the Fluke IRR1 Solar Irradiance Meter to measure and record the ETR and Watts at the given angles below for the 4 different portable VEVOR Monocrystalline Solar Panels at the given angles 0˚, 15˚, 30˚, and 45˚ for each hour.**

b) **Students will use the theoretical data from the Table 2.1 below to compare with experimental data recorded in Table 2.2.**

Theoretical Data

Table 2.1

Date	Time	0 ˚	15 ˚	30 ˚	45 ˚	Maximum ETR	Watts / Output
9/9/2023	6:00:00	231.8769	218.8687	190.9449	150.0086		
9/9/2023	7:00:00	528.3141	545.2846	525.0948	469.1208		
9/9/2023	8:00:00	793.3874	837.0956	823.7571	754.281		
9/9/2023	9:00:00	1008.422	1073.827	1066.053	985.6288		
9/9/2023	10:00:00	1158.635	1239.226	1235.365	1147.317		
9/9/2023	11:00:00	1233.758	1321.996	1320.142	1228.323		
9/9/2023	12:00:00	1228.632	1316.463	1314.579	1223.108		
9/9/2023	13:00:00	1143.6	1223.003	1219.06	1132.04		
9/9/2023	14:00:00	984.4446	1047.978	1040.093	961.3276		
9/9/2023	15:00:00	762.0406	803.3496	789.9117	722.6426		
9/9/2023	16:00:00	491.6748	505.9243	485.6958	432.368		
9/9/2023	17:00:00	192.5114	176.6862	148.8202	110.8123		

Experimental Data

Table 2.2

Date	Time	0 ˚	15˚	30˚	45˚	Maximum ETR	Watts / Output
9/9/2024	6:00:00						
9/9/2024	7:00:00						
9/9/2024	8:00:00						
9/9/2024	9:00:00						
9/9/2024	10:00:00						
9/9/2024	11:00:00						
9/9/2024	12:00:00						
9/9/2024	13:00:00						
9/9/2024	14:00:00						
9/9/2024	15:00:00						
9/9/2024	16:00:00						
9/9/2024	17:00:00						

TEKS – P.1(A)-(G) P.2(A)-(D)

Analysis of Data Report

1. **Using Excel and/or Ti-Nspire, calculate the equation of best fit for the data in Table 1.1 and Table 1.2.**

2. **Use Excel / Ti-Nspire to compare the Theoretical Data to the Experimental Data. In the data analysis, students will create visual graphs using a variety of graph types to illustrate the comparisons between the given data recorded in Table 2.1 and the experimental data recorded in Table 2.2.**

3. **Calculate the efficiency of the solar panels using the formula found on the following website. https://www.pveducation.org/pvcdrom/properties-of-sunlight/solar-radiation-on-a-tilted-surface**

4. **Determine the optimal angle to collect the maximum solar energy using the data collected in Table 2.1 and 2.2.**

5. **Calculate the average daily energy generated during the measured time period.**

6. **Create a lab report that is a summary of your findings during this activity including the items listed in number 1-5. The format should be in APA Format where applicable:**

   - **Title Page**
   - **Introduction**
   - **Experimental Procedure**
   - **Discussion (Answer questions)**
   - **Results (Data and Calculation)**
   - **Conclusion**

APPENDIX B

Module 2: Calculating Standard Deviation and Mean (TEKS – 1 A - F; 2 B - C and 3 C)

Range: The smallest to the largest number in a set of points

Mean: The average value for a given set of data

SD – Standard Deviation: How much a number is away from the middle score.

Date	Time (n)	ETR value μ	Change from mean X - μ	Change value Squared $(X - \mu)^2$
8/1/2025	6 am	231.8769		
8/1/2025	7 am	528.3141		
8/1/2025	8 am	793.3874		
8/1/2025	9 am	1008.422		
8/1/2025	10 am	1158.635		
8/1/2025	11 am	1233.758		
8/1/2025	12 pm	1228.632		
8/1/2025	1 pm	1143.6		
8/1/2025	2 pm	984.4446		
8/1/2025	3 pm	762.0406		
8/1/2025	4 pm	491.6748		
8/1/2025	5 pm	192.5114		
8/1/2025	6 pm	65.6425		
	Mean ETR value (X)		Sum of the $(X-\mu)^2$	

SD = $\sum(abs \_\_\_\_\_\_\_\_ (n(X - -1)\mu)2)1/2$

Here are the Steps to finding SD (standard Deviation)

1. Find the mean, (X) average, value for the data set
2. For each point (μ), find the square of its distance from the mean
3. Sum (add) the values from step 2
4. Divide the sum of step 3 by the sample size minus 1 (this is called the variance)
5. Take the square root of the variance to get SD

TEKS – 1 A - F; 2 B - C and 3 C

Find the average value, range and SD for each of the data sets given for each angle:

hour	ETR tilt 0	ETR tilt 10	ETR tilt 15	ETR tilt 30	ETR tilt 45	ETR tilt 60
8 am	190.768	314.1916	372.5477	528.9389	649.2838	725.381
9 am	447.588	590.3057	655.1921	818.1507	925.5336	969.4952
10 am	657.6044	816.0342	866.2241	1054.4489	1150.8149	1107.0458
11 am	805.6049	975.0929	1049.0149	1220.9362	1309.6527	1219.8654
12pm	881.376	1056.5234	1132.3551	1306.1660	1390.9641	1276.8654
1 pm	879.7091	1054.7314	1130.5209	1304.289	1389.173	1275.5973
2 pm	800.7249	969.8466	1043.6447	1215.4419	1304.4088	1215.6576
3 pm	649.8336	807.6797	877.6722	1045.6989	1143.4629	1101.1316
4 pm	437.4703	579.4322	644.0609	806.7593	914.4785	939.8624
5 pm	179.1313	301.6676	359.7216	515.7975	636.7227	743.114

Calculations for each tilt angle.

Calculations Questions to be answered:

1) Which tilt angle has the greatest range in numbers?

2) Which tilt angle has the least range in numbers?

3) Rank the tilt angles from least to greatest by their mean value.

4) Rank the tilt angles from least to greatest by the standard deviation. If two angles have the same standard deviation, the one with the largest mean value will go first.

5) Observe the range values for the tilt and the standard deviation. What observations can you make?

6) Why did you answer 5 the way you did, explain your logic.

7) Observe the mean value for the tilt angles with the standard deviation. What observations can you make?

8) Why did you answer 7 the way you did, explain your logic.

Module 2: Learning to manipulate and graph data (TEKS – 1 A - F; 2 B - C and 3 C)

Teacher Instructions: Learning the parts of a graph and what type of graph is used when.

Bar Graph are used for counted and unrelated material

Pie Graph/chart is best for looking to see what part of the graph is … You can see quickly how much or how little is used - again not a relationship

Line graph is for relationship - how far and how long did it travel - the slope of the line then becomes the rate of change in the two axes.

Using EXCEL to plot will make certain that the student can relate the shape of the slope correctly, but the student will need to hand practice drawing and predicting curves.

Hand plotting graphs:

7 parts: label and units for each axis, increments for each axis (increments must be consistent), title of the graph, then plotting point (remember X goes along the bottom and Y goes up and down), creating the smooth curve or line to match the data points

Plotting by hand helps the student to remember to do all the parts on the EXCEL graph.

EXCEL program

Students will either enter points or use the workbooks opened in the google classroom to plot. Students can plot all angles in EXCEL, but two plots are required by hand on graph paper for full credit.

To Use EXCEL once the data is uploaded or inputted:

Go to Insert and select 2 D line graph for 1 weeks worth of data.

Click on the graph to get three items to the right of the graph and click the + button. It will have boxes to click and the student must click on the box to add axis titles.

The student then will click on the axis title to add the name of the axis (Y axis should be labeled ETR with its units W/m^2 and the X axis should be labeled time in hours).

Clicking on the ETR tilt the student should add the angle of the tilt and the graph then is complete with the data. One graph has to be done with 1 week's worth of data for each angle. All axes and titles will need to be added or corrected.

The TEKS for this is for science supporting standards:

1 A-F

(1B) apply scientific practices to plan and conduct descriptive, comparative, and experimental investigations, and use engineering practices to design solutions to problems;

(1E) collect quantitative data using the International System of Units (SI) and qualitative data as evidence;

(1F) organize quantitative and qualitative data using bar charts, line graphs, scatter plots, data tables, labeled diagrams, and conceptual mathematical relationships;

(2B) analyze data by identifying significant statistical features, patterns, sources of error, and limitations;

(2C) use mathematical calculations to assess quantitative relationships in data;

(3C) engage respectfully in scientific argumentation using applied scientific explanations and empirical evidence.

Graphing

There are 7 parts to a graph:

1) Title

2 and 3) Label and units for each axis

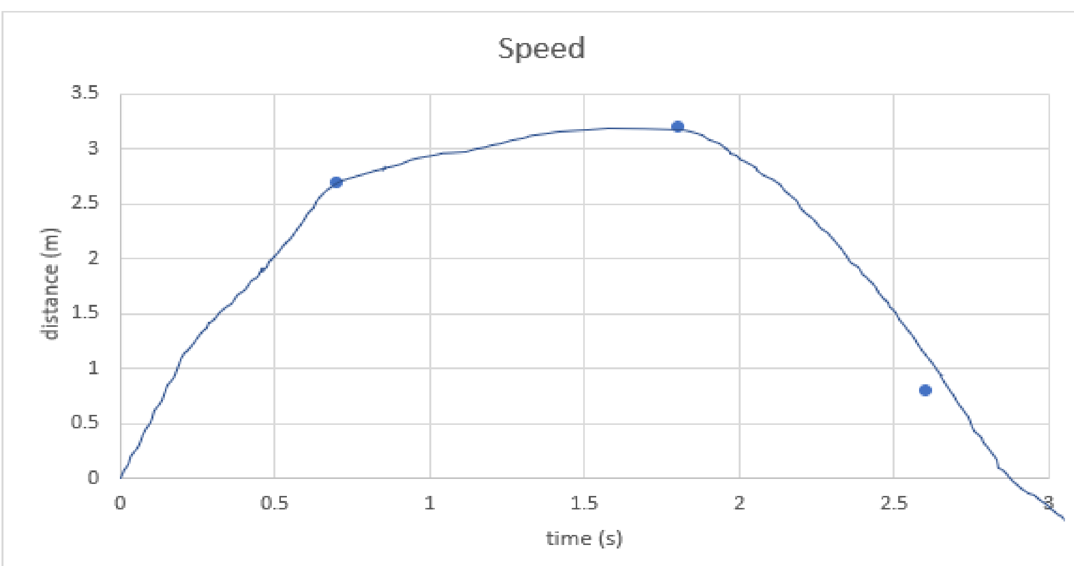
4 and 5) increments for the axis

6) plotting the points

7) creating a smooth line fitting curve to match the data points

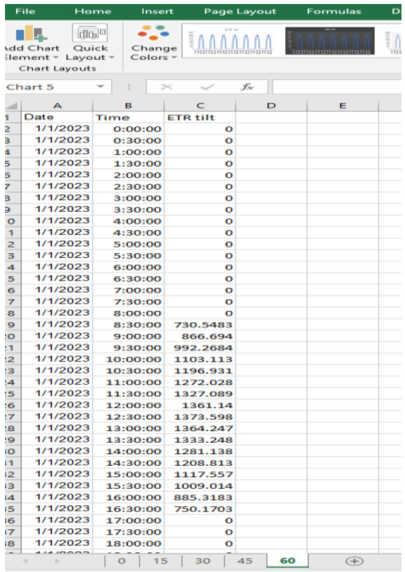
How to find the increments:

Take the highest number and subtract it from the lowest number for each axis. Then divide the difference by the number of lines. You may want to round or pick numbers that are close to the values.

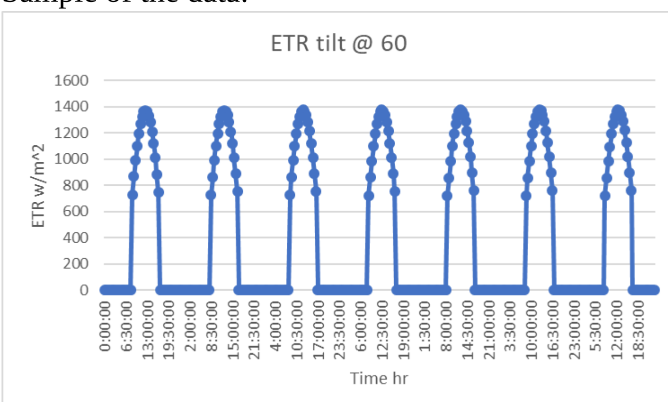


I am giving you a chart of Data. This happens to be the amount of sunlight for December 21 for each hour. I want you to plot 2 on one graph paper and the remaining three to be plotted using EXCEL.

hour	ETR tilt 0	ETR tilt 10	ETR tilt 15	ETR tilt 30	ETR tilt 45	ETR tilt 60
8 am	190.768	314.1916	372.5477	528.9389	649.2838	725.381
9 am	447.588	590.3057	655.1921	818.1507	925.5336	969.4952
10 am	657.6044	816.0342	866.2241	1054.4489	1150.8149	1107.0458
11 am	805.6049	975.0929	1049.0149	1220.9362	1309.6527	1219.8654
12pm	881.376	1056.5234	1132.3551	1306.1660	1390.9641	1276.8654
1 pm	879.7091	1054.7314	1130.5209	1304.289	1389.173	1275.5973
2 pm	800.7249	969.8466	1043.6447	1215.4419	1304.4088	1215.6576
3 pm	649.8336	807.6797	877.6722	1045.6989	1143.4629	1101.1316
4 pm	437.4703	579.4322	644.0609	806.7593	914.4785	939.8624
5 pm	179.1313	301.6676	359.7216	515.7975	636.7227	743.114

Sample of the data: 

Date	Time	ETR tilt
1/1/2023	0:00:00	0
1/1/2023	0:30:00	0
1/1/2023	1:00:00	0
1/1/2023	1:30:00	0
1/1/2023	2:00:00	0
1/1/2023	2:30:00	0
1/1/2023	3:00:00	0
1/1/2023	3:30:00	0
1/1/2023	4:00:00	0
1/1/2023	4:30:00	0
1/1/2023	5:00:00	0
1/1/2023	5:30:00	0
1/1/2023	6:00:00	0
1/1/2023	6:30:00	0
1/1/2023	7:00:00	0
1/1/2023	7:30:00	0
1/1/2023	8:00:00	0
1/1/2023	8:30:00	730.5483
1/1/2023	9:00:00	866.694
1/1/2023	9:30:00	992.2684
1/1/2023	10:00:00	1103.113
1/1/2023	10:30:00	1196.931
1/1/2023	11:00:00	1272.028
1/1/2023	11:30:00	1327.089
1/1/2023	12:00:00	1361.14
1/1/2023	12:30:00	1373.598
1/1/2023	13:00:00	1364.247
1/1/2023	13:30:00	1333.248
1/1/2023	14:00:00	1281.138
1/1/2023	14:30:00	1208.813
1/1/2023	15:00:00	1117.557
1/1/2023	15:30:00	1009.014
1/1/2023	16:00:00	885.3183
1/1/2023	16:30:00	750.1703
1/1/2023	17:00:00	0
1/1/2023	17:30:00	0
1/1/2023	18:00:00	0



Lesson 2 Calculating Mean, and Standard Deviation, range in numbers:

Teacher instructions:

Mean is the average value for a set of numbers

Range is the top number to the lowest number in a set of numbers

Standard deviation is how much from the mean is this number. The smaller the deviation the closer grouped the numbers are

Teacher will demonstrate the first grouping on numbers to have the students follow along and then do self-practice.

Leading questions:

1) Why would we need to know the range of a sample? - hint - blood work, scores etc.
2) What about the average value? sports

3) Why then a standard deviation? (in science this could help eliminate values that fall outside the bell curve and give us better results)

TEKS Science: these are supporting standards

(3C) engage respectfully in scientific argumentation using applied scientific explanations and empirical evidence.

(4A) analyze, evaluate, and critique scientific explanations and solutions by using empirical evidence, logical reasoning, and experimental and observational testing, so as to encourage critical thinking by the student;

Group Practice:

Calculating Standard Deviation and Mean

Range: The smallest to the largest number in a set of points

Mean: The average value for a given set of data

SD – Standard Deviation: How much a number is away from the middle score.

Date	Time (n)	ETR value μ	Change from mean X - μ	Change value Squared $(X - \mu)^2$
8/1/2025	6 am	231.8769		
8/1/2025	7 am	528.3141		
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8/1/2025	10 am	1158.635		
8/1/2025	11 am	1233.758		
8/1/2025	12 pm	1228.632		
8/1/2025	1 pm	1143.6		
8/1/2025	2 pm	984.4446		

8/1/2025	3 pm	762.0406		
8/1/2025	4 pm	491.6748		
8/1/2025	5 pm	192.5114		
8/1/2025	6 pm	65.6425		
	Mean ETR value (X)		Sum of the $(X-\mu)^2$	

SD =

Here are the Steps to finding SD (standard Deviation)

1. Find the mean, (X) average, value for the data set

2. For each point (μ), find the square of its distance from the mean

3. Sum (add) the values from step 2

4. Divide the sum of step 3 by the sample size minus 1 (this is called the variance)

5. Take the square root of the variance to get SD

Student work:

Find the SD, range, and average value for each of the data sets given for each angle:

hour	ETR tilt 0	ETR tilt 10	ETR tilt 15	ETR tilt 30	ETR tilt 45	ETR tilt 60
8 am	190.768	314.1916	372.5477	528.9389	649.2838	725.381
9 am	447.588	590.3057	655.1921	818.1507	925.5336	969.4952
10 am	657.6044	816.0342	866.2241	1054.4489	1150.8149	1107.0458
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3 pm	649.8336	807.6797	877.6722	1045.6989	1143.4629	1101.1316
4 pm	437.4703	579.4322	644.0609	806.7593	914.4785	939.8624
5 pm	179.1313	301.6676	359.7216	515.7975	636.7227	743.114

Answer the following questions with this worksheet:

1) Which tilt angle has the greatest range in numbers?

2) Which tilt angle has the least range in numbers?

3) Rank the tilt angles from least to greatest by their mean value.

4) Rank the tilt angles from least to greatest by the standard deviation. If two angles have the same standard deviation, the one with the largest mean value will go first.

5) Observe the range values for the tilt and the standard deviation. What observations can you make?

6) Why did you answer 5 the way you did, explain your logic.

7) Observe the mean value for the tilt angles with the standard deviation. What observations can you make?

8) Why did you answer 7 the way you did, explain your logic.

APPENDIX C

Module 3: Looking at the Properties of waves and heat

TEKS Science – 5(A) & 8(D)

5 (A) analyze different types of motion by generating and interpreting position versus time, velocity versus time, and acceleration versus time using hand graphing and real-time technology such as motion detectors, photogates, or digital applications (Use of the Fluke to collect data)

8 (D) investigate behaviors of waves, including reflection, refraction, diffraction, interference, standing wave, the Doppler effect and polarization and superposition

Teacher Instruction:

Students will take a solar panel and place it outside and collect the following information each hour: Solar irradiation, temperature.

Students will be asked for the leading question

1) What is solar power? - energy from the sun that comes to the earth on electromagnetic waves

2) How is it measured? - W/m^2

3) What about temperature? Is this transferred by the sun? (yes) How is it measured?

4) What effects would happen when you … (questions for them to think about and answer individually) - this is what we will be studying this week.

a) use a mirror?

b) Does color make a difference in the reading?

c) Does polarization make a difference?

5) What things can interfere with your readings?

Equipment needed:

Solar panel, Fluke IRR1 Solar Irradiance Meter with temperature gauges, level, polarized panels, colored panels to lay over the solar panel (Red, Blue, Yellow, Green, Purple/Violet, Orange), mirrors.

Day 1:

How would you design a table to collect the temperature outside, the temperature on the front and back of the panel, and the level of the panel for each 10 minutes.

What is the reading for the solar panel: ETR Value: Each 10 minutes

Temperature: front and back for each 10 minutes

Using a level check to see if the panel completely is flat and if it is continuing to be flat throughout this experiment.

Day 2: Changing colors:

Leading questions:

1) What color will make the largest increase, if any, to your ETR value?
2) Why do you think this?
3) Yesterday, did the solar panel experience any changes to its surface? - Did it bend?
4) What effect, if any, do you think the colors will have on the changes to the surface?
5) Why do you think this?
6) What is the use of the colors on the panel? (interference - explain interference as something that will block or change the wave) (+ interference is the waves adding together called constructive interference) (- negative interference is the waves canceling out)
7) Do you want to change your answer to question 1? Why or why not?
8) How will you design a chart to collect: time, temperature front and back, change in level? Color you used.

Day 3: Reflecting the sunlight back on the panel:

1) Can reflecting light back on the panel increase or decrease the amount of light captured?
2) Why do you think this?
3) How will you design a chart to collect: time, temperature front and back, change in level?
4) Select one person in the group to hold the mirror and practice reflecting the light back onto the panel.

Day 4: Using Polarized Sheets on the panel

1) Can reflecting light back on the panel increase or decrease the amount of light captured?
2) Why do you think this?
3) How will you design a chart to collect: time, temperature front and back, change in level?

Day 5: Analyzing the Data

1) Create a graphic organizer to summarize the data you collected.

2) What day was your control sample collected? Why do you think this?

3) What are sources of interference?

4) Is all interference going to reduce your results? How do you know this?

5) Explain using examples what were interference patterns with the different experiments that we did and how do you know this?

6) What caused the largest interference? Explain why you think this.

7) What caused the least interference? Explain your answer.

Analysis of Wind Speed Pattern Changes Before and After Wind Farm Operations

National Science Foundation (NSF) Research Experiences for Teachers (RET)
Site at Texas A&M University-Kingsville
Integrating data-driven research in Renewable Energy Across Disciplines (I-READ)

KISD Teacher Participant: Marisa Hamilton
Research Faculty Mentor: Dr. Hua Li
Student Mentor: Yahya Al Bustanji
SGISD Teacher Participant: Debra Carpentier
Curriculum Faculty Mentor: Dr. Marsha Sowell
Industrial Advisor: Rene Ramirez

Abstract

The purpose is to determine if there are significant differences in wind energy in surrounding areas from the wind farm using data science. The study focused on data collected from the National Solar Radiation Database (NSRDB) and the U.S. Wind Turbine Database (uswtdb), which were used to identify possible changes in wind speed patterns and correlations with different factors. Two areas were investigated to compare variations in wind speed possible changes. In-land areas compared to coaster areas were the focus of the study. The wind speed average was compared before and after operation in twenty years in four sites (downwind, East, West, and further downwind) around the selected wind turbine. The study will also lead to inquiries into investigations of wind energies to teach students the importance of data science to evaluate research.

Introduction

Just as drilling for oil and gas can impact the surrounding properties underground, we wonder if the same impact could affect wind in neighboring properties. Wind turbines are becoming a common and strong contributor to power our homes and way of life. Wind turbines depend on wind speeds to produce wind energy. If wind speed is reduced or increased, it will result in the amount of energy produced. Generating wind power is significantly affected by wind speed and it is important to analyze the contributions of factors affecting wind speed.

Background

Electricity is a vital part of society and concerns about keeping up with the demand of a vastly growing industry to provide to increasing populations. Texas is the top producer of oil and natural gas in the nation. In 2023, Texas accounted for 43% of the nation's crude oil production and 27% of its natural gas gross withdrawals (eia, 2024). Conservation of fossil fuels and developing cleaner energy for the health of the environment led to exploring other sources of producing energy. In 1999, George Bush deregulated the electricity market and mandated 2,000 megawatts of renewable energy by 2009. Wind energy is now an important source of power and electricity and is growing every year. One wind turbine can power an individual home or farm, but several built close together form a wind energy plant, or wind farm. (NREL, 2024) The biggest wind farm in the United States spans 100,000 acres (enough to cover half of New York City) and can power more than 250,000 homes (NREL,2024). Goal achieved by 2005 for renewable energy and a new challenge:10,000 megawatts by 2025. By April 2016, 19,000 megawatts of renewables. With growing demand and challenges of providing renewable energy, wind energy researchers are trying to learn how many wind turbines are built in which arrangements can maximize energy production in wind plants (NREL, 2024). Wind turbine and wind farm information is collected and retrieved for studies on its effectiveness. The Minco Wind Farm, just north of the state of Texas was used for this study and went operational in 2010 with coordinates of latitude: 35.26 longitude: -98.04. A coastal location, Penescal wind farm, was also studied near Baffin Bay and was operational in 2009 with coordinates of latitude: 27.102295 and Longitude: -97.503891.

Methodology

Finding Wind Turbine was the first step in the study and used US Wind Turbine Data Base to locate a turbine. Two locations were selected. The Minco Wind Farm is in Oklahoma with a latitude: 35.26 longitude: -98.04 and was online in 2010. A second wind farm was chosen near the coast of Baffin Bay. The Penescal wind farm became operational in 2009. Once locations were selected, then collection of data was retrieved to analyze.

Calculation of Wind Direction

The National Solar Radiation Database was used to gather all data available for 4 km plots at 30-minute intervals for 10 years prior to and 10 years after construction for the wind turbine. Using the data, the frequency of the wind direction was charted to determine the wind direction.

Inland Minco, Oklahoma Wind Turbine:

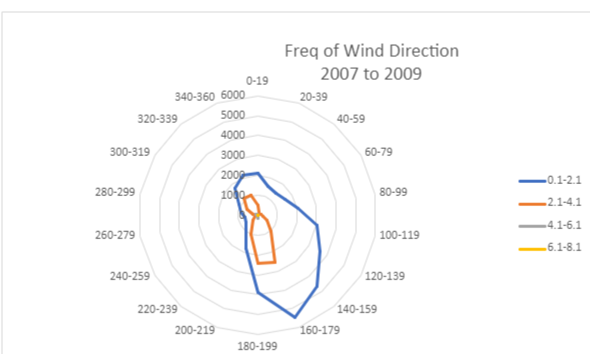


Figure 1a: Wind direction pre-construction

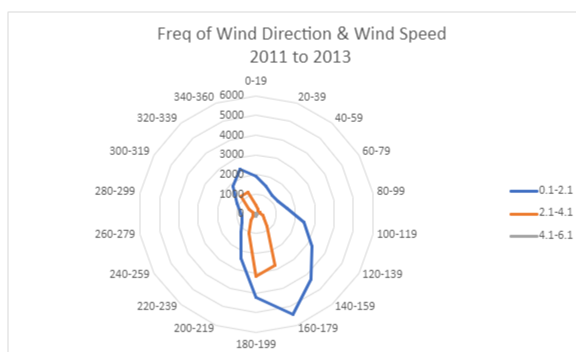


Figure 1b: Wind direction post-construction

Wind direction between 160 to 179 degrees with winds speeds being between 0.1 and 2.1 m/s.

Coastal Baffin Bay, Texas

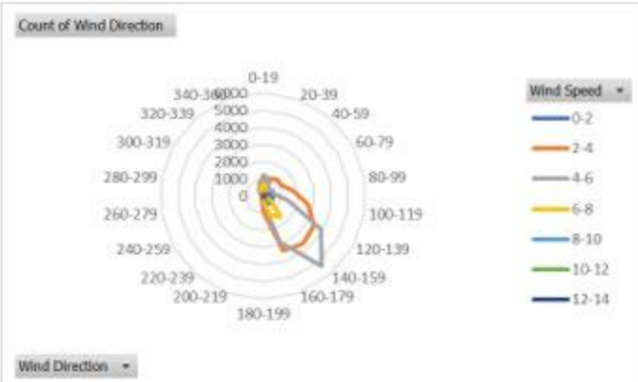


Figure 2a: Wind direction pre-construction

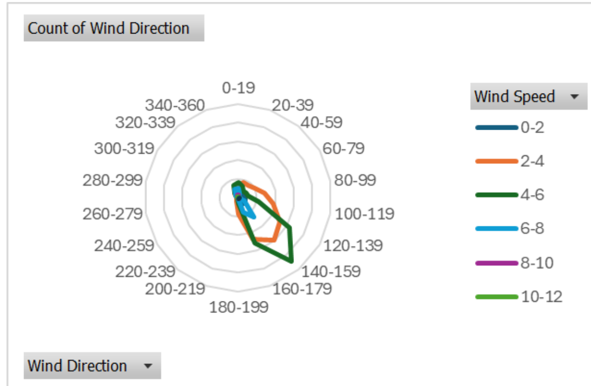
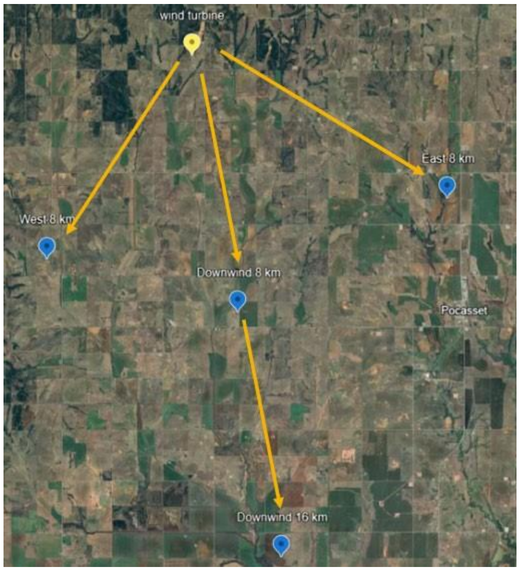


Figure 2b: Wind direction post-construction

Wind direction between 140 to 159 degrees with winds speeds being between 4 and 6 m/s.

Location of Four additional sites: two downwind, one east, and one to the west

Using Route Compass, four additional sites were located to analyze wind speeds. Three sites are approximately 8km and one site is 16km away from the original wind turbine. The sites were then transferred to Google Earth Map using topography to pinpoint the additional sites.



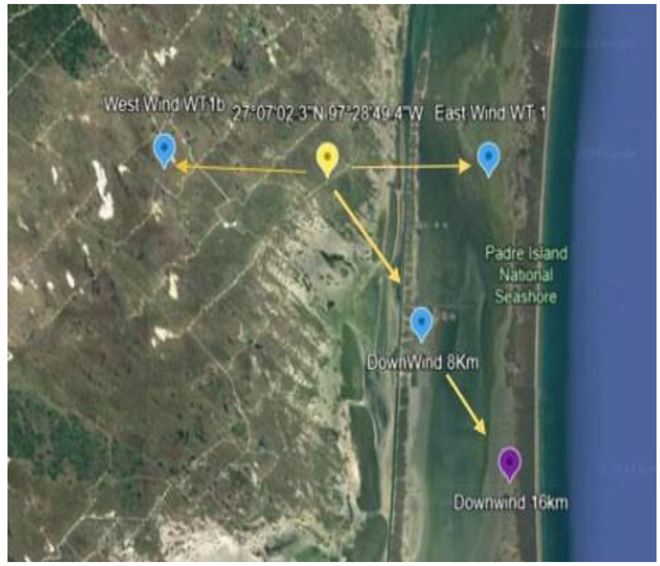


Figure 3: In-Land location-Minco Wind Farm Area to the left in yellow and Coastal location-Penescal Wind Farm to the right in yellow.

DATA

Calculation of monthly average wind speed for various yearly intervals and compared it to 10 years before the operation of the wind turbine. Monthly averages for each of the years can be found in Appendix A for the Inland and Coastal Sites.

Inland Minco Oklahoma

Inland SITE 2 Average Wind Speed 8 km downwind

	Pre-construction	Post-construction
1 year	3.288	3.369
2 year		3.353
3 year		3.404
5 year		3.314
10 year		3.284

Inland SITE 3 Average Wind Speed 8 km east

	Pre-construction	Post-construction
1 year	3.276993	3.371
2 year		3.354
3 year		3.406
5 year		3.340
10 year		3.316

Inland SITE 4 Average Wind Speed 8 km west

	Pre-construction	Post-construction
1 year	3.2707	3.364
2 year		3.350
3 year		3.400
5 year		3.336
10 year		3.311

Inland SITE 5 Average Wind Speed 16 km downwind

	Pre-construction	Post-construction
1 year	3.2678	3.345
2 year		3.335
3 year		3.385
5 year		3.291
10 year		3.291

Coastal Baffin Bay

Coastal SITE 2 Average Wind Speed 8 km downwind

	Pre-construction	Post-construction
1 year	4.01283	4.0922
2 year		4.1485
3 year		4.1327
5 year		4.0921
10 year		4.0090

Coastal SITE 3 Average Wind Speed 8 km east

	Pre-construction	Post-construction
1 year	4.0124	4.2892
2 year		4.1437
3 year		4.1338
5 year		4.0932
10 year		4.0087

Coastal SITE 4 Average Wind Speed 8 km west

	Pre-construction	Post-construction
1 year	4.0101	4.2875
2 year		4.1413
3 year		4.1308
5 year		4.0895
10 year		4.0051

Costal SITE 5 Average Wind Speed 16 km downwind

	Pre-construction	Post-construction
1 year	4.0124	4.2831
2 year		4.1415
3 year		4.1323
5 year		4.0918
10 year		4.0084

RESULTS

A T-Test Analysis of average wind speed data was conducted to determine if there was a significant difference among the wind speeds. The null hypothesis is there is no significant difference of average wind speed between pre- and post- operation of a wind farm in surrounding areas with $\alpha = 0.05$. The analysis was conducted with the 10 years pre-construction and various yearly intervals post-construction.

Inland Minco Oklahoma

	West 8 km	East 8 km	Downwind 8 km	Downwind 16 m
1 year	0.131	0.134	0.186	0.078
2 year	0.085	0.096	0.173	0.037
3 year	0.013	0.015	0.027	0.008
5 year	0.090	0.101	0.196	0.061
10 year	0.182	0.200	0.396	0.495

Coastal Baffin Penescal Baffin Bay Texas

	West 8 km	East 8 km	Downwind 8 km	Downwind 16 m
1 year	0.028	0.029	0.029	0.029
2 year	0.044	0.046	0.046	0.046
3 year	0.016	0.016	0.016	0.017
5 year	0.107	0.107	0.107	0.108
10 year	0.930	0.929	0.932	0.952

A correlation analysis was conducted to determine any relationship between wind speed and temperature or wind speed and pressure.

Inland Minco Oklahoma

Wind Speed and --	West 8 km	East 8 km	Downwind 8 km	Downwind 16 km
temperature	0.089	0.088	-0.045	0.075
pressure	-0.248	-0.248	-0.040	-0.241

Coastal Baffin Penescal Baffin Bay Texas

Wind Speed and ---	West 8 km	East 8 km	Downwind 8 km	Downwind 16 km
temperature	-0.0347	-0.04005	-0.04051	-0.04052
pressure	-0.04162	-0.03965	-0.03964	-0.03978

Conclusion

A significant increase in the average wind speed for both the inland and coastal wind farms and the surrounding areas. Inland and coastal wind farms are showing different numbers of significant differences.

Future Research

The average wind speeds pre- and post- construction are counterintuitive. Further research is needed to determine what other factors are influencing wind speed, with a closer examination of the terrain. Lastly, with the number of significant differences varying between inland and coastal areas, further research is justified.

Acknowledgment

This material is based upon work supported by the National Science Foundation under Award No. 2206864. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

Curriculum Modules

Two curriculum modules were created during this research, one for physics and one for chemistry.

The physics module, found in Appendix B, was centered around the question of "Would installing a wind turbine at our school be a viable and beneficial option for our community?" The project is a three-to-four-week project incorporating electricity, energy and power. The curriculum uses portions of the NEED Project curriculum of Wind for Schools and Your Future in Wind Energy.

Sources

NREL, National Renewable Energy Laboratory, U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy LLC.retrieved on July 2024 from Wind Energy Basics | NREL www.rnet.gov/research/re-wind.html

U.S. Energy Information Administration - EIA - Independent Statistics and Analysis retrieved on July 2024 from www.eia.gov/state/isd=TX

Appendix A

Calculation of monthly average wind speed for various yearly intervals and compared it to 10 years before the operation of the wind turbine.

Inland Minco Oklahoma

SITE 2 Average Wind Speed 8 km downwind from turbine

Prior

	10 years prior
January	3.251631232
February	3.489779491
March	3.677871457
April	3.915984848
May	3.458620479
June	3.28292298
July	3.004282747
August	2.8153348
September	2.940593434
October	3.304062805
November	3.213787879
December	3.259133675
average	3.288

After Wind Turbine Operation

	1 year	2 years	3 years	5 years	10 years
January	2.860618	3.234577	3.179256	3.295336	3.317036
February	3.643527	3.515662	3.526935	3.501086	3.5416
March	3.765457	3.78498	3.725605	3.601909	3.652702
April	4.381389	3.949861	3.930324	3.9275	3.822139
May	4.36297	4.048051	4.011246	3.824341	3.582137
June	4.625972	3.940764	3.780486	3.642347	3.395896
July	2.940457	3.014348	2.983938	3.001774	2.860168
August	2.943884	2.989483	2.850851	2.80207	2.75496
September	3.145347	2.990104	2.929722	2.990986	2.924903
October	3.223589	3.363743	3.433356	3.248038	3.362036
November	3.876944	3.563056	3.60125	3.631972	3.424493
December	2.862298	3.132964	3.078651	3.10457	3.09328
average	3.369	3.353	3.404	3.314	3.284

SITE 3 Average Wind Speed 8 km east of the turbine

Prior

	10 years
January	3.228797
February	3.480201
March	3.670874
April	3.920556
May	3.452863
June	3.265056
July	2.951902
August	2.812796
September	2.91784
October	3.315685
November	3.239868
December	3.261599
average	3.276993

After Wind Turbine Operation

	1 year	2 years	3 years	5 years	10 years
January	2.865659	3.241465	3.185663	3.301263	3.320269
February	3.650521	3.51994	3.531349	3.506399	3.543713
March	3.772379	3.791734	3.731967	3.607406	3.655565
April	4.387569	3.954653	3.934769	3.931208	3.822285
May	4.36996	4.052184	4.014583	3.827124	3.581411
June	4.622431	3.938472	3.777431	3.639792	3.388417
July	2.939583	3.014147	2.848387	2.998683	2.856277
August	2.941196	2.98797	2.848387	2.799516	2.752191
September	3.143333	2.987431	2.9275	2.989542	2.919167
October	3.223858	3.365894	3.434565	3.249368	3.360733
November	3.881181	3.567049	3.605278	3.635917	3.424535
December	2.865524	3.137702	3.083244	3.108831	3.094624
average	3.371174	3.354312	3.405547	3.339834	3.316336

SITE 4 Average Wind Speed 8 km west of the turbine

Prior

	10 years
January	3.214274
February	3.466042
March	3.658246
April	3.909868
May	3.44869
June	3.264111
July	2.952574
August	2.814422
September	2.9175
October	3.312762
November	3.232313
December	3.249126
average	3.2707

After Wind Turbine Operation

	1 year	2 years	3 years	5 years	10 years
January	2.853831	3.226747	3.171886	3.288817	3.307386
February	3.637872	3.510975	3.522197	3.495387	3.530863
March	3.760081	3.777655	3.718593	3.595497	3.643542
April	4.373611	3.943611	3.925301	3.924167	3.814583
May	4.357796	4.043817	4.007751	3.821075	3.577164
June	4.6275	3.941042	3.782269	3.643403	3.389111
July	2.940659	3.013441	2.986044	3.003387	2.857554
August	2.94375	2.988273	2.851635	2.803118	2.754012
September	3.145486	2.990729	2.930394	2.991083	2.918333
October	3.222043	3.359711	3.430869	3.245726	3.356223
November	3.871528	3.558785	3.597176	3.628264	3.416813
December	2.859677	3.128327	3.074126	3.100659	3.085739
average	3.3644	3.3500	3.4008	3.3356	3.3113

SITE 5 Average Wind Speed 16 km downwind of the turbine

Prior

	10 years
January	3.2058
February	3.4087
March	3.6086
April	3.8478
May	3.4972
June	3.2629
July	2.9994
August	2.7644

After Wind Turbine Operation

	1 year	2 year	3 year	5 year	7 year
January	3.5764	3.3159	3.5177	3.3027	3.3027
February	3.3752	3.4626	3.4273	3.4997	3.4997
March	3.7736	3.6874	3.8289	3.6134	3.6134
April	3.5025	3.6885	3.8253	3.6957	3.6957
May	3.7060	3.8179	3.7987	3.5671	3.5671
June	3.2206	3.3331	3.4951	3.2228	3.2228
July	3.0457	2.9829	2.9949	3.0132	3.0132
August	3.0145	2.7931	2.8153	2.7348	2.7348

September	2.9268
October	3.2410
November	3.2152
December	3.2360
average	3.2678

September	2.8326	2.8101	2.8864	2.9232	2.9232
October	3.4796	3.5200	3.4015	3.2826	3.2826
November	3.2333	3.4470	3.5201	3.4765	3.4765
December	3.3757	3.1599	3.1141	3.1623	3.1623
average	3.3446	3.3349	3.3854	3.2912	3.2912

Coastal Baffin Bay

SITE 2 Average Wind Speed 8 km downwind from turbine Coastal

Prior

	10 years prior
January	4.2259
February	4.21647
March	4.2229
April	4.4483
May	4.3625
June	4.0264
July	3.7842
August	3.4014
September	3.4641
October	3.8336
November	3.9881
December	4.1945
average	**4.01283**

After Wind Turbine Operation

	1 year	2 years	3 years	5 years	10 years
January	4.0109	3.9486	4.0599	4.0109	3.9719
February	4.2243	4.3351	4.2928	4.2242	4.1187
March	4.1836	4.3203	4.4006	4.1836	4.2118
April	4.5784	4.8301	4.8543	4.5784	4.3961
May	4.6272	4.6066	4.6059	4.6272	4.5071
June	4.2325	4.3675	4.0736	4.2324	4.0816
July	4.0784	3.9470	3.9765	4.0784	4.0687
August	3.5756	3.6166	3.5591	3.5755	3.7140
September	3.5892	3.6219	3.5846	3.5891	3.5055
October	3.8688	3.9106	3.9640	3.8687	3.7731
November	4.1062	4.2056	4.1281	4.1061	3.8828
December	4.0486	4.1038	4.1118	4.0486	3.8814
average	**4.0922**	**4.1485**	**4.1327**	**4.0921**	**4.0090**

SITE 3 Average Wind Speed 8 km east of the turbine Coastal

Prior

	10 years
January	4.2255
February	4.2159
March	4.2226
April	4.4479
May	4.3621
June	4.0260
July	3.7838
August	3.4011
September	3.4645
October	3.8331
November	3.9876
December	4.1940
average	**4.0124**

After Wind Turbine Operation

	1 year	2 years	3 years	5 years	10 years
January	3.8946	3.9042	4.0594	4.0105	3.9712
February	4.8673	4.3904	4.2924	4.2240	4.1181
March	4.3686	4.3479	4.4000	4.1831	4.2111
April	5.3826	5.0076	4.8538	4.5780	4.3954
May	5.0631	4.6048	4.6053	4.6267	4.5062
June	4.2677	4.0213	4.0731	4.2320	4.0809
July	3.8524	3.9585	3.9762	4.0782	4.0681
August	3.4827	3.5645	3.5586	3.5751	3.7133
September	3.4003	3.5386	3.5842	3.5887	3.5048
October	3.9130	4.0003	3.9636	3.8683	3.7724
November	4.6932	4.1614	4.1275	4.1057	3.8821
December	4.2844	4.2252	4.1111	4.0480	3.8805
average	4.2892	4.1437	4.1338	4.0932	4.0087

SITE 4 Average Wind Speed 8 km west of the turbine Coastal

Prior

	10 years
January	4.2184
February	4.2121
March	4.2230
April	4.4470
May	4.3592
June	4.0225
July	3.7807
August	3.3985
September	3.4641
October	3.8307
November	3.9803
December	4.1841
average	4.0101

After Wind Turbine Operation

	1 year	2 years	3 years	5 years	10 years
January	3.8890	3.8990	4.0528	4.0024	3.9637
February	4.8619	4.3882	4.2898	4.2207	4.1154
March	4.3695	4.3495	4.4008	4.1828	4.2105
April	5.3836	5.0076	4.8534	4.5759	4.3936
May	5.0629	4.6022	4.6035	4.6240	4.5037
June	4.2668	4.0199	4.0700	4.2283	4.0774
July	3.8536	3.9550	3.9724	4.0741	4.0647
August	3.4856	3.5661	3.5595	3.5750	3.7122
September	3.3972	3.5358	3.5816	3.5864	3.5025
October	3.9098	3.9974	3.9601	3.8649	3.7692
November	4.6911	4.1572	4.1231	4.1002	3.8759
December	4.2784	4.2177	4.1022	4.0392	3.8729
average	4.2875	4.1413	4.1308	4.0895	4.0051

SITE 5 Average Wind Speed 16 km downwind of the turbine Costal

Prior

	10 years
January	4.2254
February	4.2161
March	4.2227
April	4.4480
May	4.3622
June	4.0262
July	3.7838
August	3.4012

After Wind Turbine Operation

	1 year	2 year	3 year	5 year	10 year
January	3.8946	3.9042	4.0592	4.0103	3.9713
February	4.8673	4.3906	4.2925	4.2239	4.1183
March	4.3692	4.3484	4.4003	4.1834	4.2115
April	5.3833	5.0078	4.8542	4.5781	4.3957
May	5.0635	4.6049	4.6055	4.6268	4.5066
June	4.2679	4.0216	4.0731	4.2320	4.0810
July	3.8530	3.9587	3.9764	4.0782	4.0682
August	3.4835	3.5653	3.5591	3.5754	3.7136

September	3.4645
October	3.8330
November	3.9876
December	4.1940
average	**4.0124**

September	3.4005	3.5384	3.5841	3.5887	3.5049
October	3.9130	4.0003	3.9634	3.8683	3.7724
November	4.6930	4.1613	4.1275	4.1056	3.8821
December	4.2845	4.2255	4.1112	4.0480	3.8807
average	**4.2831**	**4.1415**	**4.1323**	**4.0918**	**4.0084**

Appendix B

Physics Lesson plan

Activity 1 – Science of Electricity Model

✪ Objective

- Students will be able to demonstrate and describe how electricity is generated. TEKS P.6B

➡ Caution

- The magnets used in this model are very strong. Refer to page 7 of this guide for more safety information.
- Use caution with nails and scissors when puncturing the bottle.

Materials

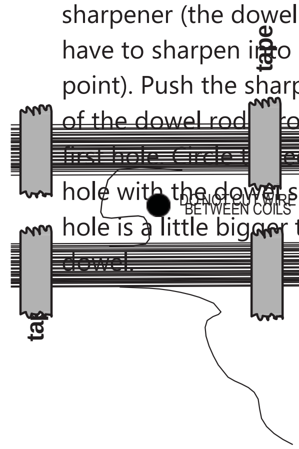
- 1 Small bottle
- 1 Rubber stopper with 1/4" hole
- 1 Wooden dowel (12" x 1/4")
- 4 Strong rectangle magnets
- 1 Foam tube
- 1 Small nail
- 1 Large nail
- Magnet wire
- Permanent marker
- 1 Pair sharp scissors
- Masking tape
- Fine sandpaper
- 1 Push pin
- 1 Multimeter with alligator clips
- Hand operated pencil sharpener
- Ruler
- Utility knife (optional)
- Student Guide, page 34

Procedure

- Assemble the model per instructions.
- Demonstrate the model and ask students to describe how electricity is generated based on what they see.
- Ask students to complete the worksheet in the student guide.
- Hold a class discussion on how the model could be enhanced or improved.

▪Preparing the Bottle

1. If needed, cut the top off of the bottle so you have a smooth edge and your hand can fit inside. This step may not be necessary. If necessary, a utility knife may be of assistance.
2. Pick a spot at the base of the bottle. (HINT: If the bottle you are using has visible seams, measure along these lines so your holes will be on the opposite sides of the bottle.) Measure 10 centimeters (cm) up from the base and mark this location with a permanent marker.
3. On the exact opposite side of the bottle, measure 10 cm up and mark this location with a permanent marker.
4. Over each mark, poke a hole with a push pin. Do not distort the shape of the bottle as you do this.
   CAUTION: Hold a rubber stopper inside the bottle behind where the hole will be so the push pin, and later the nails, will hit the rubber stopper and not your hand, once it pokes through the bottle.
5. Widen each hole by pushing a nail through it. Continue making the hole bigger by circling the edge of the hole with the side of the nail. (A 9/32 drill bit twisted slowly also works, using a rubber stopper on the end of the bit as a handle.)
6. Sharpen one end of the dowel using a hand operated pencil sharpener (the dowel does not have to sharpen into a fine point). Push the sharpened end of the dowel rod through the first hole. Circle the edge of the hole with the dowel so that the hole is a little bigger than the dowel.

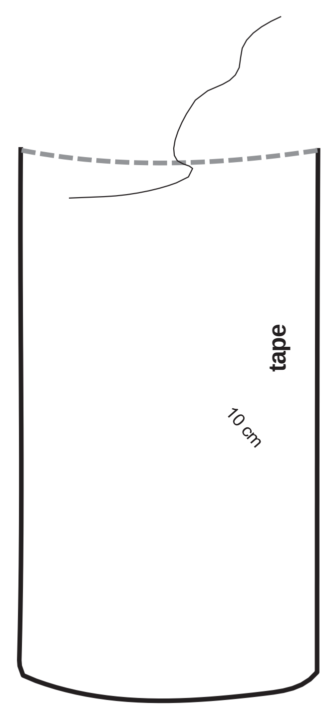


BOTTLE

7. Remove the dowel and insert it into the opposite hole. Circle the edge of the hole with the dowel so that the hole is a little bigger than the dowel. An ink pen will also work to enlarge the hole. Be careful not to make the hole too large, however.
8. Insert the dowel through both holes. Hold each end of the dowel and swing the bottle around the dowel. You should have a smooth rotation. Make adjustments as needed. Take the dowel out of the bottle and set aside.
9. With a permanent marker, label one hole “A” and the other hole “B.”

CONTINUED ON NEXT PAGE

✔



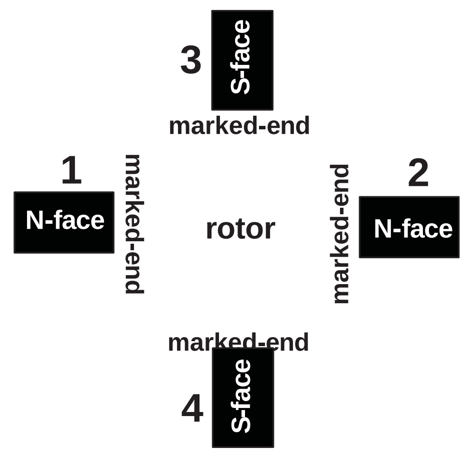
Generator Assembly: Part 1

1. Tear 6 pieces of tape approximately 6 cm long each and set aside.
2. Take the bottle and the magnet wire. Leave a 10 cm tail, and tape the wire to the bottle about 2 cm below hole A. Wrap the wire clockwise 200 times, stacking each wire wrap on top of each other. Keep the wire wrap below the holes, but be careful not to cover the holes, or get too far away from the holes.
3. DO NOT cut the wire. Use two pieces of tape to hold the coil of wire in place; do not cover the holes in the bottle with tape (see diagram).
4. Without cutting the wire, move the wire about 2 cm above the hole to begin the second coil of wraps in a clockwise direction. Tape the wire to secure it in place.
5. Wrap the wire 200 times clockwise, again stacking each wrap on top of each other. Hold the coil in place with tape (see diagram).
6. Unwind 10 cm of wire (for a tail) from the spool and cut the wire.
7. Check your coil wraps. Using your fingers, pinch the individual wire wraps to make sure the wire is close together and close to the holes. Re-tape the coils in place as needed.
8. Using fine sandpaper, remove the enamel coating from 4 cm of the end of each wire tail, leaving bare copper wires. (This step may need to be repeated again when testing the model, or saved for the very end).

Diagram 1

Stacked Magnets End View

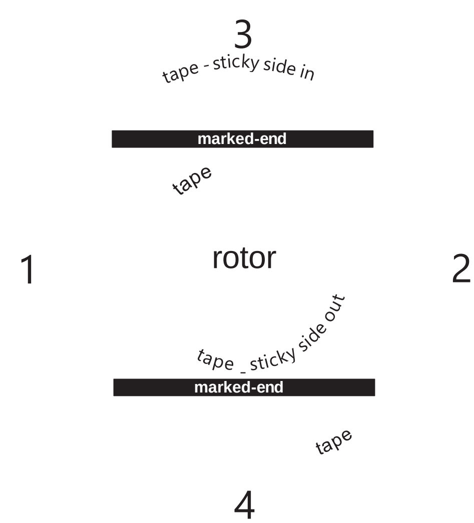
Diagram 2



Rotor Assembly

1. Measure 4 cm from the end of the foam tube. Using scissors, carefully score a circle around the tube. Snap the piece from the tube. This piece is now your rotor.
2. On the flat ends of the rotor, measure to find the center point. Mark this location with a permanent marker.
3. Insert the small nail directly through the rotor's center using your mark as a guide.
4. Remove the small nail and insert the bigger nail.
5. Remove the nail and push the dowel through, then remove the dowel and set aside. Do **NOT** enlarge this hole.
6. Stack the four magnets together. While stacked, mark one end (it does not matter which end) of each of the stacked magnets with a permanent marker as shown in Diagram 1.
7. Place the magnets around the foam piece as shown in Diagram 2. Make sure you place the magnets at a distance so they do not snap back together.
8. Wrap a piece of masking tape around the curved surface of the rotor, sticky side out. Tape it down at one spot, if helpful.
9. Lift the marked end of Magnet 1 to a vertical position and attach it to the rotor. Repeat for Magnets 2, 3, and 4.
10. Secure the magnets in place by wrapping another piece of masking tape over the magnets, sticky side in (Diagram 3).

Diagram 3



WARNING: These magnets are ***very*** *strong. Use caution when handling. See page 7 for more information.*

Generator Assembly: Part 2

1. Slide the sharp end of the dowel through Hole A of the bottle.
2. Inside the bottle, put on a stopper, the rotor, and another stopper.

Thestop
perssho
uldhold

the foam rotor in place. If the rotor spins freely on the axis, push the two stoppers closer against the rotor. This is a pressure fit and no glue is needed.

BOTTLE

3. Slide the sharp end of the dowel through Hole B until it sticks out about 4 cm from the bottle.

4. Make sure your dowel can spin freely. Adjust the rotor so it is in the middle of the bottle.

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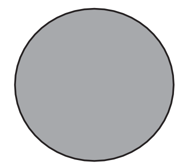
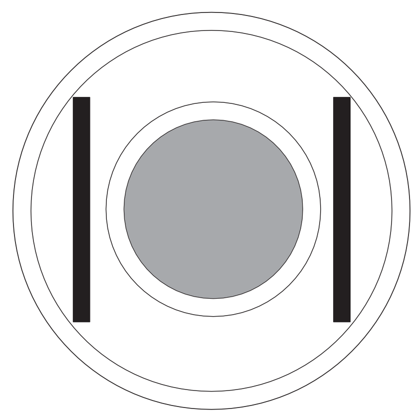
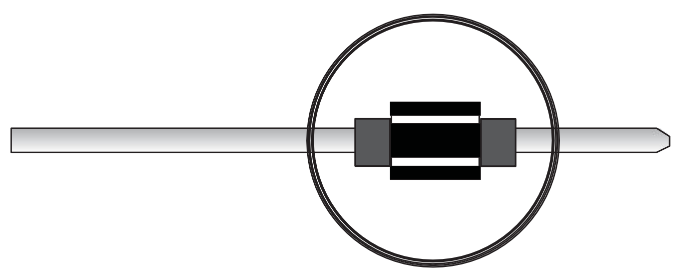






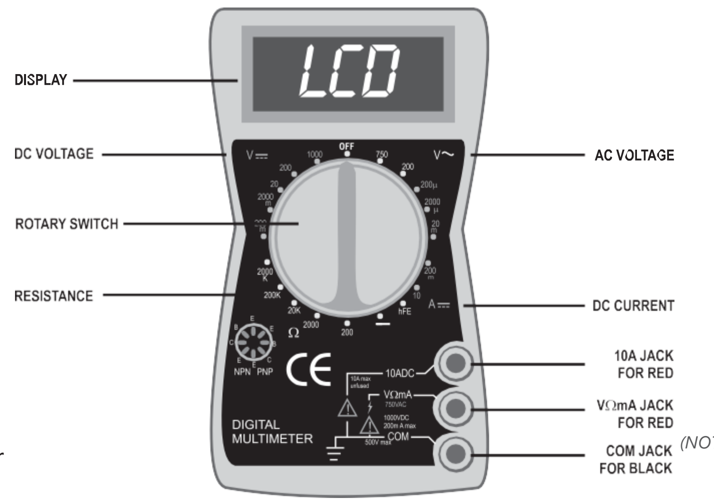
Assembly Notes

- The stoppers can be cut in half so that one stopper is made into two, to allow for more materials. These often slide more easily on the dowel. This must be done using sharp scissors or a utility knife, and can often be dangerous. As this step is not required (the kit supplies you with two stoppers to use), exercise extreme caution.
- If the foam rotor fits snugly on the dowel, put the stoppers on the outside of the bottle to help center the rotor in the bottle. Leave enough space to allow free rotation of the rotor.
- The dowel may be lubricated with lip balm or oil for ease of sliding the stoppers, if necessary.
- If a glue gun is available, magnets can be attached to the rotor on edge or on end to get them closer to the coils of wire. Use the magnet to make an indentation into the foam. Lay down a bead of glue, and attach the magnets. If placing the magnets on end, however, make sure they clear the sides of the bottle for rotation.

Testing the Science of Electricity Model

1. Connect the leads to the multimeter to obtain a DC Voltage reading.
2. Connect one alligator clip to each end of the magnet wire. Connect the other end of the alligator clips to the multimeter probes.
3. Set your multimeter to DC Voltage 200 mV (millivolts). Voltage measures the pressure that pushes electrons through a circuit. You will be measuring millivolts, or thousandths of a volt.
4. Demonstrate to the class, or allow students to test how spinning the dowel rod with the rotor will generate electricity as evidenced by a voltage reading. As appropriate for your class, you may switch the dial between 200 mV and 20 volts. Discuss the difference in readings and the decimal placement.*
5. Optional: Redesign the generator to test different variables including the number of wire wraps, different magnet strengths, and number of magnets.

*Speed of rotation will impact meter readings.



Note: Your multimeter may look different than the one shown. Read the instruction manual included in the multimeter box for safety information and complete operating instructions.

Troubleshooting

If you are unable to get a voltage or current reading, double check the following:

- Did you remove the enamel coating from the ends of the magnet wire?
- Are the magnets oriented correctly?
- The magnet wire should not have been cut as you wrapped 200 wraps below the bottle holes and 200 wraps above the bottle holes. It should be one continuous wire.
- Are you able to spin the dowel freely? Is there too much friction between the dowel and the bottle?
- Is the rotor spinning freely on the dowel? Adjust the rubber stoppers so there is a tight fit, and the rotor does not spin independently.

Notes

- The *Science of Electricity Model* was designed to give students a more tangible understanding of electricity and the components required to generate electricity. The amount of electricity that this model is able to generate is very small.
- The *Science of Electricity Model* has many variables that will affect the output you are able to achieve. When measuring millivolts,

you can expect to achieve anywhere from 1 mV to over 35 mV.

- More information about measuring electricity can be found in NEED's *Secondary Energy Infobook*. You may download this guide from
shop.NEED.org.

Activity 2 – Series and Parallel Circuits

Background

This activity introduces simple, DC circuits in series and parallel, and helps students understand the benefits and drawbacks of each type of circuit.

Objectives

- Students will be able to construct a simple series or parallel circuit. TEKS P.6D
- Students will be able to identify the benefits and drawbacks of series and parallel circuits. TEKS P.6D

Materials *PER STUDENT OR GROUP*

- 2 D-cell batteries
- 2 Battery holders
- 2 Small light bulbs
- 2 Light bulb holders
- 2 Switches
- 7 Alligator clips
- Student Guide, pages 35-36

Preparation

- Decide if you will have the class work on this activity all together, or as a part of a rotation of Activities 1-4.
- Decide if you will have students work in small groups or individually.
- Gather materials for students.

Procedure

1. Introduce the activity to students. Explain the difference between a series and parallel circuit.
2. Demonstrate the proper way to connect the wires to the battery holders, switches, and light bulb holders. Answer any questions students may have.
3. Allow students enough time to complete the activity. If students finish early, have them compare the light bulbs when the batteries are connected in series and in parallel.
4. Reconvene the group and discuss their results. Ask them the advantages and disadvantages for wiring circuits in series and in parallel.

Activity 3 – Series and Parallel Circuits with Breadboards

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Background

Breadboards provide a quick and easy way to connect components together when building basic classroom circuits. Less time is spent pinching alligator clips or the ends of battery holders and more time is spent actually connecting and testing circuit components. This activity builds on series and parallel circuits, but uses breadboards instead of switches, alligator wires, and the like.

Objectives

- Students will be able to construct simple series and parallel circuits with a breadboard. TEKS P.6D
- Students will be able to identify advantages and drawbacks of series and parallel circuits. TEKS P.6D

Materials *PER STUDENT OR GROUP*

- Breadboard (with or without VCC and GND buses)
- Battery snap or alligator clips
- 9V Battery or alternate DC power supply
- Several pieces of # 22 ga. solid hookup wire - red and blue or other colors
- 8 LEDs
- 4 Resistors (330 Ohms - 1/4 Watt)
- Multimeter (optional)
- Switches - Push Button Normally Open (PBNO) or other switches (optional)
- Student Guide, pages 37-38

CONTINUED ON NEXT PAGE

Preparation

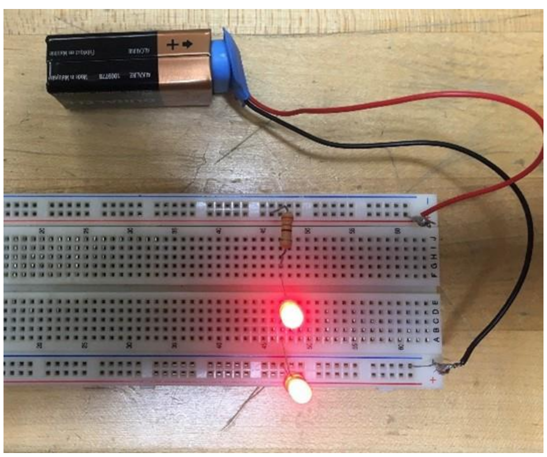
- Gather all materials for students. Test all batteries and properly discard any dead batteries.
- If you are not familiar with breadboards, familiarize yourself with their operation and use.
- Decide if you will have students work individually or in pairs. Because of the small size of the components, groups larger than 2 are not recommended for this activity.

✔ Procedure

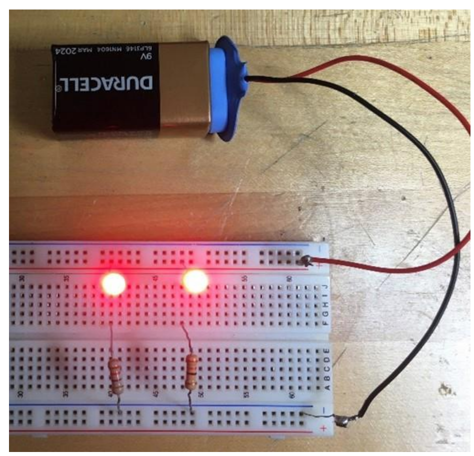
1. Preview the activity for students. Explain the difference between a series and parallel circuit. Show students assorted diagrams of series and parallel circuit schematics, explaining the symbols and tracing the pathways current can travel.
2. Demonstrate the proper use of a breadboard and how the connections should be made.
3. Allow students enough time to complete the activity, circulating among student groups to provide any troubleshooting as needed.
4. When students have completed the activity, reconvene class and work through the conclusion questions. Help students make the connection between their small, DC circuits in class and the way their home and other buildings are wired.

Circuit Wiring

The following photos show how series and parallel circuits may be constructed using resistors and a 9V battery as the power source.



LEDs wired in series



LEDs wired in parallel

Extensions

- **Multimeters and Ohm's Law** - The use of multimeters, Ohm's Law and electronics concepts is particularly appropriate for CTE students. To have extensive knowledge of how to make measurements, develop understanding and troubleshoot circuits with the use of a multimeter is an invaluable skill for all technical professionals from technicians to engineers and scientists.
- **Safety Note !!!** - If working with multimeters, please note that measuring current (series only - you must break open the circuit) and measuring voltage (you touch any two points to observe voltage difference). When measuring resistance or continuity - you must disconnect the power source (battery or power supply) to avoid damaging the meter by blowing its internal fuse.
- **Continuity and Resistance** - Furthermore, after removing the voltage source - an exploration of testing the various circuit elements for continuity and testing individual resistors to determine if they are within tolerance limits is possible.
- **Kirchhoff's Laws** - Another extension would be to explore Kirchhoff's Voltage Law for series circuits and Kirchoff's Current Law for parallel circuits using the integration of the voltmeter and ammeter functions of the multimeter into the activities above.
- **Watt's Law** - An exploration of Watt's Law is also possible with these same tools if desired. Carefully measuring current and voltage and multiplying them to get power in Watts allows students to understand power consumption in circuits that they build and use. This can extend into an analysis of the potential time that a device or system can be expected to operate, given the Ampere-Hour rating of the battery they are using.

Activity 4: Wind Can Do Work

Objective

- Students will be able to explain how wind can do work. TEKS P.7C

Materials *FOR EACH STUDENT OR PAIR*

- 1 Large foam cup approximately 14 cm tall
- 1 Extra-long straw*
- 1 Small straw
- 1 Binder clip
- 2-3 Straight pins
- Ruler
- Hole punch
- Marker
- 50 cm String or thread
- Paper clips
- Masking tape
- Scissors
- *4-Blade Windmill Template*, page 28
- *Wind Can Do Work* worksheet, Student Guide, page 39

Materials *FOR THE CLASS*

- Fan(s)

***Note:** The extra-long straw is long enough for two "turbines" when cut in half.

Preparation

- Make copies of worksheets, as needed.
- Gather supplies for the activity, and assemble stations, if necessary.

Procedure

1. Have students read *Introduction to Energy* on page 3 in the Student Guide.
2. Students should build "turbines" using the directions from the *Wind Can Do Work* worksheet.
3. Students should diagram their assembly and describe the energy transformations that occur in this system.
4. Encourage students to investigate the question, "What is the maximum load that can be lifted all of the way to the top of the turbine shaft?" Students should record data and observations.
5. Instruct students to keep their models in a safe place, as they will be used for future activities.

Extension

- Students can redesign the model to see if they can produce more work from the system. Students can also think of their own question and design their own investigation based on the system. It may be helpful for students to work from scratch if redesigning. This way they can use the original design for Activity 5 as it follows the specifications required.

Activity 5: Wind Can Generate Electricity

Background

A wind turbine uses the motion energy in the wind to generate electricity. A generator helps transfer the motion energy to electrical energy using magnets and wire. Students will use their completed *Wind Can Do Work* models from Activity 4 to create a wind turbine generator. These instructions will help students retrofit the paper clip lifting model to become an electrified wind turbine.

A changing magnetic field can induce an electrical current, especially if the electrons are given a path through which to pass their charge. Students will be wrapping magnetic coated wire in coils and using strong neodymium magnets to push the negatively charged electrons through these coils. If you can move electrons, you're generating electricity!

CONTINUED ON NEXT PAGE

✪Objectives

- Students will be able to develop and use a model to describe how a generator works and list its basic components.

➟ Safety Notes

- The magnets in this model are very strong. In order to separate them, students should slide/twist them apart. Please also take the following precautions:
    - Wear safety glasses when handling magnets.
    - Use caution when handling the magnets. Fingers and other body parts can easily be pinched between two attracting magnets.
    - When students set the magnets down, they should place them far enough away from each other that the magnets won't snap back together.
    - When you are finished with the magnets and ready to store them, put a small piece of cardboard between them.
    - Keep magnets away from your computer screen, cell phone, debit/credit cards, and ID badges, and individuals with medical devices or pacemakers.
- Use caution with hot glue and glue guns as burns can occur.

Materials *FOR EACH SMALL GROUP*

- Assembled *Wind Can Do Work* turbine model (from Activity 4)
- Magnet wire
- 2 Rectangle neodymium magnets
- Multimeter
- 2 Alligator clips
- Toilet paper roll
- Hot glue gun with glue
- Ruler
- Scissors
- Masking tape
- Sandpaper or emery board
- Fan
- *Wind Can Generate Electricity Templates*, page 29
- *Wind Can Generate Electricity*, Student Guide, pages 46-47

■ Preparation

- Preview the construction video for the activity. Decide if you will share with the class, https://youtu.be/-64paV6ooxY.
- Gather empty toilet paper rolls ahead of time. It may be helpful to alert custodial staff to collect rolls for you in advance. Students can also help in the collection by bringing in empty rolls from home.
- Gather materials for the activity, based on the number of student groups you will have assembling the model. Set up construction stations as needed, and ensure access to hot glue is on a heat-safe surface near an electrical outlet.
- Depending on the number of groups you have and the wire spools available, you may need to "rewind" larger spools of wire into smaller spools. Excess toilet paper rolls, plastic cups, PVC pipe chunks, and other objects may be useful for spooling.
- Prepare copies of the templates for each group. Make sure each group has one template for the nacelle and two templates for the magnets. You may opt to make laminated versions of these to be reused between classes.
- Ensure student models of the *Wind Can Do Work* activity are available and ready to go. If that activity was not yet completed, gather supplies for those instructions and have students construct up to step 6.

✔Procedure

1. Introduce the activity to the class and preview any instructions. Demonstrate use of the multimeter, if needed. Place students into groups and have them select a model turbine to use for the activity, if several exist for their small group.
2. Reinforce magnet safety information and safe use procedure for hot glue.
3. Students should modify and build their wind turbine using the instructions on the student handout. Monitor student construction and provide time for questions, answers, and assistance. Provide students an opportunity to troubleshoot any turbine issues they were experiencing.

4. Discuss the data, analysis, and conclusion questions as a class.
5. If you have decided to conduct the Optional Activity – Model Generating Wind Farm (page 26), students will need to preserve the models from this activity to use in the future. Have students place these models some place safe where they will be undisturbed.

Activity 6: Analysis of Data

Background

This activity uses both theorectical and actual data to determine patterns within data. Theoretical data from the National Solar Radiation Database, NSRDB, could take time to download. Actual data will be downloaded from the weather station that was previously set up.

✪Objectives

- Students will be able to analyze wind speed and wind direction data. TEKS P.2B
- Students will be able to use mathematical calcuations to assess quantitative realtionships in data. TEKS P.2C
- Students will generate graphs from wind speed data. TEKS P1.F

Materials *PER STUDENT OR GROUP*

- Internet access
- Spreadsheet program access, ie Excel or Google Sheets

- Data Anaysis of Sample Data Student sheet

Preparation

- If desired, download the weather files prior to class.
- Decide if students will work individually or in groups.

✔Procedure

1. Introduce the activity and explain that the activity is designed to help them understand how to analyze large sets of data.
2. Students will download data from https://nsrdb.nrel.gov/ using latitude and longitude identified from Google Maps.
3. Data files will need to be converted from .cvs to another spreadsheet.
4. The data can be grouped to better manage the data. Wind Speed can be grouped by 2s and the wind direction can be grouped by 20s.
5. Pivot tables will be created from the data using wind speed for the column, wind direction for the row, and count of wind direction for the values.
6. Discuss the data, analysis, and conclusion as a class.

Activity 7: Analysis of School Data

Background

This activity uses the knowledge gained from Activity 6 in analyzing data. This activity will focus on comparing and contrasting theoritcal data from the NSRDB and the actual data gathered from the local weather station.

✪Objectives

- Students will be able to analyze wind speed and wind direction data. TEKS P.2B
- Students will be able to use mathematical calcuations to assess quantitative realtionships in data. TEKS P.2C
- Students will generate graphs from wind speed data. TEKS P1.F

Materials *PER STUDENT OR GROUP*

- Internet access
- Spreadsheet program, ie Excelor Google Sheets

Activity 8: Comparing Small Wind Models

Suggested Grade Levels

- Elementary, grades 3-5
- Intermediate, grades 6–8
- Secondary, grades 9–12

✪ Objective

- Students will be able to compare and contrast small wind turbine models. TEKS P.4A

Materials

- Internet access

Procedure

1. Have students research small wind turbines from the sites listed below, and other models as appropriate.
   - www.windenergy.com
   - www.bergey.com
2. Students should create a table to record specifications of the different models including rated capacity, rated wind speed, revolutions per minute (rpm), blade length, rotor diameter, swept area, tower height, weight, gear types, and price. Select specifications based on the students and their familiarity with terms and vocabulary.
3. Discuss with students what differences exist between the different models, and why one model might be chosen over another.

Activity 9: Energy Use and Cost Analysis

Suggested Grade Levels

- Elementary, grades 3-5
- Intermediate, grades 6–8
- Secondary, grades 9–12

✪ Objectives

- Students will be able to determine the energy requirements and calculate the cost of using several electrical appliances. TEKS P2C
- Students will be able to describe that different wind systems are capable of powering different loads. TEKS P.4A

Preparation

- If desired, download the weather files prior to class.
- Decide if students will work individually or in groups.

✔ Procedure

1. Introduce the activity and explain that the activity is similar to the prior data analysis activity.
2. Allow students sufficient time to complete the download and analysis.
3. Remind students of the pivot table variables.
4. Have students use their wind speed averages to determine if there is a significant difference between the theoretical and actual databases.

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Materials

- *Electric Nameplate Investigation* worksheet, Student Guide page 39
- *What Can the Wind Power?* activity, Student Guidepages 40-41
- *Cost of Using Machines* worksheet, Student Guide page 42
- Pluggable appliances

Procedure

1. Make copies of the worksheets, as needed.
2. Show students an example of an electric nameplate. Explain the different parts of the nameplate. Make sure that students understand how to calculate wattage if it is not listed on the nameplate. Use the *Electric Nameplate Investigation* worksheet for examples.
3. Allow students time to find the nameplates on appliances and machines located in the classroom and around the school. Students should record the information on the *Electric Nameplate Investigation* worksheet, or in their science notebooks.
4. Gather the students back together and discuss how often some of the appliances and machines are used. For example, how many hours do they think the computer is on each day? Each week? Each year? What appliances and machines are used the most, which are used rarely?
5. Using the *What Can the Wind Power?* activity, have students calculate the daily electricity use in the classroom. They should calculate the average daily electricity output of various wind turbines and decide which one would best meet their needs.
6. Give students the *Cost of Using Machines* worksheet. Have students calculate the cost of the appliances and machines they found.
7. Discuss as a class what was learned during this activity. Can students and teachers change the way they use these machines? Would changing behavior be important? What are some reasons a school, business, or home would consider installing a turbine if they are expensive?

Technology Connection

- Instead of nameplate math, students can use Kill A Watt® meters to quickly determine the wattage consumed by pluggable devices.

Activity 10: Siting the School Turbine

Suggested Grade Levels

- Intermediate, grades 6–8
- Secondary, grades 9–12

Objective

- Students will be able to locate the best area for their school's (actual or fictional) wind turbine installation. TEKS P.2B

Materials

- *Measuring Tall Objects* worksheets, Student Guide pages 43-44
- Internet access
- Straws
- Cardstock

Procedure

1. Make copies of the worksheets, as needed.

• String
• Bolts

• Meter stick
• Calculators

2. Students should read the siting criteria for the Skystream and make a list of the requirements for a wind turbine. Have students visit www.windenergy.com and research siting requirements for the Skystream.
3. Using internet resources, students should obtain wind data for your area. Activity 7 provided data for local school.

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4. Teach students how to measure tall objects using the *Measuring Tall Objects* worksheets.
5. Allow students to go outside to analyze the school grounds. Students should find at least three different locations and measure the height of buildings, trees, and any other objects that are potential obstacles in a 250 foot radius of the site they are testing.
6. Ask students to brainstorm a list of other questions and concerns they might need to consider when siting their turbine (how is the land used, noise, wildlife, distance to building, etc.). What potential hang-ups might one face when siting a turbine? Students should also think of potential solutions or answers.
7. Have students write about or present what they believe is the best location for the school wind turbine and support their choice of location with data from their research and observations. Students should include information on how high the tower should be, and what type of tower, guide wire, or monopole would be most appropriate. Students should address the potential questions or concerns they've anticipated within their writing or presentation.

Home Extension

Encourage students to survey their home property and see whether a turbine would be possible or economical. Students should explain why or why not.

Activity 11: Submit an Estimate

Suggested Grade Levels

- Intermediate, grades 6–8
- Secondary, grades 9–12

Objective

- Students will be able to work in teams to prepare a plan and submit a bid for installing a wind turbine on a residence. TEKS P.3A & 3B

Materials

- *Submit an Estimate* worksheet, Student Guide page 50

Procedure

1. Make copies of the worksheet for groups.
2. Give students the *Submit an Estimate* worksheet. Students will work in small groups to prepare an installation plan and submit a bid. In the bid, students should make a case for why they should be chosen to install the turbine.
3. Items to consider when assessing student work include contingency, permitting, insurance, and bonding.

Disclaimer: Activities were larger taken from The Need Project Curriculums, specifically Winds for Schools and Your Future inWInd Energy. Both curriculums can be found at www.NEED.org

Analysis of Sample Data

Let's practice on some real data before we tackle our school data. Detailed instructions can be found using: Scribe Notes Wind Speed Data Analysis

Determine your address' latitude and longitude using Google Maps.

Address: ____

Latitude: ________________________ Longitude: __________________________

Gather data from https://nsrdb.nrel.gov/

Saved file at this location: ____

Transfer the file from a cvs file to a google sheets file.

Name of file: ____

Create a pivot table using the following parameters:

Column: wind speed Row: wind direction

Values: count of wind direction

Create a Radar Diagram to post below:

Radar Chart

Wind direction: ________________________

Create a second pivot table using the following parameters:

Column: wind speed Row: wind direction

Values: average wind

Pivot chart

Average Wind Speed: ________________________

Analysis of School Data

Using the skills learned early, perform an analysis of the school data. Recall that detailed instructions can be found using: [Scribe Notes Wind Speed Data Analysis]

Determine the school's latitude and longitude using Google Maps.

Latitude: ________________________ Longitude: ___________________________

Save data from https://nsrdb.nrel.gov/

Name and location of file: ____

Download the weather station data.

Name and location of the file ____

Create a pivot table using the following parameters for the weather station data:

Column: wind speed Row: wind direction

Values: count of wind direction

Create a Radar Diagram to post below:

Radar Chart

Wind direction: ______________________

For each set of data, create a pivot table using the following parameters:

Column: wind speed Row: wind direction

Values: average wind

Pivot chart

Weather Station Average Wind Speed: ________________________

Pivot chart

Database Average Wind Speed: ________________________

Compare the weather station average wind speed and the database average wind speed.

T-test value: ________________________

Effect of Daylighting on Students' Learning and Classroom Electricity Consumption

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Abstract:

This study examines the impact of daylighting on student learning and classroom electricity consumption. Daylighting, the use of natural light to illuminate indoor spaces, offers benefits such as improved student performance and reduced energy use. The research included both non-human and human data collection.

Non-human data was gathered using photometric sensors placed at 0, 10.5, and 21 feet from South and North-facing windows in two rooms with different orientations. Data was collected in increments of 5 minutes over a 72-hour period. Useful Daylight Illuminance (UDI), Daylight Autonomy (DA), and Energy Savings percentages were calculated for typical working/school hours (8AM to 5PM).

Human data collection involved participants in three rooms with different lighting conditions: natural light only, electric light only, and a combination of both. Participants completed reading activities and multiple-choice questions while wearing photometric sensors and provided feedback on lighting comfort.

The findings highlight the potential of daylight to enhance learning environments and reduce electricity consumption. Further research with larger samples is needed to confirm the correlation between daylighting and academic performance.

Introduction:

The research aimed to determine the correlation between student performance and different types of lighting, and to relate this to the energy consumption of a typical classroom. Previous studies identified 500 lux as optimal lighting. Students completed a literature assignment and rated the comfort of the lighting in each room. These comfort ratings were then compared with their assignment outcomes. Light levels were measured at both the head and desk levels of each participating student. Additionally, power efficiency was calculated for each room to assess potential energy savings from various lighting types.

Literature Review:

Classrooms with more daylight have been shown to improve student performance, with students in these environments progressing faster in math and reading tests compared to those in classrooms with less daylight. Increased daylight is also associated with higher student attendance rates and potential energy savings due to reduced reliance on artificial lighting (Heschong, Wright, & Okura, 2002). The impact of light levels on student learning extends beyond daylight, as window orientation and glare are more significant factors than window size alone. The quantity and quality of artificial light positively correlate with pupil performance, and temperature control, accounting for daylight heating, also affects student outcomes (Barrett, Davies, Zhang, & Barrett, 2015). Comparisons of full spectrum lighting with normal lighting reveal that full spectrum lighting contributes to healthier students, increased attendance, and improved student moods. Libraries with daylight also benefit from reduced noise levels, and other studies confirm a positive correlation between student performance and full spectrum lighting (Nicklas & Bailey). Analysis of various studies indicates that in tech-enabled schools, the position of windows is less critical than managing glare from technology. Sunshades could help mitigate this glare, and window size is not directly proportional to the amount of useful daylight received (Bernard, 2011).

Materials and Methodology:

Light sensors were used to collect data in the non-human part and the human part of the data collection process. Two rooms were set up to collect the levels of light coming in from different window orientations, Noth and West and a South and West. Human testing different sensors were used to collect the data of what they saw, headband, and the desk level light levels.

Non-Human

Two types of sensors were used in the classroom to measure the light levels. LI-COR LI-210R Photometric Sensor placed one on the windowsill of the north facing window with 2 additional sensors spread evenly across the room, at 10.5 ft and 21 feet from the window, set up is the same in the south facing room. LI-COR LI-210R Photometric Sensor (yellow). The measure of light in an environment, known as photometric measurement, assesses light in a manner like how the human eye perceives brightness. This measurement is used in various applications, including monitoring both indoor and outdoor light levels, ensuring appropriate lighting in workplaces and schools, and supporting research in environmental sciences. The sensor detects radiation only within the visible spectrum and has a linear illuminance response of up to 100 klux. The sensor has a cosine correction for an angle of incidence up to 80°, a response time of 0.01 ms, and an absolute error of 3%. One additional sensor was used on the north and south facing windows to measure the sun radiation levels, LI-COR LI-200R Pyranometer (red). Amplifies were used on each sensor provided that all sensors had different voltage levels. The rooms involved setting up the windows to be open and turning off all electric lights. pyranometers were utilized and maintain a spectral response from 280 to 2800 nm, a linear response up to 3000 W/m^2, a cosine correction for an angle of incidence up to 80°, a response time of 0.01 ms, and an absolute error of 3%. The photometers detect radiation only in the visible spectrum (390 to 750 nm) and have a linear illuminance response up to 100 klux. The photometers also have the same cosine correction, response time and absolute error. Data collection was scheduled to occur over a 72-hour period, starting from Friday (July 5,2024) at 12:00 pm and concluding on Monday (July 8, 2024) at 12:00 pm. The data was gathered in Manning Hall Rooms 220 and 224, with measurements taken undisturbed at 5-minute intervals throughout the duration. During measurements the doors were locked with lights off and were undisturbed. Use of an amplifier was used on each sensor that was then plugged into a 4-lead data HOBO logger. Data was downloaded from the data logger with the use of HOBO software to a computer, putting all the data into an excel sheet. Calculations had to consider the different amplifiers voltage. HOBOware software was used to download data from each of the HOBO data loggers onto laptops for analysis. Data was analyzed in both Microsoft Excel in order to determine the average light level, average UV level, Daylight Autonomy (DA) percentage for a typical school day, Useful Daylight Illuminance (UDI) percentage for a typical school day,

Sensor Placement MH Room 220 (south and west)
Table 1

Logger	Sensor	Position	Channel	Equation
Logger 1	PY 70	On window	Ch.1	W/m2 = (volts x 16)/0.024)
Logger 1	PH 54	Windowsill	Ch. 2	klux = ((volts x 3.66)/0.06) x 1000
Logger 1	PH 52	10.5 ft (center)	Ch. 3	klux = ((volt x 3.77)/0.12) x 1000
Logger 1	PH 56	21 ft	Ch. 4	klux= ((volts x 3.64)/0.12) x 1000

Sensor Placement MH Room 224 (North and west)
Table 2

Logger	Sensor	Position	Channel	Equation
Logger 2	PY 471	On window	Ch.1	W/m2 = (volts x 14.76)/0.02)
Logger 2	PH 53	Windowsill	Ch. 2	klux = ((volts x 3.83)/0.6) x 1000
Logger 2	PH 55	10.5 ft (center)	Ch. 3	klux = ((volt x 4.05)/3.6) x 1000
Logger 2	PH 51	21 ft	Ch. 4	klux= ((volts x 3.9)/0.06) x 1000

Sensors and data collection tools:

Figure 1:

LI-COR LI-210R Photometric Sensor

Figure 2

LI-COR LI-200R Pyranometer

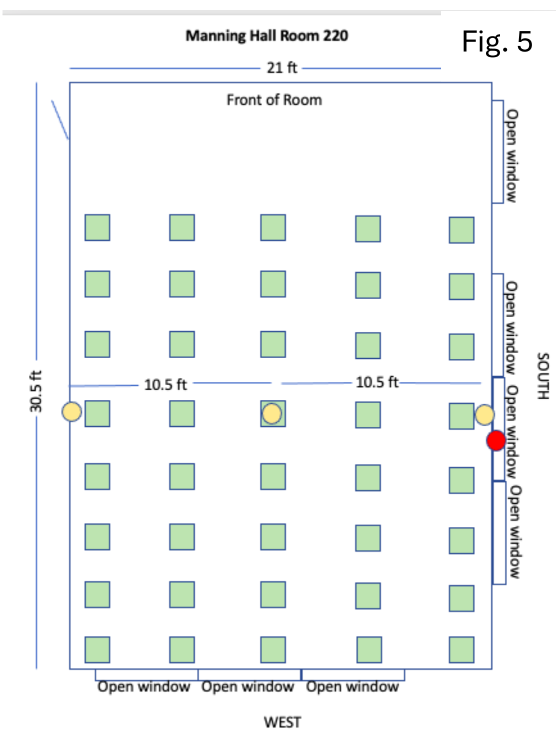
Figure 3:

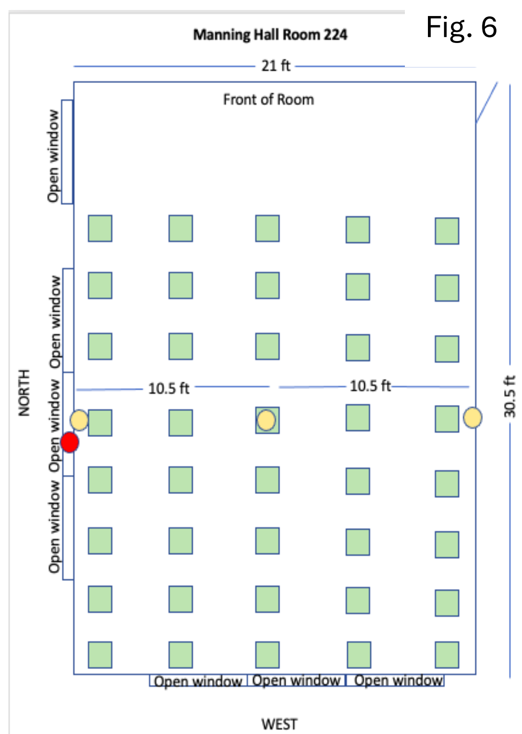
EME Systems UCLC Amplifier

Figure 4:

HOBO 4-Channel Data Logger

Room Set Up:





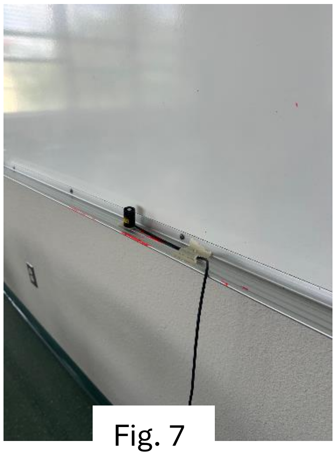


Fig. 7


Fig. 8


Fig. 9

Human Testing

The participants of the trial were volunteers taken from college students and professors, different age ranges. Participants placed one sensor on their head and another on their desk, using the Solar Light PMA2100 (error possibilities +/- 4). They were then instructed to read a passage, followed by taking a short quiz consisting of five questions. All passages were approximately 1300 Lexile Level and 500-700 words long. The articles were consistent to each room. After completing each quiz, participants rated the comfort of the lighting on a scale of 1 to 5, with 1 being not comfortable and 5 being very comfortable. The lux level was recorded after reading each passage before moving to the next room. This process was repeated in three different lighting scenarios: Mixed Lighting in Manning Hall Room 220, Only Electric Lighting in Manning Hall Room 222, and Only Natural Lighting in Manning Hall Room 224.

Fig. 10: Room 220

Fig 11: Room 222

Fig 12: Room 224

Analysis and Discussion:

The gathered data from the HOBOware into a series of excel sheets, non-human testing. The two data loggers were downloaded and populated into a set of excel sheets. The data was then separated by office hours 8 AM – 5 PM from all the sensors. We were then able to calculate the lux value for each period, every 5 minutes. See chart tables 1 and 2 earlier in this report for formulas. Daily autotomy was then singled out for each of the photometric sensors, using a conditional formula in excel to note when the lux level reached over 500 lux and calculated the percentage of time the lux was above 500 lux (the minimum light required). Then the Useful daylight illuminance was set to conditional statements to find the percentage of time the sensor had values of, 100 -500 lux, 500 – 1000 lux, 1000-2000 lux and greater than 3000. Results for each room with daylight are in the tables below, tables 3 and 4.

Table 3

Manning RM 220 South and West Windows 8am-5pm			
LUX	**Windowsill**	**10.5 ft from Window**	**21ft from Window**
DA >500	98.77%	39.51%	0.00%
UDI (>=100,<500)	1.23%	60.49%	2.16%
UDI (>=500,<1000)	15.74%	39.51%	0.00%
UDI (>=1000,<2000)	39.51%	0.00%	0.00%
UDI (>3000)	15.74%	0.00%	0.00%

The was a possible issue with the sensor that was 21 feet away from the window.

Table 4

Manning RM 224 North and West Windows 8am-5pm			
LUX	**Windowsill**	**10.5 ft from Window**	**21ft from Window**
DA >500	100.00%	39.69%	7.69%
UDI (>=100,<500)	0.00%	60.31%	89.54%
UDI (>=500,<1000)	6.77%	39.69%	7.69%
UDI (>=1000,<2000)	61.54%	0.00%	0.00%
UDI (>3000)	5.85%	0.00%	0.00%

Once the percentages were calculated, the energy costs for each room were calculated. Based on what it would take for the lighting to be 500 lux. For each time point, we calculate the

power (in wattage) according to electric light dimming Illuminance (needed)/500(target illuminance) x installed electric power.

Then we convert the power into energy use the relation:

energy use (in Joule) = power (in wattage) x time (in second).

For our measurement, the time interval is 5 minute (we took one measurement every 5 minute) or 300 second, so we calculated energy as:

power x 300 seconds = energy use (in J), divide it by 1000 obtain energy use in kJ,

Lastly, we sum up to obtain total energy use over the whole measurement period (within office hours) and then convert it into kWh. The results are shown in the chart below.

Chart 1

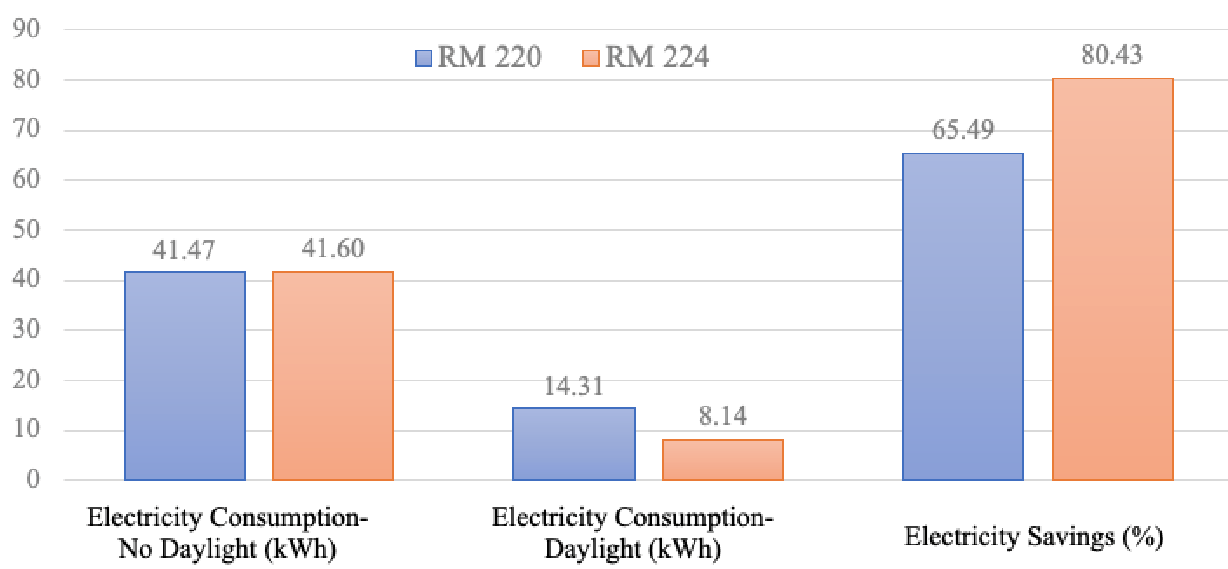
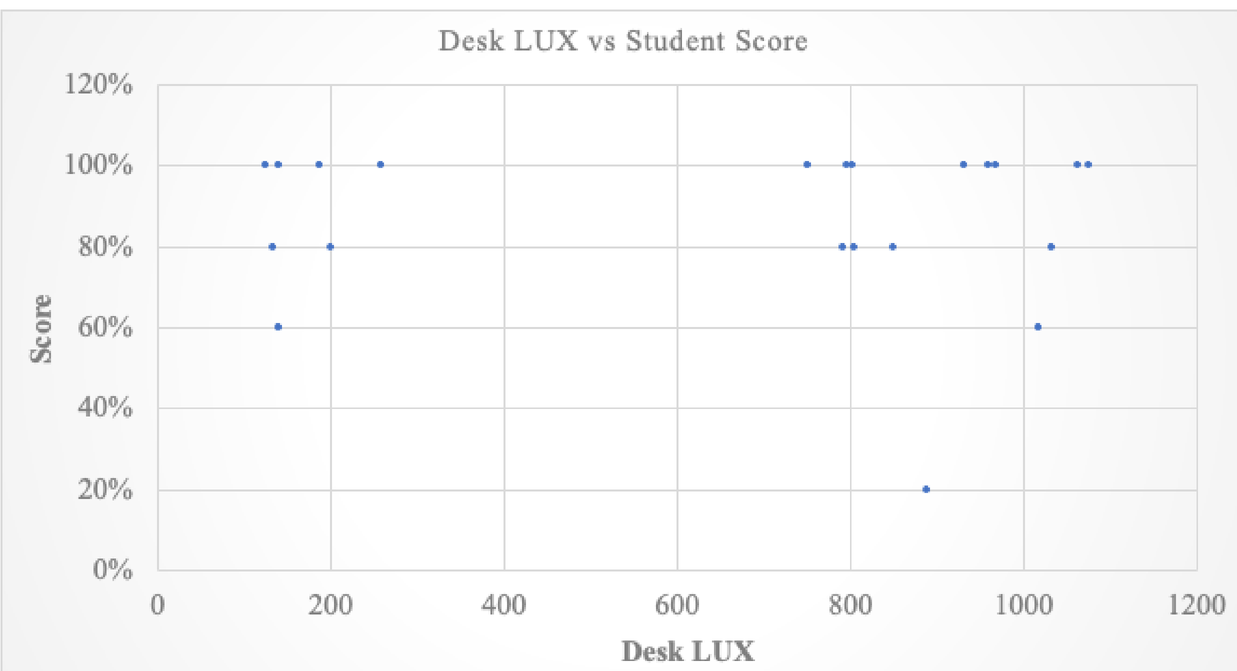


Chart 1: Energy Consumption and Electrical Savings

Electricity consumption was first based on each room without the use of daylight in kWh. The second was based on consumption with daylight, just enough to reach that 500 lux optimal level. Then when the no daylight and daylight use were compared the energy savings could be calculated. Total savings percentages, room 220 65.49 % and room 224 80.43 %.

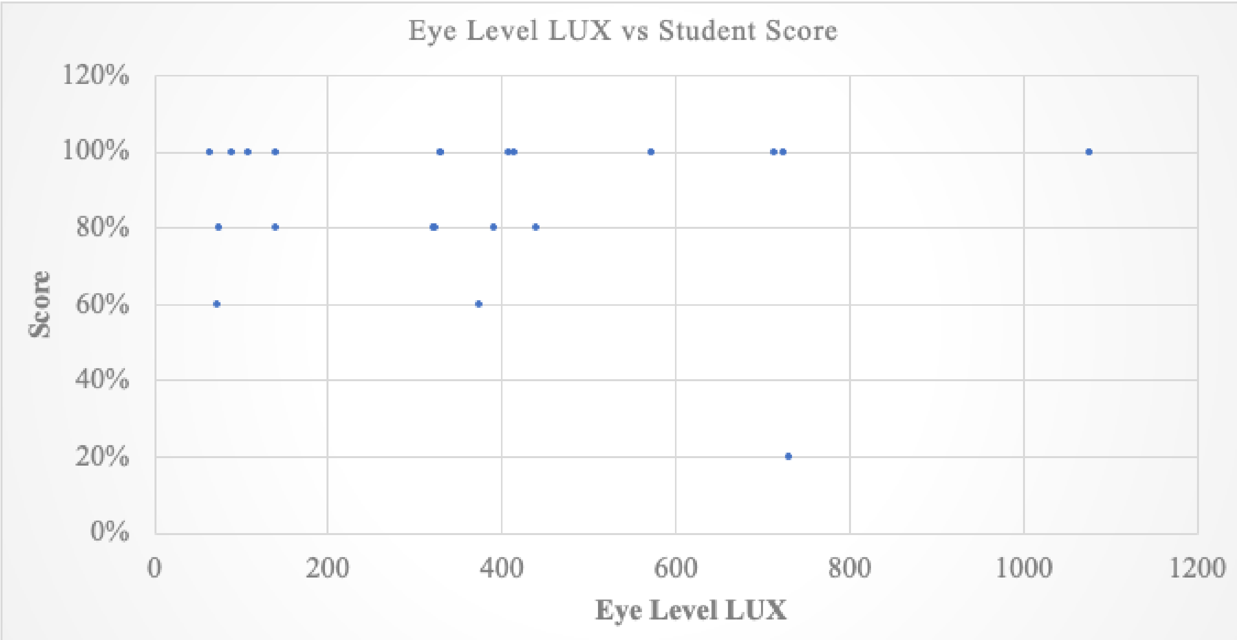
For the human testing, the participants answered questions (5) about the article that was read and rated the light comfortability of the room. One article per room, articles were the same for the same room. After the participant read and rated for each article the lux levels were taken to see if there was a correlation between luminance and efficacy of learning (scores).

Graph 1: Desk lux vs. Student Score



As depicted in the graph above, there is little significant correlation between these two values.

Graph 2: Eye level lux vs. Student Score



As depicted in this graph there is little correlation between these values as well. Though there seems to be a collection around the lower lux levels with higher scores, not enough to be significant.

The participants then rated how comfortable they felt with the different lighting levels. Results show that the most favored room was the room only lit by daylight. The least preferred room was the room with both daylight and full artificial lights on. As shown in table 5 below.

Table 5

Participant Light Comfortability Rating			
Participant	**Mixed Light RM 220**	**Electric Light RM 222**	**Natural Light RM 224**
1	2	4	5
2	2	4	5
3	2	2	5
4	3	5	1
5	3	5	4
6	3	4	5
7	4	3	5
Average Rating:	**2.71**	**3.86**	**4.29**

KEY				
1	2	3	4	5
Not Comfortable	Semi-Comfortable	Neutral	Comfortable	Very Comfortable

The results for the lighting of the rooms showed there could be significant savings on electrical power if daylight is used in the classroom. The human testing was limited by the number of participants available to be tested. A correlation could not be significant with such a low number of participants.

Conclusion:

In conclusion, the ideal UDI range of 500-1000 lux was achieved approximately 40% of the time in the center of each classroom. Notably, Room 220 observed energy savings of 65.49% with the use of daylighting, while Room 224 achieved an even higher savings rate of 80.43%. Additionally, participants showed a preference for Room 224, which relied solely on natural lighting. However, no significant correlation was found between the lux levels and student scores.

To obtain a more robust data set and achieve statistically significant results, future studies should include more classrooms and students. Extending the study over a longer period would also help account for variations in student performance and lighting conditions. Implementing additional sensors and loggers would enable more extensive data collection. Furthermore, including a broader range of activities from multiple disciplines could provide a more comprehensive understanding of the impact of daylighting on various aspects of the educational environment.

Acknowledgements:

This material is based upon work supported by the National Science Foundation under Award No. 2206864. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

Curriculum Modules: see Appendix A (math) and appendix B (biology)

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Appendix A

Grade Level: Algebra 1 **Topic:** The Effect of Daylighting on Student Performance **Number of Days:** 7 **Objective:** Students will investigate how daylighting affects their performance in a classroom setting. They will collect and analyze data, apply algebraic concepts such as linear regression, correlation coefficient, and distinguish between association and causation.

TEKS	Objective(s) & Vocabulary	Agenda/Activities

	Objective(s): 1. Understand the concept of daylighting and its potential impact on student performance. 2. Learn to use photometric sensors to measure lux levels and gather data. **Lesson Vocabulary:** • Daylighting • Photometric Sensor • Lux	**Warm-Up**: • Display a photograph or video of a well-lit classroom and a dimly lit classroom. • Ask students to brainstorm and discuss in pairs: ○ How might natural light affect students' ability to learn? **Discussion**: • Facilitate a whole-class discussion based on student responses. Review the concept of variables (e.g., amount of natural light, student performance metrics) and explain that they will investigate if there is a relationship between these variables. **Introduction**: • Explain the project objectives and outline the plan for the next six days. • Discuss the importance of daylighting in schools and its potential benefits for learning and energy savings. **Introduction to Materials**:

		• Introduce the materials (photometric sensors) and explain their function. • Demonstrate how to use the photometric sensors to measure lux levels. **Exit Ticket**: • What are some things you learned today about daylighting and photometric sensors?
	Objective(s): **Lesson Vocabulary:** • Natural light	**Warm-Up**: • Write a hypothesis on how you think natural light will affect student performance. **Activity**: • Distribute a cumulative worksheet to be completed in a **naturally lit** classroom. • Students will measure and record the lux levels on their worksheet. **Exit Ticket**:

		• Complete a survey on how the **natural light** affected their ability to complete the worksheet. • Rate the light comfortability in the room.
	Objective(s): **Lesson Vocabulary:** • Artificial light	**Warm-Up**: • Write a hypothesis on how you think artificial light will affect student performance. **Activity**: • Distribute a cumulative worksheet to be completed in an **artificially lit** classroom. • Students will measure and record the lux levels on their worksheet. **Exit Ticket**: • Complete a survey on how the **artificial light** affected their ability to complete the worksheet. • Rate the light comfortability in the room.
A.4C	**Objective(s):**	**Warm-Up**: • Review the concept of linear regression. **Hands-On Activity:**

	1. Create a graph of data points with and without technology. 2. Determine an equation for a line of best fit by visual approximation of a hand-drawn line. 3. Determine a linear regression equation using technology. 4. Make predictions about data using a linear regression equation. **Lesson Vocabulary:** • regression line • interpolation	• Provide each group with a dataset containing quantitative variables related to daylighting (e.g., measured lux levels) and student performance (e.g., test scores). • Instruct students to: ○ Input the data into a spreadsheet and create a scatter plot. ○ Write a linear function that provides a reasonable fit to the data (A.4(C)). ○ Use the function to estimate potential improvements in student performance based on changes in daylighting conditions. ○ Discuss the practical implications of their predictions. **Exit Ticket:** • Interpret the slope and y-intercept of the linear regression equation. What do these values represent in terms of the problem situation?

	• extrapolation • slope • y-intercept	

A.4A	**Objective(s):**
	1. Determine the correlation coefficient using technology.
	2. Interpret the correlation coefficient for a set of data.
	
	Lesson Vocabulary:
	• Correlation
	• correlation coefficient
		Warm-Up:
		• Review correlation coefficient and its significance.
		Activity:
		• Provide each group with a dataset containing quantitative variables related to daylighting (e.g., measured lux levels) and student performance (e.g., test scores).
		• Instruct students to:
		    ○ Input the data into a spreadsheet and create a scatter plot.
		    ○ Use technology (spreadsheet software) to calculate the correlation coefficient between daylighting and student performance.

		○ Interpret the correlation coefficient as a measure of the strength and direction of the linear association (A.4(A)). **Exit Ticket:** • What does the correlation coefficient value indicate about the relationship between daylighting and student performance? • How strong is the linear association between the variables based on the correlation coefficient?
A.4B	**Objective(s):** 1. Compare and contrast association vs. causation in real-world problems. **Lesson Vocabulary:** • common response • association	**Warm-Up**: • Review the difference between association and causation. **Activity**: • Discuss whether the correlation between lux levels and scores implies causation. • Provide examples of association vs. causation in different contexts. • Group activity: Identify and justify whether scenarios provided are examples of association or causation.

	• causation	**Exit Ticket:** • Have students record at least two common responses that could affect student performance.
	Objective(s): 1. Reflect on the findings of the project and communicate results effectively.	**Warm-Up**: • Brief discussion on key takeaways from the project. **Reflective Activity**: • Students will be divided into groups and will make a PowerPoint presentation on their findings and experience. ○ Topics to include, but not limited to: initial hypotheses, data collection process, results, and implications. **Presentation**: • Each group will present their findings and reflections to the class. • Encourage questions and discussions to deepen understanding and share insights.

Appendix B

Lesson Plan: Types of Lighting Influence the Growth of Plants

Objectives:

Student will:

1. **Investigate the influence of different types of lighting on the growth of plants.**
2. **Identify the factors that affect the growth and energy conservation in plants (TEKS B.11A).**
3. **Analyze the amount of growth dependent on the lighting source.**

TEKS for Biology:

1. **§112.34. Biology, Grade 9-12:**
    - **(1) Scientific and engineering practices.**
        - **(A) Ask questions and define problems based on observations or information from texts, phenomena, models, or investigations.**
        - **(B) Develop and use models to explain phenomena or test solutions to problems.**
        - **(C) Plan and carry out investigations individually and collaboratively to produce data to serve as the basis for evidence.**
        - **(D) Analyze and interpret data to provide evidence for phenomena.**
        - **(E) Use mathematics and computational thinking to analyze data.**
        - **(F) Construct explanations and design solutions based on evidence.**

  - **(G) Engage in argument from evidence to evaluate and critique conclusions.**
  - **(H) Obtain, evaluate, and communicate information from multiple sources.**

2. **§112.34. Biology, Grade 9-12:**
   - **(9) Science concepts.**
     - **(A) Compare and contrast the structures and functions of different types of cells, including those of plants, animals, and bacteria.**
     - **(B) Explain the role of the cell membrane in maintaining homeostasis.**
3. **§112.34. Biology, Grade 9-12:**
   - **(10) Science concepts.**
     - **(A) Describe the interactions that occur among systems that perform the functions of regulation, nutrient absorption, reproduction, and defense from injury or illness in animals.**
     - **(B) Investigate and explain the interactions in an ecosystem, including the effects of organisms on the environment.**
4. **§112.34. Biology, Grade 9-12:**
   - **(11) Science concepts.**
     - **(A) Describe the role of internal feedback mechanisms in the maintenance of homeostasis.**
     - **(B) Investigate and analyze the conditions necessary for plant growth and the factors that influence plant growth, including the role of light, water, and nutrients.**

5. **§112.34. Biology, Grade 9-12:**
    - **(12) Science concepts.**
        - **(A) Describe the structure and function of nucleic acids and their role in the transfer of genetic information.**
        - **(B) Compare the processes of photosynthesis and cellular respiration in terms of energy transformation, reactants, and products.**

Lesson Alignment with 2020 TEKS:

1. **Investigate the influence of different types of lighting on the growth of plants:**
    - **§112.34 (1)(C), (1)(D), (11)(B)**
2. **Identify the factors that affect the growth and energy conservation in plants:**
    - **§112.34 (10)(B), (11)(B)**
3. **Analyze the amount of growth dependent on the lighting source:**
    - **§112.34 (1)(D), (1)(E), (11)(B)**

Materials:

- Potted plants (same species, same size)
- Different types of light sources (e.g., natural sunlight, incandescent bulbs, fluorescent bulbs, LED lights, solar lamps)
- Light meters (possible phone app)
- Rulers or measuring tapes
- Data recording sheets or notebooks
- Graph paper or software for data visualization

- Watering can and water
- Soil
- Timer or clock

Vocabulary Words and Definitions:

1. **Photosynthesis:**
    - **Definition:** The process by which green plants and some other organisms use sunlight to synthesize foods with the help of chlorophyll. Photosynthesis typically involves the intake of carbon dioxide and the release of oxygen.
2. **Chlorophyll:**
    - **Definition:** A green pigment found in the chloroplasts of plants, algae, and some bacteria that absorbs light to provide energy for photosynthesis.
3. **Incandescent Light:**
    - **Definition:** A type of electric light that produces light through the heating of a filament wire to a high temperature by passing an electric current through it until it glows.
4. **Fluorescent Light:**
    - **Definition:** A type of lighting that uses electricity to excite mercury vapor. The excited mercury atoms produce short-wave ultraviolet light that then causes a phosphor to fluoresce, producing visible light.
5. **LED Light (Light Emitting Diode):**

- **Definition:** A semiconductor light source that emits light when current flows through it. LEDs are known for their efficiency and long lifespan compared to other light sources.

6. **Light Intensity:**
   - **Definition:** The amount of light energy per unit area. In plant growth, light intensity can affect the rate of photosynthesis and, subsequently, plant growth.
7. **Energy Efficiency:**
   - **Definition:** The goal to reduce the amount of energy required to provide products and services. In the context of lighting, it refers to the amount of light produced per unit of energy consumed.
8. **Natural Light:**
   - **Definition:** Light that comes from the sun. It is the most natural source of light for plants and is critical for their growth and development.
9. **Artificial Light:**
   - **Definition:** Light produced by electrical sources, such as bulbs and LEDs, as opposed to natural light from the sun. Artificial lighting can be used to supplement or replace natural light for plant growth.
10. **Growth Rate:**
    - **Definition:** The speed at which a plant increases in size. Growth rate can be influenced by various factors, including light, water, nutrients, and temperature.
11. **Photosynthetically Active Radiation (PAR):**
    - **Definition:** The range of light wavelengths that are useful to plants for photosynthesis, typically from 400 to 700 nanometers.

12. **Spectrum:**
    - **Definition:** The range of different wavelengths of light. Different types of lighting have different spectral outputs, which can affect plant growth.
13. **Heat Production:**
    - **Definition:** The amount of heat generated by a light source. Excessive heat can be detrimental to plant growth and can impact the overall energy efficiency of the lighting system.
14. **Hydroponics:**
    - **Definition:** A method of growing plants without soil by using mineral nutrient solutions in a water solvent. Artificial lighting is often used in hydroponic systems to optimize plant growth.
15. **Photoperiod:**
    - **Definition:** The period of time each day during which an organism receives illumination; day length. Photoperiod can influence plant processes such as flowering and growth.
16. **Lumens:**
    - **Definition:** A measure of the total amount of visible light emitted by a source. Higher lumen values indicate a brighter light.
17. **Wavelength:**
    - **Definition:** The distance between successive peaks of a wave, typically used to describe light waves. Different wavelengths correspond to different colors of light.
18. **Ultraviolet (UV) Light:**

- **Definition:** A type of electromagnetic radiation with a wavelength shorter than that of visible light but longer than X-rays. UV light can have effects on plant growth and health.

19. **Light Meter:**
    - **Definition:** An instrument used to measure the intensity of light. Light meters can help ensure that plants receive the optimal amount of light for growth.
20. **Sustainable Practices:**
    - **Definition:** Methods of using resources in a way that does not deplete them and that supports long-term ecological balance. In agriculture, sustainable practices can include energy-efficient lighting and reduced water usage.

Introduction (15 minutes):

1. **Hook:** Show a short video or time-lapse of plants growing under different light conditions.
2. **Discussion:** Briefly discuss with students how light affects plant growth and why it is essential for photosynthesis.
3. **Objective Overview:** Explain the objectives of the lesson and what students will be doing.

Homework Given before the activity starts:

- **Research Assignment:** Assign students to research and write a short report on the use of artificial lighting in agriculture (e.g., hydroponics, greenhouses) and its impact on plant growth and energy efficiency.

Activity Part 1: Setting Up the Experiment (30 minutes):

1. **Grouping:** Divide students into small groups and assign each group a type of lighting.
2. **Planting:** Ensure each group has a potted plant and the assigned light source set up in different areas of the classroom or school.
3. **Measurement:** Have students measure and record the initial height of their plants.
4. **Lighting Setup:** Ensure proper placement of lights at an appropriate distance from the plants. Use light meters to measure the light intensity if available.
5. **Watering Schedule:** Establish a consistent watering schedule for all plants.

Activity Part 2: Observation and Data Collection (Daily for 2-3 weeks):

1. **Daily Observation:** Students will observe and measure the growth of their plants daily, recording data such as height, leaf number, and any other noticeable changes.
2. **Factors Discussion:** Have students note other factors that might affect plant growth (e.g., temperature, water, soil type).

Activity Part 3: Data Analysis and Interpretation:

1. **Graphing:** Students will use graph paper or software to create growth charts of their plants under different lighting conditions.
2. **Comparison:** Have students compare their results with other groups, noting differences and similarities in plant growth.
3. **Factors Affecting Growth:** Discuss and identify the factors affecting plant growth and energy conservation based on their observations and data.

Conclusion:

1. **Group Presentations:** Each group presents their findings, including graphs and interpretations of the data.
2. **Class Discussion:** Discuss as a class the overall results and how different light sources influenced plant growth. Highlight any patterns or anomalies.
3. **Energy Conservation:** Talk about how energy conservation in plants relates to the type of light they receive and the efficiency of photosynthesis under different lighting conditions.
4. **Reflection:** Have students reflect on what they learned and how they can apply this knowledge to real-world situations, such as agriculture or indoor gardening.

Assessment:

1. **Lab Reports:** Students submit a lab report detailing their experiment, observations, data analysis, and conclusions. Compile the data with other groups to analyze each lighting set up, compare and form a conclusion about the whole of the class data
2. **Quizzes:** Conduct a quiz covering the key concepts discussed in the lesson, including factors affecting plant growth and the role of different light sources in photosynthesis and energy conservation.

Discussion Questions: Types of Lighting Influence the Growth of Plants

1. **General Understanding:**
    - Why do you think light is important for plant growth?
    - Can you explain the role of photosynthesis in plant development and how light contributes to this process?

2. **Specific Observations:**
    - What differences did you observe in plant growth under different types of lighting?
    - How did the plants under natural sunlight compare to those under artificial light sources in terms of growth and health?
3. **Factors Influencing Growth:**
    - Besides light, what other factors do you think play a crucial role in the growth of plants? Why?
    - How did you ensure that these other factors were kept constant during your experiment?
4. **Energy Efficiency:**
    - Which type of lighting do you think is the most energy-efficient for plant growth? Why?
    - Discuss the pros and cons of using artificial lighting versus natural sunlight for growing plants.
5. **Practical Applications:**
    - How can the findings from your experiment be applied in real-world scenarios, such as agriculture or indoor gardening?
    - What are some benefits and challenges of using artificial lighting in commercial plant production?
6. **Experiment Design:**
    - If you were to design this experiment again, what changes or improvements would you make? Why?

- What challenges did you face during the experiment, and how did you overcome them?

7. **Broader Implications:**
    - How might changes in natural light availability (e.g., seasonal changes, climate change) impact plant growth on a larger scale?
    - What are some innovative technologies or methods currently being used to optimize lighting for plant growth in agriculture?
8. **Critical Thinking:**
    - How can understanding the influence of different types of lighting on plant growth help in conserving energy in agricultural practices?
    - Do you think there is an ideal type of lighting for all plants, or does it vary depending on the plant species? Explain your reasoning.
9. **Interpreting Data:**
    - Based on your data, which type of light resulted in the most significant plant growth? What specific evidence supports your conclusion?
    - Were there any unexpected results in your experiment? How do you explain these anomalies?
10. **Comparative Analysis:**
    - Compare the growth rates of plants under natural sunlight versus artificial lighting. What might be the reasons for any observed differences?
    - If a plant species thrives better under a specific type of artificial light, what characteristics of that light might be contributing to its growth?
11. **Energy and Efficiency:**

- Considering energy consumption and cost, which lighting type would you recommend for indoor gardening? Why?
- How might the energy efficiency of different lighting types impact large-scale agricultural practices and food production?

12. **Environmental Impact:**
    - How does the use of artificial lighting for plant growth impact the environment? Consider factors such as energy consumption, heat production, and light pollution.
    - In what ways can sustainable practices be incorporated into the use of artificial lighting for growing plants?
13. **Future Innovations:**
    - What future technologies or advancements could improve the efficiency of lighting for plant growth?
    - How might advancements in LED technology change the way we approach indoor and commercial plant cultivation?
14. **Adaptation and Evolution:**
    - How might plants adapt over time if exposed continuously to a specific type of artificial light? What evolutionary changes could occur?
    - Could certain plants be genetically modified to optimize growth under artificial lighting? What ethical considerations might this entail?
15. **Interdisciplinary Connections:**
    - How can knowledge from other scientific disciplines (e.g., physics, chemistry) enhance our understanding of plant growth under different lighting conditions?

  - How might principles of engineering be applied to design more effective lighting systems for plant growth?

16. **Global Perspectives:**
    - How do different regions of the world utilize artificial lighting for plant growth, especially in areas with limited natural sunlight?
    - What role does artificial lighting play in food security, particularly in urban or densely populated areas?
17. **Long-term Implications:**
    - If artificial lighting becomes more prevalent in agriculture, what long-term effects might this have on traditional farming practices and rural economies?
    - How could widespread use of artificial lighting for plants influence biodiversity and natural ecosystems?
18. **Ethical and Social Considerations:**
    - What are the ethical implications of relying heavily on artificial lighting for plant growth, especially in terms of energy consumption and environmental sustainability?
    - How might socio-economic factors influence the accessibility and adoption of advanced lighting technologies in agriculture?

Quiz Questions

1. **Multiple Choice:** What is the main role of light in plant growth? a) Providing warmth b) Supplying nutrients c) Facilitating photosynthesis d) Supporting root development

2. **True or False:** All types of artificial lighting provide the same amount of energy for plant growth.
3. **Fill in the Blank:** The process by which plants convert light energy into chemical energy is called ___________.
4. **Short Answer:** Name two factors, other than light, that can affect the growth of plants.
5. **Multiple Choice:** Which type of lighting is most energy-efficient for plant growth? a) Incandescent bulbs b) Fluorescent bulbs c) LED lights d) Natural sunlight
6. **True or False:** LED lights are known to produce less heat compared to incandescent bulbs.
7. **Fill in the Blank:** The green pigment in plants that absorbs light for photosynthesis is called ___________.
8. **Short Answer:** Explain how light intensity can influence the growth rate of plants.
9. **Multiple Choice:** Which of the following is a potential drawback of using incandescent bulbs for plant growth? a) High energy efficiency b) Excessive heat production c) Low light intensity d) UV radiation emission
10. **Short Answer:** Describe how you would design an experiment to test the effects of different types of lighting on plant growth.

Answer Key:

1. **c) Facilitating photosynthesis**
2. **False**
3. **Photosynthesis**
4. **Possible answers: temperature, water availability, soil type, nutrients**
5. **c) LED lights**

6. **True**
7. **Chlorophyll**
8. **Light intensity influences the rate of photosynthesis; higher light intensity can increase the rate of photosynthesis and promote faster growth, while lower light intensity can slow down the growth rate.**
9. **b) Excessive heat production**
10. **Design an experiment by setting up several groups of plants under different types of lighting (natural sunlight, incandescent, fluorescent, LED), measure their initial height, keep other variables constant (water, soil type, temperature), observe and record their growth over a specified period, and analyze the data to compare the effects of each lighting type on plant growth.**

Assessing Heat Generation in Anaerobic Composting of Yard and Food Waste for Backyard Renewable Energy Potential

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RET Site: Integrating Data-Driven Research in
Renewable Energy Across Disciplines (I-READ)

Texas A&M University – Kingsville
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July 26, 2024

Table of Contents

Abstract

This research project investigates the potential of anaerobic composting of yard and food waste to generate usable heat energy using controlled bin environments. Comparing temperature data across different bin configurations—Bin A with grass, Bin B with grass in a rotating bin, and Bin C with a mixture of grass and food waste in a rotating bin—revealed significant variations in heat production. Core temperature analysis demonstrated distinctive thermal regions within the composting material, showcasing the efficiency of heat generation across different waste compositions. Findings indicate that mixed waste compositions (Bin C) produced higher core temperatures compared to grass-only compositions (Bin A and Bin B), suggesting optimized heat recovery potential in mixed waste scenarios. This research provides valuable insights into the enhancement of waste management systems and their integration into renewable energy solutions. Additionally, this project laid the foundation for developing interdisciplinary curriculum modules for high school students, aligning with Environmental Systems and Physics standards. The environmental systems module focuses on the ecological and economic impacts of composting, resource conservation, and sustainable waste management practices. The physics modules engage students in hands-on activities to explore thermoelectric generation, fostering a deeper understanding of energy conversion principles.

Introduction

Proper waste management will aid in ensuring the Earth's environmental stability. Effective waste management practices, such as recycling, composting, and waste reduction, play a significant role in minimizing pollution, conserving natural resources, and mitigating the negative impacts on ecosystems. By managing waste efficiently, we can reduce greenhouse gas emissions, prevent soil and water contamination, and support the health and balance of our planet's ecosystems. This paper focuses on how composting on a small scale level within the household may help mitigate some of the harmful effects of food and yard waste on the environment by generating heat that could possibly be harvested and utilized.

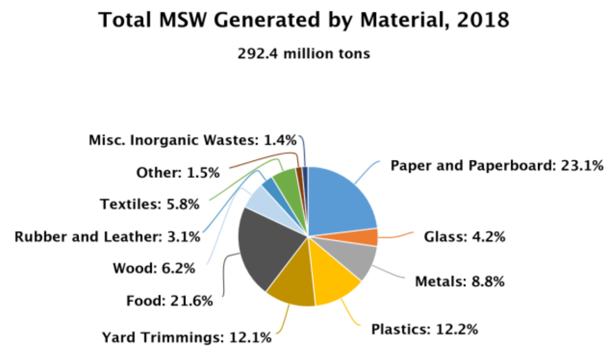

Figure 1: Shows the percent composition of municipal solid waste in 2018.

In 2018, food and yard waste accounted for 33.7% of the 292.4 million tons of total municipal solid waste generated by material in the U.S. (Fig.1).[1] Throughout most of human history, biomass from plants (yard waste) was the main energy source.[2] Biomass was burned for warmth and light, to cook food, and to feed the animals people used for transportation and plowing.[2] Yard waste is categorized into three main classifications: grass clippings, small yard waste, and heavy brush. Grass clippings consist of the trimmings from lawns, which decompose quickly and can be used for composting or mulching. Small yard waste includes brush and leaves, which are typically lighter and easier to manage; these materials are also excellent for composting and improving soil health. Heavy brush encompasses larger items such as tree trimmings greater than 3 inches in diameter, tree trunks, and root balls. Managing these categories effectively can aid in waste reduction and promote sustainability through composting and mulching.

According to FAO, 2014, as cited in Dhir 2020, Food waste is defined as the use of food meant for consumption by humans for non-consumption purposes, the redirection of food to feed animals, or the disposal of edible food.[3] Food waste is a significant issue in modern society, originating from various sources such as food processing plants, domestic and commercial kitchens, cafeterias, and restaurants. Traditionally, food waste has been incinerated; however, this process

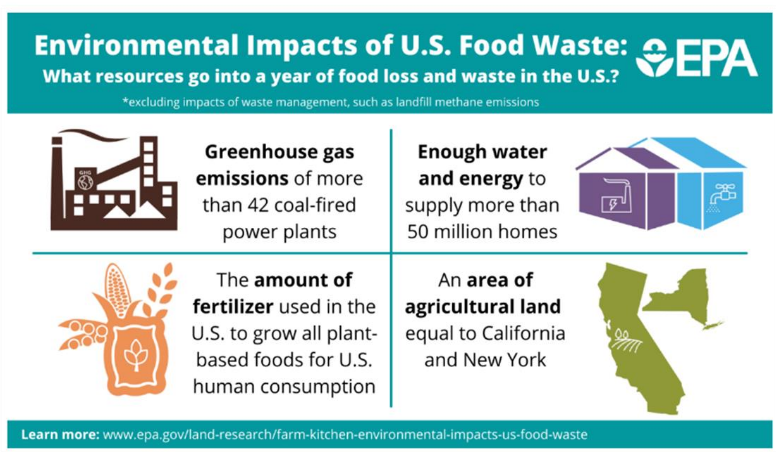

Figure 2: Depicts the effects of food waste on the environment in the U.S. in 2018.

can cause air pollution and result in the loss of the chemical values of food waste.[4] In the United States, each person wastes approximately 422 grams of food daily, amounting to an annual total of 51,608,760,000 metric tons.[5] Food waste is the single most common material landfilled and incinerated in the United States, with one-third of the food produced never being consumed. In 2019, 66 million tons of wasted food were generated, with 60% ending up in landfills.[6] Over one-third of the food produced in the United States is never eaten, wasting the resources used to produce it and creating a myriad of environmental impacts.[7] These staggering figures highlight the urgent need for improved food waste management and more efficient resource use.[5]

Figure 3: Depicts what types of material to compost.

Composting, particularly the heat produced during the process, offers a promising solution to this problem. As an essential process in waste management, composting can be broadly categorized into aerobic and anaerobic processes, each playing a significant role in renewable energy production by generating heat. Aerobic composting relies on the presence of oxygen and adequate moisture to facilitate the decomposition process. This method promotes the generation of heat, which can be harnessed for energy, making it a valuable contributor to renewable energy solutions. The aerobic process is relatively fast, typically taking around six weeks to complete. Various methods include open pile, windrow, static pile, in-vessel, and vermicomposting, each with unique applications and benefits.

On the other hand, anaerobic composting is fueled by bacteria and moisture, functioning without the need for oxygen. This method also generates heat along with producing end products like biogas, which can be used for energy production, thus aligning with the goals of sustainable and renewable energy generation. Although anaerobic composting is slower, often taking around six months to complete, it offers significant energy benefits. Common methods include covered static compost heaps or bins, submersion or underwater composting, and pits or trenches (landfills).

Both aerobic and anaerobic composting are integral to renewable energy initiatives. Future research will look into harnessing the heat generated using thermoelectric generators, converting heat into electrical energy. Other research may investigate how the biogas produced from anaerobic composting on a small scale can be utilized as a renewable energy source for electricity and heat, contributing to the reduction of fossil fuel dependence. By converting organic waste into compost, we can reduce the volume of waste sent to landfills, decrease greenhouse gas emissions, and recover valuable nutrients for soil health (Fig. 2). Addressing food and yard waste through composting not only helps manage waste more sustainably but also offers potential benefits in renewable energy generation. This dual approach not only supports waste management but also aligns with global efforts to enhance renewable energy adoption, ultimately fostering a more sustainable future.

Methodology

In order to devise an appropriate setup, researchers carefully considered the study's objectives, which were influenced by the available equipment and types of waste to be used. It was decided to purchase two rotating 43-gallon compost bins and to utilize an 115-gallon trash bin. These bins were chosen to house the biomass material for measuring heat generation within each container. Additionally, the researchers had access to two HOBO loggers and seven temperature sensors, with each logger capable of recording data from four sensors.

Researchers brainstormed multiple variations of comparing and analyzing the bins to get results. Initial brainstorming led to a thought of comparing anaerobic versus aerobic heat production. The two 43-gallon bins would be each divided by a septum, creating two compartments within each bin. The first compartment was designated for grass only, and the second compartment for grass and leaves. The same setup was intended for the second bin. One bin was to be completely sealed to allow for anaerobic decomposition, while the other was to be open to air and oxygen to enable aerobic decomposition.

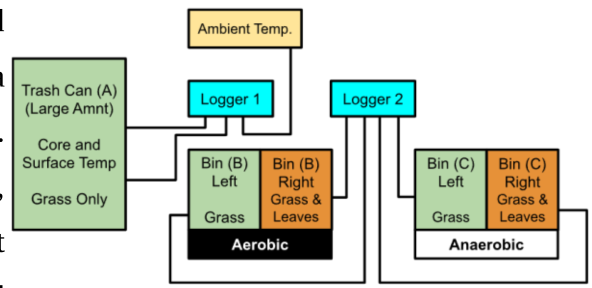

Figure 4: Depicts initial setup idea comparing heat generated due to Anaerobic vs Aerobic composting methods.

Further contemplation led to another approach where one rotating compost bin would contain grass only on one side of the septum and grass with leaves on the other side, while the second bin would hold grass and food on one side and food only on the other. However, both of these plans were rejected upon assembling the bins, as the septum allowed excessive heat transfer between compartments, which would hinder accurate measurement of heat generation on each side.

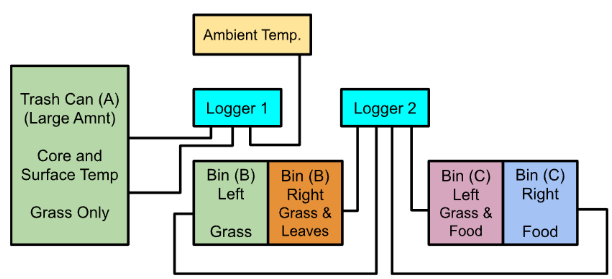

Figure 5: Depicts a secondary setup idea comparing heat generated by various biomass material types.

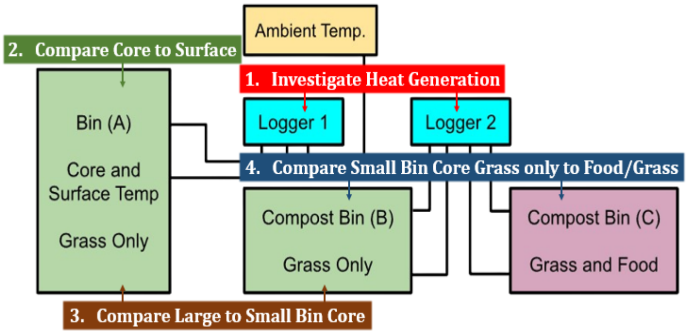

Figure 6: Depicts a actual setup comparing heat generated by various 2 bin types and 2 biomass material types. Also shows the location of each research objective.

The final methodology involved removing the septum from each bin, resulting in two single-compartment bins. The 115-gallon trash can was designated as Bin A, while the two 43-gallon rotating compost bins were labeled Bin B and Bin C. Bin A was filled with grass only, Bin B with grass only, and Bin C with a mixture of grass and food. Although carbon and nitrogen balance is ideal for composting, the project focused on using primarily nitrogen-based materials due to the available resources.

The seven temperature sensors were distributed as follows: One sensor attached to Logger 1 measured the ambient temperature, another measured the core temperature of Bin A, and a third recorded the surface temperature of Bin A (Fig. 6). Bin A, being 108 cm deep, had sensors placed approximately 13 cm and 54 cm from the top. Two small holes were drilled into Bin A, 15 cm below the sensor placements, to accommodate the sensors' movement with the decomposing biomass. Two additional sensors connected to Logger 2 measured core temperatures on the left and right sides of Bin B, while the final two sensors measured core temperatures on the left and right sides of Bin C.

Prior to filling with biomass, the rotating bins were tested for leakage by adding water. Leakage through some crevices and holes was observed. All bins were sealed with Flex Tape, including the areas where temperature sensors were inserted. After being filled with their respective biomass materials—110.8 lbs of grass in Bin A, 42.2 lbs of grass in Bin B, and 26.4 lbs of food plus 16 lbs of grass in Bin C— the small bins were rotated to ensure the contents were evenly mixed. All bins and loggers were then placed in a garage unit to begin the decomposition process. Temperature data collection commenced on July 14, 2024, at 8:00 p.m. and concluded on July 21, 2024, at 8:00 p.m., with data recorded every 30 minutes.

Throughout the experiment, the garage was kept closed to maintain a controlled baseline atmosphere. Access to the garage was restricted to entry through a utility room door, which occurred approximately 4 to 8 times per day. This access was used to verify that the loggers were continuously collecting data and to check the conditions of each bin (observing for leakage).

Experimentation

Primary Objectives of the Experiment:

1. **Investigate Heat Generation from Anaerobic Composting:**
    - The first objective was to assess heat generation from anaerobic composting of yard and food waste. Heat generation was evaluated by comparing the initial temperatures within the bins to the maximum temperatures recorded throughout the testing process. The temperature differential was observed and analyzed.

2. **Compare Large Bin Core and Surface Level Temperatures:**
    - The second objective was to compare core and surface level temperatures within Bin A. This comparison aimed to determine if surface-level temperatures generated more heat compared to core temperatures. Both maximum temperatures, average temperatures, and rates of temperature change were analyzed.

3. **Compare Core Temperatures Between Large and Small Bins:**
    - The third objective was to compare core temperatures between large and small bins. By examining the maximum and average core temperatures, as well as the rates of temperature change, the goal was to determine whether larger bins or smaller bins generated more heat at their cores.

4. **Compare Core Temperatures of Small Bins with Different Contents:**
    - The fourth objective was to compare core temperatures in small bins with different contents. Specifically, Bin B contained grass only, while Bin C contained a mixture of grass and food. The comparison of core temperatures, average temperatures, and rates of temperature change aimed to determine if a small bin with grass and food produced more heat compared to a small bin with grass alone.

Analysis

Objective 1: Investigate Heat Generation from Anaerobic Composting

The analysis of heat generation from anaerobic composting indicated a significant rise in temperature within the bins. By comparing the initial temperatures to the maximum temperatures reached during the experiment, it was evident that anaerobic composting of yard and food waste results in considerable heat production. As shown in Figure 7, the ambient temperature differential from the onset of the experiment to the maximum recorded temperature was 7°F. Each bin, labeled A, B, and C, exhibited a notable increase in temperature. The minimum temperature rise from initial to peak temperatures was 29.655°F, while the maximum increase reached 62.917°F. On average, the temperature increase across all bins was 41.42°F.

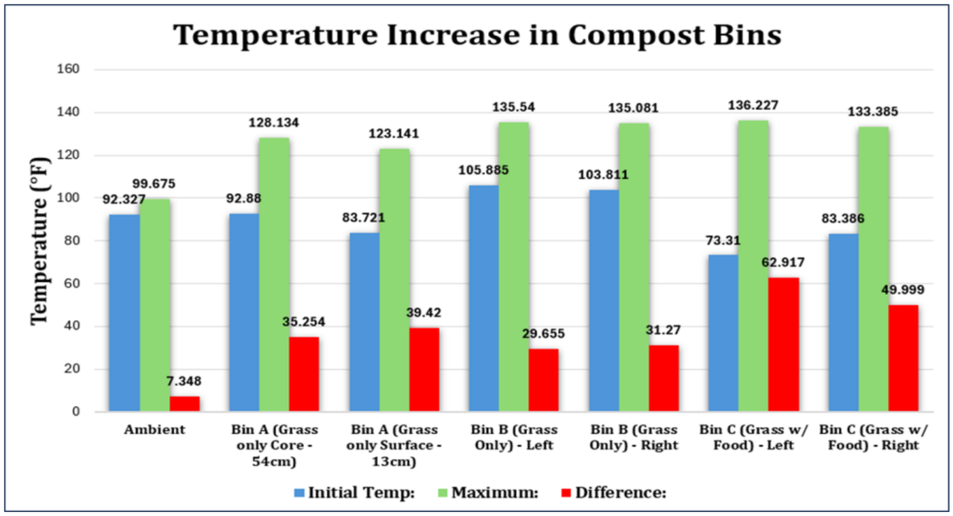

Figure 7: The figure shows the initial temperature readings of each sensor compared to the maximum temperature reading. Also shown is the difference between the initial and maximum temperatures.

Objective 2: Compare Large vs Bin Core and Surface Level Temperatures

For the second objective, the comparison between core temperatures and surface temperatures of the large bins revealed interesting findings. Data from Bin A, as illustrated in Figure 8, showed that both core and surface temperature readings exhibited similar rates of change at the beginning of the decomposition process. Despite these initial similarities, the core temperature ultimately reached a higher maximum temperature compared to the surface temperature. Additionally, as detailed in Table 1, the core temperature consistently maintained a higher average temperature throughout the week.

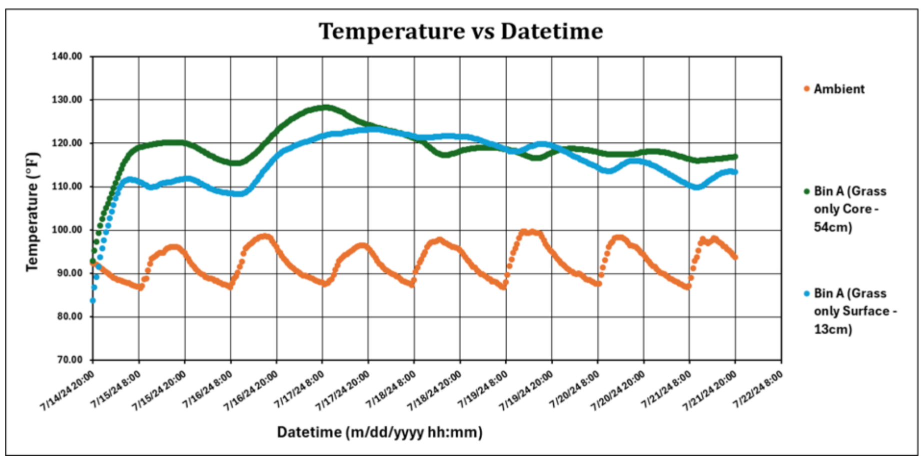

Figure 8: The figure shows the comparison of the Ambient temperature to Bin A

Categories	Ambient	Bin A (Grass only Core - 54cm	Bin A (Grass only Surface - 13cm	Bin B (Grass Only) - Lef	Bin B (Grass Only) - Righ	Bin C (Grass w/ Food) - Lef	Bin C (Grass w/ Food) - Righ
Minimum:	86.536	92.88	83.721	105.885	103.811	73.31	83.386
Maximum:	99.675	128.134	123.141	135.54	135.081	136.227	133.385
Median:	92.22	118.27	115.81	127.65	127.37	129.84	128.18
Mode:	88.461	117.73	111.463	132.494	126.592	129.843	133.381
Average:	92.53822552	118.8337804	115.4593175	127.8938279	127.2977774	126.7720564	127.0610504

Table 1: The table shows the minimum, maximum, median, mode, and average temperatures for each bin.

Objective 3: Compare Core Temperatures Between Large and Small Bins

The third objective involved comparing the core temperatures of Bin A, the large 115-gallon bin, with Bin B, the smaller 43-gallon bin. Analysis of the data, as depicted in Figure 9, revealed that Bin B exhibited a higher initial rate of temperature change compared to Bin A. Additionally, Bin B reached a higher maximum temperature, as shown in Table 1. Throughout the week, Bin B also maintained a higher average temperature than Bin A. These results suggest that the smaller bin experienced more rapid and intense heat generation in the core compared to the larger bin.

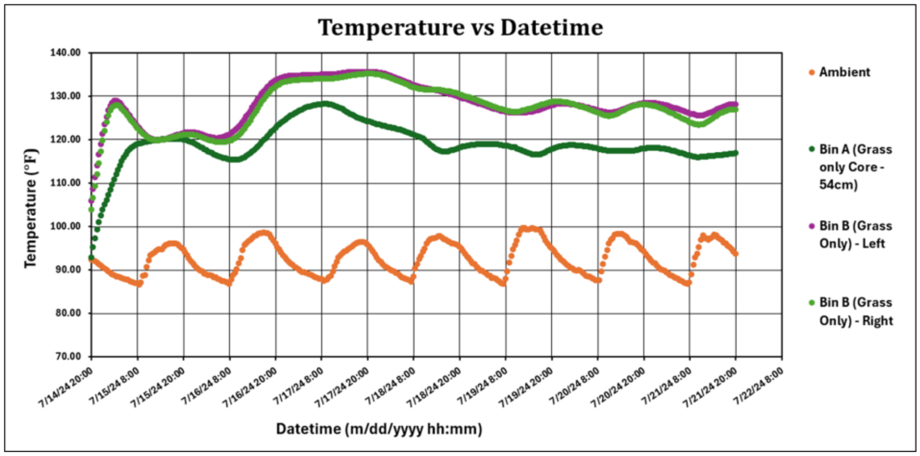

Figure 9: The figure shows the comparison of the Ambient temperature to

Objective 4: Compare Core Temperatures of Small Bins with Different Contents

The fourth objective involved comparing the core temperatures of the two small 43-gallon bins, Bin B and Bin C. Bin B contained only grass, while Bin C was a mixture of food and grass. The data indicated that Bin C experienced a longer sustained initial rate of temperature change, as illustrated in Figure 10. By the end of the week, Bin C also achieved a higher maximum temperature compared to Bin B, which is evident from the same figure. However, Bin B maintained a slightly higher average temperature throughout the week, with a difference of only 0.679°F.

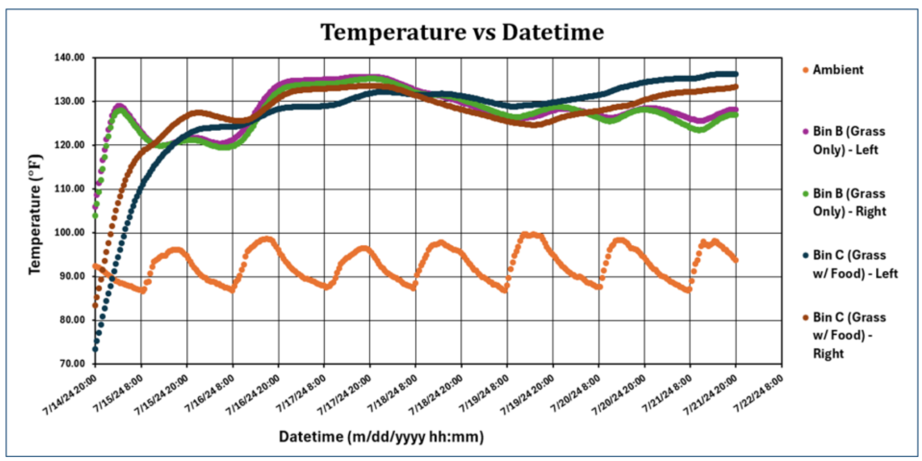

Figure 10: The figure shows the comparison of the Ambient temperature to

Conclusion

Data analysis reveals several important conclusions regarding composting systems and their heat generation capabilities. First, the comparison between different bin sizes and contents indicates that smaller bins, particularly those containing a mixture of grass and food, are more effective at generating heat in the short term. The observed higher temperatures and more rapid initial temperature changes in these bins suggest that they reach peak heat levels more efficiently compared to larger bins. This could be attributed to the smaller bin's greater heat concentration and more rapid decomposition process due to its higher surface area-to-volume ratio. However, the one-week duration of the experiment limits the ability to fully assess the long-term heat generation capabilities of the various bin configurations. To gain a comprehensive understanding, future studies should extend the observation period to encompass the entire composting cycle. This would provide insights into how heat production evolves over time and whether certain configurations continue to perform better or if different trends emerge as the composting process progresses.

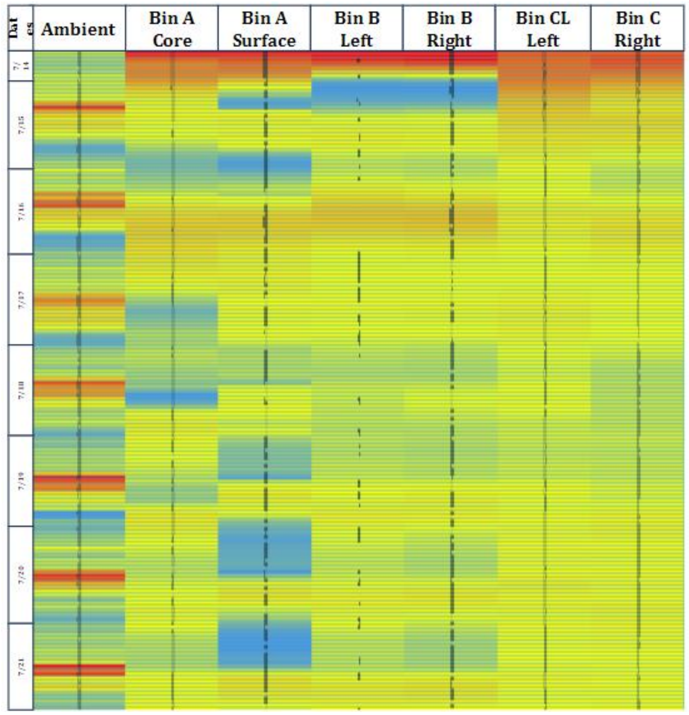

Figure 11: Heat map of the rate of change in temperature for each bin. A zero rate of change is colored yellow, positive rates of change are colored red, and negative rates of change are colored blue. Darker colors indicate higher magnitudes of the rate of change. Each column uses its own values as its baseline.

The fluid leakage observed on July 17, 2024, introduces a variable that may have influenced the temperature readings. Fluid loss from the bins potentially carried away heat, affecting the overall temperature data. This underscores the need for further research into how fluid management impacts temperature and heat retention. It is possible that the heat carried away by the fluids could be quantified to better understand its effect on the composting process and validate the principles of energy conservation in this context.

Future research should also explore additional factors that could influence heat generation. Comparing anaerobic with aerobic composting methods could provide insights into which method is more efficient in producing heat. Additionally, experiments designed to test the effects of fluid release versus insulation would help determine how these factors influence heat loss and retention. Investigating different types of composting materials, including various carbon-based additives, could further optimize heat production by identifying the most effective combinations of materials.

In conclusion, while the current study highlights the efficiency of smaller bins with mixed contents in generating heat over a short period, a more detailed and extended analysis is necessary to draw definitive conclusions.

Addressing the limitations of fluid leakage and experimenting with additional variables will contribute to a deeper understanding of composting heat dynamics and enhance strategies for maximizing heat generation in composting systems.

Environmental Systems Learning Modules

A Student Learning Module
(Elementary to High School)

Objectives and Assessment should be adjusted to fit the grade level. (Prepared for High School)

Composting Investigations: Exploring Environmental Systems Principles

Composting in the Classroom

Environmental Systems TEKS

§112.50(c)(6)Science concepts. The student knows the interrelationships among the resources within the local environmental system.

- (A) Compare and contrast land use and management methods and how they affect land attributes such as fertility, productivity, economic value, and ecological stability.
- (C) Document the use and conservation of both renewable and non-renewable resources as they pertain to sustainability.
- (F) Evaluate the impact of waste management methods such as reduction, reuse, recycling, upcycling, and composting on resource availability in the local environment.

§112.50(c)(7) Science concepts. The student knows the sources and flow of energy through an environmental system.

- (A) Describe the interactions between the components of the geosphere, hydrosphere, cryosphere, atmosphere, and biosphere.
- (B) Relate biogeochemical cycles to the flow of energy in ecosystems, including energy sinks such as oil, natural gas, and coal deposits.
- (C) Explain the flow of heat energy in an ecosystem, including conduction, convection, and radiation.
- (D) Identify and describe how energy is used, transformed, and conserved as it flows through ecosystems.

§112.50(c)(10) Science concepts. The student knows how humans impact environmental systems through emissions and pollutants.

- (C) Investigate the effects of pollutants such as chlorofluorocarbons, greenhouse gases, pesticide runoff, nuclear waste, aerosols, metallic ions, and heavy metals, as well as thermal, light, and noise pollution.

§112.50(c)(12) Science concepts. The student understands how ethics and economic priorities influence environmental decisions.

- (A) Evaluate cost-benefit trade-offs of commercial activities such as municipal development, food production, deforestation, over-harvesting, mining, and use of renewable and nonrenewable energy sources.

- (B) Evaluate the economic impacts of individual actions on the environment such as overbuilding, habitat destruction, poaching, and improper waste disposal.
- (C) Analyze how ethical beliefs influence environmental scientific and engineering practices such as methods for food production, water distribution, energy production, and the extraction of minerals.

Day One: Background Information and Vocabulary Exploration

Background Information: Composting

Composting is a natural process where organic materials, such as food scraps, yard waste, and certain paper products, decompose into a nutrient-rich soil amendment called compost. This process is facilitated by microorganisms, such as bacteria and fungi, which break down the organic matter. Composting can be categorized into two main types: aerobic and anaerobic composting.

Aerobic Composting: This method of composting occurs in the presence of oxygen. It is the preferred method for most home and community composting systems. Oxygen-loving bacteria decompose organic materials efficiently in aerobic conditions, producing heat as a byproduct. The heat helps to break down the materials faster and kills pathogens and weed seeds, resulting in a high-quality compost.

Anaerobic Composting: In contrast, anaerobic composting occurs in the absence of oxygen. This process typically happens in landfills or in sealed containers. Anaerobic bacteria decompose organic materials, but this process is slower and produces methane gas, which is a potent greenhouse gas and contributes to climate change. Anaerobic composting also produces an unpleasant odor due to the gasses released during decomposition.

Vocabulary Terms:

1. **Compost**: Compost is the nutrient-rich soil amendment produced through the decomposition of organic materials.

2. **Organic Matter**: Organic matter refers to materials that come from living organisms or were once living. In composting, this includes food scraps, yard waste, and certain paper products.

3. **Microorganisms**: Microorganisms are tiny living organisms, such as bacteria and fungi, that break down organic matter during composting.

4. **Decomposition**: Decomposition is the process by which organic matter breaks down into simpler organic compounds through the action of microorganisms.

5. **Aerobic vs. Anaerobic**: Aerobic means "with oxygen," while anaerobic means "without oxygen." Aerobic composting is faster and produces high-quality compost, while anaerobic composting is slower and can produce methane gas.

6. **Biodegradable**: Biodegradable materials can be broken down into simpler substances by microorganisms, reducing environmental impact.

7. **Sustainability**: Sustainability refers to practices that meet the needs of the present without compromising the ability of future generations to meet their own needs.

8. **Nutrient Cycle**: The nutrient cycle describes how nutrients move through the environment, including their absorption, use, release, and recycling through living organisms and nonliving elements.

9. **Carbon Footprint**: A carbon footprint measures the total greenhouse gas emissions caused directly and indirectly by human activities.

10. **Landfill Diversion**: Landfill diversion refers to efforts to reduce the amount of waste sent to landfills by recycling, composting, or reusing materials.

Worksheet Questions:

1. What is composting, and why is it beneficial for the environment?
2. Explain the difference between aerobic and anaerobic composting. Which method will you be using in this module?
3. Define "microorganisms" and explain their role in composting.
4. Why is aerobic composting preferred over anaerobic composting for most home and community composting systems?
5. Describe the concept of sustainability as it relates to composting.
6. What is meant by the term "biodegradable"? Provide examples of biodegradable materials.
7. Explain the nutrient cycle and how composting fits into this cycle.
8. Define "carbon footprint." How does composting contribute to reducing carbon footprints?
9. What does "landfill diversion" mean, and why is it important in waste management?
10. How can composting help reduce greenhouse gas emissions?

Weeks 1 through 6: Composting Project

Objective: Students will create compost using different materials and analyze the environmental and economic impacts of their composting methods. Over the next several weeks, you will explore the process of composting using different materials in composting bins. Your goal is to produce nutrient-rich compost that can be used to enrich soil in school gardens. Each composting bin will contain different materials, and you will observe and record how these materials decompose over time.

Activities over Several Weeks:

1. **Setting Up Composting Bins:**
    - Provide three composting bins with different materials:
        - Bin 1: Grass clippings and yard waste (vegetative materials).
        - Bin 2: Food scraps and leftover lunch items (organic food waste).
        - Bin 3: Combination of grass clippings and food scraps.
    - Explain the process of layering and managing compost materials (brown vs. green materials).

2. **Daily Monitoring and Rotation:**
    - Instruct students to rotate the compost bins daily to aerate the materials and to ensure even decomposition.
    - Use a compost thermometer to monitor the internal temperature of each bin.
    - Record observations such as smell, moisture level, and visible decomposition.

3. **Data Collection:**
    - Create a data log to record daily observations for each composting bin.
    - Measure and record the temperature of each bin daily.
    - Take notes on any changes observed in the materials over time.

4. **Week-by-Week Progress:**
    - Weekly, students will assess the decomposition progress of each bin.
    - Measure the volume reduction and quality of compost produced.
    - Discuss the differences in decomposition rates and quality based on the materials in each bin.
    - Week 1-2: Observe initial decomposition and changes in temperature.
    - Week 3-4: Note changes in appearance, odor, and texture of composting materials.
    - Week 5-6: Evaluate the quality of compost produced and its readiness for use in gardens.

5. **Final Report and Presentation:**
    - Compare the decomposition rates and quality of compost produced in each bin.
    - Discuss the economic and environmental impacts of composting versus landfill disposal.
    - Students may prepare a presentation summarizing your findings and recommendations for sustainable waste management practices or prepare a final report summarizing their findings.

Conclusion:

- Recap the key learnings from the module, emphasizing the importance of sustainable practices and resource management.
- Discuss how students can apply their knowledge of composting and environmental systems concepts in their daily lives.

Physics Learning Modules

A Student Learning Module
(Elementary to High School)

Objectives and Assessment should be adjusted to fit the grade level. (Prepared for High School)

Thermoelectric Generator Investigations: Exploring Physics Principles

Physics TEKS

1. **§112.45(c)(1) Scientific and engineering practices.**
    - (A) ask questions and define problems based on observations or information from text, phenomena, models, or investigations;
    - (B) apply scientific practices to plan and conduct descriptive, comparative, and experimental investigations, and use engineering practices to design solutions to problems;
    - (C) use appropriate safety equipment and practices during laboratory, classroom, and field investigations as outlined in Texas Education Agency-approved safety standards;
    - (D) use appropriate tools such as multimeters (current, voltage, resistance), ... or other equipment and materials that will produce the same results;
    - (E) collect quantitative data using the International System of Units (SI) and qualitative data as evidence;
    - (F) organize quantitative and qualitative data using bar charts, line graphs, scatter plots, data tables, labeled diagrams, and conceptual mathematical relationships;
    - (G) develop and use models to represent phenomena, systems, processes, or solutions to engineering problems;
    - (H) distinguish among scientific hypotheses, theories, and laws.
2. **§112.45(c)(2) Scientific and engineering practices.**
    - (B) analyze data by identifying significant statistical features, patterns, sources of error, and limitations;
    - (C) use mathematical calculations to assess quantitative relationships in data;
    - (D) evaluate experimental and engineering designs;
3. **§112.45(c)(3) Scientific and engineering practices.**
    - (A) develop explanations and propose solutions supported by data and models and consistent with scientific ideas, principles, and theories;
    - (B) communicate explanations and solutions individually and collaboratively in a variety of settings and formats;
    - (C) engage respectfully in scientific argumentation using applied scientific explanations and empirical evidence.
4. **§112.45(c)(4) Scientific and engineering practices.**
    - (A) analyze, evaluate, and critique scientific explanations and solutions by using empirical evidence, logical reasoning, and experimental and observational testing, so as to encourage critical thinking by the student.

5. **§112.45(c)(5) Science concepts.**
    - (B) identify and describe examples of electric and magnetic forces and fields in everyday life such as generators, motors, and transformers;
6. **§112.45(c)(6) Science concepts.**
    - (B) identify and describe examples of electric and magnetic forces and fields in everyday life such as generators, motors, and transformers;
    - (D) analyze, design, and construct series and parallel circuits using schematics and materials such as switches, wires, resistors, lightbulbs, batteries, voltmeters, and ammeters;
    - (E) calculate current through, potential difference across, resistance of, and power used by electric circuit elements connected in both series and parallel circuits using Ohm's law.
7. **§112.45(c)(7) Science concepts.**
    - (B) investigate and calculate mechanical, kinetic, and potential energy of a system;
    - (C) apply the concept of conservation of energy using the work-energy theorem, energy diagrams, and energy transformation equations, including transformations between kinetic, potential, and thermal energy;

Thermoelectric Generator Investigation Background Activity

Investigating Heat Gradient Changes and Energy Conversion in Thermoelectric Generators

Thermoelectric generators (TEGs) are devices that convert temperature differences directly into electrical energy. The fundamental principles behind TEGs involve the Seebeck effect, where a voltage is generated in response to a temperature gradient across different materials. This guide provides an overview of the physics principles involved and prepares students for hands-on investigations.

Thermoelectric Generators and the Physics of Energy Conversion

TEGs harness thermal energy to generate electricity, employing the following key principles and components:

1. **Thermoelectric Effect:**
   - The Seebeck effect occurs when a temperature difference between two dissimilar conductors or semiconductors generates a voltage. This voltage is proportional to the temperature gradient.
   - The efficiency of this energy conversion depends on the materials' properties, including their Seebeck coefficient, electrical conductivity, and thermal conductivity.

2. **Heat Transfer:**
   - Heat transfer in TEGs involves conduction, where heat moves from the hot side to the cold side.
   - Understanding conduction, convection, and radiation is crucial to optimizing TEG performance.

3. **Electrical Circuits:**
   - Ohm's law (V = IR) relates the voltage (V), current (I), and resistance (R) in a circuit.
   - Kirchhoff's voltage and current laws help analyze complex circuits, ensuring energy conservation and current flow continuity.

Key Components of a Thermoelectric Generator

1. **Thermocouples:**
   - P-type and N-type semiconductors form thermocouples. When subjected to a temperature gradient, they generate a voltage.
   - In thermoelectric generators (TEGs), P-type and N-type semiconductors are crucial components that form thermocouples. These thermocouples are the basic units responsible for converting heat into electrical energy through the Seebeck effect.

   - **P-type Semiconductor:**
     i. P-type semiconductors have a deficiency of electrons, known as "holes," in their crystal lattice structure. These holes behave like positive charges.

     ii. When two different materials, one P-type and one N-type, are joined at their ends to form a thermocouple, electrons flow from the N-type material (which has excess electrons) to the P-type material (which has holes). This flow creates a voltage difference due to the temperature gradient across the junctions.

   - **N-type Semiconductor:**
     i. N-type semiconductors have an excess of electrons, making them negatively charged.
     ii. In a thermocouple, the junction between an N-type semiconductor and a P-type semiconductor allows electrons to flow from the N-type to the P-type in response to the temperature difference. This flow of electrons generates an electrical potential difference.

- **Working Together:**
    i. When multiple pairs of P-type and N-type semiconductors are connected in series, they create a thermoelectric module. Each module produces a small voltage based on the temperature difference applied across it.

    ii. The cumulative effect of these modules, often arranged in arrays, can generate usable electrical power from heat differentials.

2. **Heat Source and Sink:**
    - A heat source (e.g., candle) provides thermal energy.
    - A heat sink dissipates heat, maintaining the temperature gradient across the TEG.

3. **Load:**
    - An electrical load (e.g., LED, resistor) utilizes the generated electrical energy.

4. **Measurement Tools:**
    - Multimeters measure voltage, current, and resistance, providing data for analysis.

    - **Using a Multimeter in a Circuit**

        i. A multimeter is a versatile tool used to measure electrical parameters such as voltage, current, and resistance in a circuit. Here's a brief tutorial on how to set up and use a multimeter for these measurements:

        ii. **Voltage Measurement:**

        1. **Setup:**
            a. Turn the multimeter dial to the DC voltage (V) setting if measuring direct current voltage, or AC voltage (V~) for alternating current voltage.
            b. Connect the black (negative) lead to the common (COM) terminal and the red (positive) lead to the voltage (VΩmA) terminal on the multimeter.
            c. Ensure the circuit or component under test is de-energized before making connections.

        2. **Measurement:**
            a. Touch the multimeter probes to the points in the circuit where you want to measure voltage.
            b. Read the voltage value displayed on the multimeter screen.

        iii. **Current Measurement:**

        1. **Setup:**
            a. Turn the multimeter dial to the current (A) setting for measuring current.
            b. Move the red lead from the voltage terminal to the current terminal marked with the highest current rating suitable for your measurement.

            c. Break the circuit and insert the multimeter in series with the load (component) where you want to measure current.

        2. **Measurement:**
            a. Close the circuit and allow current to flow through the multimeter.
            b. The multimeter displays the current flowing through the circuit.

iv. **Resistance Measurement:**

1. **Setup:**
    a. Turn the multimeter dial to the resistance (Ω) setting.
    b. Connect the black lead to the COM terminal and the red lead to the terminal marked with the resistance (Ω) symbol.
    c. Ensure there is no power flowing through the circuit or component being measured to avoid damage to the multimeter.

2. **Measurement:**
    a. Touch the multimeter probes across the component or circuit where resistance is to be measured.

    b. Read the resistance value displayed on the multimeter screen.

v. **Precautions:**
1. Always start with the highest range setting and adjust downward as needed to prevent damage to the multimeter.
2. Ensure proper connections and safety precautions, especially when dealing with live circuits or high currents.

Background and Definitions

1. **Seebeck Effect:**
    - The phenomenon where a temperature difference across a material generates a voltage.

2. **Conduction:**
    - The transfer of heat through a material without the material itself moving.

3. **Ohm's Law:**
    - A fundamental principle in electronics that describes the relationship between voltage, current, and resistance.

4. **Kirchhoff's Laws:**
    - Laws used to analyze complex electrical circuits: Kirchhoff's voltage law (sum of all voltages around a loop equals zero) and Kirchhoff's current law (sum of currents entering a junction equals the sum of currents leaving).

Demonstration (10-15 minutes)

- Show a simple demonstration of a thermoelectric generator in action. Use a TEG connected to a multimeter and a small heat source and cooling source. Show how the temperature difference generates voltage and can power a small device like an LED.

Discussion Questions

1. What is the primary role of thermoelectric generators in energy conversion?

2. How do thermoelectric generators convert heat energy into electrical energy?

3. Explain the Seebeck effect and how it contributes to the operation of thermoelectric generators.

4. Define conduction and its role in the heat transfer process within thermoelectric generators.

5. How does Ohm’s law apply to the circuits involving thermoelectric generators?
6. Describe Kirchhoff’s voltage law and how it can be used to analyze a thermoelectric generator circuit.
7. What factors influence the efficiency of thermoelectric generators?
8. How can varying the heat source (e.g., number of candles) affect the voltage output of a thermoelectric generator?
9. Why is it important to understand the principles of heat transfer when working with thermoelectric generators?
10. How can the use of a multimeter aid in understanding the performance of thermoelectric generators?

Four Day Activity

Day 1: In-depth Background

Objective: Students will gain a comprehensive understanding of thermoelectric generators, the Seebeck effect, and related principles.

Materials (as needed):
- Whiteboard and markers
- Projector and screen
- Handouts or slides on thermoelectric generators, Seebeck effect, Ohm's law, Kirchhoff's rules
- Internet access for videos or simulations

Activities:

1. **Introduction to Thermoelectric Generators:**
   - Explain what thermoelectric generators are and how they work.
   - Discuss the Seebeck effect in detail, including historical context and applications.
   - Show a video or animation that demonstrates the Seebeck effect and thermoelectric generators in action.

2. **Principles of Heat Transfer:**
   - Review conduction, convection, and radiation.
   - Discuss how heat transfer is relevant to thermoelectric generators.
   - Use examples and demonstrations to illustrate each type of heat transfer.

3. **Ohm's Law and Kirchhoff's Rules:**
   - Review Ohm's law and its application in electrical circuits.
   - Introduce Kirchhoff's voltage and current laws.
   - Solve a few sample problems on the board to illustrate these principles.

4. **Discussion and Q&A:**
   - Open the floor for questions and discussion.
   - Address any misconceptions and provide additional examples if needed.
   - Prepare students for the hands-on activities they will be doing over the next three days.

Day 2: LED Module

Objective: Students will use a thermoelectric generator to power an LED and understand the conversion of heat energy to electrical energy.

Materials:
- Thermoelectric generators (TEGs)
- Candles
- Heat sink or metal block
- LED lights
- Multimeter
- Wires
- Safety goggles

Background Information: Students should understand the basics of thermoelectric generation, the Seebeck effect, and the role of TEGs in converting thermal gradients into electrical energy. Basic knowledge of circuits, including how to connect an LED and use a multimeter, is necessary.

Take this day to also demonstrate proper use of a Multimeter:
1. Measuring current, voltage, and resistance.

Safety Briefing
2. Emphasize the importance of safety when handling heat sources, electrical equipment, and other materials. Ensure all students wear heat-resistant gloves and safety goggles.

Activities:

1. **Recap and Setup:**
   - Briefly recap the key points from Day 1.
   - Divide students into small groups (3-4 students per group).
   - Distribute materials to each group: TEGs, heat sources, cooling sources, multimeters, wires, connectors, small fans or LEDs, thermometers, beakers, and insulating materials.

2. **Lab Instructions**
   - Explain the procedure:
     i. Attach the TEG to the multimeter to measure voltage and current.
     ii. Create a temperature gradient by placing the TEG between a heat source and a cooling source.
     iii. Record the voltage and current generated as the temperature difference changes.
     iv. Optionally, connect the TEG to a small fan or LED to demonstrate the practical use of the generated electricity.

3. **Data Collection and Analysis:**
   - Students perform the experiment, recording their observations and data in a lab notebook.
   - Encourage students to try different combinations of heat sources and cooling sources to see how it affects the generated voltage.
   - Discuss the results and the energy conversion process.

4. **Discussion and Cleanup:**
   - Share observations and discuss any challenges faced during the experiment.
   - Safely extinguish candles and clean up materials.

Day 3: EMF Module

Objective: Students will measure the EMF produced by the TEG and calculate the current using a known resistance.

Materials:
- Thermoelectric generators (TEGs)
- Candles
- Heat sink or metal block
- Multimeter
- Resistors of known resistance
- Wires
- Safety goggles

Background Information: Students should understand Ohm's law and Kirchhoff's rules. They should be familiar with measuring voltage and current in a circuit.

Activities:
1. **Recap and Setup:**
   - Review Ohm's law and Kirchhoff's rules.
   - Explain how to use a multimeter to measure current and voltage.
   - Divide students into small groups.
   - Distribute materials to each group: TEGs, candles, ice packs, multimeters, resistors, wires, connectors, thermometers, beakers, and insulating materials.
   - Each group sets up a TEG with one side in contact with a heat sink and the other side exposed to a candle.
   - Connect the TEG to a known resistor and a multimeter.

2. **Hands-On Experiment:**
   - Light the candle and position it under the TEG.
   - Measure and record the voltage across the resistor and the current flowing through the circuit.
   - Use Ohm's law to calculate the EMF of the TEG.

3. **Data Collection and Analysis:**
   - Record voltage and current readings.
   - Compare the calculated EMF with the measured voltage.
   - Discuss any discrepancies and potential sources of error.

4. **Discussion and Cleanup:**
   - Share observations and discuss potential sources of error.
   - Safely extinguish candles and clean up materials.

Day 4: Heat vs EMF Module

Objective: Students will measure and graph the voltage output of the TEG as the heat input is varied.

Materials:

- Thermoelectric generators (TEGs)
- Candles (1, 2, and 3 candles for varying heat input)
- Heat sink or metal block
- Multimeter
- Stopwatch or timer
- Graph paper or computers for graphing
- Wires
- Safety goggles

Background Information: Students should understand the relationship between temperature gradients and voltage output in TEGs. Basic graphing skills and knowledge of data analysis are necessary.

Activities:

1. **Recap and Setup:**
    - Briefly recap the resistance module and key principles.
    - Explain the importance of accurate data collection and graphing.
    - Divide students into small groups.
    - Each group sets up a TEG with one side in contact with a heat sink and the other side exposed to a candle.
    - Connect the TEG to a multimeter.

2. **Hands-On Experiment:**
    - Each group records the initial voltage before adding a heat source.
    - Light one candle and record voltage every 10 seconds for 2 minutes.
    - Add a second candle and continue recording for another 2 minutes.
    - Add a third candle and continue recording for another 2 minutes.

3. **Data Analysis and Graphing:**
    - Plot the voltage versus time for each stage of the experiment.
    - Discuss the relationship between the number of candles (heat input) and the voltage output.
    - Identify the maximum voltage produced and discuss any observed plateaus or limits.

4. **Discussion and Cleanup:**
    - Share observations and discuss any patterns observed in the data.
    - Safely extinguish candles and clean up materials.

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Acknowledgement

This material is based upon work supported by the National Science Foundation under Award No. 2206864. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

2024

Modeling Impacts of Wake Steering on Wind Farm Development

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7/31/2024

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MODELING THE IMPACT OF WAKE STEERING ON WIND FARM DEVELOPMENT:

IMPLICATIONS ON WIND POWER EFFICIENCY

Abstract

This study investigates the impact of wake steering on wind farm development and its implications for power production efficiency by modeling various configurations and analyzing data. The research aims to optimize turbine placement and angles to maximize energy output. Preliminary results indicate significant improvements with wake steering. This paper presents the methods and analysis using model turbines in a controlled setting.

Introduction

Electricity production via wind turbine generation has proven to be a beneficial carbon-free source of energy. As of 2020, wind-generated electricity has surpassed coal and is growing rapidly (Watson, 2019). It is now the second largest source of energy generation, accounting for about 25%, while coal contributes around 16-18%. Natural gas remains the largest source at about 45%. Wind farms in Texas have experienced a steady increase in energy capacity, from 1,187 million kWh in 2001 to nearly 114,000 million kWh in 2022 (Office of Energy Efficiency & Renewable Energy, 2022). The success of wind-generated energy underscores the importance of factors that can increase the efficiency of each turbine, thereby enhancing cost-effectiveness.

Wind turbines have grown in both height and width. Larger wind spans have been found to generate more power, leading to an increase in turbine height over the years. Projections indicate that turbines may reach about 500 feet in height by 2035, with wind spans exceeding 800 feet (Office of Energy Efficiency & Renewable Energy, 2022). However, wake effects between turbines can decrease energy production for wind farms. Previous data suggest that as displacement between turbines increases, efficiency decreases.

The purpose of this study is to investigate the effects of wake steering on power production (Stanley, Ning, & Dykes, 2019), building on ongoing research initiated by William Johnson and Kurt Mann (Johnson & Mann, n.d.). Wake steering is a wind farm control strategy that redirects the wakes of upstream turbines away from downstream turbines by adjusting the yaw angle of the turbines. This technique has shown to improve energy production by up to 13% (Howland, Lele, & Dabiri, 2019). Horizontal variations were experimented with to explore the potential of wake steering.

Literature Review

Previous studies have shown that the efficiency of wind turbines can be significantly affected by wake effects. As turbines become larger, the potential for wake interactions increases, which can reduce overall energy production. Research by Stanley et al. (2019) and Simley et al. (2024) has indicated that optimizing turbine design and placement can mitigate these effects. Additionally, Howland et al. (2019) demonstrated that wake steering could improve energy production. This review synthesizes findings from multiple studies to provide a comprehensive understanding of wake effects and wake steering in wind farms.

Wake Effect:

Wake effect is a consistently studied phenomenon in wind turbine operation and wind farm layout optimization, where the interaction between the turbine blades and the wind creates a downstream area with reduced wind speed and increased turbulence (**Figure 1.**). The wind turbine wake effect refers to the disturbance in the airflow caused by a wind turbine. When wind passes through a turbine, it generates power but also creates a wake. This wake is a region of slower, turbulent air that is formed behind the turbine. This wake can impact the performance of downstream turbines by reducing their efficiency and power output turbulence (Watson, S. K. (2019, September 26). This effect is similar to how a boat leaves a wake in the water behind it. To minimize this effect, turbines are strategically placed to ensure optimal distance and alignment with prevailing winds. Effective wind farm design strategies can mitigate wake interference and enhance overall wind farm performance. Understanding and addressing the wake effect is fundamental to maximizing energy yield, reducing costs, and advancing sustainable wind energy solutions. Ongoing research aims to further optimize these strategies for even greater efficiency.

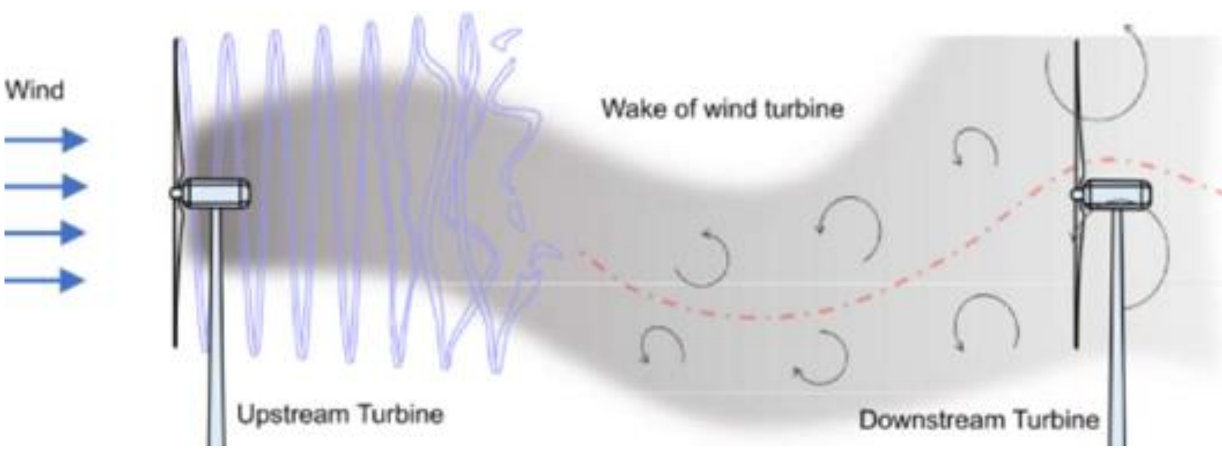

Figure 1. Wake effect created by an upstream turbine on turbine located downstream. Adapted from Balakrishnan and Hur (2022).

Wake Loss:

Wind turbine wake losses refer to the reduction in energy production caused by the wake effect. When a wind turbine operates, it creates a wake of slower, turbulent air behind it (**Figure 2**). This wake can affect other turbines by causing them to operate in less optimal conditions which diminishes their efficiency and overall energy output. As a result, these downstream turbines generate less power than they would in undisturbed wind which leads to a significant reduction in the overall energy output of the wind farm. Wake losses are a critical consideration in wind farm layout design. By strategically spacing turbines and optimizing their alignment with prevailing winds, it is possible to minimize these losses and improve the efficiency of the entire wind farm. Proper turbine placement ensures that each turbine can operate in the best possible wind conditions, and therefore maximizing power production and the economic viability of the wind farm.

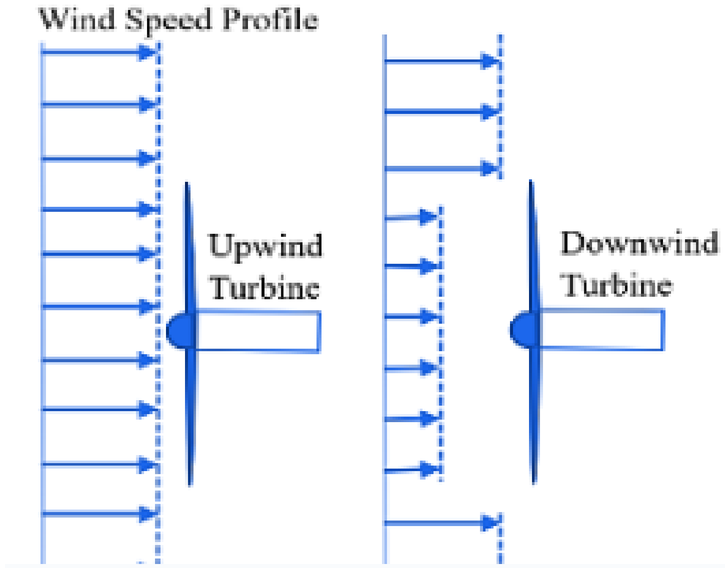

Figure 2. Wind speed profile and impact of wake effects from an upwind turbine on a downwind turbine. Adapted from Balakrishnan and Hur (2022).

Wake Steering:

This project focuses on utilizing wake steering **(Figure 3.)** to optimize wind farm layout and increase power production (Watson, S. K. (2019, September 26). This allows downstream turbines to experience higher wind speeds and produce more power, although there is a slight reduction in power production at the upstream turbines. By mitigating wake losses through strategic orientation adjustments, wake steering enables downstream turbines to operate more efficiently and extract more energy from the wind (Tri, B., & Johnson, M. (2023, August 14). This approach not only increases the overall power production of the wind farm but also enhances its economic potential, particularly in locations with land constraints or larger capacities. Field trials and simulation studies have demonstrated the success of wake steering in increasing energy production, providing design flexibility, and optimizing wind farm layouts.

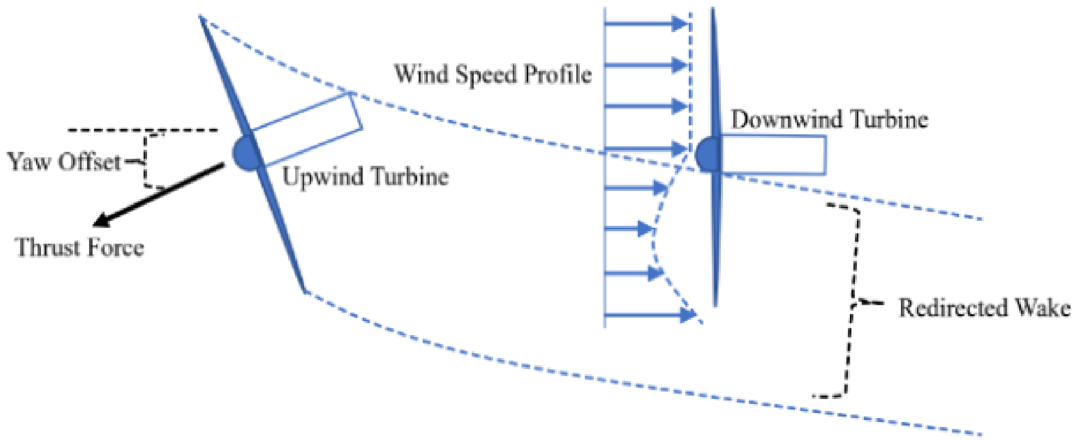

Figure 3: Aerial view of turbine placement and wake interactions.
Adapted from Balakrishnan and Hur (2022).

Materials

The materials used in this study include:

- Turbine models
- Industrial blowers
- Anemometer
- Multimeter
- Measuring tape
- Marking tape
- Data recording sheets

Methods

1. Turbine Model Construction: Build four turbine models according to provided directions.
2. Industrial Blower Setup: Position four industrial blowers so that the air hits the front turbine with maximum force.
3. Floor Markings: Mark the floor approximately 31.5 inches in front of each industrial blower.
4. Incremental Markings: Mark one-foot increments from the initial marking in front of column B up to 10 feet from the front turbine.
5. Initial Wind Speed Collection: Turn on the blower in front of column B and collect wind speeds without any turbines using an anemometer.
6. Wind Speed Measurement: Using an anemometer, measure the wind speeds at the front turbine position and at one-foot increments up to 10 feet to obtain initial wind speeds.
7. Fan Disturbance Test: Repeat step 6 with all fans on to check for wind disturbance between the fans.
8. First Turbine Setup: Position turbine 31.5 inches from industrial fan without wake steering.

9. Second Turbine Measurement: Place a second turbine one foot behind the first turbine and record wind speed (using an anemometer) and voltage (using a multimeter).
10. Incremental Measurements: Move the second turbine at one-foot increments, recording wind speed and voltage after each movement. Allow the turbine to equilibrate for one minute before collecting data.
11. Data Collection: Move the second turbine up to 10 feet, recording wind speed and voltage at each point. Take five readings at each point and calculate the average.
12. Wake Steering Test: Change the first turbine from no wake steering to wake steering (yaw angle of 13 degrees was used in our study- **Figure 4**) and repeat steps 9-11.

Figure 4: Determining the yaw angle used in this study.

13. Additional Turbine Setup: Add turbines in front of the other two industrial fans, alternating between no wake steering and wake steering, and record wind speeds and voltage for the second turbine.

    Additional turbines are shown as Turbine C and Turbine D (**Figure 5**), and were used to observe potential interference of our wake steering efforts. After we observed and recorded measurements with Turbines C and D, and determined a suitable distance to avoid the interference, we ultimately used only A and B for our experiment. This process was performed as one of the controlled measures.

14. Variation Testing: Change the front turbines to various wake and angled wake steering configurations to study the effects of these variations.

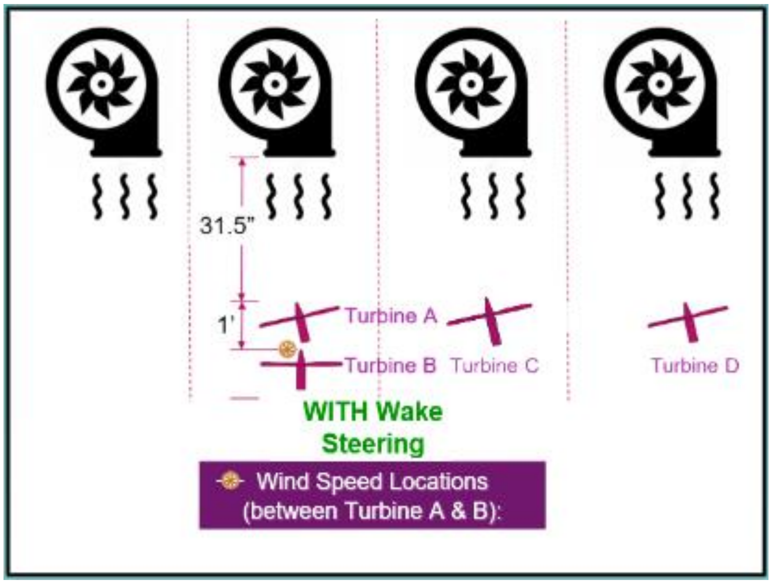

Figure 5: Aerial View of Equipment Set Up and anemometer locations during wind speed readings.

Data Analysis

The results indicate that wake steering can lead to significant improvements in wind farm efficiency. Wind speed collected from the downstream turbines showed an increase in speed when the upstream turbine was set a 13-degree yaw angle when compared to no yaw placement (**Figure 6**). The voltage data also supported these results (**Figure 7**). There was an initial decrease of voltage output on the upstream turbine, however, the downstream turbine showed a significantly greater output that outweighed the initial loss (**Figure 8**).

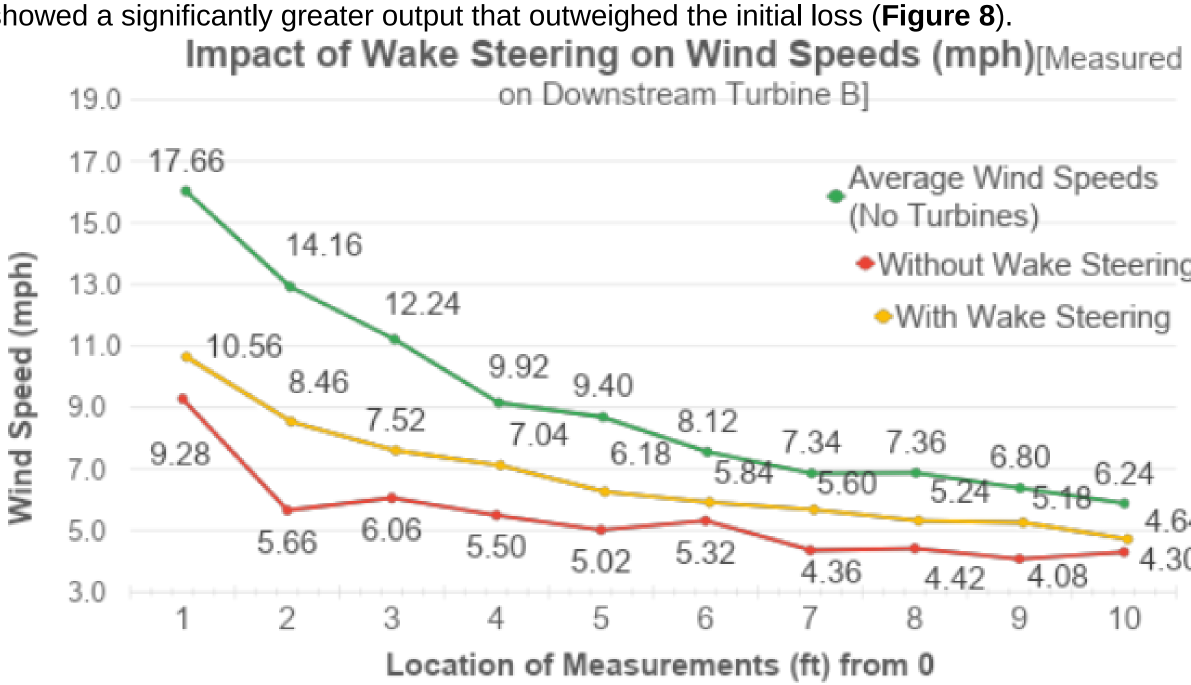

Figure 6: Wind speed at various turbine locations. Green line represents the baseline wind speed without any turbines present. (No wind Interference). Red line represents the wind speeds downstream from turbine A without wake steering efforts. Yellow line represents the wind speeds downstream from turbine A with wake steering efforts.

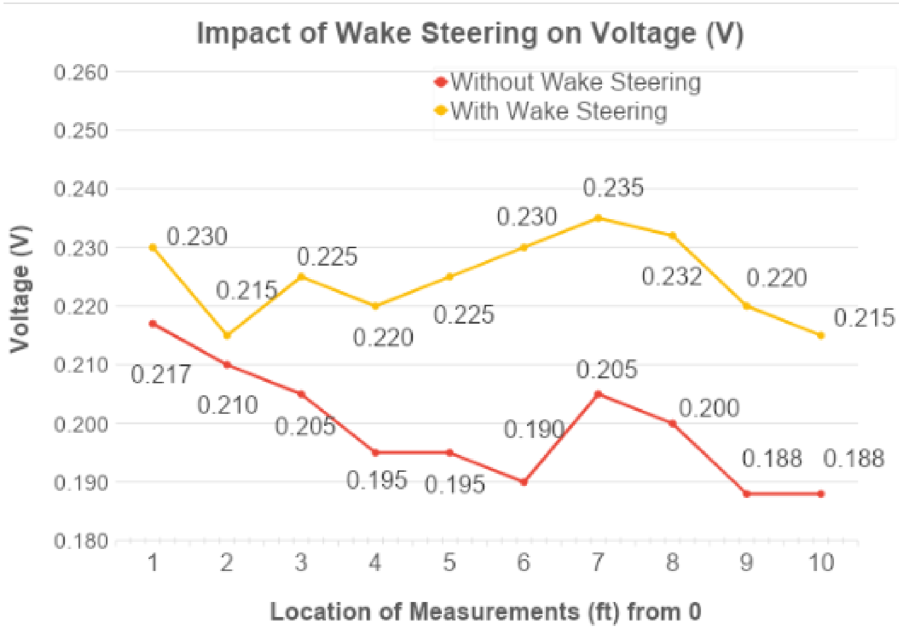

Figure 7: Voltage at various turbine locations. Red line represents voltage with no yaw angle. Yellow line represents voltage with wake steering efforts.

Turbine Layout:		A — B —	A / B —	Difference (%)
Wake Steering:		No	Yes	
Location of Measurements (ft from X_0)	X_0	0.250	0.210	-16.00%
	1	0.217	0.230	5.99%
	2	0.210	0.215	2.38%
	3	0.205	0.225	9.76%
	4	0.195	0.220	12.82%
	5	0.195	0.225	15.38%
	6	0.190	0.230	21.05%
	7	0.205	0.235	14.63%
	8	0.200	0.232	16.00%
	9	0.188	0.220	17.02%
	10	0.188	0.215	14.36%
			Increase %:	5%

Figure 8: Voltage data comparison. X_0 represents the voltage of upstream turbine at yaw angle of 13 degrees. All other measurements were taken at various distances from the upstream turbine.

Conclusions

The purpose of this research project was to show the effects that wake steering has on increasing energy production through optimizing wind farm layouts. This project showed that wind speed and voltage were increased when yaw angles of upstream turbines were adjusted to deflect the wakes and mitigate wake losses. Although voltage of the upstream turbine showed lower voltage compared to that taken without mitigating efforts, the succeeding turbines increased to the point that this initial loss was offset. A fog machine was used to determine how the air flow through the turbines. This image was enhanced to show how the air was manipulated after it left the upstream turbine. (**Figure 9**). The data of this study supports the use of wake steering and stresses the importance of optimizing wind farm layouts. The model turbines effectively replicated a scaled-down, controlled simulation of a wind farm layout. Adjustments of turbine angles can lead to significant efficiency gains. The findings suggest that further research of wake steering can enhance the overall performance of wind farms.

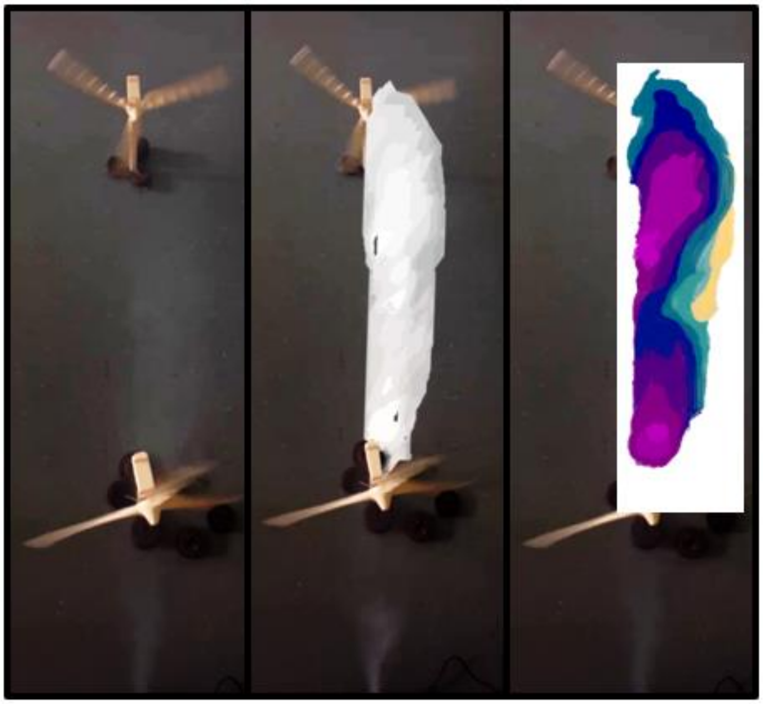

Figure 9: Aerial view of fog machine used to determine air travel. Picture on the left is the original image. Central and image to right show the enhanced images. The image at the right shows where speed is traveling at its fastest (purple color). The yellow color indicates wind traveling at a slower speed.

Curriculum Modules

Physics Module

PB1. Module: Physics in Wind Turbine Analysis

TEKS Standards

- **P. (b) (1):** Conduct laboratory and field investigations, use scientific practices during investigations, and make informed decisions using critical thinking and scientific problem solving. Acquire factual knowledge within a conceptual framework, practice experimental design and interpretation, work collaboratively with colleagues, and develop critical-thinking skills.
- **P. (c) 1 (B):** Conduct laboratory and field investigations, use scientific practices.
- **P. (c) 3 (A):** Analyze, evaluate, and critique scientific explanations by using empirical evidence, logical reasoning, and experimental and observational testing to encourage critical thinking.
- **P. (c) 1 (A):** Demonstrate safe practices during laboratory and field investigations.
- **P. (c) 4 (C):** Analyze and describe accelerated motion in two dimensions, including using equations, graphical vector addition, and projectile and circular examples.
- **P. (c) 4 (B):** Describe and analyze motion in one dimension using equations and graphical vector addition with the concepts of distance, displacement, speed, average velocity, instantaneous velocity, frames of reference, and acceleration.
- **P. (c) 5 (D):** Identify and describe examples of electric and magnetic forces and fields in everyday life such as generators, motors, and transformers.
- **P. (c) 5 (F):** Investigate and calculate current through, potential difference across, resistance of, and power.

Objective

We will observe effects of wake steering on turbine models and analyze physics properties to optimize wind farm layouts.

We will explain how wind speed and generated energy vary between different turbine locations.

Materials Needed:

- Graph paper
- Rulers
- Protractors
- Scientific calculators
- Anemometer
- Multimeter
- Wind Turbine Models

- Worksheets with coordinate grids and wind turbine layout scenarios
- Software for storing generated data
- Markers and colored pencils

Lesson Components:

Introduction: Begin with a discussion on the importance of clean energy produced by wind farms and how wind power increases electricity production while maximizing land usage. Introduce the day's focus on determining wind speed and energy production in different turbine layouts.

Set-Up: Review key physics concepts including distance, displacement, speed, velocity, voltage, current, resistance, and power. Distribute the necessary materials and worksheets to students.

Distance/Displacement and Speed: Provide clear instructions on the concepts of speed (distance/time) and velocity (displacement/time). Demonstrate how to use an anemometer and multimeter. Guide students through the process of analyzing how changing the layout affects wind speed for optimal power generation. Allow students to independently work on provided scenarios to calculate power generated at each location.

Data Analysis: Students will plot their calculated data and analyze the power produced. They will interpret the data to determine the efficiency of the turbine layouts and compare different scenarios, discussing the advantages and disadvantages of each.

Conclusions: Summarize key findings from the analysis and discuss how wind speed impacts the efficiency of energy production in different turbine layouts.

Recommendations: Encourage students to suggest changes to the turbine layouts to enhance efficiency based on their geometric analysis. They should also provide justifications for why these changes would be beneficial.

Discussion: Reflect on the importance of precision in these calculations in real-world applications. Connect the skills learned to careers in renewable energy and engineering.

Extensions (Homework or Additional Class Activity):

- **Regular Physics:** Create new scenarios and predict energy production at various layouts.
- **PreAP Physics:** Include additional variables like horizontal and vertical turbine differences and varying wind speeds in the calculations.

Levels of Rigor:

- **Regular Physics Level:** Basic understanding of terms dealing with speed, velocity, and energy. Activities include practice calculations and worksheet completion.
- **PreAP Physics Level:** Deeper understanding with real-world applications, incorporating additional variables and more complex scenarios. Assessment includes reports of findings at each wind turbine model layout.

Safety Guidelines: Maintain classroom conduct for a positive environment during calculations and discussions. Ensure proper use of all physics and mathematical tools (models, rulers, calculators) to avoid accidents or damage. Follow software use instructions to prevent data loss and ensure accurate calculations.

Emphasis on Rigor: Ensure all calculations are precise and double-checked for errors. Encourage critical thinking about the implications of findings and how they can be applied in real-world scenarios. Relate lab data to practical applications in renewable energy and engineering to reinforce understanding.

Encouragement: Students are encouraged to ask questions, discuss their findings, and explore the implications of their analyses throughout the lesson.

Teacher Role:

- Introducing the topic and explaining the data obtained from turbine models.
- Reviewing key concepts and providing clear instructions.
- Guiding students through initial calculations and ensuring understanding.
- Facilitating data analysis and discussions.
- Encouraging critical thinking and application of concepts.

Student Role:

- Engaging in discussions about renewable energy and the importance of turbine layouts.
- Reviewing key concepts and following instructions for calculations.
- Working on independent practice scenarios to apply physics properties.
- Plotting data and analyzing results.
- Discussing findings and suggesting improvements.
- Completing extensions and engaging in higher levels of rigor.

Visuals and Images:

- Example Wind Turbine Layout:
- Graphical Representation of Physics Properties:

AP Biology Module

Module will address the following areas of AP Biology:

- Determine Standard Deviation between Turbine Models With and Without Wake Steering
- Standard deviation: mean, median, mode, interquartile range, outlier, measures of center, measures of spread, histograms, box plot, dot plot, standard deviation, data set, skewed data.

Students will conduct wind turbine labs and determine if there is significance between various wind turbine setups.

Student Assessment:

- Lab Reports including graphs and charts of findings
- Project-Based (Create a Project-Based Report)

Lesson: Determining Significant Differences Between Various Wind Turbine Layouts

TEKS Standards

B(b)(4)(B): Students should be able to identify problems and design solutions using appropriate tools and models.

Objective:

- We will identify and interpret relationships in wind speed and turbine output data.
- We will analyze data on wind speeds and turbine outputs to identify variations between turbine locations and possible effects of wake steering.

Materials Needed:

- Rulers
- Scientific calculators
- Worksheets with wind speed and turbine output data
- Anemometer
- Multimeter tool
- Wind Turbine Models
- Worksheets with coordinate grids and wind turbine layout scenarios
- Software for storing generated data
- Markers and colored pencils

Lesson Components:

Introduction: Begin with a discussion on how wind turbine models can represent real-world phenomena, such as wind speeds and turbine outputs. Discuss how turbines can be affected by environmental factors. Introduce today's focus on using standard deviation to analyze significant difference on wake steering on wind turbine.

$$\mathrm{SD} = \sqrt{\frac{\sum |x - \mu|^2}{N}}$$

Where **SD**= standard deviation, ∑= sum of, **x**= value in the data set, **μ**= mean of the data set and **N** is the number of data points.

You will be dealing with the following terms Count (N); sum (∑); min= smallest number in data set; max= largest number in data set, range= difference between the max and min numbers; median= the number that separates the max and min values; mode= any number that appears more than once; mean= , total divided by the number of values in the data set; and standard deviation= the distance between each data point and the mean. You will also be dealing with square and square root.

Set-Up: Review key standard deviation formula and the factors involved in determining variability within a database.

Distance/Displacement and Speed: Provide clear instructions on the concepts of N, sum, min, max, range, median, mode, mean, variance, and standard deviation, including the standard deviation equation. Allow students to independently work on provided scenarios to calculate deviation amongst each variation and determine if there are significant differences between these variations.

Data Analysis: Students will plot their calculated data and wind speed and voltage ate each turbine layout. They will interpret the data to determine the standard deviation between turbine locations and analyze if there are any significant differences between them.

Conclusions: Summarize key findings from the analysis and discuss how turbine locations were impacted by the location of other turbines and if and how wind steering affected the energy production at each location.

Recommendations: Encourage students to suggest changes to the turbine layouts to reduce the wake effects, if any. They should also provide justifications for why these changes would be beneficial.

Discussion: Reflect on the importance of precision in these calculations in real-world applications. Connect the skills learned to careers in renewable energy and engineering practices.

Extensions (Homework or Additional Class Activity): Create new scenarios and predict the effects of various wind steering and turbine layouts on energy production. Further studies could possibly suggest studies to determine how these changes could have ecological influences and how this could be set up to study this.

AP Biology Level of Rigor:

- **Objective:** Deeper understanding with real-world applications.
- **Activities:** Incorporate additional variables and more complex scenarios.
- **Assessment:** Make reports of findings at each wind turbine model layout determining significant differences if there are any.

Safety Guidelines: Maintain classroom conduct for a positive environment during lab setup, lab analysis, calculations, and discussions. Ensure proper use of all physics and mathematical tools (models, rulers, multimeters, etc.) to avoid accidents or damage. Follow software use instructions to prevent data loss and ensure accurate calculations.

Emphasis on Rigor: Ensure all calculations are precise and double-checked for errors. Encourage critical thinking about the implications of findings and how they can be applied in real-world scenarios. Relate lab data to practical applications in renewable energy and ecological effects to reinforce understanding.

Encouragement: Students are encouraged to ask questions, discuss their findings, and explore the implications of their analyses throughout the lesson.

Teacher Role:

- Introducing the topic and explaining the data obtained from turbine models.
- Reviewing key concepts and providing clear instructions.
- Guiding students through initial calculations and ensuring understanding.
- Facilitating data analysis and discussions.
- Encouraging critical thinking and application of concepts.

Student Role:

- Engaging in discussions about renewable energy and the importance of turbine layouts.
- Reviewing key concepts and following instructions for calculations.
- Working on independent practice scenarios to apply physical properties.
- Plotting data and analyzing results.
- Discussing findings and suggesting improvements.

- Completing extensions and engaging in higher levels of rigor.

Visuals and Images:

- Example Wind Turbine Layout:
- Mathematical and Graphical Representation of significant differences between turbine layouts

Geometry Modules

Objective: Understand the Geometric Principles of Wind Turbine Design and Placement

Modules will address the following areas in geometry:

- Measurement: Length, area, volume
- Angles: Types of angles, angle measurement, angle bisectors
- Triangles: Properties of triangles, types of triangles, Pythagorean theorem
- Circles: Radius, diameter, circumference, area, sector area
- Transformations: Translation, rotation, reflection, dilation
- Coordinate Geometry: Graphing points, lines, and shapes; calculating slope, distance, and midpoint

Student Activities: Calculate the height and area swept by turbine blades given different diameters.

- Determine the optimal placement of turbines using coordinate geometry to minimize wake effects.
- Use geometric transformations to simulate the effect of wake steering on wind flow.

Student Assessment:

- Lab Reports including graphs and charts of findings
- Project-Based (Create a Project-Based Report)

G9A. Module: Calculating Distances and Analyzing Slopes in Wind Turbine Layouts

TEKS Standards:

G.9(A): Derive and apply formulas involving length, slope, and midpoint. Calculate distances between turbines and analyze the slope of the wind flow across different layouts.

Objective:

- Derive and apply formulas to calculate distances and analyze slopes.

- Calculate distances between wind turbines and analyze the slope of wind flow across different layouts.

Materials Needed:

- Graph paper
- Rulers
- Protractors
- Scientific calculators
- Computers/tablets with GeoGebra or similar software
- Worksheets with coordinate grids and turbine layout scenarios
- Wind turbine data (coordinates, heights, distances)
- Markers and colored pencils

Lesson Components:

Introduction: Begin with a discussion on renewable energy and the importance of wind turbines. Explain how engineers must consider distances and slopes when planning turbine layouts for optimal efficiency. Introduce the day's focus on calculating distances between turbines and analyzing wind flow slopes.

Set-Up: Review key concepts of distance formula, midpoint formula, and slope formula. Distribute the necessary materials and worksheets.

Measurement: Provide clear instructions on the following formulas:

- **Distance Formula:** Given two points (x_1, y_1) and (x_2, y_2), the distance ddd is calculated as d=(x2−x1)2+(y2−y1)2d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}d=(x2−x1)2+(y2−y1)2.
- **Midpoint Formula:** The midpoint MMM between two points (x_1, y_1) and (x_2, y_2) is M=(x1+x22,y1+y22)M = \left(\frac{x_1 + x_2}{2}, \frac{y_1 + y_2}{2}\right)M=(2x1+x2,2y1+y2).
- **Slope Formula:** The slope mmm between two points (x_1, y_1) and (x_2, y_2) is m=y2−y1x2−x1m = \frac{y_2 - y_1}{x_2 - x_1}m=x2−x1y2−y1.

Guided Practice:

- **Distance:** Calculate the distance between two turbines given their coordinates.
- **Midpoint:** Determine the midpoint between two turbines.
- **Slope:** Analyze the slope of the line connecting two turbines and its implication on wind flow.

Independent Practice: Students work on provided turbine layout scenarios to apply the formulas.

Data Analysis: Students plot their calculated points on graph paper or use GeoGebra to visualize the layouts. They will analyze the plotted points to determine the efficiency of the turbine layouts based on distances and slopes. They will compare different layouts and discuss the advantages and disadvantages of each.

Conclusions: Summarize key findings from the analysis and discuss how the calculations impact the design and efficiency of wind turbine layouts.

Recommendations: Encourage students to suggest changes to the turbine layouts to enhance efficiency based on their analysis. They should also provide justifications for why these changes would be beneficial.

Discussion: Reflect on the importance of precision in these calculations in real-world applications. Connect the skills learned to careers in renewable energy and engineering.

Extensions (Homework or Additional Class Activity):

- **Standard:** Create new turbine layout scenarios and calculate distances, midpoints, and slopes.
- **Honors:** Include additional variables like turbine height and varying wind speeds in the calculations.
- **MYP:** Research and present a report on how these mathematical concepts are used in the design and optimization of renewable energy projects.

Levels of Rigor:

Standard Level:

- **Objective:** Basic understanding of distance, midpoint, and slope formulas.
- **Activities:** Calculate distances and slopes with provided coordinates.
- **Assessment:** Worksheet completion and correct application of formulas.

Honors Level:

- **Objective:** Deeper understanding with real-world applications.
- **Activities:** Incorporate turbine height and wind speed variations.
- **Assessment:** Analyze more complex scenarios and present findings.

MYP Level:

- **Objective:** Advanced application and research skills.
- **Activities:** Conduct independent research on turbine layout optimization.
- **Assessment:** Present a detailed report with data analysis and recommendations.

Safety Guidelines: Maintain classroom conduct for a respectful and focused environment during calculations and discussions. Ensure proper use of all mathematical tools (rulers, calculators, etc.) to avoid accidents or damage. Follow instructions for using GeoGebra or other software to prevent data loss and ensure accurate calculations.

Emphasis on Rigor: Ensure all calculations are precise and double-checked for errors. Encourage critical thinking about the implications of findings and how they can be applied in real-world scenarios. Relate mathematical concepts to practical applications in renewable energy and engineering to reinforce understanding.

Encouragement: Students are encouraged to ask questions, discuss their findings, and explore the implications of their analyses throughout the lesson.

Teacher Role:

- Introducing the topic and explaining the importance of calculations in turbine layouts.
- Reviewing key concepts and providing clear instructions.
- Guiding students through initial calculations and ensuring understanding.
- Facilitating data analysis and discussions.
- Encouraging critical thinking and application of concepts.

Student Role:

- Engaging in discussions about renewable energy and turbine layouts.
- Reviewing key concepts and following instructions for calculations.
- Working on independent practice scenarios to apply formulas.
- Plotting data and analyzing results.
- Discussing findings and suggesting improvements.
- Completing extensions and engaging in higher levels of rigor.

Visuals and Images:

- Example Wind Turbine Layout:
- Graphical Representation of Math Properties:

G10A. Module: Using Trigonometric Ratios to Solve Problems Involving Right Triangles in Real-World Problems

TEKS Standards

G.10(A): Use trigonometric ratios to solve problems involving right triangles in real-world and mathematical problems.

Objective:

We will use trigonometric ratios to calculate angles and solve problems involving right triangles.
I will utilize trigonometric ratios to calculate the angles at which wind strikes the turbines and analyze the resulting wake effects.

Materials Needed:

- Graph paper
- Rulers
- Protractors
- Scientific calculators
- Computers/tablets with GeoGebra or similar software
- Worksheets with coordinate grids and turbine layout scenarios
- Wind turbine data (coordinates, heights, distances)
- Markers and colored pencils
- Trigonometric ratio reference sheets

Lesson Components

Introduction:

1. Engage: Begin with a discussion on the importance of understanding wind angles and their effects on wind turbines.
2. Discuss: How trigonometric ratios are used in real-world engineering to solve problems involving right triangles.
3. Introduce: Today's focus on using trigonometric ratios to calculate the angles at which wind strikes turbines and the resulting wake effects.
4. Set-Up
5. Review: Key concepts of trigonometric ratios (sine, cosine, tangent).
6. Distribute: Materials and worksheets.

Measurement

1. Clear Instructions:
    a. Sine Ratio: sin(θ) = opposite / hypotenuse
    b. Cosine Ratio: cos(θ) = adjacent / hypotenuse
    c. Tangent Ratio: tan(θ) = opposite / adjacent
2. Guided Practice:
    a. Identify the right triangles in the given wind turbine scenarios.
    b. Use trigonometric ratios to calculate the angles at which wind strikes the turbines.
    c. Analyze the resulting wake effects.
3. Independent Practice: Students work on provided scenarios to apply the trigonometric ratios.

Data Analysis:

1. Graphing: Students plot their calculated angles and analyze the wind turbine wake effects.
2. Interpretation: Analyze the plotted angles to determine the efficiency of the turbine layouts based on wake effects.
3. Comparison: Compare different scenarios and discuss the advantages and disadvantages of each angle calculation.
4. Conclusions
5. Summarize: Key findings from the analysis.
6. Discussion: Discuss how the trigonometric calculations impact the design and efficiency of wind turbine layouts.
7. Recommendations
8. Improvement Suggestions: Students suggest changes to the turbine layouts to enhance efficiency based on their trigonometric analysis.
9. Justification: Explain why these changes would be beneficial.

Discussion:

1. Reflect: On the importance of precision in these calculations in real-world applications.
2. Career Connection: Discuss how these skills are crucial for careers in renewable energy and engineering.

Extensions (Homework or Additional Class Activity)

1. Standard: Create new scenarios and calculate angles using trigonometric ratios.
2. Honors: Include additional variables like turbine height and varying wind speeds in the calculations.
3. MYP: Research and present a report on how trigonometric ratios are used in the design and optimization of renewable energy projects.

Levels of Rigor

Standard Level

1. Objective: Basic understanding of trigonometric ratios and their application.
2. Activities: Calculate angles using provided scenarios.
3. Assessment: Worksheet completion and correct application of trigonometric ratios.

Honors Level

1. Objective: Deeper understanding with real-world applications.
2. Activities: Incorporate turbine height and wind speed variations.
3. Assessment: Analyze more complex scenarios and present findings.

MYP Level

1. Objective: Advanced application and research skills.
2. Activities: Conduct independent research on turbine layout optimization using trigonometric ratios.
3. Assessment: Present a detailed report with data analysis and recommendations.

Safety Guidelines

1. Classroom Conduct: Maintain a respectful and focused environment during calculations and discussions.
2. Tool Usage: Properly use all mathematical tools (rulers, calculators, etc.) to avoid accidents or damage.
3. Software Use: Follow instructions for using GeoGebra or other software to prevent data loss and ensure accurate calculations.

Emphasis on Rigor

1. Accuracy: Ensure all calculations are precise; double-check work for errors.
2. Critical Thinking: Encourage students to think about the implications of their findings and how they can be applied in real-world scenarios.
3. Application: Continuously relate the mathematical concepts to practical applications in renewable energy and engineering to reinforce understanding.

Encouragement

Apply Understanding: Students are encouraged to ask questions, discuss their findings, and explore the implications of their analyses throughout the lesson.

Teacher Role:

1. Introducing the topic and explaining the importance of trigonometric calculations in turbine layouts.
2. Reviewing key concepts and providing clear instructions.
3. Guiding students through the initial calculations and ensuring understanding.
4. Facilitating data analysis and discussions.
5. Encouraging critical thinking and application of concepts.

Student Role:

1. Engaging in discussions about renewable energy and turbine layouts.
2. Reviewing key concepts and following instructions for calculations.
3. Working on independent practice scenarios to apply trigonometric ratios.
4. Plotting data and analyzing results.
5. Discussing findings and suggesting improvements.
6. Completing extensions and engaging in higher levels of rigor.

Visuals and Images

Example Wind Turbine Layout:
Graphical Representation of Trigonometric Ratios

G11A - G15A. Module: Geometry in Wind Turbine Analysis

TEKS Standards

G.11(A): Apply the area and perimeter formulas to solve problems.
G.12(A): Analyze the geometric properties of circles.
G.13(A): Use similarity and scaling to solve problems.
G.14(A): Use coordinate geometry to solve problems.
G.15(A): Apply geometric transformations to solve problems.

Objective

We will analyze geometric properties to optimize wind farm layouts.
I will calculate area, perimeter, and other geometric properties to propose optimal wind farm layouts.

Materials Needed

- Graph paper
- Rulers
- Protractors

- Scientific calculators
- Computers/tablets with GeoGebra or similar software
- Worksheets with coordinate grids and wind turbine layout scenarios
- Wind turbine data (coordinates, dimensions, distances)
- Markers and colored pencils

Lesson Components

Introduction

1. Engage: Begin with a discussion on the importance of optimizing wind farm layouts.
2. Discuss: How geometric principles are used in real-world engineering to optimize land use and maximize power generation.
3. Introduce: Today's focus on applying various geometric concepts to wind turbine layouts.

Set-Up

1. Review: Key geometric concepts: area, perimeter, circles, similarity, scaling, coordinate geometry, and transformations.
2. Distribute: Materials and worksheets.

Area and Perimeter

1. Clear Instructions:
   - Area Formula: $A = l * w$ for rectangles; $A = \pi r^2$ for circles.
   - Perimeter Formula: $P = 2(l + w)$ for rectangles; $C = 2\pi r$ for circles.
2. Guided Practice:
   - Calculate the area and perimeter of a given wind farm layout.
   - Analyze how changing the layout affects land use and power generation.
3. Independent Practice: Students work on provided scenarios to calculate area and perimeter.

Circles and Circular Motion

1. Clear Instructions:
   - Circle Properties: Circumference ($C = 2\pi r$), Radius (r), and Angular Velocity (ω).
2. Guided Practice:
   - Calculate the circumference and angular velocity of wind turbine blades.
   - Analyze the impact of blade length on power generation.
3. Independent Practice: Students work on provided scenarios involving circle properties.

Similarity and Scaling

1. Clear Instructions:

- Similarity Ratios: Understand the proportional relationships between similar figures.
- Scaling: Apply scaling factors to change the size of wind turbine models.

2. Guided Practice:
   - Scale up or down a model wind turbine and calculate new dimensions.
   - Analyze how scaling affects efficiency and land use.
3. Independent Practice: Students work on provided scaling scenarios.

Coordinate Geometry

1. Clear Instructions:
   - Plotting Points: Use (x, y) coordinates to map wind turbines.
   - Distance Formula: $d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$
2. Guided Practice:
   - Plot the optimal positions of wind turbines on a coordinate plane.
   - Calculate distances between turbines to ensure efficiency and minimal interference.
3. Independent Practice: Students work on provided coordinate geometry scenarios.

Geometric Transformations

1. Clear Instructions:
   - Transformations: Translations, rotations, and reflections.
2. Guided Practice:
   - Apply transformations to simulate and optimize wind turbine layouts.
   - Analyze the impact of transformations on turbine efficiency.
3. Independent Practice: Students work on provided transformation scenarios.

Data Analysis

1. Graphing: Students plot their calculated data and analyze the geometric properties.
2. Interpretation: Analyze the plotted data to determine the efficiency of the turbine layouts.
3. Comparison: Compare different scenarios and discuss the advantages and disadvantages of each.

Conclusions

1. Summarize: Key findings from the analysis.
2. Discussion: Discuss how the geometric calculations impact the design and efficiency of wind turbine layouts.

Recommendations

1. Improvement Suggestions: Students suggest changes to the turbine layouts to enhance efficiency based on their geometric analysis.
2. Justification: Explain why these changes would be beneficial.

Discussion

1. Reflect: On the importance of precision in these calculations in real-world applications.
2. Career Connection: Discuss how these skills are crucial for careers in renewable energy and engineering.

Extensions (Homework or Additional Class Activity)

1. **Standard:** Create new scenarios and calculate geometric properties.
2. **Honors:** Include additional variables like turbine height and varying wind speeds in the calculations.
3. **MYP:** Research and present a report on how geometric principles are used in the design and optimization of renewable energy projects.

Levels of Rigor

Standard Level

1. Objective: Basic understanding of geometric properties and their application.
2. Activities: Calculate geometric properties using provided scenarios.
3. Assessment: Worksheet completion and correct application of geometric concepts.

Honors Level

1. Objective: Deeper understanding with real-world applications.
2. Activities: Incorporate additional variables and more complex scenarios.
3. Assessment: Analyze more complex scenarios and present findings.

MYP Level

1. Objective: Advanced application and research skills.
2. Activities: Conduct independent research on wind turbine layout optimization using geometric principles.
3. Assessment: Present a detailed report with data analysis and recommendations.

Safety Guidelines

1. Classroom Conduct: Maintain a respectful and focused environment during calculations and discussions.
2. Tool Usage: Properly use all mathematical tools (rulers, calculators, etc.) to avoid accidents or damage.
3. Software Use: Follow instructions for using GeoGebra or other software to prevent data loss and ensure accurate calculations.

Emphasis on Rigor

1. Accuracy: Ensure all calculations are precise; double-check work for errors.
2. Critical Thinking: Encourage students to think about the implications of their findings and how they can be applied in real-world scenarios.
3. Application: Continuously relate the mathematical concepts to practical applications in renewable energy and engineering to reinforce understanding.

Encouragement

Apply Understanding: Students are encouraged to ask questions, discuss their findings, and explore the implications of their analyses throughout the lesson.

Teacher Role:

1. Introducing the topic and explaining the importance of geometric calculations in turbine layouts.
2. Reviewing key concepts and providing clear instructions.
3. Guiding students through the initial calculations and ensuring understanding.
4. Facilitating data analysis and discussions.
5. Encouraging critical thinking and application of concepts.

Student Role:

1. Engaging in discussions about renewable energy and turbine layouts.
2. Reviewing key concepts and following instructions for calculations.
3. Working on independent practice scenarios to apply geometric properties.
4. Plotting data and analyzing results.
5. Discussing findings and suggesting improvements.
6. Completing extensions and engaging in higher levels of rigor.

Visuals and Images

Example Wind Turbine Layout:
Graphical Representation of Geometric Properties:

Statistic Modules

Modules will address the following areas in statistics:
Descriptive Statistics: Mean, median, mode, range, variance, standard deviation
Data Visualization: Histograms, box plots, scatter plots, line graphs
Inferential Statistics: Hypothesis testing, confidence intervals, p-values

Correlation and Regression: Linear regression, correlation coefficients
Probability: Basic probability, conditional probability, probability distributions
Student Activities:

Analyze wind speed and power output data to determine the average efficiency of different turbine configurations.
Use statistical methods to compare the performance of turbines with and without wake steering.
Create visualizations to represent the distribution of wind speeds and power outputs.
Student Assessment:

Lab Reports including graphs and charts of findings
Project-Based (Create a Project-Based Report)

A2B. Module: Analyzing Quadratic Functions in Wind Turbine Data

TEKS Standards

A.2(B): Identify and interpret parts of quadratic functions using symbolic, tabular, and graphical representations.

Objective

We will identify and interpret quadratic relationships in wind speed and turbine output data.
I will analyze data on wind speeds and turbine outputs to identify quadratic relationships.

Materials Needed

- Graph paper
- Rulers
- Scientific calculators
- Computers/tablets with GeoGebra or similar software
- Worksheets with wind speed and turbine output data
- Markers and colored pencils
- Quadratic function reference sheets

Lesson Components

Introduction

1. Engage: Begin with a discussion on how quadratic functions can model real-world phenomena, such as wind speeds and turbine outputs.
2. Discuss: How identifying and interpreting quadratic relationships can help optimize wind turbine performance.

3. Introduce: Today's focus on using symbolic, tabular, and graphical representations to analyze quadratic relationships in wind turbine data.

Set-Up

1. Review: Key concepts of quadratic functions: standard form, vertex form, and factoring.
2. Distribute: Materials and worksheets.

Measurement

1. Clear Instructions:
   - Standard Form: $y = ax^2 + bx + c$
   - Vertex Form: $y = a(x-h)^2 + k$
   - Factoring: Finding the roots of the quadratic function.
2. Guided Practice:
   - Symbolic: Identify the quadratic function that models the data.
   - Tabular: Create a table of values for wind speed and turbine output.
   - Graphical: Plot the data and fit a quadratic curve.
3. Independent Practice: Students work on provided data to identify and interpret quadratic relationships.

Data Analysis

1. Graphing: Students plot their data and fit a quadratic function.
2. Interpretation: Analyze the quadratic function to determine key features such as vertex, axis of symmetry, and roots.
3. Comparison: Compare different datasets and discuss the implications of their quadratic models.

Conclusions

1. Summarize: Key findings from the analysis.
2. Discussion: Discuss how quadratic relationships impact the performance and optimization of wind turbines.

Recommendations

1. Improvement Suggestions: Students suggest changes to turbine settings or layouts based on their quadratic analysis.
2. Justification: Explain why these changes would be beneficial.

Discussion

1. Reflect: On the importance of precision in these calculations in real-world applications.

2. Career Connection: Discuss how these skills are crucial for careers in renewable energy and engineering.

Extensions (Homework or Additional Class Activity)

1. Standard: Create new scenarios and analyze quadratic functions.
2. Honors: Include additional variables like turbine height and varying wind speeds in the calculations.
3. MYP: Research and present a report on how quadratic functions are used in the design and optimization of renewable energy projects.

Levels of Rigor

Standard Level

1. Objective: Basic understanding of quadratic functions and their application.
2. Activities: Identify and interpret quadratic functions using provided data.
3. Assessment: Worksheet completion and correct application of quadratic concepts.

Honors Level

1. Objective: Deeper understanding with real-world applications.
2. Activities: Incorporate additional variables and more complex datasets.
3. Assessment: Analyze more complex scenarios and present findings.

MYP: Level

1. Objective: Advanced application and research skills.
2. Activities: Conduct independent research on wind turbine performance optimization using quadratic functions.
3. Assessment: Present a detailed report with data analysis and recommendations.

Safety Guidelines

1. Classroom Conduct: Maintain a respectful and focused environment during calculations and discussions.
2. Tool Usage: Properly use all mathematical tools (rulers, calculators, etc.) to avoid accidents or damage.
3. Software Use: Follow instructions for using GeoGebra or other software to prevent data loss and ensure accurate calculations.

Emphasis on Rigor

1. Accuracy: Ensure all calculations are precise; double-check work for errors.

2. Critical Thinking: Encourage students to think about the implications of their findings and how they can be applied in real-world scenarios.
3. Application: Continuously relate the mathematical concepts to practical applications in renewable energy and engineering to reinforce understanding.

Encouragement

Apply Understanding: Students are encouraged to ask questions, discuss their findings, and explore the implications of their analyses throughout the lesson.

Teacher Role:

1. Introducing the topic and explaining the importance of quadratic calculations in turbine performance.
2. Reviewing key concepts and providing clear instructions.
3. Guiding students through the initial calculations and ensuring understanding.
4. Facilitating data analysis and discussions.
5. Encouraging critical thinking and application of concepts.

Student Role:

1. Engaging in discussions about renewable energy and turbine performance.
2. Reviewing key concepts and following instructions for calculations.
3. Working on independent practice scenarios to apply quadratic functions.
4. Plotting data and analyzing results.
5. Discussing findings and suggesting improvements.
6. Completing extensions and engaging in higher levels of rigor.

Visuals and Images

Symbolic, Tabular, and Graphical Representations of Quadratic Functions

A4A. Module: Analyzing Wind Farm Data Using Scatterplots and Regression Lines

TEKS Standards

A.4(A): Analyze data using scatterplots, regression lines, or exponential functions to model data.

Objective

We will create scatterplots of wind farm data, fit regression lines to predict energy output, and analyze the effects of different layouts on efficiency.
I will analyze wind farm data using scatterplots and regression lines to predict energy output and suggest layout improvements.

Materials Needed

- Graph paper
- Rulers
- Scientific calculators
- Computers/tablets with GeoGebra or similar software
- Worksheets with wind farm data
- Markers and colored pencils

Lesson Components

Introduction

1. Engage: Begin with a discussion on how scatterplots and regression lines can model real-world data, such as wind farm efficiency.
2. Discuss: The importance of using data analysis to predict energy output and optimize wind farm layouts.
3. Introduce: Today's focus on using scatterplots and regression lines to analyze wind farm data.

Set-Up

1. Review: Key concepts of scatterplots, regression lines, and exponential functions.
2. Distribute: Materials and worksheets.

Measurement

1. Clear Instructions:
   - Scatterplots: Plotting data points on a graph.

- Regression Lines: Fitting a line that best represents the data trend.
- Exponential Functions: Using exponential models to describe data trends.

2. Guided Practice:
   - Create scatterplots of wind farm data.
   - Fit regression lines to the data to predict energy output.
   - Analyze the effects of different layouts on efficiency.
3. Independent Practice: Students work on provided data to create scatterplots and fit regression lines.

Data Analysis

1. Graphing: Students plot their data and fit regression lines or exponential models.
2. Interpretation: Analyze the scatterplots and regression lines to determine key trends and predictions.
3. Comparison: Compare different datasets and discuss the implications of their models.

Conclusions

1. Summarize: Key findings from the analysis.
2. Discussion: Discuss how data analysis impacts the performance and optimization of wind farms.

Recommendations

1. Improvement Suggestions: Students suggest changes to turbine settings or layouts based on their data analysis.
2. Justification: Explain why these changes would be beneficial.

Discussion

1. Reflect: On the importance of precision in these calculations in real-world applications.
2. Career Connection: Discuss how these skills are crucial for careers in renewable energy and engineering.

Extensions (Homework or Additional Class Activity)

1. Standard: Create new scenarios and analyze data using scatterplots and regression lines.
2. Honors: Include additional variables like turbine height and varying wind speeds in the calculations.
3. MYP: Research and present a report on how data analysis is used in the design and optimization of renewable energy projects.

Levels of Rigor

Standard Level

1. Objective: Basic understanding of scatterplots and regression lines.
2. Activities: Create scatterplots and fit regression lines using provided data.
3. Assessment: Worksheet completion and correct application of data analysis concepts.

Honors Level

1. Objective: Deeper understanding with real-world applications.
2. Activities: Incorporate additional variables and more complex datasets.
3. Assessment: Analyze more complex scenarios and present findings.

MYP Level

1. Objective: Advanced application and research skills.
2. Activities: Conduct independent research on wind farm performance optimization using data analysis.
3. Assessment: Present a detailed report with data analysis and recommendations.

Safety Guidelines

1. Classroom Conduct: Maintain a respectful and focused environment during calculations and discussions.
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3. Application: Continuously relate the mathematical concepts to practical applications in renewable energy and engineering to reinforce understanding.

Encouragement

Apply Understanding: Students are encouraged to ask questions, discuss their findings, and explore the implications of their analyses throughout the lesson.

Teacher Role:

1. Introducing the topic and explaining the importance of data analysis in turbine performance.

2. Reviewing key concepts and providing clear instructions.
3. Guiding students through the initial calculations and ensuring understanding.
4. Facilitating data analysis and discussions.
5. Encouraging critical thinking and application of concepts.

Student Role:

1. Engaging in discussions about renewable energy and turbine performance.
2. Reviewing key concepts and following instructions for calculations.
3. Working on independent practice scenarios to apply data analysis.
4. Plotting data and analyzing results.
5. Discussing findings and suggesting improvements.
6. Completing extensions and engaging in higher levels of rigor.

Visuals and Images

Scatterplots and Regression Lines

Future Studies

Future studies will focus on:

- Determining the effects of wake steering on columns C and D.
- Graphing the effects of wind steering on plant growth.
- Investigating the long-term impacts of wake steering on turbine longevity and maintenance.
- Exploring the economic implications of large-scale implementation of wake steering in wind farms.

Acknowledgments

This material is based upon work supported by the National Science Foundation under Award No. 2206864. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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