Turn the Lights On!

8th Grade

Engr TEAMS

EngrTEAMS: Engineering to Transform the Education of Analysis, Measurement, and Science in a Team-Based Targeted Mathematics-Science Partnership

CISTAR

NSF Engineering Research Center

Center for Innovative and Strategic Transformation of Alkane Resources

Northwestern University

NSF

PURDUE UNIVERSITY

TEXAS The University of Texas at Austin

UNIVERSITY OF NOTRE DAME

THE UNIVERSITY OF NEW MEXICO

This material is based upon work supported by the National Science Foundation under grant NSF DRL-1238140 and EEC-1647722. 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.

Acknowledgments

Authors

Author(s): Ruben Lopez, Barbara Fagundes, Diallo Wallace, Nrupaja Bhide
Mentor(s): Tamara Moore

EngrTEAMS Leadership

Principal Investigator: Tamara Moore

CISTAR Engineering Workforce Development Leadership

Director: Allison Godwin
Co-director: Michael Harris
Assistant director: Maeve Drummond Oakes
Post Doctoral Researcher: Joana Marques Melo

Educational Content Creation

Manager: Tanya Faltens

Teacher Partners

Ashley Tatum, Westwood High School, TX
Marie Mikels, Tecumseh Middle School, IN
Joseph Vance, Goshen Middle School, IN
Cecilia Osornio, Delco Elementary School, TX

About EngrTEAMS

Purpose

The project is designed to help 200+ teachers develop engineering design-based curricular units for each of the major science topic areas within the Next Generation Science Standards, as well as data analysis and measurement standards for grades 4-8. With a focus on vertical alignment and transition from upper elementary to middle-level, this project will impact at least 15,000 students over the life of the grant.
To learn more about the project and find additional curricular units go to www.engrteams.org.

About CISTAR

Purpose

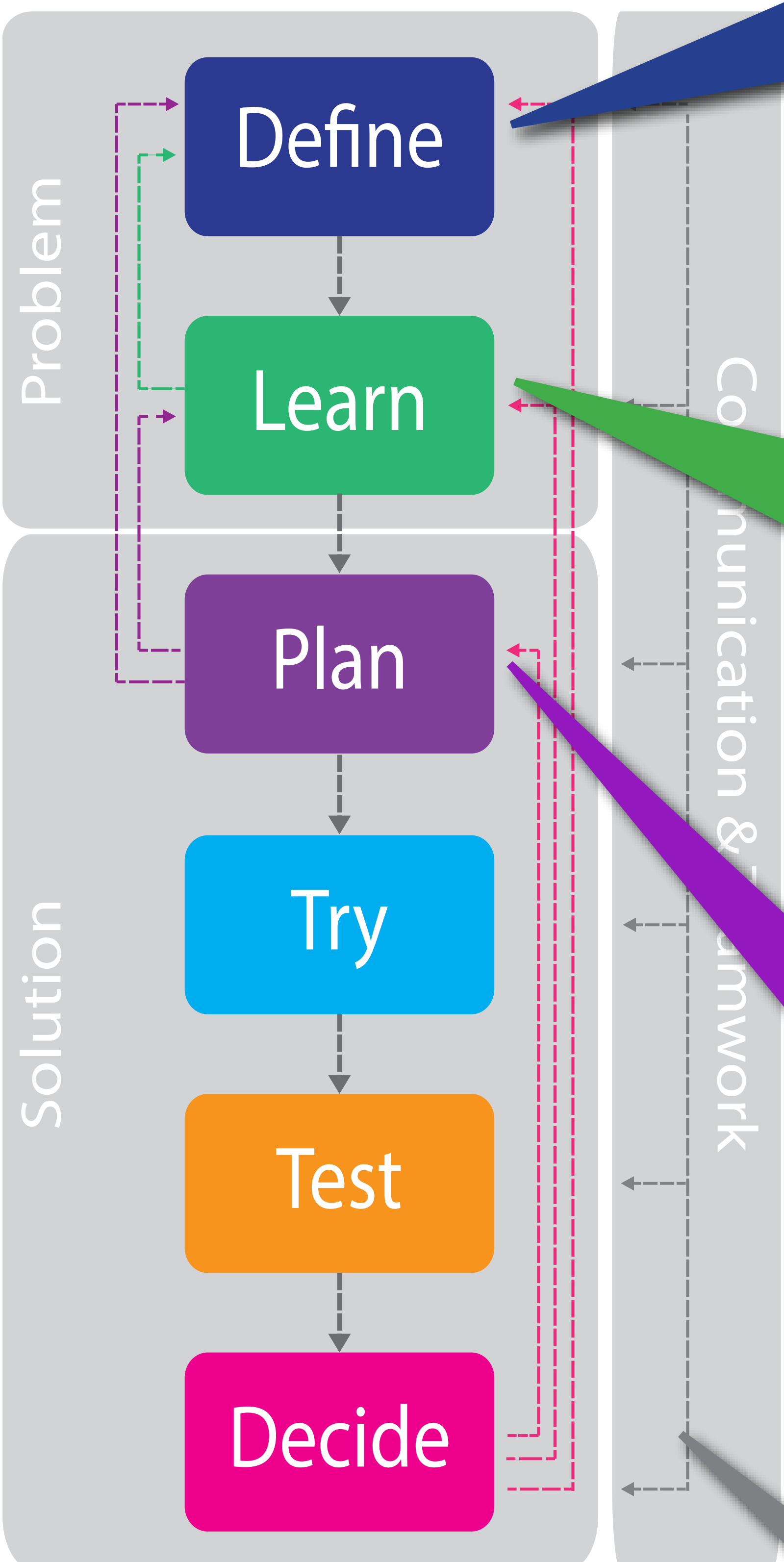
CISTAR is the name of a newly funded National Science Foundation (NSF) Engineering Research Center (ERC). The acronym stands for Center for Innovative and Strategic Transformation of Alkane Resources. The ERC brings together researchers from five premier U.S. research universities and industrial collaborators from more than a dozen companies to focus on developing breakthrough solutions to more effective conversion of America's shale derived light hydrocarbon resources. The center will focus on developing novel modular technologies that more efficiently convert the light hydrocarbons to advanced fuels and petrochemicals. These technologies will provide a bridge to a sustainable future where renewables replace shale resources as the hydrocarbon resources. CISTAR Pre-College Education objectives are to stimulate interest in engineering careers at the middle and high school levels and to strengthen pathways to promote the participation of female and URM students in engineering at the college level. You can learn more about this initiative by going to their website.

Contents

The Engineering Design Process

Engineering Design Process

A way to improve



DEFINE THE PROBLEM

- Who is the client?
- What does the client need?
- Why does the client need it?
- Who is the end user?
- Why might the end user want it?
- What are the criteria (requirements) and constraints (limits) of the solution?

Problem Scoping:
WHO needs WHAT because WHY

LEARN ABOUT THE PROBLEM

- What kind of background knowledge is needed?
  - What science/math knowledge will be needed?
  - What materials will be needed?
- What has already been done to solve the problem?
- What products fill a similar need?
- How should we measure success and improvement?

PLAN A SOLUTION

- Continue to specify the criteria/ constraints
- Generate ideas of possible solutions
- Develop multiple solution paths
- Consider constraints, criteria, and trade-offs (criteria that compete with one another)
- Choose a solution to try
- Develop plans (blueprints, schematics, cost sheets, storyboards, notebook pages, etc.)

COMMUNICATION

- Communicate the solution clearly and make sure it is easily understandable
- Use evidence to support why the client should use your solution

The Engineering Design Process

TRY A SOLUTION

- Put the plan into action
- Consider risks and how to optimize work
- Use criteria/constraints and consider trade-offs from the problem/plan to build a prototype (a testable representation of a solution), model, or product

TEST A SOLUTION

- Consider testable questions or hypotheses
- Develop experiments or rubrics to determine if the solution is meeting the stated criteria, constraints, and needs
- Collect and analyze data

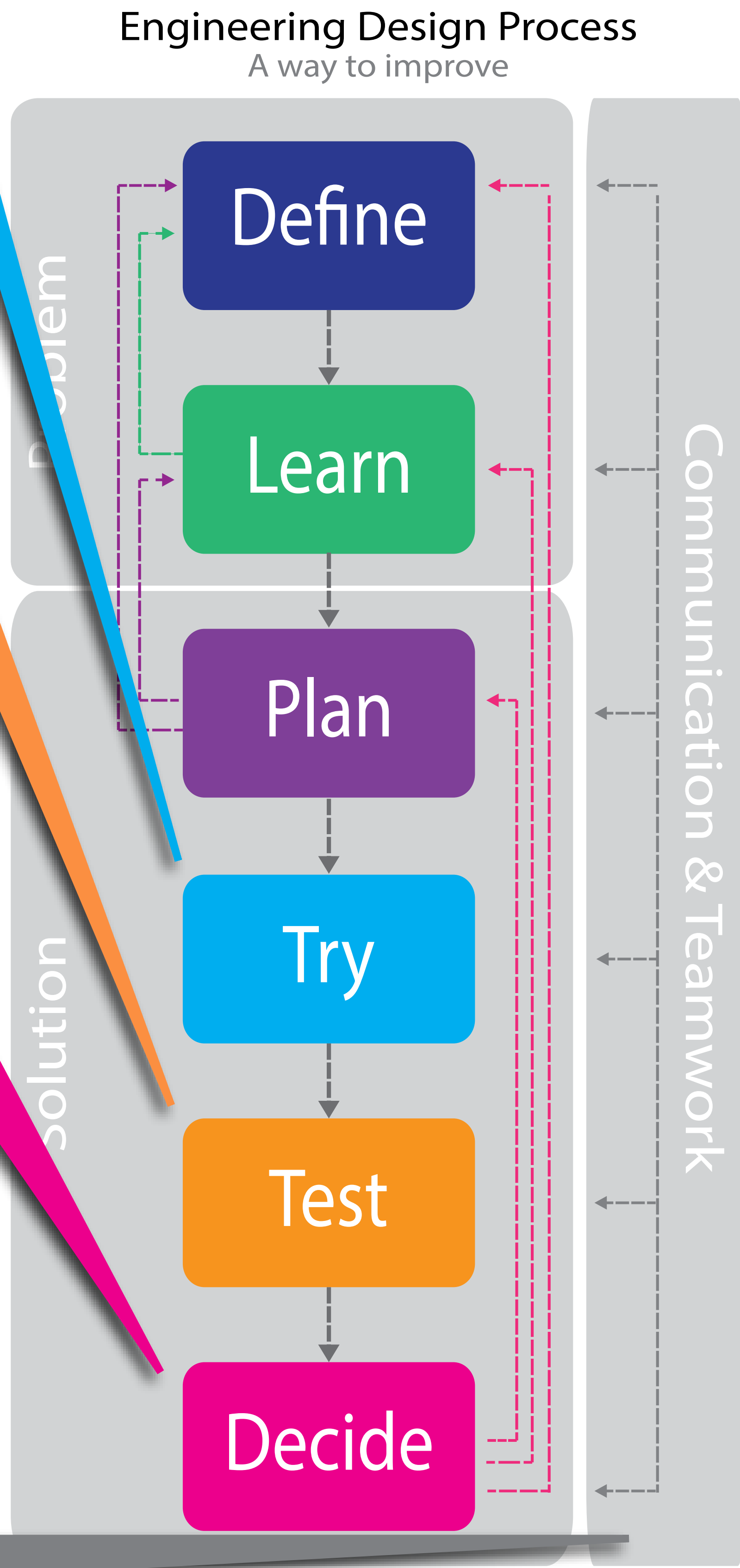
DECIDE IF THE SOLUTION IS GOOD ENOUGH

- Are users able to use the design to help with the problem?
- Does the design meet the criteria and constraints?
- How could the design be improved based on test results and feedback from the client/user?

Iterative nature of design: Always consider which step should be next!

TEAMWORK

- Discuss in teams how the solution meets the criteria and needs of the client
- Consider different viewpoints from each teammate



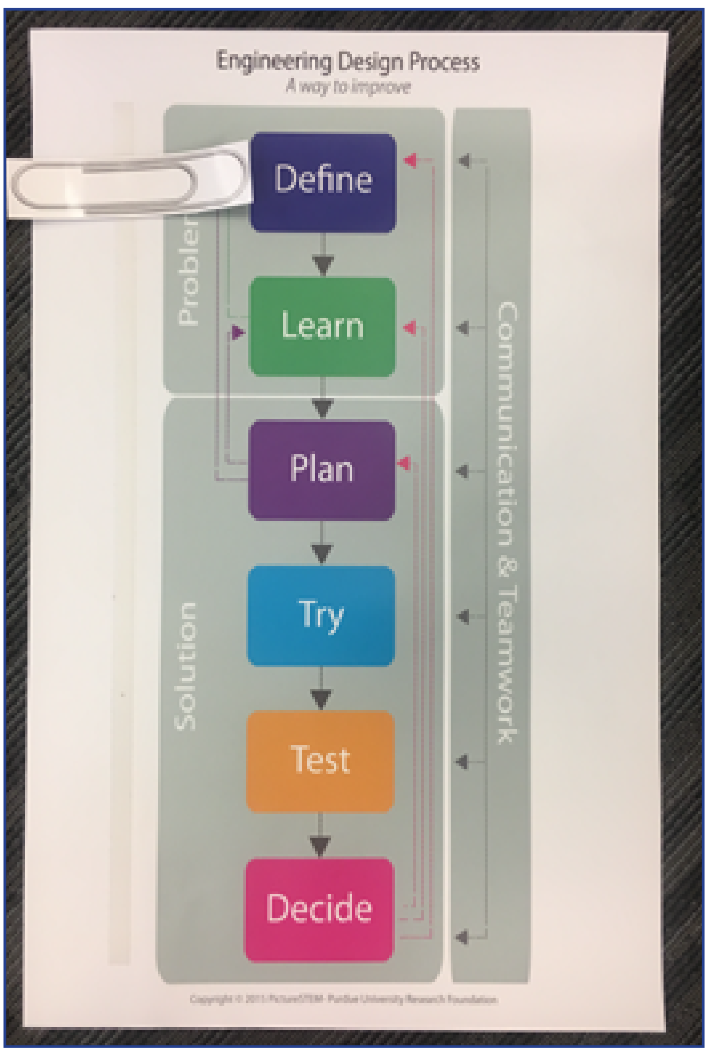
How to make EDP Sliders

HOW TO CREATE THE POSTER

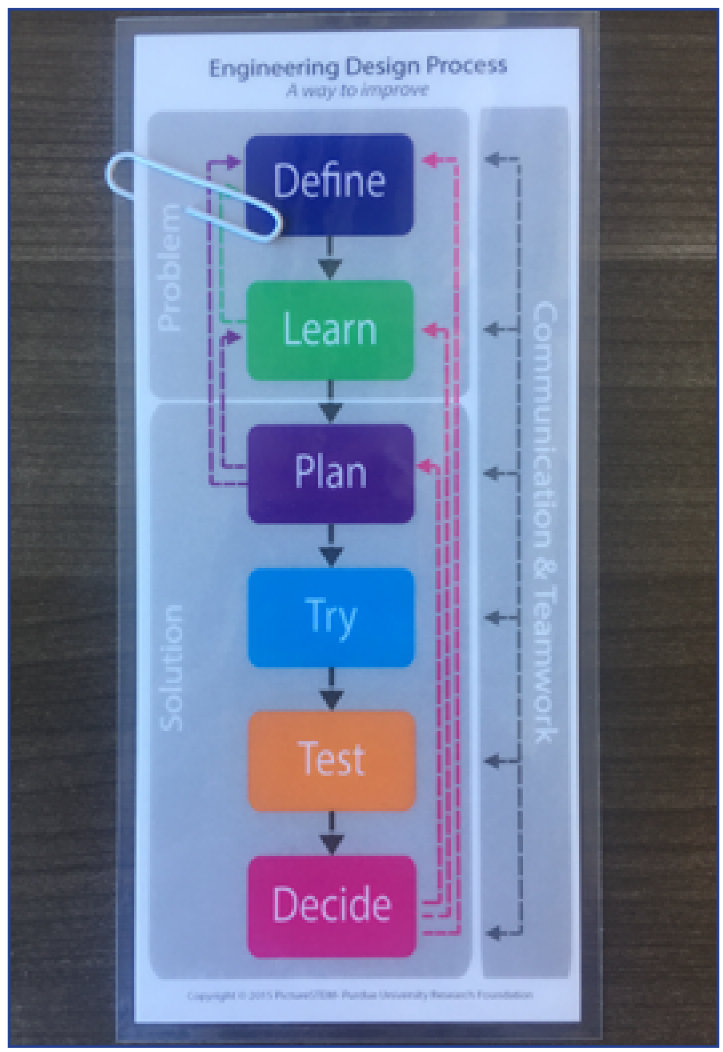
1. Download the high-quality PictureSTEM Slider Poster and the paper clip images from PictureSTEM.org.
2. Print the poster and the paper clip on poster-sized paper and cut to size. High-gloss or semi-gloss paper is the best choice.
3. Use self-sticking Velcro on the back of the paper clip and down the side of the poster so that the paper clip can be placed to point at all 6 sections of the slider.

HOW TO CREATE INDIVIDUAL SLIDERS

1. Print the sliders on the opposite page - enough for one slider per student in your class.
2. Cut the sliders apart.
3. Laminate the sliders individually.
4. Use a jumbo paper clip as the pointer for each slider.

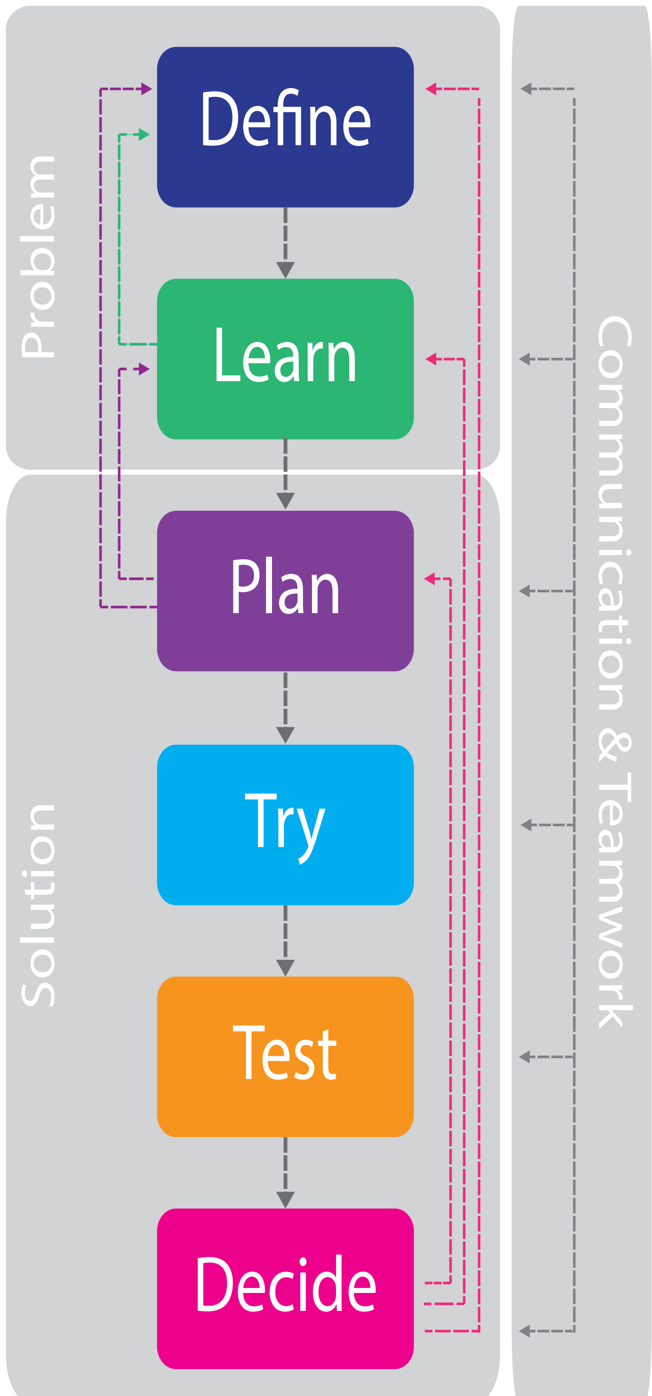


Poster

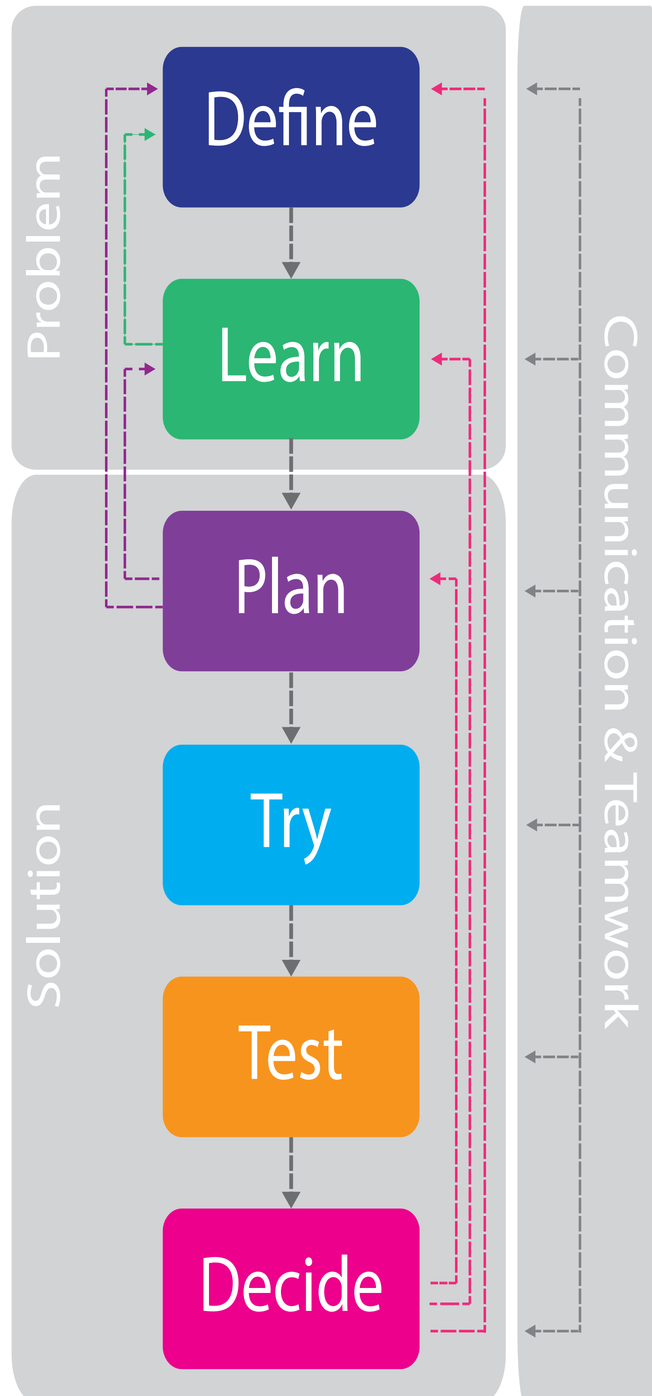


Individual slider

Engineering Design Process
A way to improve

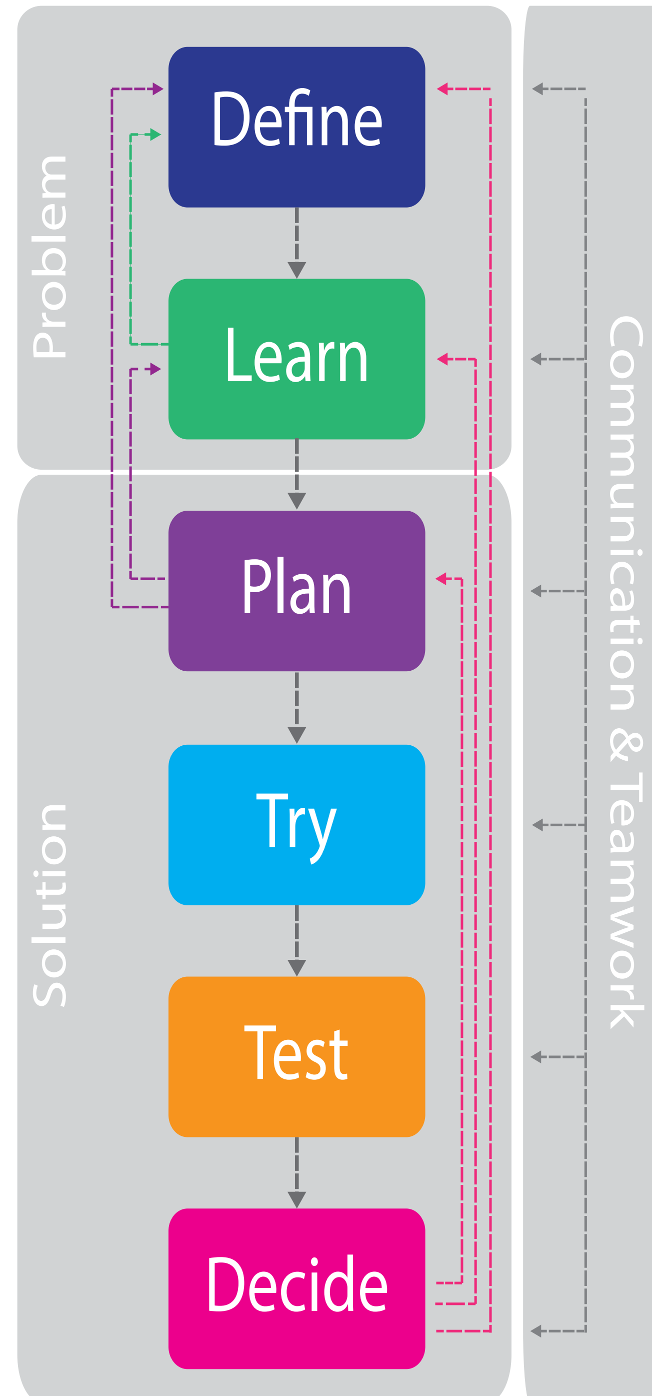


Engineering Design Process
A way to improve



Copyright © 2015 PictureSTEM- Purdue University Research Foundation

Engineering Design Process
A way to improve



Copyright © 2015 PictureSTEM- Purdue University Research Foundation

Unit Overview

Grade Levels

8th Grade

Approximate Time Needed to Complete Unit

This curriculum can be completed in eighteen 50-minute class periods.
Total time = 18x50 = 900 minutes

Unit Summary

In this unit, students are taught the mathematical and scientific concepts related to electrical energy and renewable resources by incorporating an engineering design challenge. At the outset of the unit, students are introduced to power generation and the client, the members of Indiana Office of Energy Development, who need to determine a new power generation system that will effectively reduce contamination of chemical releases in the environment. Students use what they know about electrical energy and renewable resources to develop a strategy to test for electrical power generating systems. Finally, students write a final letter, including their designs and design justifications, to pitch their experimental design to the client.

Science Connections	Technology & Engineering Connections	Mathematics Connections
• Chemical and physical changes • Kinetic and potential energy • Variance energy • Electrical energy • Ecosystem and biodiversity • Renewable and non renewable resources	• Complete full engineering design process, including problem scoping (define and learn about the problem), solution generation (plan, try/build, test, decide about a solution), redesign, and communication of final design to client. • Use of measuring instruments such as anemometer,thermometer etc.	• Proportional reasoning • Representing graphics and analyzing diagrams • Collecting and representing data

Unit Standards

Common Core State Standards - Mathematics

- MP.4 Model with mathematics.
- 6.SP.B.4 Display numerical data in plots on a number line, including dot plots, histograms, and box plots.
- 6.SP.B.4 Display numerical data in plots on a number line, including dot plots, histograms, and box plots.
- 6.RP.A.1 Understand the concept of a ratio and use ratio language to describe a ratio relationship between two quantities.
- 6.RP.A.3 Use ratio and rate reasoning to solve real-world and mathematical problems.

Unit Overview

Next Generation Science Standards

- MS-ETS1-1. Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.
- MS-ETS1-2. Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.
- MS-ETS1-3. Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.
- MS-ETS1-4. Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.
- MS-PS1-2. Analyze and interpret data on the properties of substances before and after the substances interact to determine if a chemical reaction has occurred.
- MS-PS3-1. Construct and interpret graphical displays of data to describe the relationships of kinetic energy to the mass of an object and to the speed of an object
- MS-PS4-1. Use mathematical representations to describe a simple model for waves that includes how the amplitude of a wave is related to the energy in a wave.
- MS-PS4-2 Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials.
- MS-LS2-5. Evaluate competing design solutions for maintaining biodiversity and ecosystem services.

Unit Assessment Summary

- Throughout this unit, students individually maintain an engineering notebook to document their engineering design processes. In this, students make observations, collect data, and plan for their design. Part of the engineering notebook includes answering specific questions related to that day's activities. You may choose to post the questions on your overhead/PowerPoint slides or give them printed versions (included as duplication masters in each applicable lesson) to tape into their notebooks. Students use their notebooks as a reference to maintain the information they are learning through design. Additionally, students reflect on their work throughout the design process. It is important for modeling what real-life engineers do. Collect the engineering notebooks at the end of each class. You will use the notebooks to assess student learning through their design process. Provide feedback to students on their notebook responses - rubrics are provided. You are encouraged to assign points for responses in the engineering notebooks. Provide feedback often - especially lessons for which rubrics are provided.
- The notebook pages are often set up as handouts in each lesson. If you prefer to use notebooks without having students paste copied pages in them, there is an appendix at the end of this unit that includes notebook prompts and how to have students title each entry.
- The final summative piece of this unit requires students to communicate with the client recommending design and justifying its success as a solution to the engineering problem.

Lesson Summaries

Lesson 1: Introduction to Engineering Design

Students will be introduced to the Engineering Design Process (EDP) by the teacher. They will then work in small teams to review their understanding of the EDP. They will watch videos and discuss the global problem of supplying energy. Students will read a client letter that introduces them to the context of their engineering design challenge, a desire for an electrical power generating system that supplies the electrical power grid of New Albany.

Lesson 2: Power Grid Energy Transformation

Students will establish an understanding of what electric current is and comprehend the different types of engineering systems that generate electric current. Students will develop an understanding of what is the system that allows distribution of electric current from the power plants to houses/homes. Students will implement a preliminary prototype of the electrical power generating system to better understand the problem. Students will also gain experience utilizing Geographic Information Systems (GIS) toolsets to propose candidate locations for the establishment of the Electric Power Plant.

Lesson 3: Fossil-Fuel Power Plants and Chemical Energy

Students will work on the science concepts related to the first available electrical generating plant for their designs: Fossil-fuel power plants. Students shall understand how fuels are generated from the remains of prehistoric creatures and plants (fossil fuels). The stored energy of the fuel is released through chemical interactions. Through several experiments, students will apply the concepts of physical and chemical change and relate them to the thermal energy store in the substances.

Lesson 4: Wind Turbines and Hydropower Plants

Students will work on the science concepts related to the second and third available electrical generating plant for their designs: wind turbines and small hydropower plants. They will learn how air and water movement can be used to produce electrical energy. As the air or water passes through the blades of the turbine, they cause the attached electrical generator to produce electrical current. Students will use the physics of wind energy to understand the relationship between kinetic energy and speed based on experimental data.

Lesson 5: Solar Panels and Radient Energy

Students will work on the science concepts related to the fourth available electrical generating plant for their designs: solar panels. They will learn about the radiant energy of light and how it can be used to generate electricity. They will learn about the speed of light and how this is used to determine the energy associated with each frequency of light. By doing experiments and analyzing data, they will review the properties of light in the context of solar photovoltaic panels.

Lesson 6: Environmental Impact of the Power Generation System

Students will gain an understanding and reflect about the environmental impacts from electrical power generating plants upon the ecosystems. Students will evaluate and modify their previous prototype based on minimizing their environmental impact to meet the client's requirement.

Lesson Summaries

Lesson 7: Cost Analysis and First Prototype

Students will finalize their first full electric power generating plant prototype that meets all criteria and constraints. They will continue working on their prototype from Lesson 6 to meet the criterion of cost. Students will establish construction and operating costs to build and sustain an electrical power generating plant. They will use proportions and rate reasoning to analyze their costs and will use an Excel platform to calculate the specific values.

Lesson 8: Redesigning the Electrical Power Generation System

Students take the lessons learned from their prototypes, cost analysis, and operating procedures of their electrical generator plants to improve them. The project is examined for potential increases in efficiency, return rates, and decreases in environmental impacts, and cost. Students will come to realize the project is never completely done, just simply initial design specifications are met.

Lesson 9: Decision and Communication with the Client

Students will utilize presentation skills to communicate rationale for their electric power generation system. They will use multiple forms of communication to present graphs, numerics, and policies that influenced their recommendations and design solutions.

Lesson Overview

Lesson	Time Needed	**Objectives** The student will be able to:
1: Introduction to Engineering Design	One 50-minute class period	• Describe the essential features of an engineering design process. • Define an engineering problem from the perspective of stakeholders. • Engage in problem scoping - define the problem and the needs of the client and end-users.
2: Power Grid Energy Trnasformation	Two 50-minute class periods	• Describe the concept of a power grid and how it works. • Define the criteria and constrains of the engineering design problem
3: Fossil-Fuel Power Plants and Chemical Energy	Three 50-minute class periods	• Describe how thermal power plants use chemical energy to get electrical energy. • Analyze experimental data to identify if a chemical or physical change has happened. • Recognize that chemical reactions absorb or release thermal energy.

Lesson Overview

Materials	Duplication Masters
Per classroom: • 1 Engineering Design Process Poster • Digital technologies for videos **Per student:** • 1 Engineering Notebook • Engineering Design Sliders • Device to take a picture (preferably per team, otherwise one per classroom)	• Worksheet 1.a. Introduction to the problem • Worksheet 1.b. Client Letter • Worksheet 1.c. Context Maps • EDP Sliders
Per classroom: • 1 poster size sticky note paper labeled “Questions for client” • Digital technologies for videos **Per team:** • Prototype: board map, contexts maps, generating plant models, and information sheets of each generating plant. • Device to take picture (preferably per team,otherwise one per classroom) **Per student:** • 2 different colors or types of writing utensils • 1 engineering notebook • 1 Engineering Design Process slider	• Handouts: 1. Fossil-Fuel Power Plant: Combined-Cycle Power Plant 2. Hydropower Plant: Small Run-of-the-River Hydropower Plant 3. Wind Turbines 4. Solar Panels: Photovoltaic Cells • Worksheet 2.a. - Problem Scoping
Per classroom: • 1 Engineering Design Process Poster • Digital technologies for videos • Hydrogen peroxide at 12%, 30ml (or clear developer 40 volume) • For Soda Can Engine: Soda Can, String, Nails (for making holes) **Per team:** • 1 candle • Food coloring • 1 Lighter • Water • 3 glasses • Hydrogen Peroxide at 3% • Plastic container • Liquid soap (5ml) • Chopped potato (20g) • Potassium iodide (less than 1 tsp) • Vinegar (30ml) • Baking soda (1tsp) • 1 Volumetric cylinder (50 mL) • 2 Plastic spoon • 1 Thermometer **Per student:** • Engineering Notebook • 1 Pair of gloves	• Worksheet 3.a. • Worksheet 3.b. • Information sheet - Description of fossil-fuel power plants

Lesson Overview

Lesson	Time Needed	Objectives The student will be able to:
4: Wind Turbines and Hydropower Plants	Two 50-minute class periods	• Identify the fundamental parts of a wind turbine and hydropower plant. • Explain how the power generating plant transforms kinetic energy into electrical energy. • Describe the relationship between kinetic energy and the speed of the wind.
5: Solar Panels and Radient Energy	Two 50-minute class periods	• Comprehend that solar radiation is energy made up of different wavelengths • Relate the light's wavelength with the amount of electrical current produced by the solar panel.
6: Environmental Impact of the Power Generation System	Two 50-minute class periods	• Evaluate their electric power generating systems according to the physical and biological impacts upon the biodiversity of nearby ecosystems. • Use a model to test their electrical power generating system and determine how well it meets criteria and constraints. • Reflect on how the engineering and their own decisions impact the environment.

Lesson Overview

Materials	Duplication Masters

Per classroom:
• 1 Engineering Design Process Poster
• Digital technologies for videos
Per team:
• 1 Multimeter
• 1 LED
• 1 - 100 Ohm Resistor
• 4 alligator cables
• Wind Turbine Kit:
» EUDAX Kit (https://www.amazon.com/ search for EUDAX DIY DC Power Micro Motor Wind Turbine Electricity Generator Blades Model)
  • 1 x Micro generator DC motor
  • 1 x Hobby motor propellers
  • 1 x Quick wire connector
» Vernier kit: This option is a little more expensive, but the results are more precise.
  • Blades: 8- inch diameter wind turbine blades (https://www.vernier.com/product/kidwind-red-blade-set/)
  • DC Motor: shaft, generator, wires https://www.vernier.com/product/high-torque-generator-with-wires/
Per student:
• 1 Engineering Notebook
• 1 Engineering Design Process slider
	• Worksheet 4.a
	• Worksheet 4.b.
	• Information sheets 2 and 3 (Wind and Hydropower)

Per classroom: • 1 Engineering Design Process Poster **Per team:** • 1 LED • 1 Solar Panel • 100 W white daylight LED lamp (Around 1600 lumens) • Multimeter • 100 Ohm Resistor • 4 alligator cables • Multiple colors of cellophane **Per student:** • 1 Engineering Design Process slider	• Worksheet 5.a. • Worksheet 5.b. • Information sheet 4 (Solar Panels)
Per classroom: • 1 Engineering Design Process Poster • Digital technologies for picture (ideal 1 per team) **Per team:** • Materials for the prototype (maps, models) **Per student:** • 1 Engineering Design Process slider	• Worksheet 6.a. • Worksheet 6.b. Environmental Impact Assessment Sheet

Lesson Overview

Lesson	Time Needed	Objectives The student will be able to:
7: Cost Analysis and First Prototype	Two 50-minute class periods	• Use ratio and rate reasoning to calculate the construction and operation cost of their electrical power generating system. • Develop a model to compute the total construction and operation cost of their electrical power generating system. • Evaluate how their system meets the criteria and constraints of the engineering problem.
8: Redesigning the Electrical Power Generation System	Two 50-minute class periods	• Use evidence from problem scoping, core science/mathematics concepts, and initial design test analysis to plan an improved design. • Plan, try, and test a new power generation system based on a set of criteria and constraints. • Evaluate competing electrical power generating designs to determine how much they fill the criteria and choose the one that better solves the problem.
9: Decision and Communication with the Client	Two 50-minute class periods	• Evaluate the alignment between their proposed solution and the problem. • Communicate their design solution using evidence-based reasoning. • Justify why their design solution is appropriate based on application of core science/mathematics concepts, information obtained in problem scoping, and interpretation of acquired or gathered evidence.

Materials	Duplication Masters
Per classroom: • 1 Engineering Design Process Poster • Optional - 1 printer (to print pictures of teams' prototypes) • Digital technologies to take pictures (of the prototype) **Per team:** • Materials for the prototype (maps, models,...) **Per student:** • 1 Engineering Design Process slider • Engineering Notebook	• Worksheet 7.a. Cost Analysis Design • Worksheet 7.b. Evidence-Based Reasoning
Per team: • Materials for the prototype (maps, models,...) **Per student:** • Engineering Notebook	• Handout: The Client's Email • Worksheet 7.a. • Worksheet 8.a.
Per class: • One Engineering Design Process Poster **Per student:** • Engineering Notebook • 1 Engineering Design Process Slider	• Worksheet 9.a. - Reflect About Engineering Design

LESSON 1

Introduction to Engineering Design

LESSON OBJECTIVES

Students will be able to:

- Describe the essential features of an engineering design process.
- Define an engineering problem from the perspective of stakeholders.
- Engage in problem scoping - define the problem and the needs of the client and end-users.

TIME REQUIRED

One 50-minute period

MATERIALS

Per classroom:

- 1 Engineering Design Process Poster
- Digital technologies for videos

Per student:

- 1 Engineering Notebook
- Engineering Design Sliders
- Device to take a picture (preferably per team, otherwise one per classroom)

Lesson Summary

Students will be introduced to the Engineering Design Process (EDP) by the teacher. They will then work in small teams to review their understanding of the EDP. They will watch videos and discuss the global problem of supplying energy. Students will read a client letter that introduces them to the context of their engineering design challenge, a desire for an electrical power generating system that supplies the electrical power grid of New Albany.

Background

Teacher Background

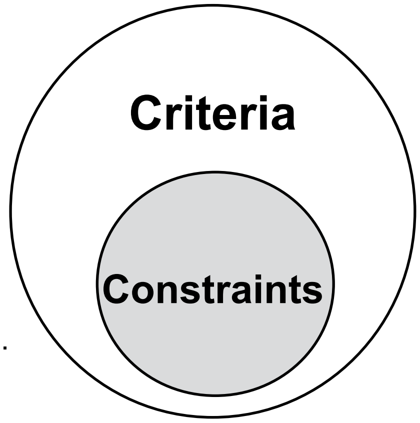
Teamwork: Students should be teamed strategically and may or may not be assigned roles within their team. When forming student teams, consider academic, language, and social needs. In place of strategic teaming, a random teaming can be substituted. Students will work in these teams or "teams" of three or four throughout the unit. Effective teamwork is essential in this unit as well as in engineering in general; however, this unit does not provide specific support to develop those skills. If students do not have experience with teamwork, targeted team-building activities are highly recommended prior to beginning this unit.

Engineering Design Process: Students should have some familiarity with the engineering design process before beginning the unit. If they do not, the teacher will need to spend additional time explaining it, so this lesson may take more than one day. The engineering design process (EDP) is an iterative, systematic process used to guide the development of solutions to engineering problems. There is no single engineering design process, just like there is not one scientific method. However, various engineering design processes have similar components. The engineering design process (EDP) is an iterative process that involves understanding the problem, learning background information necessary to solve the problem, planning, trying, testing the solution, making changes based on the tests, and communicating their ideas. Students will use an engineering design process slider throughout the unit to help them understand where they are in the design process. For more information about the steps of the engineering design process presented in this unit, see the front matter section.

Some common misconceptions about the EDP:

- Engineers do not have to learn anything new when they are working on a project.
- In reality: Engineers need to learn throughout their lives continually.
- The engineering design process is linear, and you never need to go back to previous phases.
- In reality: The EDP is a cyclical process that requires many iterations.
- Once engineers are done with a project, they never think about it again.
- In reality: A project is never really "done," and engineers often continue to improve and make changes.

Criteria and constraints: One difficulty students might have is distinguishing between criteria and constraints. Criteria are the things required for a successful design, or goals of the designed solutions. They help engineers decide whether the solution has solved the problem. Another way of thinking about criteria is that they are anything that the client and the engineers will use to judge the quality of a solution. Constraints are a specific type of criteria; they are those that limit design possibilities or how the problem can be solved. If constraints are not met, the design solution is by default not a viable solution to the problem. The relationship between criteria and constraints is represented in the figure. It may be helpful to post the definitions with the figure somewhere in the classroom for future reference.



Cost is a typical example of something that can be a criterion and a constraint. If the client requires engineers to stay within a specific budget, then this budget is a constraint. Any design solution that requires more money than the budget is automatically disqualified from being a quality solution. However, cost is also a relative criterion. Multiple design solutions that stay within the budget can be proposed. The costs of these solutions could be compared as one factor to determine which of the solutions is preferable.

Problem Scoping: In this lesson, students will be in the Problem Scoping section of the engineering design process, specifically on the define the problem step. Define the problem and learn about the problem combined to make Problem Scoping. At this stage, students will be first introduced to the engineering problem through a client letter and then be given a chance to ask the client to receive more information about the problem. The problem statements given in the client memos purposefully do not provide all the information necessary to solve the problem. Students are tasked with generating questions about the problem to try to fill in this missing information. Based on all information from the client, students will then define the problem in terms of: what the problem is and why it is important, who are the client and end users, what are the criteria and constraints, and what other information they may need to learn about in order to solve the problem. This process of generating ideas and questions for the client is an important skill on its own both in engineering and in other fields, but it also helps to ensure that the students fully understand the problem and their task in the engineering design challenge.

Solution Generation: The Solution Generation section of the engineering design process includes plan the solution, try out the plan of the solution, test the solution, and decide whether the solution is good enough. When engineers are generating solutions, they will use iteration to continually improve their solution, reflect back on the problem definition and what they have learned about the problem, and consider criteria, constraints, and trade-offs. Trade-

STANDARDS ADDRESSED

Next Generation Science Standards:

MS-ETS1-1: Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.

Common Core Mathematics:
None

LESSON 1 Introduction to Engineering Design

EDUCATOR RESOURCES

- Definition for criteria and constraints: (https://www.pbslearningmedia.org/resource/criteria-constraints/identify-criteria-and-constraints-engineering-for-good/)
- Engineering Design Process Definition: (https://www.instructables.com/id/What-Is-the-Engineering-Design-Process/, https://www.eie.org/overview/engineering-design-process)
- Definition for Engineering Notebook: (https://bizfluent.com/about-6502064-purpose-engineering-notebook-.html#:~:text=An%20engineering%20notebook%20is%20intended,to%20the%20progression%20of%20information)

offs involve having to make compromises about which criteria to emphasize because they compete with one another in terms of making the solution effective. For example, the cost could be a trade-off for durability.

Engineering notebook: Throughout the unit, students will be recording information in an engineering notebook, and they will need the notebook immediately in Lesson 1. Students' engineering notebooks will support their communication of ideas and should be used consistently throughout the unit. Some worksheets are provided as duplication masters. If these worksheets are printed for students, they should be taped or stapled into their engineering notebooks so all of the unit information is stored within the notebooks.

Vocabulary: Students will be introduced to many new science and engineering vocabulary terms throughout the unit. It may be helpful to create a vocabulary section in their notebook with term definition and memory clue or picture. Additionally, the class could maintain a word wall.

Word	Definition
Engineering Design Process	To solve engineering problems, engineers follow a series of steps called the "Engineering Design Process. The steps consist in defining the problem, doing research, thinking of solutions, building a prototype, testing your solution, and redesign your solution or accept your solution.
Prototype	A testable representation of a solution, in this case, it is a model of the design.
Client	Person or team who asks engineers to design something to solve a problem.
End-user	People who end up using the design solution

Before the Activity

Documents to print:

- Worksheet 1.a. Client Letter
- Worksheet 1.b. Client Perspective
- Worksheet 1.c. Context Maps
- EDP Sliders

Videos to prepare:

- Retirement of Major Indiana Coal Plant Indicates Shift Toward Sustainable Energy Future
(https://www.youtube.com/watch?v=7iTrnEwD6mM)
- Pros and Cons of Coal Power: In a Nutshell
(https://www.youtube.com/watch?v=agvBTmR_wTo)

Classroom Instruction

Introduction

1. **Introduce the unit.** Say: We will be working on an engineering project to solve a problem for a local community in southern Indiana.
2. **Introduce the engineering design notebooks.** Say: Engineers use notebooks to document their design process and keep notes. We will also

be using engineering notebooks throughout our engineering challenge. Each day, you will use the notebooks to take notes and record what you are learning. Also, there are questions that you will be asked to answer. Sometimes you will answer the questions on your own, then in your teams. Each day turn in your engineering notebooks before you leave class. The engineering notebook is an important tool that you will use as an ongoing record of the project. “It is intended to capture essential details of the engineering process including ideas, inventions, insights, observations, and other important details”.

3. **Introduce engineering.** Say/Ask: We will be working as engineers to create solutions to our problem. What do you know about engineers? Do you know any engineers? How do engineers solve problems? Take students’ answers. Say: Engineers are people who solve problems to help people by using science, mathematics, and creativity. These solutions are new or improved technologies, which can be both objects and processes.
4. **Introduce the engineering design process.** Introduce the Engineering Design Process (EDP) poster and tell students that we will be using this poster during the project. Pass out the Engineering Design Process sliders to each student. Explain to students the meaning of each part of it. During this time, try to ask students to see if they can predict the meaning of each phase of the EDP you go through, rather than just give the answer.
5. **Before introducing the problem.** Say/Ask: The engineering problem that we are going to address is related to Power generation. Have you ever thought about how the energy that you have at your home is generated? Let students give their thoughts while you instigate their thinking. Walk them through the ways the energy is produced and distributed and make connections with real situations. For example, ask: Has anyone seen wind turbines, hydroelectric plants, or any other type of power generators? How do you think they work? Do you think these types of solutions to generate electricity are environmentally friendly? Say: Let us learn a little more about power generation.

Activity

6. **Learning about the Power Generation through coal.** Organize the class in teams of four students. These teams will remain for the duration of the project. Say: We are going to watch a video about one of the most common processes to get electricity: coal-fired power plants; pay attention to how these plants get electricity from coal (Duke Energy Indiana).
7. **Learning about the environmental impact of coal-fired power plants.** Say: Burning coal is an old technology with several problems. Let’s see the following video about the current situation of coal-fired power plants and, while you watch it, take notes about some problems of the coal-fired power plants (Retirement Of Major Indiana Coal Plant Indicates Shift Toward Sustainable Energy Future and Pros and Cons of Coal Power: In a Nutshell) (Worksheet 1.b.). After the video, discuss with the students the problems of this technology; emphasize the big impact that burning coal has on the environment and have them reflect on the effects on health.
8. **Introduce the engineering problem and give more context about the**

ASSESSMENTS

Pre-Activity Assessment
Check students’ verbal responses as they make observations and discuss their Engineering Design Process sliders.

Activity Embedded Assessment
Walk around during the 1.c. Questions for the client activity and check their understanding as they produce written responses and team conversations.

Post-Activity Assessment
Check students’ verbal responses during the whole class discussion about their answers to the 1.a. Introduction to the problem and use the Rubric 1.a. to provide feedback to student responses.

DUPLICATION MASTERS
- Worksheet 1.a. Introduction to the problem
- Worksheet 1.b. Client Letter
- Worksheet 1.c. Context Maps
- EDP Sliders

problem. Present the hypothetical scenario of a client that wants to hire us as their engineering consultant group. The Gallagher Station is getting old and needs to be replaced by a new sustainable power generation system. The client wants to hire us as the expert engineering consultants to advise them about how the system should be. They need to think about a sustainable solution to produce electricity for the community. Next, pass out the Client Letter (Worksheet 1.a.) and the Context Maps (Worksheet 1.c.) to students. Read the letter using whatever method of reading is preferred (e.g., reading in small teams, teacher reading aloud to the whole class, annotate the text, volunteers in the class reading aloud to the whole team). After the reading, ask them why it is important to solve the problem presented. Then, in their teams ask students to highlight the information they consider essential to solving the problem. During this activity, walk around to help students with their questions. Use the Context Maps Worksheet 1.c. to show students the future location of the electrical generating power system.
Note: You may need to explain to students that solving complex engineering problems requires time to learn and reflect. They will be working on different parts of the problem throughout the unit; thus, they can propose a successful solution at the end of the entire unit.

9. **Introduce the concept of a prototype.** Point out that the student engineers have been asked to create an electrical generating system for the power grid. Explain to students that a prototype is a testable representation of a solution; in this case it is a model of their design. They will not create a real power generating system, like a huge wind turbine on a mountain; instead, they will build a prototype, which is a smaller version made from easily available materials.
10. **Introduce the concepts of clients and end-users.** Say/Ask: A “client” is a person or team who asks engineers to design something to solve a problem. This is different from the “end users,” which are the people who end up using the design solution. As engineers, we design solutions for a client and end-users, it is very important to understand their context, their needs, and their expectations; so, our design will more likely be successful. For example, it is not the same to design a solution for people who live in a large-city compared to a solution for indigenous people who live in a more rural-type area. According to this letter, who is our client? Who are the end-users? Note: The client is Deepti Rajeshwari, who is the Director of the Indiana Office of Energy Development (OED). On behalf of the OED, she is asking the student engineers to solve the engineering problem. The end users are the employees of the OED, who will be implementing the power generation system we design. There are other important stakeholders to be considered, such as the people living in New Albany, who will use the electricity and also have to live with other environmental consequences of power generation.
11. **Develop questions for the client**. Say: We will not be able to speak with the end users directly, but we now have an opportunity to ask the client questions about the problem so we can understand it better. Have students think of possible questions individually (three questions) at first and record

them on the Worksheet 1.b. or in their notebooks. Then, give them time to share their list with their team and choose as a team two final questions. You can remind the students that the client does not have the time to answer too many questions, so we need to choose the most important ones. Note. You may want students to write down their team questions in sticky notes and sort them as an activity with the full class.

Closure

Share questions. As a whole team, share these questions. Record students' questions for the client on a chart labeled "Questions for Client." Leave space near each question for the answer to be recorded later. Possible questions students could ask (as well as their corresponding answers) are listed below. Students are not expected to ask all of these questions; however, it is important to address these points: the limitation of costs, the availability of natural resources, and the specific location of the generators. If the class has not thought of these three possibilities, guide them toward asking questions about them. Students may also ask questions not on this list. Use your judgment to answer them. Possible questions and appropriate responses:

? What available space do we have to place the power generators?
→ The client has identified the available space for the entire system.
Note: The students will work with the predefined maps during the next lesson.

? How much money can we spend?
→ The client does not have a fixed budget for the project; their initial estimate is less than 510 million dollars for the total construction cost and less than 20 million dollars for the total operating cost per year.
Note: These numbers should give the students enough space to make decisions about their designs. If you want to constrain the problem more, you can establish the total construction cost by a maximum 480 million dollars and the total operating cost to a maximum of 19 million dollars.

? What type of natural resources or generators can we choose?
→ The client has identified four possible generators: fossil-fuel power plants, small hydro power plants, solar panels farms, and wind turbines farms.

LESSON 1

Name__________________________________ Date____________ Period _____

1.a. Client Letter

The Indiana Office of Energy Development
New Albany, IN

Dear Student Engineers,

We are contacting you to help us find a solution to a problem here in New Albany, Indiana. As members of the Indiana Office of Energy Development (OED), our job is to provide electricity for the whole community. Our main provider of electricity is the Gallagher Station; however, the station is reaching its retirement time after more than 50 years of generating energy. Due to all the environmental problems to the neighbors, we want to replace it with a new electric power generating system that utilizes sustainable technologies.

Gallagher Station is a coal power plant located in Floyd County, Indiana, that began operating in 1958. In early 2012, the Gallagher Station was updated with new technologies to produce 280 Megawatts (MW) of power, 265,000,000 kilowatt-hours/year (kWh/yr) of electrical energy and reduce its environmental impact. However, this update was not enough to eliminate all hazardous emissions. Now, we are considering replacing the plant with a more sustainable electrical power generating system that fulfills the community's requirements.

We ask you to design a successful electric generating system for our power grid that provides the same amount of power that Gallagher Station (280 MW) did, but with a minimum impact on the environment. After you have decided upon a design, we request that you communicate to us the following points:

- A description of the engineering problem
- A clear description of your recommended electrical power generating system, including where the units will be located, how you plan to reduce their environmental impact, and the cost analysis of your proposal (total construction cost and total operating cost per year).
- Supporting evidence and explanations of why this design works well to solve the engineering problem

We appreciate your willingness to help provide electricity to this community. We look forward to hearing about your engineering design solution.

Sincerely,

Deepti Rajeshwari
Director,
Indiana Office of Energy Development

Name________________________________ Date___________ Period _____

LESSON 1

1.b. Client Perspective

1. What are the main problems associated with using coal-fired power plants to get electricity?

2. What are the three questions you want to ask the client that will help you better understand the problem? Make sure to ask about all critical aspects of the problem.

3. What are the two questions that you decided with your team to ask the client?

Name________________________________ Date____________ Period _____

1.c. Context Maps

Figure 1. Indiana and Floyd County.

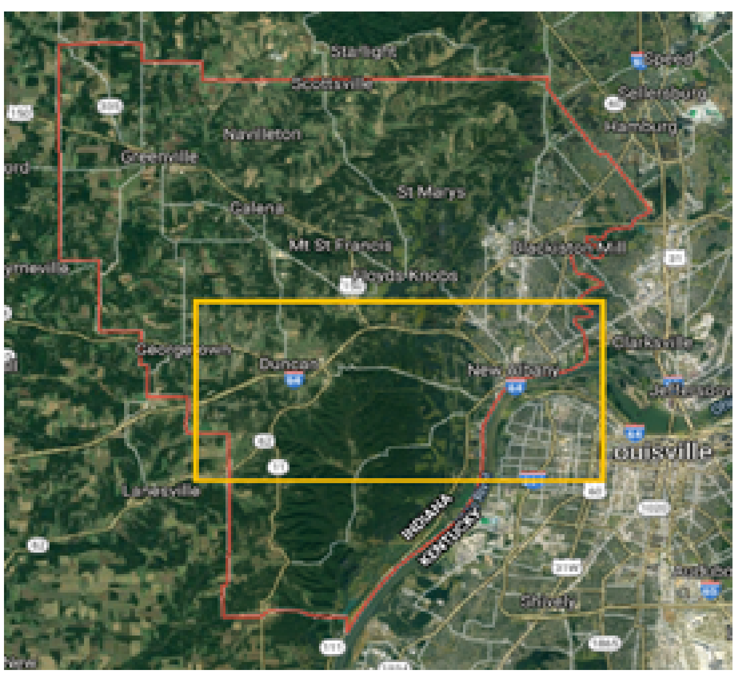


Figure 2. Floyd County (red region) and the area for the prototype (Yellow region).

Name______________________________ Date__________ Period _____

LESSON 1

1.c. Context Maps

Figure 3. The available region for designing the electrical power generating system.

Figure 4. Important places for the localization of the generating plants. The yellow region indicates the availability of fossil fuels.

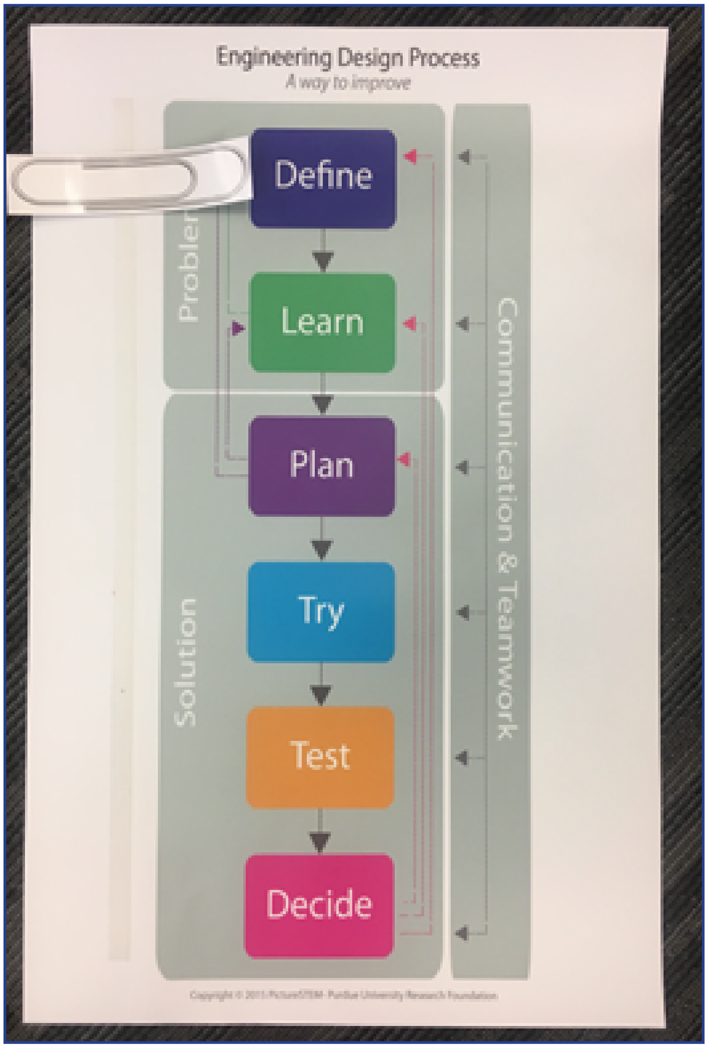
How to make EDP Sliders

HOW TO CREATE THE POSTER

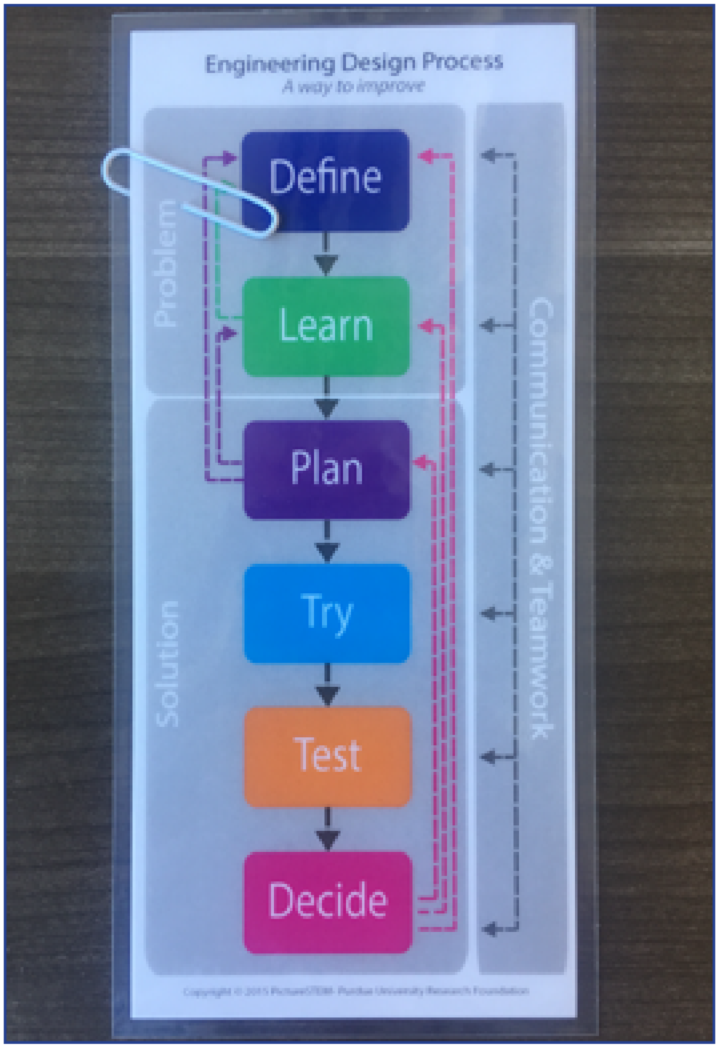
1. Download the high-quality PictureSTEM Slider Poster and the paper clip images from PictureSTEM.org.
2. Print the poster and the paper clip on poster-sized paper and cut to size. High-gloss or semi-gloss paper is the best choice.
3. Use self-sticking Velcro on the back of the paper clip and down the side of the poster so that the paper clip can be placed to point at all 6 sections of the slider.

HOW TO CREATE INDIVIDUAL SLIDERS

1. Print the sliders on the opposite page - enough for one slider per student in your class.
2. Cut the sliders apart.
3. Laminate the sliders individually.
4. Use a jumbo paper clip as the pointer for each slider.



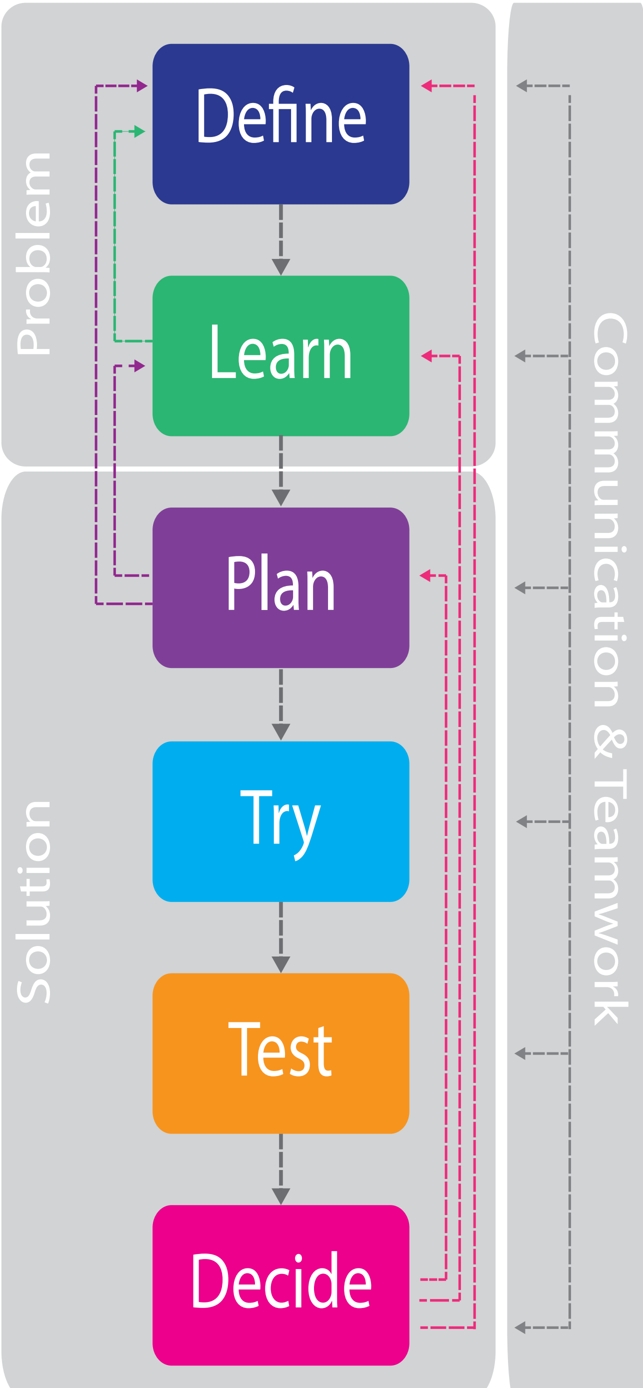
Poster



Individual slider

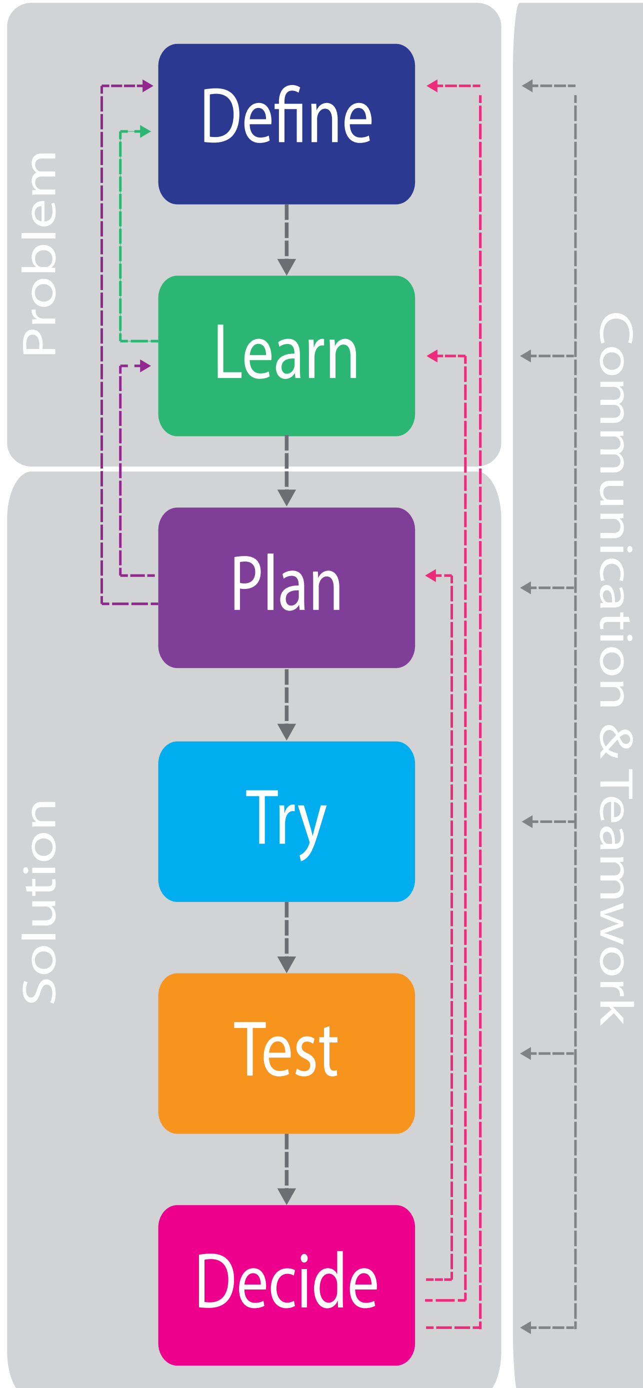
Engineering Design Process

A way to improve



Engineering Design Process

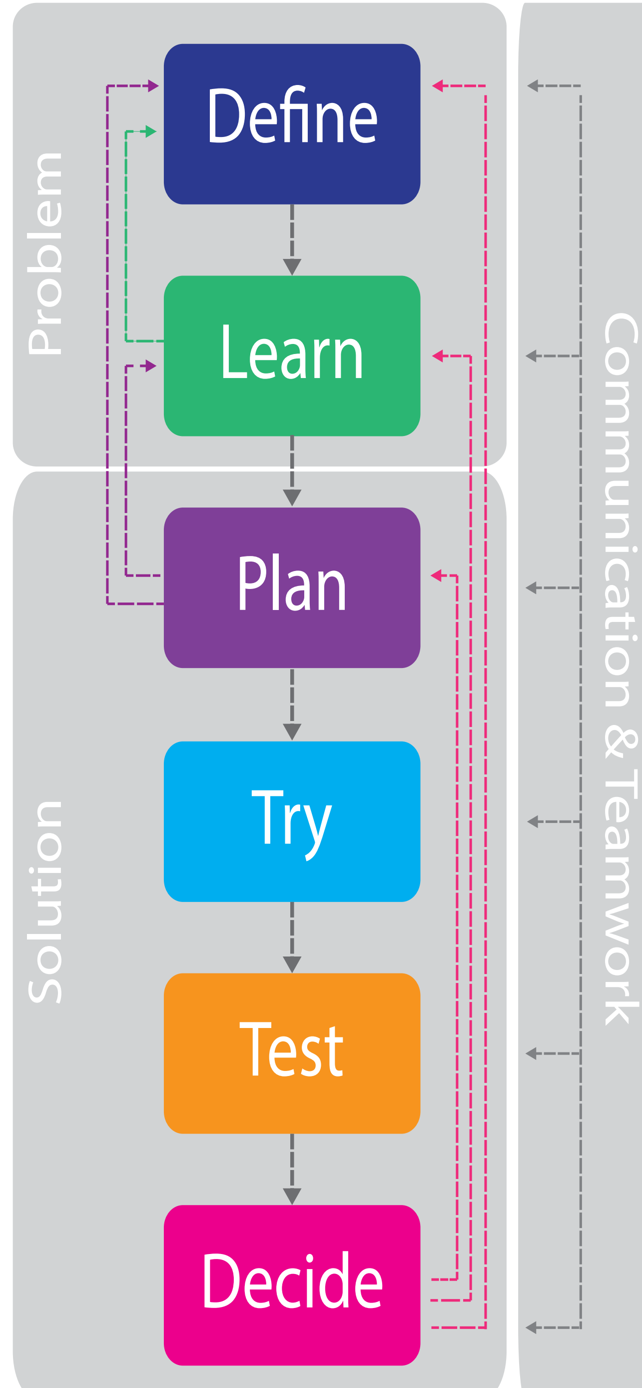
A way to improve



Copyright © 2015 PictureSTEM- Purdue University Research Foundation

Engineering Design Process

A way to improve



Copyright © 2015 PictureSTEM- Purdue University Research Foundation

LESSON 1

Name________________________________ Date__________ Period _____

Problem Scoping Rubric

Problem	Question	Learning Objectives	Rubric	
1.c.1	What are at least 3 questions that you want to ask the client? Ask questions that will help you understand the problem better. Make sure to ask about all important aspects of the problem.	Ask a variety of relevant questions to better understand problem.	**Asked at least 3 questions** CIRCLE: 0 1 2 3 4+	
			At least 3 questions are relevant to the problem CIRCLE: 0 1 2 3 4+	
			Considered at least 2 different aspects of the problem CIRCLE: 0 1 2 3 +	
1.d.1	Who is the client?	Identify the client.	yes no	**Correctly identified the client**
1.d.2	What is the client's problem that needs a solution? Explain why this is important to solve. Use information from your client to support your reasons.	Explain the problem based on a synthesis of information.	yes no	**Identified problem**
		Explain why the problem is important to solve based on evidence that is relevant to the problem.	yes no	**Explained why the problem is important**
			yes no	**Provided rationale from client information**
1.d.3	Who are the end-users?	Identify a specific and relevant end user.	yes no	**Correctly identified at least 1 end user**
1.d.4	What will make your solution effective (criteria)? Use detailed information you have from the client.	Explain criteria based on given information.	yes no	**Identified at least 1 criterion**
			yes no	**Connected information from client to criteria**

LESSON 2

Power Grid Energy Transformation

LESSON OBJECTIVES

Students will be able to:

- Describe the concept of a power grid and how it works.
- Define the criteria and constrains of the engineering design problem.

TIME REQUIRED

Two 50-minute periods

MATERIALS

Per classroom:

- 1 poster size sticky note paper labeled “Questions for client”
- Digital technologies for videos

Per team:

- Prototype: board map, contexts maps, generating plant models, and information sheets of each generating plant.
- Device to take picture (preferably per team,otherwise one per classroom)

Per student:

- 2 different colors or types of writing utensils
- 1 engineering notebook
- 1 Engineering Design Process slider

Lesson Summary

Students will establish an understanding of what electric current is and comprehend the different types of engineering systems that generate electric current. Students will develop an understanding of what is the system that allows distribution of electric current from the power plants to houses/homes. Students will implement a preliminary prototype of the electrical power generating system to better understand the problem. Students will also gain experience utilizing Geographic Information Systems (GIS) tool-sets to propose candidate locations for the establishment of the Electric Power Plant.

Background

Teacher Background

Students learn about electrical power and how a power distribution grid works. Electric current, commonly referred to as Electricity is the movement of electrons passing through a wire. The number of electrons passing a point is referred to as an Ampere, which is the unit of measurement established by the International System of Units (SI). This unit of measure is named after French mathematician Andre-Marie Ampere who lived from 1175-1836. The movement of these electrons begins at the power plant. In almost all cases, the power plant consists of an electrical generator. This generator spins magnets around a coil of wire causing electrons to move. Those moving electrons are what make up electric current that is used to turn lights on, power microwaves, and activate security systems. The electrical current travels from the power plant to your house through a system called the power distribution grid. The power distribution grid must respond quickly to shifting demand and continuously generate and route electricity to where it is needed the most [Extracted from howStuffworks website]. New technologies now let us connect our own home-generated electricity to the grid - using solar panels or wind generators - and get paid back by utilities. Around the world many governments are also investing in a smart grid that employs digital technology to manage energy resources more efficiently.

Examples of electrical power generating system prototypes:
The following examples are intended to help you understand the final prototype of the students’ design. You should not show them to the students to avoid bias in their reasoning process.

Example 1: 1 Fossil-fuel power plant (50 MW); 1 small hydro power plant (30 MW); 5 Wind turbines of 30 MW (150 MW); 5 Solar panels of 10 MW (50 MW). Total construction cost: $ 460 million dollars. Total operating cost: $11.9 million dollars.

Example 2: 1 Fossil-fuel power plant (50 MW); 2 small hydro power plants of 30 MW (60 MW); 5 Wind turbines of 30 MW (150 MW); 2 Solar panels of 10 MW (20 MW). Total construction cost: $ 436 million dollars. Total operating cost: $13 million dollars.

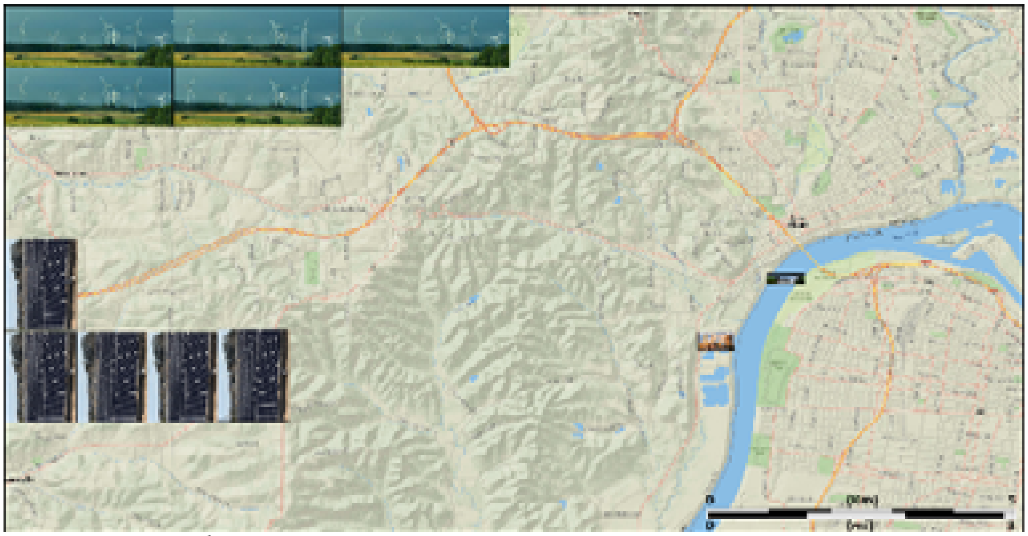


Figure 1 Example 1

Figure 2. Example 2

STANDARDS ADDRESSED

Next Generation Science Standards:

MS-ETS1-1. Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, considering relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.

MS-ETS1-4. Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.

Common Core Mathematics:
None

LESSON 2

Power Grid Energy Transformation

EDUCATOR RESOURCES

- Electrical power and power grid information (howStuffWorks website) (https://science.howstuffworks.com/environmental/energy/power.htm)
- Fossil-Fuel Power Plant (Information sheets) -(https://www.bgs.ac.uk/discoveringGeology/climateChange/CCS/FossilFuelPowerPlant.html)
- Wind turbine (Information sheets)(https://www.energy.gov/eere/wind/how-do-wind-turbines-work#:~:text=Wind%20turbines%20work%20on%20a,a%20generator%2C%20which%20creates%20electricity)
- Solar Panels (information sheets)(https://www.nationalgeographic.com/environment/global-warming/solar-power/)

Vocabulary:

Word	Definition
Criteria	The requirements the designer needs to complete to have a successful design.
Constraints	Things that limit the design possibilities.
Electrical Power Generating System	Combination of different technologies (thermal power plants, wind turbines, hydro power plants, solar panels, etc.) to generate electrical power for residential, industrial, or commercial consumers.

Before the Activity

Documents to print:

- Handouts:

Fossil-Fuel Power Plant: Combined-Cycle Power Plant
Hydro power Plant: Small Run-of-the-River Hydro power Plant
Wind Turbines
Solar Panels: Photo-voltaic Cells
Criteria and Constraints for the Electric Power Generating System

- Worksheet 2.a. - Define the Problem
- Rubric 2.a. - Problem Scoping Rubric

Videos to prepare:
Electrical Grid 101 : All you need to know!
(https://www.youtube.com/watch?v=nbPmsBmo03Y)

Activity Preparation: Electrical power generating system prototypes
Students will design per team a preliminary prototype of the electrical power generating system in this lesson. You need to prepare the materials for the

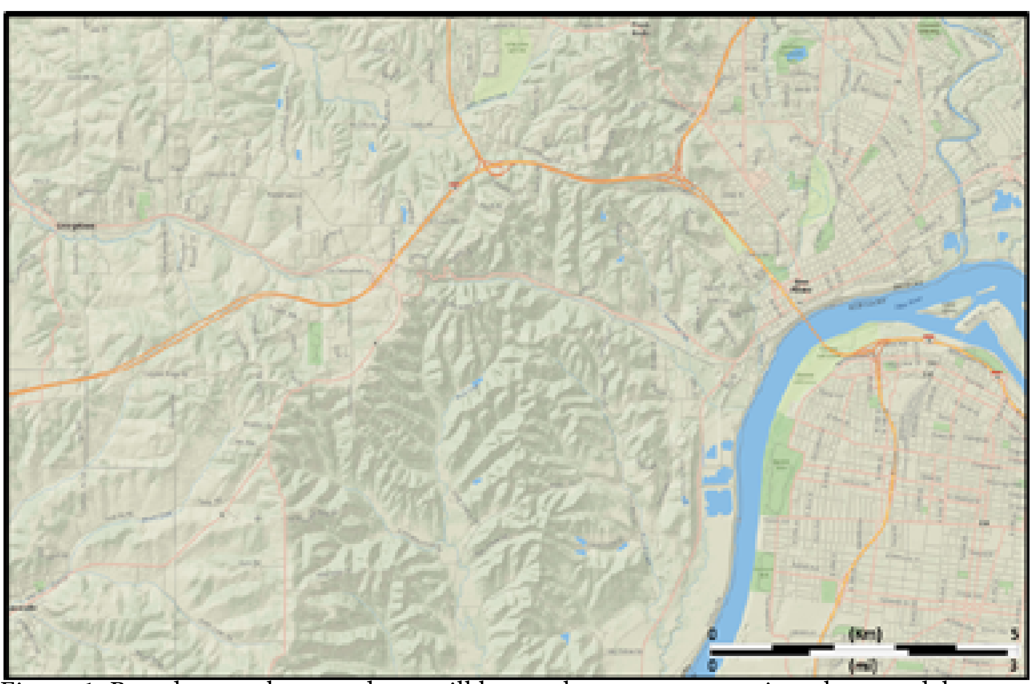


Figure 1: Board map where students will locate the power generating plant models.

prototype in advance: **board map and the generating plant models**.
The board map. The board map is an A2 size (16.53 x 23.39 inches or approximately 4 letter sheets) map where students are going to locate the generating plants (Figure 1). There are two options for building the map according to your available resources. You can plot full size maps using the file Board_Map_Full_Size.pptx and paste it on a cardboard or similar hard paper. If you do not have available a plotter, you can print out a four-sheets map (Prototype_Materials.pptx), cut them and assemble to make a full-size map for

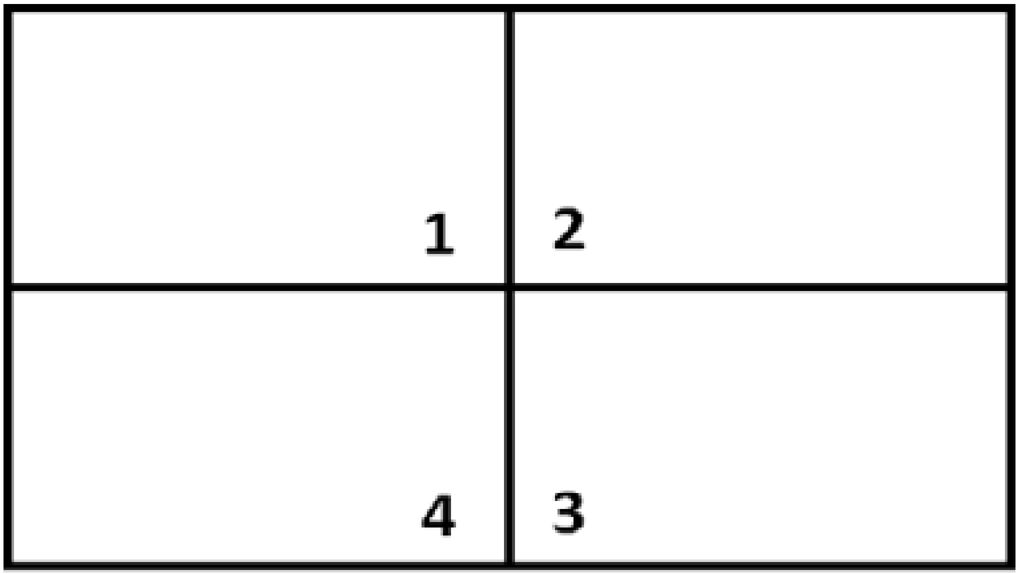


Figure 2: Schema to paste the four sheets of the board map together.

each team. You can place the four sheets together according to figure 2.
The generating plant models. Students have the option to choose between four types of generating plants: fossil-fuel power plants, small hydro power plants, wind turbines, and solar panels. Each one generates different amounts of electrical power, conveys different impacts upon the ecosystems, has different construction and operating costs, and occupies different land areas. All this information is summarized in the Information Sheet of each generating plant.

Before the activity, you need to cut the pieces that students will use as models for the generating plants. The typical area for any of the available fossil-fuel power plants is 50 acres and the area for the small run-of-the-river hydro power plant is 10 acres (see figure 3). Although these generating plants can produce different amounts of electrical power, the size of the plants do not change significantly. In contrast, the size of the wind turbines and the solar panel plants is directly proportional to the amount of electrical power that they produce. Namely, there are three different sizes for the wind turbines (30, 300, and 900 acres) and solar panels (35, 175, and 350 acres) according to the electrical power that students want to get (Figure 4). You may want to paste the models on a harder sheet, so they will last longer. You can print multiple copies of the file Prototype_Materials.pptx and cut a several generating plant models for the classroom.

ASSESSMENTS

Pre-Activity Assessment
Check students' verbal responses as they make observations and discuss their Engineering Design Process sliders.

Activity Embedded Assessment
Check students' progressive understanding through their verbal and written responses during the 2.a. Define the problem activity and discussions. This is particularly important when students are answering the 2.a. Define the problem worksheet questions, since they are doing so individually and in teams; circulate during this part of the activity and check their understanding as they emerge in the written responses and team conversations.

Post-Activity Assessment
Check students' verbal responses during the whole class discussion about their answers to 2.a. Define the Problem questions. Use the Rubric 2.a Problem Scoping Rubric to provide feedback to students for their responses to 2.a. Define the Problem.

DUPLICATION MASTERS

- Handouts:

Fossil-Fuel Power Plant: Combined-Cycle Power Plant
Hydro power Plant: Small Run-of-the-River Hydro power Plant
Wind Turbines
Solar Panels: Photo-voltaic Cells

- Worksheet 2.a. - Problem Scoping

Figure 3: Generating plant models for the fossil-fuel power plants and hydro power plants. The sizes represent 50 and 10 acres respectively according to board map scale.

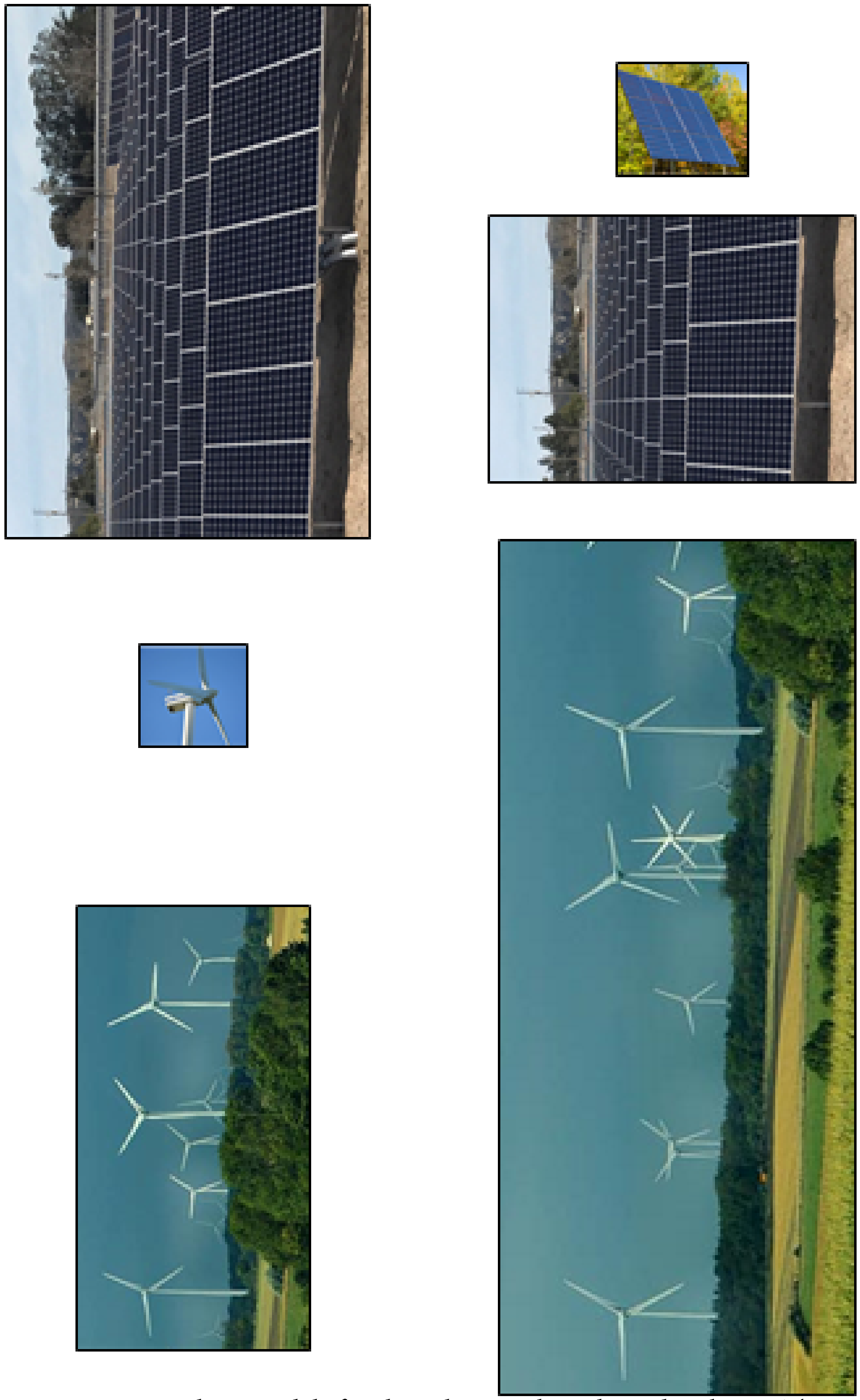


Figure 4: Generating plant models for the solar panels and wind turbines. The sizes are proportional to the scale of the board map.

Power Grid Energy Transformation

Note: If you want to implement an online version of the electrical power generating system prototype, you have available the PowerPoint files to send them to the teams. You could ask students to do their prototype using PowerPoint and send their screenshots to you for evaluation.

Classroom Instruction`

Introduction

1. **Tie to the engineering problem.** Say/Ask: Today we are going to go over the client's response to your questions from the last class and define the criteria and constraints for the project. For now, can anyone remind me of what is the problem that we need to solve?
2. **Identify where they are in the engineering design process. (Define and Learn).** Use the Engineering Design Process poster and students' Engineering Design Process sliders to help students identify what they have done so far and what step they are currently on. Say/Ask: According to our poster, today we are going to continue working on defining the problem and start learning some scientific concepts that help us to solve it.

Activity

3. **Provide answers to student's questions for the client.** This may be done in several ways. This includes, but is not limited to: including the client answers on the day's memo; pretending to call the client and ask the questions; telling the students that the client has already provided a list of answers to questions they anticipated student engineers would ask; or inviting a guest speaker to pretend to be the client and answer students' questions.
4. **Record the client's answers.** Record the answers to the questions on the chart labeled "Questions for Client", preferably in a different color than the questions.

? What available space do we have to place the power generators?

→ The client has identified the available space for the entire system.
Note: The students will work with the predefined maps during the next lesson.

? How much money can we spend?

→ The client does not have a fixed budget for the project; their initial estimate is less than 510 million dollars for the total construction cost and less than 20 million dollars for the total operating cost per year.
Note: These numbers should give the students enough space to make decisions about their designs. If you want to constrain the problem more, you can establish the total construction cost by a maximum 480 million dollars and the total operating cost to a maximum of 13 million dollars.

? What type of natural resources or generators can we choose?

→ The client has identified four possible generators: fossil-fuel power plants, small hydro power plants, solar panels farms, and wind turbines farms.
NOTE: If students continue to ask questions about the problem in later lessons, write the questions and answers on the "Questions for Client" chart. Keep this chart on display as a reminder to students about the criteria and constraints of the problem.

5. **Define the problem, including identifying the client and end users.** Pass out the worksheet 2.a. and have students attach them in their notebooks or provide students with the prompts to answer in their notebooks. Say: Let us review what we have learned about the problem so far from the letter and the questions we asked the client. Ask students to individually answer the questions on the 'Define the Problem worksheet' up to the questions about criteria and constraints. When students finish answering the questions on their own, instruct them to share their responses in small teams, decide what their team answer is, and write down the revised answer on the 'Define the Problem worksheet' or directly in the students' engineering notebooks. If some teams seem to be struggling with a question, address it as a whole class.
6. **Describe the criteria and constraints of the problem.** Say: The "criteria" for an engineering problem are the requirements, the designed solutions must meet. The criteria help us decide whether the solution has solved the problem. The "constraints" of an engineering problem are the things that limit the design possibilities. These may be materials available, the cost of the materials, the amount of time for the design, etc. Important constraints arise from nearby communities that are impacted by the solution (i.e., cultural beliefs about the relocation of different places, negative impact on the economy of the families, lack of interest in the usage of the design, etc.). Can you tell me some criteria or constraints of our engineering problem? Identifying the criteria and constraints could be challenging, let us learn more about our problem to gain a better understanding of what must be accomplished with our design. This would be a good place to split the context between two class periods. The next steps (7 and 8) allow students a chance to revisit some of the things we did previously, before continuing with activities.
7. **Introduction to power grid and power generation:** Present the video (Electrical Grid 101 : All you need to know !) which explains how the power grid works. Have students answer the following questions first individually and then as a full class discussion:

- What are the main components of an electrical power grid? Generation, transmission and distribution, and consumption.
- How does a power grid work? The electricity is generated in the generating plants; then, it is transmitted to sub-stations to increase the voltage and decrease the current; then, it goes to another sub-station near the consumers where the voltage is decreased; finally, distribution lines transport the electricity to the final residential, commercial, e industry consumers.
- Which generating plants did you see in the video? Coal-fired power plants, hydro power plants, and wind turbines.
  Note: Take this opportunity to remind the students of our engineering problem: design the power generation system for the power grid. Namely, we need to decide which generating plants use (fossil-fuel power plants, hydro power plants, wind turbines, solar panels), how many of them, and where we should locate them.

8. **Re-introduce the concept of a prototype.** Point out that the student

engineers have been asked to create an electrical generating system for the power grid. Explain to students that a prototype is a testable representation of a solution; in this case it is a model of their design. They will not create a real power generating system, like a huge wind turbine on a mountain; instead, they will build a prototype, which is a smaller version made from easily available materials.

9. **Introduction to our prototype of the power generation system.** Have each team with the prototype materials to start designing their power generation system (See the Prototype_Materials.ppt file with the board map, generating plant models, and the information sheets of each generating plant). Say: we are going to create our prototype by using a scale map of the region where we are going to locate the generating plants. Let students get familiar with the board and context maps (section of Floyd County).
10. **Introduction to the generating plants.** Ask students to take the generating plant models and their information sheets. Say: The Indiana Office of Energy Development has already identified four possible generating plants that we can use in our electrical power generating system: fossil-fuel power plants, small hydro power plants, wind turbines, and solar panels. The suppliers of these plants sent information sheets about each type of generating plant. We need to consider all of the information to make accurate decisions. Ask students to read the titles and briefly explain what they are about. All the content will be covered in the upcoming lessons.
These are the titles and a description of their content for your reference:

- General description: Briefly introduces the characteristics of the generating plant.
- Available sizes: Each generation plant has specific sizes which are usually proportional to the power that they generate.
- Environmental impact: Describes how the generating plant impacts the ecosystem and biodiversity of the area.
- Typical costs: Includes estimations of the construction and operating costs per each generator.

11. **Try the first prototype.** Ask the students to generate one initial prototype of the electrical power generating system for the electrical power grid of New Albany. This is not going to be a final successful solution for the problem. Instead, the purpose of the activity is to have students get familiar with the material and reflect about the complexity of the engineering problem (For example: What do they need to learn? How do they know if the solution works? How long does it take to address a real problem?). Say/Ask: We are going to do the first prototype of our electric power generating system; this does not have to be perfect. Let's focus on where and how many generating plants we should place in our system. Where do you think we should locate the plants? Do you think we can place a wind turbine in the middle of the forest? For this prototype, we are going to assume that we have enough wind, and sunlight across the available area. However, we only have fossil fuels in the yellow area of the map (Worksheet 1.c.). This is an important constraint of our design. As the

students work in their designs, encourage them to think about how to evaluate the prototype. How do they know that their design accomplishes the expectations of the client? If some teams finish fast, you can encourage them to compute how much power they are producing. Note: Point out to the students that solving real engineering problems may be frustrating and overwhelming sometimes due to the uncertainty and lack of knowledge. To deal with that, engineers break down the problem in more manageable tasks and spend a lot of time working on each small step to have a successful design at the end. Students will spend the next seven lessons working on learning the concepts and designing their solutions.

12. **Define the criteria and constraints of the problem.** Ask students to individually answer the questions about criteria and constraints on the Worksheet 2.a. Suggest them to find information in the clients' letter (Worksheet 1.b.) and also in the answers from the client. When students finish answering the questions on their own, instruct them to share their responses in the small teams. Review the students answers and, as a whole class discussion. Guide the discussion, so students will end up with the following criteria and constraints to evaluate their electrical power generating system:

- The electrical power generating system should provide at least 280 MW of power.
- The generating plants (fossil-fuel plants, small hydro power plants, wind turbines, and solar panels) should be located near the energy source.
- The electrical power generating system should look to minimize the environmental impact.
- The total construction cost should be less than 510 Million dollars.
- The total operating cost per year should be less than 20 Million dollars.

Note. Write the criteria and constraints on a separate chart and keep it in a visible place for the class. The students will review this information several times throughout the engineering unit. For your convenience, we provide a full sheet in the appendices with this list of criteria and constraints to print it out.

13. **Wrap-up:** Ask students to take a picture or you can take the pictures of their prototype as a first model of their electrical power generating system. They will continue working on this prototype after lessons 5.

Closure

14. **Describe the background knowledge needed.** Say/Ask: Today we have learned a lot about the problem from the client. However, we need to learn more before we can design a good solution to the problem. What else do you think we need to learn to create a successful electrical power generating system design? Ask students to individually answer the final question on the 'Define the Problem' worksheet. When students finish answering the questions on their own, instruct them to share their responses in small teams, decide what their team answer is, and write down that revised answer on the 'Define the Problem' worksheet or directly in their engineering notebooks.
15. **Conclusion and reflection activity.** Review the concept of the electrical

power generating system, criteria, and constraints. Ask questions to review the students' learning process such as what was the most difficult part for them? How was their work as a team? What else do they need to learn or to do to design a successful solution?

LESSON 2

Name________________________________ Date____________ Period _____

Information Sheet 1

Fossil-Fuel Power Plant: Combined-Cycle Power Plant

Description: A fossil-fuel power plant is one that burns fossil fuels such as coal, natural gas or petroleum (oil) to produce electricity. Fossil-fuel power plants are designed on a large scale for continuous operation. In many countries, such plants provide most of the electrical energy used, or the 'base load'. A fossil fuel power plant uses a turbine that turns an electrical generator. The turbine may be turned by steam, gas or — as in some small isolated plants — an internal combustion engine (Extracted from BGS British Geological Survey).

The installed, or nameplate capacity of a generation unit in a power plant is used to indicate the maximum mega-watt (MW) electrical power capacity that the unit can generate. The actual electrical generation corresponds to this generation capacity, and is measured in megawatt hour (MW h).

Available Sizes

Prototype Model	Real Area (Acres)	Electrical Power Capability (MW)	Maximum Energy per Year (MW h)
	50	50	438,000
		150	1,314,000
		300	2,628,000

Environmental Impact:
The combined-cycle power plants have a technology that uses both natural gas and coal to get electrical energy. This is an improved technology with less hazardous emissions than traditional coal-fired power plants. However, we recognize that our power plants can generate the following impacts to the environment:

- The power plant's construction and operation produces air contaminants that will deposit on leaves affecting their photosynthesis.
- The power plant construction and operation require highly invasive techniques, including the perforation of soil and mountains to extract the fuels, which disrupt the habitat of many organisms.
- The manipulation of coal requires the usage of specialized face masks. However, some employees avoid them which produce chronic health disorders like pneumoconiosis.
- The extraction of natural gas from shale formations needs and contaminates large amounts of water.

Overall Environmental Impact: High

Typical Costs

Variable	Value
Construction Cost per Megawatt (USD/MW)	$1,800,000
O&M* Cost per Megawatt per year (USD/MW)	$ 27,000
Fuel cost per Megawatt (USD/MW)	0.00003
EPA Fee for GHG Emissions (USD/ton)	$ 20
*O&M: Operation and Maintenance	

Name________________________________ Date___________ Period _____

Information Sheet 2

LESSON 2

Hydro power Plant: Small Run-of-the-River Hydro power Plant

Description:
Hydroelectric power, also called hydro power, is the electricity produced from generators driven by turbines that convert the potential energy of falling or fast-flowing water into mechanical energy. In the early 21st century, hydroelectric power was the most widely utilized form of renewable energy. In 2019 it accounted for more than 18 percent of the world’s total power generation capacity (Extracted from Encyclopedia Britannica).

Available Sizes

Prototype Model	Real Area (Acres)	Electrical Power Capability (MW)	Maximum Energy per Year (MW h)
	10	5	43,800
		10	87,600
		30	262,800

Environmental Impact:
Small run-of-the river hydro power plants have a technology that uses the kinetic energy from flowing rivers to produce electrical energy. They do not require to build a dam which reduces the area of the plant and the construction cost. Although the amount of electrical power is not too high and will depend on the river level, this technology reduces the cost and impact of constructing big dams. Some additional environmental impacts include:

- The plant may disrupt the flow and temperature of the river affecting fish populations.
- The construction of the plant has some contribution to the emissions of greenhouse gases.
- Placing the plant in the river may affect the composition of the water which damages aquatic ecosystems.
- The disruption of the river may require relocating people who get fish from the river.

Overall Environmental Impact: Medium-low

Typical Costs

Variable	Value
Construction Cost per Megawatt (USD/MW)	$ 1,500,000
O&M* Cost per Megawatt per year (USD/MW)	$ 52,000
*O&M: Operation and Maintenance	

LESSON 2

Information Sheet 3

Wind Turbines

Description:

Wind turbines work on a simple principle: instead of using electricity to make wind—like a fan—wind turbines use wind to make electricity. Wind turns the propeller-like blades of a turbine around a rotor, which spins a generator, which creates electricity. Wind is a form of solar energy caused by a combination of three concurrent events:

- The sun unevenly heating the atmosphere
- Irregularities of the earth's surface
- The rotation of the earth.

The terms "wind energy" and "wind power" both describe the process by which the wind is used to generate mechanical power or electricity. This mechanical power can be used for specific tasks (such as grinding grain or pumping water) or a generator can convert this mechanical power into electricity (Extracted from energy.gov).

Available Sizes

Prototype Model	Real Area (Acres)	Electrical Power Capability (MW)	Maximum Energy per Year (MW h)
	30	1	8,760
	300	10	87,600
	900	30	262,800

Environmental Impact:

The wind turbines use wind energy to produce electrical energy. Overall, they are an environmentally friendly solution to provide energy, but they depend on the typical wind speed of each region. Some concerns of wind turbines include:

- The wind turbines are tall structures that occupy space and block the migration paths of birds.
- Wind turbines may visually affect the landscape due to the large areas they occupy.
- People do not like having large wind turbines near their homes due to the shadow and noise that they generate.
- Most wind power projects on land require service roads that fragments the animals' habitat and the transportation of the turbines contribute with greenhouse gases.

General Environmental Impact: Low

Typical Costs

Variable	Value
Construction Cost per Megawatt (USD/MW)	$ 1,400,000
O&M* Cost per Megawatt per year (USD/MW)	$ 26,000
*O&M: Operation and Maintenance	

Name____ Date_____________ Period ______

LESSON 2

Information Sheet 4

Solar Panels: Photo-voltaic Cells

Description:
Solar energy is the technology used to harness the sun’s energy and make it usable. As of 2011, the technology produced less than one tenth of one percent of global energy demand. Many are familiar with so-called photo-voltaic cells, or solar panels, found on things like spacecraft, rooftops, and handheld calculators. The cells are made of semiconductor materials like those found in computer chips. When sunlight hits the cells, it knocks electrons loose from their atoms. As the electrons flow through the cell, they generate electricity (Extracted from National Geographic Global Warming).

Available Sizes

Prototype Model	Real Area (Acres)	Electrical Power Capability (MW)	Maximum Energy per Year (MW h)
	35	1	8,760
	175	5	43,800
	350	10	87,600

Environmental Impact:
Photo-voltaic cells use radiant energy from the sun to produce electrical energy. Overall, they are an environmentally friendly solution to provide energy, but they depend on the sun radiation of each region. Some concerns of the solar panels include:

- Solar panel farms require large areas contributing to land degradation and habitat loss.
- The solar panels like other electronic devices need special treatment for recycling after decommissioning.
- The manufacturing of the cells requires hazardous materials that may contaminate the soil and water.
- The construction and transportation of the solar panels generate some emissions of greenhouse gases.

Overall Environmental Impact: Low

Typical Costs

Variable	Value
Construction Cost per Megawatt (USD/MW)	$ 2,300,000
O&M* Cost per Megawatt per year (USD/MW)	$ 15,000
*O&M: Operation and Maintenance	

LESSON 2

Name_________________________________ Date___________ Period _____

2.a. Worksheet - Problem Scoping (1/2)

First, on your own, answer each of the following questions beside the “My Response” space. Then, in your teams, each person is to share their response and discuss. In the space, “Team Response” write your revised answer to the question, based on discussion with your team. You may use a different color writing utensil to distinguish your answer and how it changed after talking with teammates.

1. Who is the client?
My response:

Team response:

2. What is the client’s problem that needs a solution? Explain why this is important to solve. Use information from your client to support your reasons.
My response:

Team response:

3. Who are the end-users?
My response:

Team response:

Name___________________________________ Date____________ Period _____

LESSON 2

(2/2)

2.a. Worksheet - Problem Scoping

4. What will make the solution effective (criteria)? Use detailed information you have from the client.
My response:

Team response:

5. What will limit how you can solve the problem (constraints)? Use detailed information you have from the client.
My response:

Team response:

6. In terms of being able to properly design the power generation system for our client, what are at least 2 things you need to learn to accomplish a successful design? Make sure to consider all important aspects of the problem. Be specific.
My response:

Team response:

LESSON 2

Name________________________ Date____________ Period _____

Problem Scoping Rubric

No.	Question	Learning Objectives		Rubric
2.a.1	Who is the client?	Identify the client.	Yes No	Correctly identified the client
2.a.2	What is the client's problem that needs a solution? Explain why this is important to solve. Use information from your client to support your reasons.	Explain the problem based on a synthesis of information.	Yes No	Identified problem
		Explain why the problem is important to solve based on evidence that is relevant to the problem.	Yes No	Explained why the problem is important
			Yes No	Provided rationale from client information
2.a.3	Who are the end-users?	Identify a specific and relevant end user.	Yes No	**Correctly identified at least 1 end user**
2.a.4	What will make the solution effective (criteria)? Use detailed information you have from the client.	Explain criteria based on given information.	Yes No	**Identified at least 1 criterion**
			Yes No	**Connected information from client to criteria**
2.a.5	What will limit how you can solve the problem (constraints)? Use detailed information you have from the client.	Explain constraints based on information.	Yes No	**Identified at least 1 constraint**
			Yes No	**Connected information from client to constraints**
2.a.6	In terms of being able to properly design the power generation system for our client, what are at least 2 things you need to learn to accomplish a successful design? Make sure to consider all important aspects of the problem. Be specific.	Explain the background knowledge needed to develop a solution.	Identified at least 2 topics they needed to learn CIRCLE: 0 1 2 3+	
			Topics are relevant to the problem CIRCLE: 0 1 2 3+	
			Considered at least 2 different aspects of the problem CIRCLE: 0 1 2 3+	

Notes:

Name________________________________ Date___________ Period _____

LESSON 2

2.a. Worksheet - Possible Answers

1. Who is the client?
The client is the Indiana Office of Energy Development

2. What is the client's problem that needs a solution? Explain why this is important to solve. Use information from your client to support your reasons.
The members of the Indiana Office of Energy Development want to replace the Gallagher Station, an old power station, with a new electric power generating system that utilizes sustainable technologies. This replacement is crucial to minimize hazardous emissions in the environment around that may affect the local population in a negative way.

3. Who are the end-users?
The population in New Albany, Indiana who directly benefits from the electricity system provided to the community through the power station generator.

4. What will make the solution effective (criteria)? Use detailed information you have from the client's letter and the answers.
The electric generating system should provide the same amount of power that Gallagher Station (280MW) did, but with a minimum impact on the environment.

5. What will limit how you can solve the problem (constraints)? Use detailed information you have from the client.
The generating plants should be located near the energy source. Also, the total construction cost should be less than 510 Million dollars and the total operating cost per year should be less than 20 Million dollars.

6. In terms of being able to properly design the power generation system for our client, what are at least 2 things you need to learn to accomplish a successful design? Make sure to consider all important aspects of the problem. Be specific.
This will not be graded on the correctness of the answer, just that it is clear that students are thinking about what information would help them design. Answers vary, but may include: types of generating plant, the best environmentally friendly power generating system, etc.

Criteria and Constraints for the Electric Power Generating System

- The electrical power generating system should provide at least 280 MW of power.
- The generating plants (fossil-fuel plants, small hydro power plants, wind turbines, and solar panels) should be located near the energy source.
- The electrical power generating system should look to minimize the environmental impact.
- The total construction cost should be less than 510 Million dollars.
- The total operating cost per year should be less than 20 Million dollars.

LESSON 3 Fossil-Fuel Power Plants and Chemical Energy

LESSON OBJECTIVES

Students will be able to:

- Describe how thermal power plants use chemical energy to get electrical energy.
- Analyze experimental data to identify if a chemical or physical change has happened.
- Recognize that chemical reactions absorb or release thermal energy.

TIME REQUIRED

Three 50-minute periods

MATERIALS

Per classroom:

- 1 Engineering Design Process Poster
- Digital technologies for videos
- Hydrogen peroxide at 12%, 30ml (Clear developer 40 volume also works)
- Plastic container
- 1 pair of gloves
- Liquid soap (5ml)
- Chopped potato (20g)
- Potassium iodide (less than 1 tsp)
- 5 Glasses
- 1 Volumetric cylinder (50 ml)
- 1 Plastic spoon
- Soda can
- String
- Nails (for making holes in the soda can)

Per team:

- 1 candle
- Food coloring
- Water
- 1 Lighter
- 3 glasses
- Hydrogen Peroxide at 3%
- Plastic container
- Liquid soap (5ml)
- Chopped potato (20g)
- Potassium iodide (less than 1 tsp)
- Vinegar (30ml)
- Baking soda (1tsp)

Lesson Summary

Students will work on the science concepts related to the first available electrical generating plant for their designs: Fossil-fuel power plants. Students shall understand how fuels are generated from the remains of prehistoric creatures and plants (fossil fuels). The stored energy of the fuel is released through chemical interactions. Through several experiments, students will apply the concepts of physical and chemical change and relate them to the thermal energy store in the substances.

Background

Teacher Background

All atoms have energy stored within them. These atoms when combined with other atoms develop into molecules of a substance. Chemistry is a means to liberate that energy from these molecules enabling work to be accomplished. Here is a YouTube video that gives some background explanation of chemical energy.
Here is a video explaining chemical energy:
https://www.youtube.com/watch?v=_77fcVFw6co

Fossil fuels are substances that were formed from ancient plants and organisms nearly 400 million years ago. As these organisms and plants died, their remains deposited on the land and water and decomposed. The combination of temperature, pressure, and type of material determined the type of fossil fuel. There are three main types of fossil fuels: coal, oil, and natural gas. Each of these types have different amounts of energy release. Coal is formed from prehistoric plants that are hardened due to pressure from gradual layers of silt over time. Oil and natural gas were formed from microorganisms that decomposed. Fossil fuels have a high energy density that can be used in many different applications.
Here are videos explaining fossil fuels and how they are used:
https://www.youtube.com/watch?v=zaXBVYr9Ij0
https://www.youtube.com/watch?v=bEeUIa9EeBw

Vocabulary:

Word	Definition
Chemical change	Also known as a chemical reaction, it is a process in which one or more substances, the reactants, are converted to one or more different substances, the products. Substances are either chemical elements or compounds.
Physical change	It is a change in one or more physical properties of matter without any change in chemical properties. In other words, matter doesn't change into a different substance in a physical change
Combustion	It is a rapid chemical reaction of a substance with oxygen, involving the production of heat and light in the form of a flame.

Before the Activity

Fossil-Fuel Power Plants and Chemical Energy

LESSON 3

Documents to print:
- Worksheet 3.a.
- Worksheet 3.b. activity 1
- Worksheet 3.b. activity 2
- Worksheet 3.b. activity 3
- Information sheet - Description of fossil-fuel power plants

Videos to prepare:
For the class:
- Fossil Fuels 101 (https://www.youtube.com/watch?v=zaXBVYr9Ij0)
- Coal Fired Power Plant (https://www.youtube.com/watch?v=rEJKiUYjW1E)
- Decomposition of hydrogen peroxide (https://www.youtube.com/watch?v=Ta4DomSDzF8)
- Simple Soda Can Steam Engine (https://www.flinnsci.com/simple-soda-can-steam-engine/vfm0378/)

For the teacher:
- Chemical energy (https://www.youtube.com/watch?v=_77fcVFw6co)
- Fossil fuels (https://www.youtube.com/watch?v=zaXBVYr9Ij0)
- Fossil fuel power generation (https://www.youtube.com/watch?v=bEeUIa9EeBw)

Classroom Instruction`

Introduction

1. **Tie to the engineering problem.** Ask: What is our engineering design problem? Take the students answers as a prompt to recall the engineering design problem, the criteria, and constraints. Emphasize the types of generating plants that we have available for the power generation system: fossil-fuel power plants, hydro power plants, wind turbines, and solar panels.
2. **Identify where they are in the engineering design process. (Learn).** Use the Engineering Design Process poster and students' Engineering Design Process sliders to help students identify what they have done so far and what step they are currently on. Say/Ask: We were working on defining our problem, and we discussed that we need to learn more information to design a successful solution. What step of the engineering design process do we need to do next?
3. **Identify what students still need to learn about.** Say/Ask: What were some of those ideas we needed to learn? Students should say something about how to choose between different generating plants, how we get electrical energy from each energy source, etc. Say: Today we are going to learn about fossil-fuel power plants, and how we can use the chemical energy from coal and natural gas to get electricity for the power grid of New Albany.

Activity

4. **Introduction to fossil fuels.** Say/Ask: All generating plants need some source of potential energy that will be turned into kinetic energy to finally

- 1 Volumetric cylinder (50 ml)
- 2 Plastic spoon
- 1 Thermometer

Per student:
- Engineering Notebook
- 1 Pair of gloves
- Safety goggles

Optional:
- Lime Water (Calcium Hydroxide)

STANDARDS ADDRESSED

Next Generation Science Standards:
MS-PS1-2. Analyze and interpret data on the properties of substances before and after the substances interact to determine if a chemical reaction has occurred.

Common Core Mathematics:
None

EDUCATOR RESOURCES

- Chemical change definition extracted from Britannica (https://www.britannica.com/science/chemical-reaction)
- Physical change definition extracted from k-12 FlexBooks (https://flexbooks.ck12.org/cbook/ck-12-middle-school-physical-science-flexbook-2.0/section/2.8/primary/lesson/physical-change-ms-ps)
- Combustion definition extracted from Britannica (https://www.britannica.com/science/combustion)

produce electricity. Can anyone remind me what the difference between kinetic and potential energy is? Take the students' answers and check their understanding of these fundamental concepts. Say: In the case of fossil-fuel power plants, we transform potential energy from fossil fuels to electricity. Let's see the following video to learn about this source of energy: Fossil Fuels 101. Lead a full class discussion about what the fossil-fuels are and what their advantages and disadvantages are. Pass around the worksheet 3.a. and let students complete the table of item 1 in teams.

5. **Introduction to fossil-fuel power plants.** Say: The Gallagher station that we want to replace is a fossil-fuel power plant that uses coal as a source of potential energy. Although we want to replace it, we can always propose to build a similar one or use another fossil-fuel such as natural gas. (Show the video (Coal Fired Power Plant)). Let's read the description of fossil-fuel power plants in our information sheet. Point out that we can use fossil-fuel power plants for our design with a technology called combined-cycle which uses natural gas and coal together as energy sources. It makes the plant a little more efficient and less contaminant. Ask the students about the main components of a coal-fired power plant. Ask students to complete item 2 of Worksheet 3.a. If you are splitting this content over 3 days. This would be a good place to stop for day 1. The chemistry experiments can be split over the following two days depending on the time it takes your class to conduct the experiments.
6. **Characterize the experiment materials.** Say: One form of potential energy is chemical energy which is stored in the molecules of any substance. Let us learn how we can release that energy from the molecules. Show the students the materials that they are going to use in the experiments and ask them to describe their physical properties (odor, texture, color, state) in their engineering notebook (Worksheet 3.b. item 1).
   Important Note: Please make sure that you advise students before hand on how to handle each material safely.
7. **Explain how to differentiate between physical and chemical changes.** Explain to students what physical and chemical changes are and remind them that we can use some clues to differentiate them from observation. For example, chemical changes typically imply color change, production of an odor, change of temperature, formulation of bubbles, or formation of solids. A physical change is like folding a piece of paper. It changes size and shape, but it is still the same sheet of paper.
8. **Experiments to differentiate between physical and chemical changes.** Perform the following experiments in front of the full class or allow the students to perform the experiments in teams and ask them if a chemical or physical change has happened and why.

- Burn the wick of the candle (Chemical change)
- Melt wax (Physical change)
- Mix water with food coloring (Physical change)

9. **Experiment to observe the speed of chemical reactions.** Say: Chemical changes are very important in our world, and we call them chemical reactions. They have different characteristics. One of them is how fast the reaction happens. Sometimes the chemical reactions are fast and

sometimes they are slow. To make a reaction faster, we add a catalyst. A catalyst is a substance that accelerates the reaction without being consumed in the process. Show the following two reactions to the students and ask them to write down their observations (item 2 of worksheet 3.b). (See the following video to have an idea of the set up [Decomposition of hydrogen peroxide]):

Note. You may use peroxide at 12% (Clear developer 40 volume also works) with this demonstration to make it more impactful for the students. However, this concentration could be dangerous for the students, they should use only peroxide at 3% for their experiments. This is safer, although the reaction time may be slower. If the reaction takes too much time to start, you can mix or shake the mixture a little to speed it up. The reaction could be messy, you may want to perform it inside a plastic container to avoid spills.

Mix in the following order:

- Liquid soap (5 ml), chopped potato (Approx. 20 g), and hydrogen peroxide 12% (30 ml).
- Mix in order potassium iodide (less than 1 tsp), liquid soap (5 ml), and hydrogen peroxide, 12% (30 ml).

10. **Experiment about thermal energy and chemical reactions.** Say: Another property of chemical reactions is if they absorb or release thermal energy. All substances have chemical energy that allow the atoms to stick together. Sometimes, we can use that energy to release thermal energy. However, sometimes all the energy is spent in making new substances. We can see that by measuring the change of temperature. Show the students the following reaction and ask them if they think the temperature increased or decreased.
    - Mix vinegar (30 ml) with baking soda (1 tsp)
11. **Apply the scientific inquiry to determine the change in temperature.** In teams, have the students with the materials for repeating the last two experiments (Peroxide 3%, potassium iodide, vinegar, and baking soda) and thermometers (We do not add liquid soap to avoid additional substances in the experiment). Ask the students to repeat the experiments in teams following the indications of the worksheet 3.b.
12. **Socialization of the results.** Discuss the change of the temperature with the class. Point out that when the temperature decreased, the chemical energy from the reaction was used to form new substances instead of being released in the form of heat.
13. **Introduction to combustion in fossil-fuel power plants.** Say: When the chemical reaction releases thermal energy, we can use it to do some work. One of the natural sources of energy that we have for our power generation system are fossil fuels such as coal, oil, or natural gas. These fuels are burned in the combustion chambers of power plants to create water steam and then electricity. Years ago, we didn't know how to use these fuels; so, people usually used wax and wood as a fuel for light and heat. Ask students to light on the candle and describe the physical and chemical changes that they observe. The students could say:
    - The wax melts

ASSESSMENTS

Pre-Activity Assessment
Check students' verbal responses as they make observations about the videos. Look for their previous knowledge about fossil-fuel power plants and chemical reactions.

Additionally, look for students' previous knowledge about kinetic and potential energy when they are doing the item 4 of the activity. These are important concepts for this and the next two lessons.

Activity Embedded Assessment
Walk around and read the students' responses of worksheet 3.b. to check students' understanding of physical and chemical changes. Be aware of their ability to use scientific inquiry: make observations, formulate hypotheses, collect data, analyze results, conclude the work by evaluating the hypothesis, communicate the results, and formulate future questions.

Post-Activity Assessment
Evaluate for correctness of the Worksheet 3.a. to determine students' understanding of fossil-fuel power plants. Check students comprehension of the learning goals during the closure activities of the lesson.

DUPLICATION MASTERS
- Worksheet 3.a.
- Worksheet 3.b.
- Information sheet - Description of fossil-fuel power plants

- The candle wick is not consume as before
- The wax is being consumed

14. **Description of the combustion principles.** Say: This reaction is called combustion. The wax is made by a compound called paraffin and was used before as fuel to get thermal energy and light energy by burning it. The fuel reacts with oxygen from the air to produce heat. The reaction also produces an undesired product which is carbon dioxide, one of the most contaminant greenhouse gases (GHG). This is one of the reasons for avoiding fossil-fuel power plants. Although burning fuels produce contaminant gases, this process releases a lot of energy that we can use to get electricity or perform work. Let us make a system to use the thermal energy from the combustion of the candle.
Note: You can use lime water (calcium hydroxide) to show the students how the candle produces carbon dioxide (See Chemical reaction candle and lime water experiment). This is an interesting experiment where you can talk more about chemical reactions and the characteristics of combustion.
15. **Experiment with the soda can and candles.** This experiment can be done as a full class demonstration or if your students are mature enough, they could do it per team. Take a previously prepared empty soda can with two holes. Add some water inside and tie a string by slipping it under the pull tab. Attach a ring clamp to a support stand and tie a length of string to the outside edge of the ring. Tie the other end to the fishing swivel about 1 cm below the ring and cut off any extra string. (See: Simple Soda Can Steam Engine).
16. **Prediction of the experiment.** Say/Ask: What do you think will happen when we light the candles and place it below the can? Why do you think that will happen? Heat the can using three candles or an alcohol burner. You will see the can spinning. Conclude with the students if their prediction was accurate or not.
17. **Identify the forms of energy that are involved in the experiment.** Discuss with the students why the can spins and ask them to complete the final questions of worksheet 3.b.

Closure

18. **Review the terms.** Lead a class discussion about the difference between physical and chemical changes, how we can differentiate them, and how we use chemical changes to get energy.
19. **Conclude the lesson.** Say: We have learned a little about chemical energy, and how we can use it in fossil-fuel power plants. The next lesson we are going to learn about another energy that we can use in our power generation system.

LESSON 3

Name_________________________________ Date___________ Period _____

3.a. Worksheet

1. In teams, fill the following table according to the videos and class discussion:

Advantages of fossil fuels	Disadvantages of fossil fuels

2. Complete the blank spaces with the following words and according to the information in the video that you watched about Fossil-fuel power plants and Chemical Energy.

turbine generator kinetic energy combustion chamber electrical energy

a. A _______________________ is an engine or boiler where the fuel mix is burned.

b. When burning fossil fuels, greenhouse gases are produced such as _______________________

c. A _______________________ a device that extracts thermal energy from pressurized steam and uses it to do mechanical work on a rotating output shaft.

d. The _______________________ mechanical energy into electrical power.

e. _______________________ is a type of _______________________ caused by moving electric charges.

3. Explain the different forms of energy that are involved in a thermal power plant (i.e. chemical, mechanical, electrical, etc.).
Response:

Activity 1. Characterization of reagents

1. Complete the following table by analyzing each material from the experiment.

Material	Physical Properties (odor, texture, color, state)
Wax	
Candle wick	
Water	
Food coloring	
Baking soda (Sodium Bicarbonate)	
Vinegar (Acetic Acid)	
Peroxide (Hydrogen Peroxide 3%)	
Chopped potato	
Potassium iodide	
Liquid Soap	

Name_________________________________ Date____________ Period _____

3.b. Worksheet

Activity 2. Physical and Chemical Changes

2. Write down the changes you observed in the following experiments that your teacher performed:

a. Mixture of hydrogen peroxide, liquid soap, and chopped potato
Observations:

Is it a chemical or physical change? Why?

b. Mixture of hydrogen peroxide, liquid soap, and potassium iodide
Observations:

Is it a chemical or physical change? Why?

3. What are the differences you observed during the experiments mentioned above? Describe.
Response:

Activity 3. Thermal Energy

1. Write down the changes in the temperature that you have observed in the following experiments that your teacher performed.

a. Hypothesis Reaction 1: What will happen with the temperature when you mix peroxide with potassium iodide?

b. Hypothesis Reaction 2: What will happen with the temperature when you mix vinegar with baking soda?

2. Experiment: Measure the initial temperature and final temperatures after 2 minutes

Reaction	Initial Temperature	Final Temperature
Peroxide 3% + Potassium Iodide		
Vinegar + Baking Soda		

3. Analysis and conclusions: Evaluate your hypothesis based on the data.

Activity 4. Combustion

1. Explain with your own words what a combustion is?

2. What different forms of energy are involved in the can's experiment?

LESSON 3

Name________________________________ Date___________ Period _____

3.a. Worksheet - Possible Answers

1. In teams, fill the following table according to the videos and class discussion:

Advantages of fossil fuels	Disadvantages of fossil fuels
• Abundant and accessible resource • Source of generous amount of concentrated energy • Low cost • Easy transportation	• Not green sources of energy increasing global warming • Non-renewable energy sources • The drilling process may be dangerous • It causes acid rain by releasing sulfur dioxide gas when it burns.

2. Complete the blank spaces with the following words and according to the information in the video that you watched about Fossil-fuel power plants and Chemical Energy.

turbine generator kinetic energy combustion chamber electrical energy

a. A __ combustion chamber_____________ is an engine or boiler where the fuel mix is burned.

b. When burning fossil fuels, greenhouse gases are produced such as _carbon dioxide________

c. A ______turbine_________ a device that extracts thermal energy from pressurized steam and uses it to do mechanical work on a rotating output shaft.

d. The _______generator_________ mechanical energy into electrical power.

e. __Electrical energy_______ is a type of __Kinetic energy________ caused by moving electric charges.

3. Explain the different forms of energy that are involved in a thermal power plant (i.e. chemical, mechanical, electrical, etc.).
Response: Mechanical Energy, thermal energy

Name_________________________________ Date___________ Period _____

LESSON 3

(1/3) 3.b. Worksheet - Possible Answers

Activity 1. Characterization of reagents

1. Complete the following table by analyzing each material from the experiment.

Material	Physical Properties (odor, texture, color, state)
Wax	Solid at room temperature Color may vary Smooth texture Low odor
Candle wick	Stiffness texture Neutral color Solid Low odor
Water	Neutral odor Liquid Wet texture Colorless
Food coloring	Color may vary Odor may vary Solid state Coarse texture
Baking soda (Sodium Bicarbonate)	White color Solid Powder Not odor
Vinegar (Acetic Acid)	Colorless Liquid Some odor
Peroxide (Hydrogen Peroxide 3%)	Colorless Liquid Some odor
Chopped potato	Yellow Solid Liquid texture – soft Cubes shape
Potassium iodide	White color Solid Powder Not odor
Liquid Soap	Color may vary Liquid Odor may vary

3.b. Worksheet - Possible Answers

2. Write down the changes you observed in the following experiments that your teacher performed:

a. Mixture of hydrogen peroxide, liquid soap, and chopped potato
   Observations: Foam starts forming slowly from the mixture. It has a white color.

   Is it a chemical or physical change? Why?
   Chemical, some bubbles are forming, and almost all the physical properties are different compared to the initial pure substances.

b. Mixture of hydrogen peroxide, liquid soap, and potassium iodide
   Observations: Same as previous experiment but producing much more foam and faster.

   Is it a chemical or physical change? Why?
   Chemical, some bubbles are forming, and almost all the physical properties are different compared to the initial pure substances.

3. What are the differences you observed during the experiments mentioned above? Describe.
   Response: The reaction with the potassium iodide is much faster and “stronger” than the reaction with chopped potato. Both are chemical reactions, but the potassium iodide acts better as a catalyst than chopped potato.

Name________________________________ Date___________ Period _____

LESSON 3

(3/3) **3.b. Worksheet - Possible Answers**

Activity 2. Change of temperature (thermal energy)

1. Write down the changes in the temperature that you have observed in the following experiments that your teacher performed.

a. Hypothesis Reaction 1: What will happen with the temperature when you mix peroxide with potassium iodide?
   Students can say the temperature will increase, or the temperature will decrease.

b. Hypothesis Reaction 2: What will happen with the temperature when you mix vinegar with baking soda?
   Students can say the temperature will increase, or the temperature will decrease.

2. Experiment: Measure the initial temperature and final temperatures after 2 minutes

Reaction	Initial Temperature	Final Temperature
Peroxide 3% + Potassium Iodide	23.3° C	37.9 °C
Vinegar + Baking Soda	28 °C	23 °C

3. Analysis and conclusions: Evaluate your hypothesis based on the data.
Students should recall their initial hypothesis and conclude based on the data. The temperature increases in the reaction of peroxide and decreases in the reaction of vinegar.

Activity 3. Combustion

1. Explain with your own words what a combustion is?
Combustion is a process of oxidation that leads to the consumption of fuel and the oxidizer as the heat and light is released.

2. What different forms of energy are involved in the can's experiment?
The chemical energy stored in the wax of the candle is transformed in light and heat through the reaction of combustion. Then, the thermal energy of the heat is transported to the can and the water making the water boils. Thus, the thermal energy of the boiling water is transformed into mechanical energy when the can start spinning.

LESSON 4 Wind Turbines and Hydro power Plants

LESSON OBJECTIVES

Students will be able to:

- Identify the fundamental parts of a wind turbine and hydro power plant.
- Explain how the power generating plant transforms kinetic energy into electrical energy.
- Describe the relationship between kinetic energy and the speed of the wind.

TIME REQUIRED

Two 50-minute periods

MATERIALS

Per classroom:

- 1 Engineering Design Process Poster
- Digital technologies for videos

Per team:

- 1 Multimeter
- 1 LED
- 1 - 100 Ohm Resistor
- 4 alligator cables
- Wind Turbine Kit:

» EUDAX Kit (https://www.amazon.com/ search for EUDAX DIY DC Power Micro Motor Wind Turbine Electricity Generator Blades Model)
  - 1 x Micro generator DC motor
  - 1 x Hobby motor propellers
  - 1 x Quick wire connector

» Vernier kit: This option is a little more expensive, but the results are more precise.
  - Blades: 8- inch diameter wind turbine blades (https://www.vernier.com/product/kidwind-red-blade-set/)
  - DC Motor: shaft, generator, wires https://www.vernier.com/product/high-torque-generator-with-wires/

Lesson Summary

Students will work on the science concepts related to the second and third available electrical generating plant for their designs: wind turbines and small hydro power plants. They will learn how air and water movement can be used to produce electrical energy. As the air or water passes through the blades of the turbine, they cause the attached electrical generator to produce electrical current. Students will use the physics of wind energy to understand the relationship between kinetic energy and speed based on experimental data.

Background

Teacher Background

Temperature changes in an area cause air movement, known simply as the wind. The wind movement can do work moving objects. The faster the wind moves over an object the lower the pressure becomes over that object. A wind turbine's blades are nothing more than a wing, similar to an airplane wing. As wind moves over the top and bottom, the wind across the top must move faster causing pressure or the force to drop. The pressure under the blade is greater than on top of the blade and this difference generates lift to make the wing go up. Now instead of making an airplane go up it is rotated 90 degrees and allows the wind to pass and causes a spinning motion on the rotor. Again this spinning motion causes the generator to spin and produce electricity.

Both air and water are considered fluids, just having different densities. So for hydro power the same principles apply for a hydro power turbine as the air turbine. The movement of the fluid across the blade top and bottom causes a difference in force between the two regions. The bottom force is greater and pushes the turbine to rotate. The end of the turbine is connected to a generator that produces electricity.

In order to measure the amperage or the flowing electrons in a circuit, the meter must be setup in a series fashion to have the current pass through it. The setup to do so is depicted in this video:
https://www.youtube.com/watch?v=fxz8MO9LvAQ
Here is a video on wind turbines:
https://www.youtube.com/watch?v=qSWm_nprfqE
Here are videos on hydro power using the falling or movement of water to spin a generator.
https://www.youtube.com/watch?v=RqmnksWL5Pk

Energy is the ability to do work. It is a quantitative property that must be transferred into an object or substance to be able to do work. Throughout the unit, the students will use several different units (volts, amperes, ohms, meter per second, watts, etc.). Depending on the previous knowledge of your students, you may want to do an additional lesson to review IS and conversions. Some important concepts are:

- The work is moving an object or transferring a material from one state to another. The units are Joules.
- Power is a rate. It is the measure of energy expended over time. This is

Joules/sec.

- The force pushing electrons through a circuit is known as Voltage. The units are Volts.
- The movement of electrons from a positive lead through a circuit to a negative lead is known as current. The units are Amperage.

Vocabulary:

Word	Definition
Kinetic Energy	Energy which a body possesses by virtue of being in motion
Mechanical Energy	Energy related to an objects' motion
Wind Turbine	Device that converts the wind's kinetic energy into electrical energy
Hydro power	A form of energy derived from the conversion of free-falling (and moving) water.
Hydro Turbine	A machine that converts the kinetic energy of falling water into mechanical energy by use of a rotating shaft connected to spinning blades.

Before the Activity

Documents to print:

- Worksheet 4.a
- Worksheet 4.b.
- Information sheet

Videos to prepare:
For the teacher:

- Measuring current with a multimeter (https://www.youtube.com/watch?v=fxz8MO9LvAQ)
- How do wind turbines work? (https://www.youtube.com/watch?v=qSWm_nprfqE)
- Hydro power (https://www.youtube.com/watch?v=RqmnksWL5Pk)

For the class:

- Hydro power (https://www.youtube.com/watch?v=q8HmRLCgDAI)
- Working of wind turbine (https://www.youtube.com/watch?v=y6fG-aIP_PU)

Classroom Instruction`

Introduction

1. **Tie in to the engineering problem.** Say/Ask: We learned about fossil-fuel power plants in the last lesson. Why is that important? What is our engineering design problem? What electrical power generating plants do we have available? Take the students' answers as a prompt to recall the engineering design problem, the criteria, and constraints.
2. **Identify where they are in the engineering design process. (Learn).** Use the Engineering Design Process poster and students' Engineering Design Process sliders to help students identify what they have done so

Per student:

- 1 Engineering Notebook
- 1 Engineering Design Process slider

STANDARDS ADDRESSED

Next Generation Science Standards:
MS-PS3-1. Construct and interpret graphical displays of data to describe the relationships of kinetic energy to the mass of an object and to the speed of an object

Common Core Mathematics:
MP.4 Model with mathematics.

6.SP.B.4 Display numerical data in plots on a number line, including dot plots, histograms, and box plots.

LESSON 4 Wind Turbines and Hydro power Plants

far and what step they are currently on.

3. **Identify what students still need to learn about.** Say: We have been learning about science concepts that will help us design a solution for the engineering challenge. What have we already learned about? Review with the students the concept of physical change, chemical reaction, and chemical energy. Say: Similar to the last lesson, today we are going to learn about other sources of energy that we have available: the kinetic energy from the wind and the rivers, and how we can use that energy to get electricity for the power grid.

Activity

4. **Introduction to hydro power plants.** Say/Ask: We could construct hydro power plants to use in our electrical power generating system. Has anyone ever seen a hydro power plant? Let's see the following video to understand how they work and, based on that, decide if we want to utilize one for our design. (Hydro power 101). Have students read the information sheet of the hydro power plant to identify which type of plant (run-of-the-river hydro power plant) we have available for our system.
   Note: Small run-of-the-river hydro power plants do not need dams because they use the kinetic energy from flowing rivers.
5. **Introduction to wind turbines.** Say/Ask: Wind turbines are another source that we can use to generate electricity. They have similar working principles to hydro power plants. What aspects do you think they have in common? Let's see this other video and compare both plants (How do wind turbines work?) Have students read the description section of the information sheet of wind turbines. Lead a class discussion about the generating plants and ask students to complete the worksheet 4.a.
   Note: Take this moment to check students previous knowledge of electricity concepts such as voltage, current, resistance, and power. Ensure that students are familiar with all of these concepts. If resistance is a new concept, you can show students this video to explain What is a resistor?. Modify the following steps appropriately.
6. **Distribute materials for the experiment.** Say: We are going to learn the physics and principles of the wind turbines. Specifically, how the wind energy is converted into electricity power. Split the class into the engineering teams and pass around the wind energy kits (DC motor, rotor blade, fan, multimeter, LED, alligator clips, and 100 Ohm resistor). Have students follow the diagram of item 1, worksheet 4.b.
7. **Test of the wind turbine with the LED.** Guide the students connecting the blades to the DC motor. Then, connect the motor to the LED (If the LED does not light and the generator is moving, try exchanging the cables from the motor to the LED. It may be wrongly polarized). Have students turn on the fan and place the wind turbine close enough to make the LED turn brighter. Take this opportunity to remind the students of the parts and working principles of the wind turbine.
   Note: Sometimes the torque generated by the LED requires moving the blades manually before putting the turbine near the fan.
8. **Measure at least four wind speeds.** Have students measure four

EDUCATOR RESOURCES

- Kinetic energy definition extracted from saveonenergy.com (https://www.saveonenergy.com/learning-center/kinetic-potential-energy/#:~:text=Kinetic%20Energy%20is%20defined%20as,virtue%20of%20being%20in%20motion)
- Mechanical Energy definition extracted from teachingengineering.org (https://www.teachengineering.org/lessons/view/cub_dams_lesson04)
- Wind Turbine definition extracted from apps.leg.wa.gov (https://apps.leg.wa.gov/wac/default.aspx?cite=504-49-400)
- Hydro power definition extracted from teacherengineering.org (https://www.teachengineering.org/lessons/view/cub_dams_lesson04)
- Hydro Turbine definition extracted from teacherengineering.org (https://www.teachengineering.org/lessons/view/cub_dams_lesson04)

DUPLICATION MASTERS

- Worksheet 4.a
- Worksheet 4.b.
- Information sheets 2 and 3

different wind speeds using an anemometer and record their values in the Worksheet 4.b. Remind students the units for distance (meter) and for speed (meter per second) and the prefixes of the units.
Note: You can use a fan with different wind speed options placing the anemometer near the fan (Around 3 cm from the blades). You can also place the anemometer at four different distances from the fan (Around 2 cm, 10 cm, 25 cm, and 50 cm). Remind the students to measure and always use the same distances from the fan with the anemometer or the wind turbine.

9. **Measure the electrical current produced by the wind turbine.** Ask students to replace the LED with a 100 Ohm resistor and connect the multimeter in series with the engine and resistor. Have students place the wind turbine at the four different wind speeds and record the electrical current in the worksheet 4.b. You may need to remind students the concepts of voltage, current, and resistance for an electrical circuit.
10. **Compute the power generated by the wind turbine and plot it.** Ask students to convert the milliamperes to amperes by multiplying the value by 0.001. Then, they can compute the power of the wind turbine per each wind speed in watts by applying the formula W=I^2*R (where I is electrical current in Amperes and R is resistance in ohms). Plot the wind speed versus the power.
Note: Explain the difference between power and energy to students. You can multiply the turbine power by 60 to determine how much energy is produced after one minute of operation if the power is maximum. Energy is directly proportional to the power.
11. **Discuss the relationship between energy and speed.** Lead a class discussion about the trend of their graphs and how the power or energy produced by the wind turbine is proportional to the wind speed. You may ask questions about its implications for our power generation system. For example: Can there be too much wind? Does it level off? Most turbines have to shut down at a certain point. Ask students to finish the worksheet 4.b.
12. **Explain the relationship between power and the engineering problem.** Say/ask: Take out the information sheet and read the available sizes that we have for hydro power plants and wind turbines. Usually, the providers sell the generating plants in terms of how much power they produce. How much power do we need for our power grid?

Closure

13. **Review the lesson concepts.** Review with the students the concepts of kinetic energy and how hydro power plants and wind turbines generate electricity.
14. **Conclude the lesson.** Say/ask: Today, we learned about two other generating plants that we have available to supply New Albany with electrical energy. Can you tell me something that you learned by doing this lesson? How could you improve the experiments to get better results? Do you have any questions so far? How can you self-evaluate your learning? What else do we need to design the power generation system?

ASSESSMENTS

Pre-Activity Assessment
Check students' verbal responses as they make observations about the videos. Look for their previous knowledge about wind turbines, hydroelectric plants, and electricity.

Activity Embedded Assessment
Walk around and ask students reflection questions about the experiment with the DC motor. For example, why is the current decreasing with less wind? How could be a better shape for the blades? How could the blades of a hydro turbine be? Is the current always the same or it is fluctuating?

Post-Activity Assessment
Evaluate for correctness of the Worksheet 4.a. to determine students' understanding of wind turbines and hydro power plants. Check students' comprehension of the learning goals in the items 5 and 6 of the worksheet 4.b. and during the closure activities of the lesson.

LESSON 4

Name___________________________________ Date____________ Period _____

4.a. Worksheet

1. Complete the blank spaces using the following words and according to the information in the video about wind turbines and hydro power.

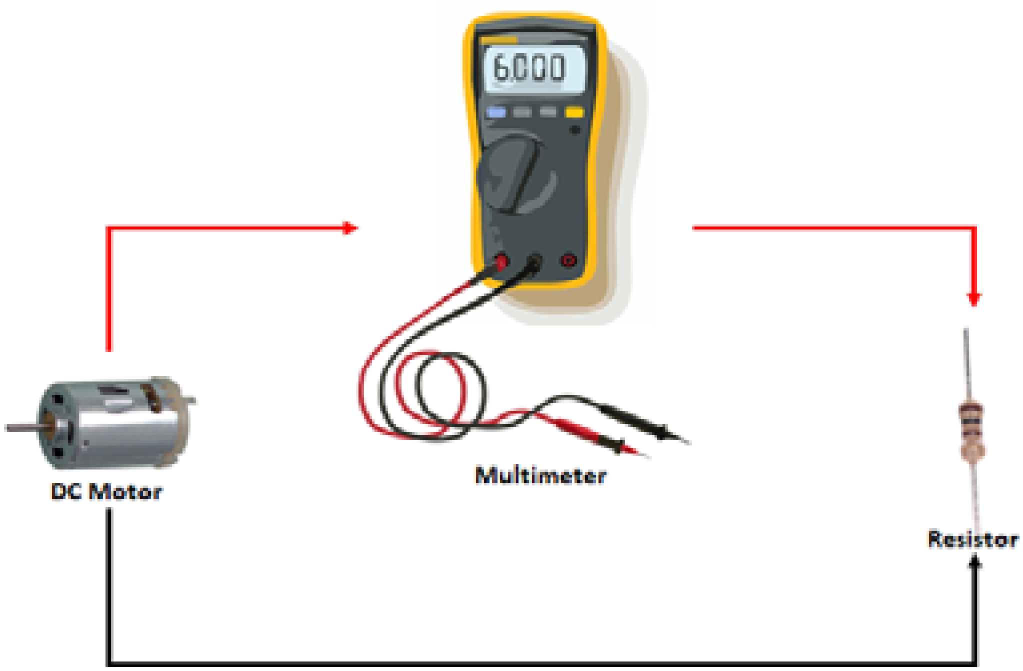
kinetic energy   generator   electrical energy   turbines   mechanical energy

The movement of the wind or the flowing of the water in rivers interacts with a_________________ produce electricity. It has a rotor with blades that converts the ______________________ and rotate, turning it into __________________________________. The rotation of the rotor allows the ___________________ to produce ______________________.

2. Explain the different forms of energy that are involved in hydro power plants and wind turbines
Response:

4.b. Worksheet

1. Connect the multimeter in series with the DC motor and the resistor to measure the current. Switch the multimeter in the milliamperes section (mA). Use the following diagram as a guide:



2. Record your measurements of wind speed and current in the following table. Ignore the power column for now.

Wind speed (m/s)	Current (mA)	Power (W)

3. Convert the units from milliamperes to amperes and compute the power produced by each wind speed using the following formula (Record your values in the above table):

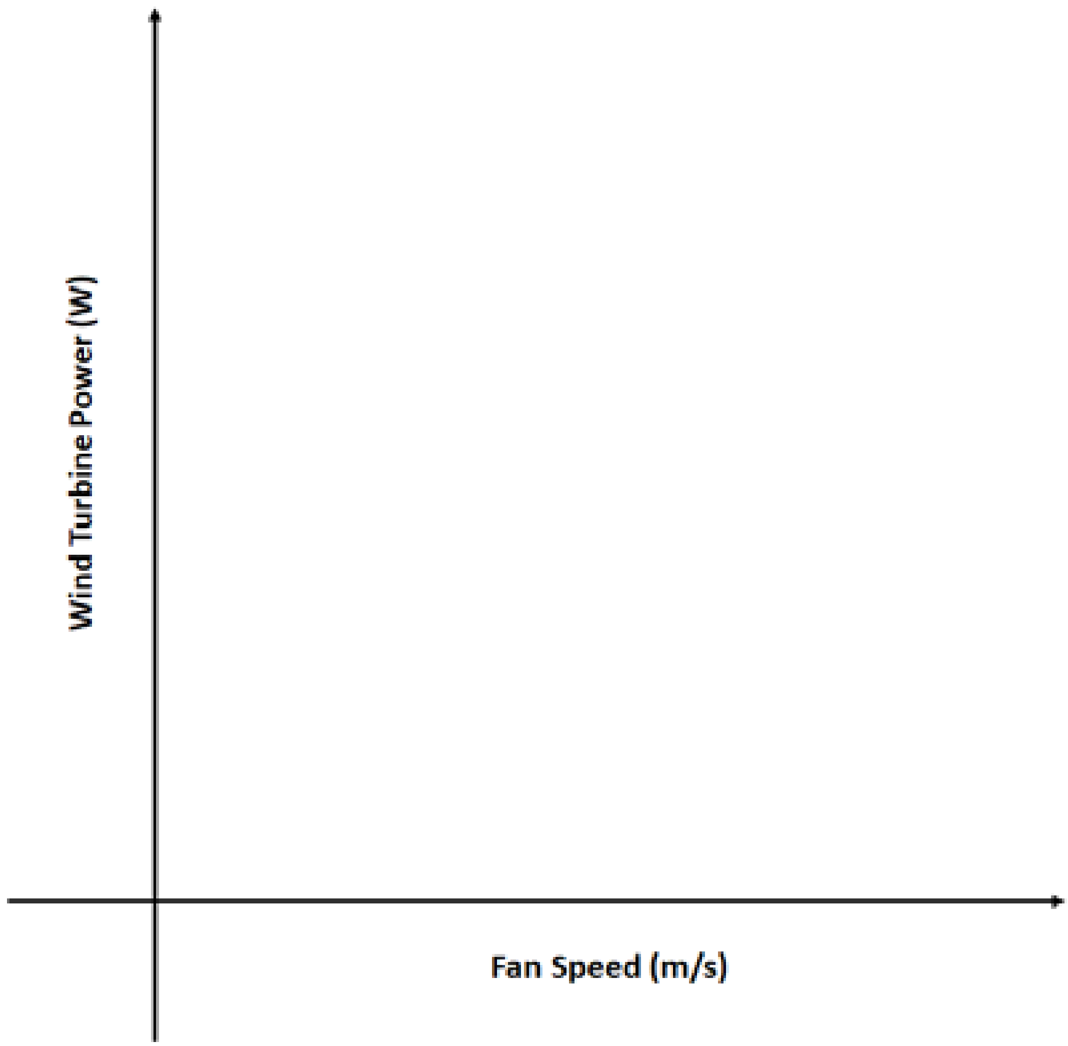
P = I^2 * R

P=Power (W)
I=Electrical current (Amperes)
R= Resistance (Ohms)

Name____________________________________ Date____________ Period _____

4.b. Worksheet

4. Plot a graph comparing speed of the wind and the wind turbine power (which is proportional to the kinetic energy) based on the previous table results.



5. How does the wind turbine power change according to the fan speed?

6. How the relationship between electrical power and wind speed can influence our prototype?

Name___________________________________ Date____________ Period _____

LESSON 4

4.a. Worksheet- Answers

1. Complete the blank spaces using the following words and according to the information in the video about wind turbines and hydro power.

kinetic energy generator electrical energy turbines mechanical energy

The movement of the wind or the flowing of the water in rivers interacts with a____turbine__________ produce electricity. It has a rotor with blades that converts the _____kinetic energy_______ and rotate, turning it into _________mechanical energy_________. The rotation of the rotor allows the ______generator____ to produce ______electrical energy_____.

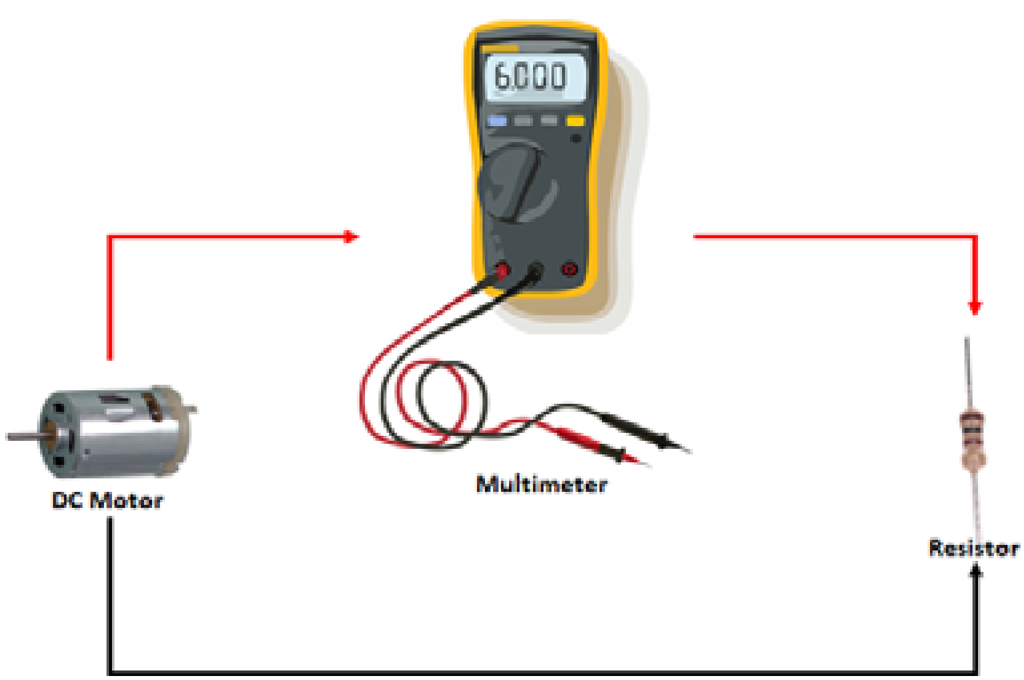
2. Explain the different forms of energy that are involved in hydro power plants and wind turbines
Response:
There is potential energy store in the air and water. When they get move by some force, the potential energy is released as kinetic energy that impacts the blades of a turbine. The turbine transforms the kinetic energy from the wind or water flowing into mechanical energy. Then, the mechanical energy is transformed into electrical energy through the generator.

LESSON 4

Name_______________________________ Date___________ Period _____

4.b. Worksheet Answers

1. Connect the multimeter in series with the DC motor and the resistor to measure the current. Switch the multimeter in the milliamperes section (mA). Use the following diagram as a guide:



2. Record your measurements of wind speed and current in the following table. Ignore the power column for now.

The values depend a lot on the students' set up, but the trend shows in the plot 4 should be kept

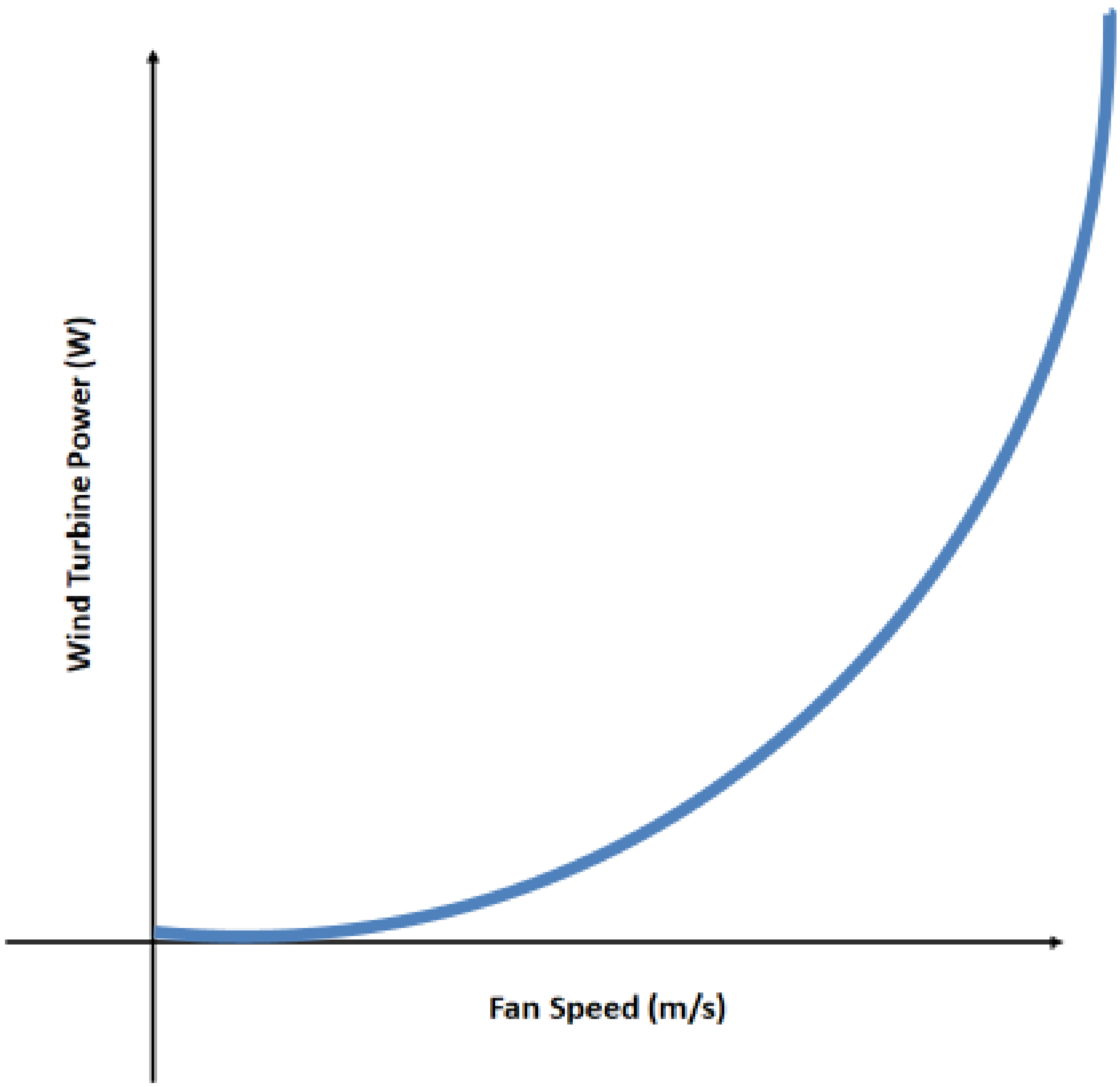
Wind speed (m/s)	Current (mA)	Power (W)

3. Convert the units from milliamperes to amperes and compute the power produced by each wind speed using the following formula (Record your values in the above table):

$$P = I^2 * R$$

P=Power (W)
I=Electrical current (Amperes)
R= Resistance (Ohms)

4. Plot a graph comparing speed of the wind and the wind turbine power (which is proportional to the kinetic energy) based on the previous table results.



5. How does the wind turbine power change according to the fan speed?

The fan speed is directly proportional to the power. The relationship is not linear. The power of the wind turbine changed according to the amount of kinetic energy generated by the fan (speed). Students might realize that distance can also have effect on the current. Farther distance generates less current because the wind speed decreases since the wind needs a longer time to reach the turbine

6. How the relationship between electrical power and wind speed can influence our prototype?

The amount of electrical power produced by the generator depends on the wind speed. Students should locate the wind turbines in places where the wind speed is higher. For example, higher areas where there are not tall trees and buildings are better. As a rule, higher wind turbines are better but more expensive.

LESSON 5 Solar Panels and Radiant Energy

LESSON OBJECTIVES

Students will be able to:

- Comprehend that solar radiation is energy made up of different wavelengths
- Relate the light's wavelength with the amount of electrical current produced by the solar panel.

TIME REQUIRED

Two 50-minute periods

MATERIALS

Per classroom:

- 1 Engineering Design Process Poster

Per team:

- 1 LED
- 1 Solar Panel
- 100 W white daylight LED lamp (Around 1600 lumens)
- Multimeter
- 100 Ohm Resistor
- 4 alligator cables
- Multiple colors of cellophane

Per student:

- 1 Engineering Design Process slider

Lesson Summary

Students will work on the science concepts related to the fourth available electrical generating plant for their designs: solar panels. They will learn about the radiant energy of light and how it can be used to generate electricity. They will learn about the speed of light and how this is used to determine the energy associated with each frequency of light. By doing experiments and analyzing data, they will review the properties of light in the context of solar photo voltaic panels.

Background

Teacher Background

The wave-particle duality of light is a difficult concept for students and people overall. In this lesson, students will have an introduction to this phenomenon. Light can be studied as a set of particles called photons that are moving and waving at specific wavelengths. Each photon has its own wavelength and frequency with more or less energy that we can use in photo voltaic panels. These photons interact, collide with the electrons of the solar panel' atoms; so, they can move through an electrical circuit. The following video helps to understand duality nature of light:

https://www.youtube.com/watch?v=J9q1jwtuYho

The sun produces light in all wavelengths, and each wavelength has a different amount of radiant energy. This energy is absorbed by photo voltaic solar panels and transformed in electrical current. The wavelengths that human beings can see (known as visible light) are red, orange, yellow, green, blue, indigo, and violet, also known by the acronym, ROY G. BIV. Each wavelength has a specific energy level associated with it. The shorter the wavelength - the more energy. Red wavelength (long) has less energy than blue wavelengths (short) of light. Waves can be reflected, absorbed, and transmitted. A solar panel absorbs wavelengths and causes electrons to be liberated or to be freed from within the material. These free electrons with a negative charge are attracted to positive ends of the solar panel. As the electrons move, this causes electric current to flow. The shorter wavelength (blue light) will cause more electrons to be liberated than longer wavelengths (red light). Modern solar panels are built using layers of multiple materials to improve their efficiency; they can easily absorb the limited amount of energy from long wavelengths. In this lesson, the white bulb will simulate the light being emitted by the sun and cellophane will be used to filter different wavelengths.

Here is a video on the explanation of how solar panels work:
https://www.youtube.com/watch?v=xKxrkht7CpY

The below table shows the typical amount of energy released by each color of light with the respective wavelength.

Color	Energy (J)
Red ($\lambda=700\times10^{-9}$ m)	2.8×10^{-19} J
Orange ($\lambda=600\times10^{-9}$ m)	3.3×10^{-19} J

Yellow (λ=570×10^{-9} m)	3.4×10^{-19} J
Green (λ=500×10^{-9} m)	3.9×10^{-19} J
Blue (λ=450×10^{-9} m)	4.4×10^{-19}J
Indigo (λ=400×10^{-9} m)	4.9×10^{-19}J
Violet (λ=380×10^{-9} m)	5.2×10^{-19}J

Vocabulary:

Word	Definition
Solar	Related to energy from the sun as a source
Solar-Induced Current	Movement of electrons from solar energy
Solar Panel	Device that converts solar energy into electrical current
Plank's Constant (h)	A constant multiplied by a photon's frequency is equal to a photon's energy. h= 6.62×10^{-34} J•s
Speed of Light (c)	Speed at which light waves propagate through different materials. It is approximately 3.0×108 m/s
Wavelength (λ)	The length from zero that a wave possesses along the horizontal axis
Frequency (f)	The number of repetitions a wavelength can make in 1 second.
Absorption	Process in which matter accepts a wave without repelling it.

Before the Activity

Documents to print:

- Solar panel information sheet
- Worksheet 5.a.
- Worksheet 5.b.

Videos to prepare:
For the teacher:

- How do solar panels work? (https://www.youtube.com/watch?v=xKxrkht7CpY)

Classroom Instruction`

Introduction

1. **Tie in to the engineering problem.** Say/Ask: We have experienced different sources of energy for our electrical power generating system and today we will see how the energy of the Sun called radiant energy can be used to power things here on Earth.
2. **Identify where they are in the engineering design process. (Learn).** Use the Engineering Design Process poster and students' Engineering Design Process sliders to help students identify what they have done so far and what step they are currently on. Remind the students the concepts of chemical energy in the context of fossil-fuel power plants, and kinetic

STANDARDS ADDRESSED

Next Generation Science Standards:

MS-PS4-1. Use mathematical representations to describe a simple model for waves that includes how the amplitude of a wave is related to the energy in a wave.

MS-PS4-2 Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials.

Common Core Mathematics:
MP.4 Model with mathematics.

6.SP.B.4 Display numerical data in plots on a number line, including dot plots, histograms, and box plots.

Solar Panels and Radiant Energy

EDUCATOR RESOURCES

- Speed of light, definition extracted from Britannica.com (https://www.britannica.com/science/speed-of-light)

DUPLICATION MASTERS

- Information sheet 4(Solar panel)
- Worksheet 5.a.
- Worksheet 5.b.

energy in the context of hydro power plants and wind turbines.

3. **Identify what students still need to learn about.** Say: What generating system haven't we studied yet? Today, we are going to learn about how solar panels can generate electricity to meet our engineering requirements.

Activity

4. **Introduction to solar panel farms.** Say/ask: Have you seen before a solar farm? Who can tell me how the solar panels are arranged? How do they work? Take advantage of the students' answers to introduce the topic. The working principles of solar panels are challenging for students; you can use analogies such as photosynthesis to make it easier for them. Have students read in teams the first part (description and available sizes) of the solar panel information sheet.
5. **Convert wavelengths of different colors to energy levels (J).** You may want to use the equation $E=h\cdot f=hc/\lambda$; with this students will be able to determine the amount of energy that each wavelength of light possesses. Have the students populate the table below substituting the wavelength (λ) from the color column into the formula column. The result for the energy for that wavelength will be put in the E column with a unit of Joules (J). The E column is populated for end comparison (Worksheet 5.a.). After the calculation, say/ask: we are going to do an experiment with a real solar panel to see how different wavelengths or frequencies can generate different amounts of electrical current.
   Note: This activity may be demanding for students with a limited math and physics background. If you prefer you can skip the calculation of the energy, and, instead, focus on explaining that energy is proportional to a very tiny number called h (Planck's constant) and the color of the light which is its frequency ($E=h\cdot f$).
6. **Check the functioning of the solar panel and explain its functioning.** Have students connect a LED to the solar panel and use the 100 W lamp to turn it on. Say/ask: Can somebody explain to me how the electrical energy is produced? Use the students' responses to briefly remind the students the three properties of any wave: reflection, refraction, and absorption. Say: the radiant energy from the bulb light interacts with the solar panel. This panel absorbs light at specific wavelengths to produce the movement of electrons and turn on the LED.
7. **Explain the characteristics of the sunlight or the white light (100 W bulb).** Say/Ask: We are using a bulb to represent the sunlight. Both are sources of light with many wavelengths. Each wavelength provides the solar panel with some energy; if we remove or filter the wavelengths, the panel would get a different amount of energy. Let's make an experiment to see how filtering the light impacts the amount of current produced by the solar panel.
8. **Connect the multimeter and measure the current.** Say/Ask: We are going to take advantage that cellophane absorbs certain light wavelengths and let others pass through. Put the cellophane in front of the light bulb and tell me how the light's color changes. You can see, for example, blue cellophane absorbs most of wavelengths and lets mostly blue light cross

through. Now let's measure the current produced by the solar panel with these filtered light. Have students replace the LED of the previous experiment for a resistor of 100 Ohm and connect the multimeter in series with the panel and the resistor. Place the multimeter into amperage mode and measure current produced by the solar panel when it is covered by different colors of cellophane. Ask students to fill the table of item 1, Worksheet 5.b.

9. **Plot and discuss the energy versus the current. Have students complete the item 2 and 3 of Worksheet 5.b. and discuss the trend of the graph.**
   Note: The measures of current maybe not be totally proportional to the amount of energy. Some panels are improved by using layers of different materials, so they can respond efficiently even if the source of light has been filtered. Make emphasis on the change of the current when the students use different filters, instead of the specific values.

Closure

10. **Conclude and review concepts.** Say/ask: The light from the sun is made up of different wavelengths. These different wavelengths vary in energy levels. According to these different energy levels, the solar panel produces less or more electrical energy. Which wavelength produced the greatest and the less amount of current? How does this information help us to improve our design? Where should we locate the solar panels of our electrical power generating system? Help students to connect the science concepts with their prototype and ask them to finish the worksheet 5.b. For example, they can think about positioning the solar panels in places where the radiant or light energy is maximum; thus, the maximum energy can be obtained.

ASSESSMENTS

Pre-Activity Assessment
Check students' verbal responses during numeral 4 of the activities section. According to their previous knowledge of waves and light, you may need to extend the lesson to assure students have the basic background knowledge.

Activity Embedded Assessment
Walk around and ask students reflection questions about the experiment with the solar panel. Some questions are embedded in the numbers 6, 7, and 8 of the activity section.

Post-Activity Assessment
According to your criteria, evaluate how well students constructed the graph, analyzed the trend and made connections with the engineering problem (items 2, 3, and 4 of Worksheet 5.b.) Check students' comprehension of the learning goals during the closure activities of the lesson.

LESSON 5

Name_________________________________ Date____________ Period _____

5.a. Worksheet - Energy Calculation

1. Calculate the energy generated by each wavelength of light using the below formula. Complete the table with your results.

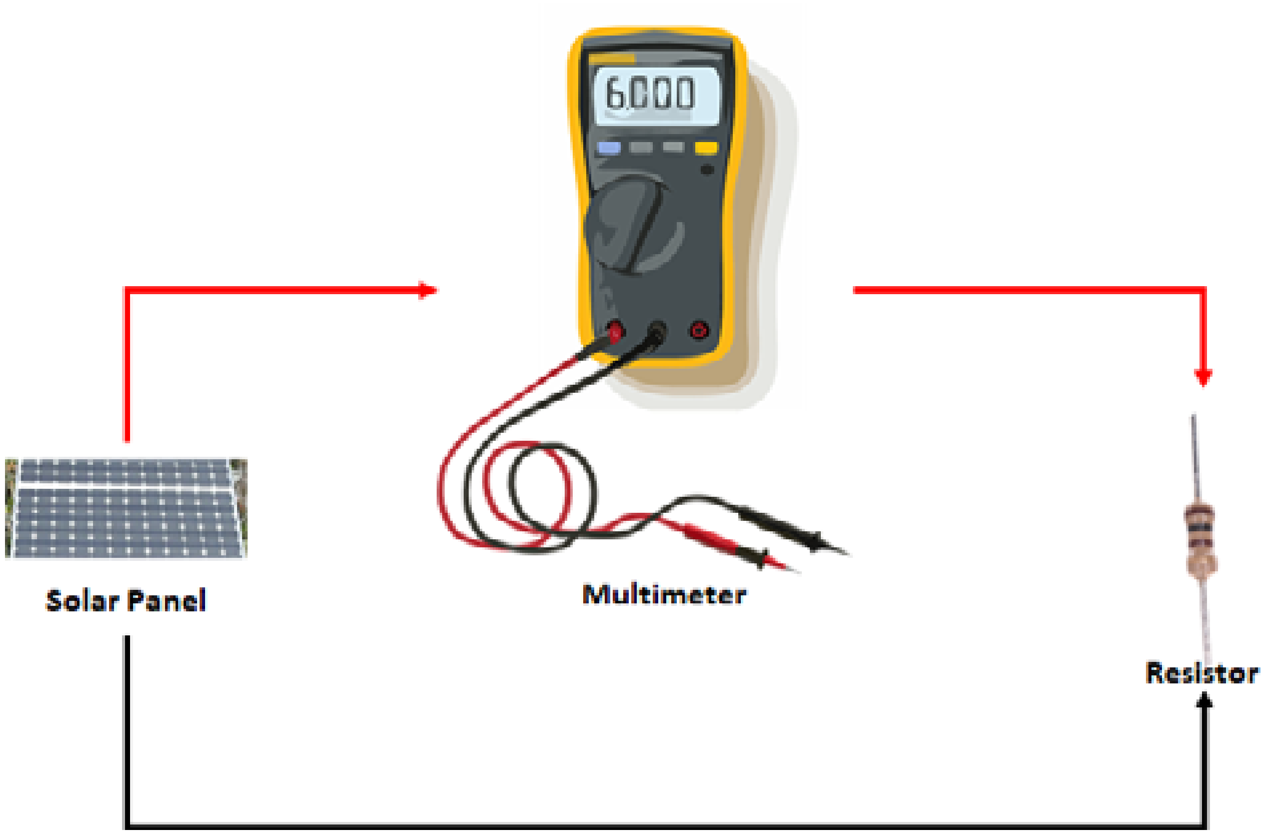
$$E(J)=hc/\lambda= (6.62\times10^{-34}\ J\cdot s)(3.0\times10^{8}\ m/s)/\ \lambda$$

Color	Energy (J)
Red ($\lambda=700\times10^{-9}$ m)	
Orange ($\lambda=600\times10^{-9}$ m)	
Yellow ($\lambda=570\times10^{-9}$ m)	
Green ($\lambda=500\times10^{-9}$ m)	
Blue ($\lambda=450\times10^{-9}$ m)	
Indigo ($\lambda=400\times10^{-9}$ m)	
Violet ($\lambda=380\times10^{-9}$ m)	

Name_________________________________ Date___________ Period _____

1/2 5.b. Worksheet - Current Measurement

1. Connect a 100-Ohm resistor in series with the multimeter and the solar panel according to the following diagram. Then, measure the current produced by the solar panel when it is covered by each color of cellophane

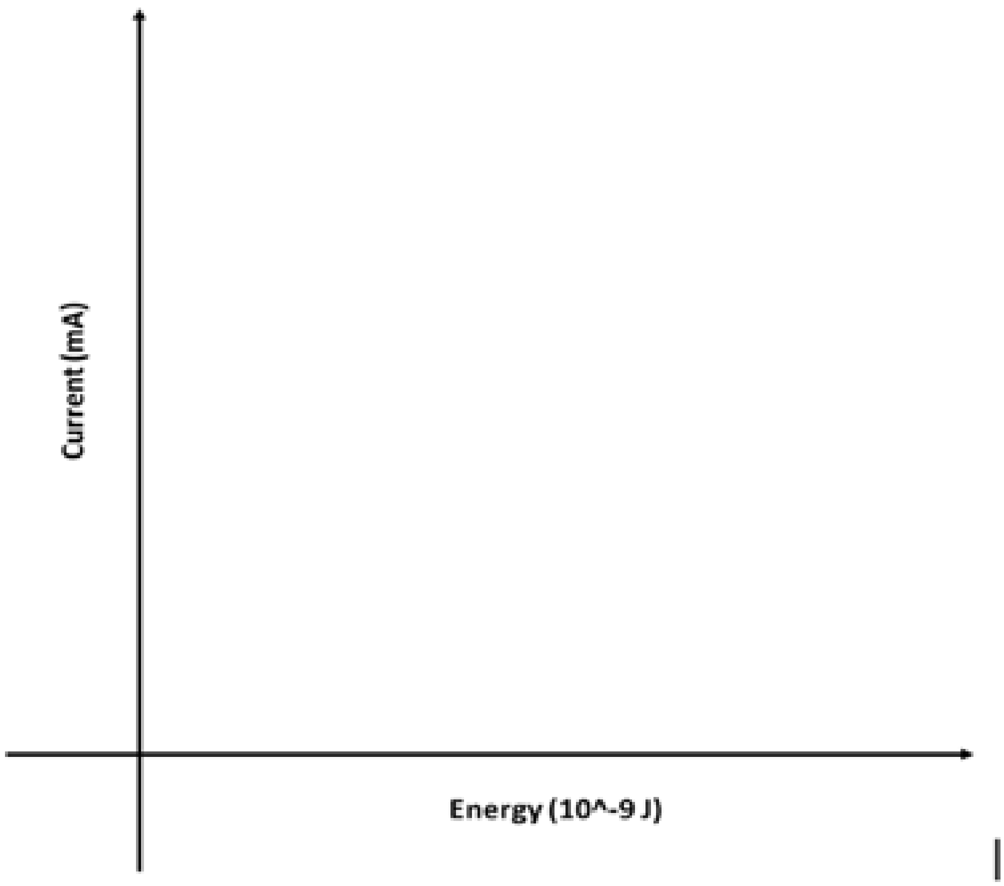


Cellophane Color	Energy (J)	Current (mA)
Red	2.8×10^{-19} J	
Orange	3.3×10^{-19} J	
Yellow	3.4×10^{-19} J	
Green	3.9×10^{-19} J	
Blue	4.4×10^{-19}J	
Indigo	4.9×10^{-19}J	
Violet	5.2×10^{-19}J	

Name________________________________ Date___________ Period _____

5.b. Worksheet - Current Measurement

2. Plot in the following diagram the energy and current.



3. What is the relationship between the energy being absorbed from the wavelength and the amount of current being produced?

4. How do these scientific concepts help us to improve the design of our electrical power generating system?

Name________________________________ Date____________ Period _____

LESSON 5

5.a. Worksheet - Answers

1. Calculate the energy generated by each wavelength of light using the below formula. Complete the table with your results.

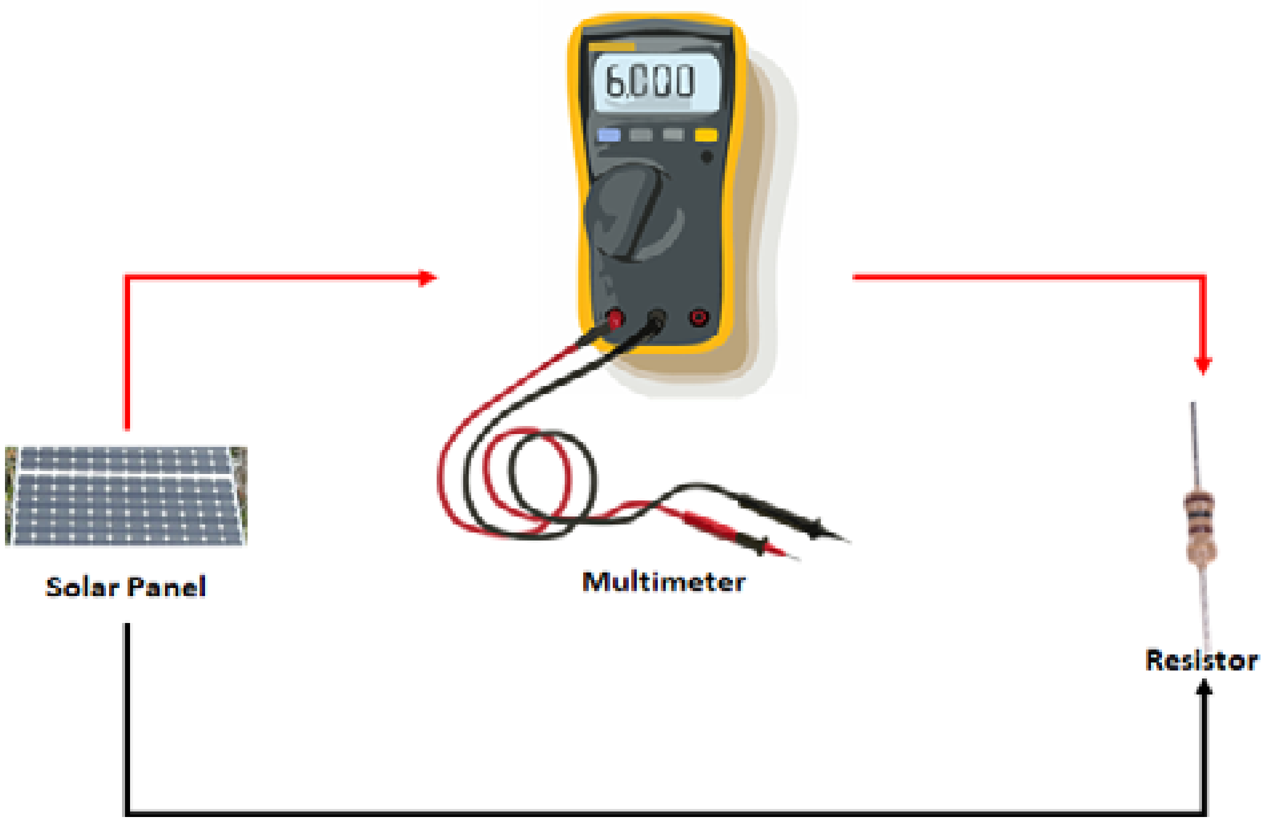
$$E(J)=hc/\lambda= (6.62\times10^{-34}\ J\cdot s)(3.0\times10^{8}\ m/s)/\ \lambda$$

Color	Energy (J)
Red ($\lambda=700\times10^{-9}$ m)	2.8×10^{-19} J
Orange ($\lambda=600\times10^{-9}$ m)	3.3×10^{-19} J
Yellow ($\lambda=570\times10^{-9}$ m)	3.4×10^{-19} J
Green ($\lambda=500\times10^{-9}$ m)	3.9×10^{-19} J
Blue ($\lambda=450\times10^{-9}$ m)	4.4×10^{-19}J
Indigo ($\lambda=400\times10^{-9}$ m)	4.9×10^{-19}J
Violet ($\lambda=380\times10^{-9}$ m)	5.2×10^{-19}J

Name_________________________________ Date____________ Period _____

5.b. Worksheet - Answers

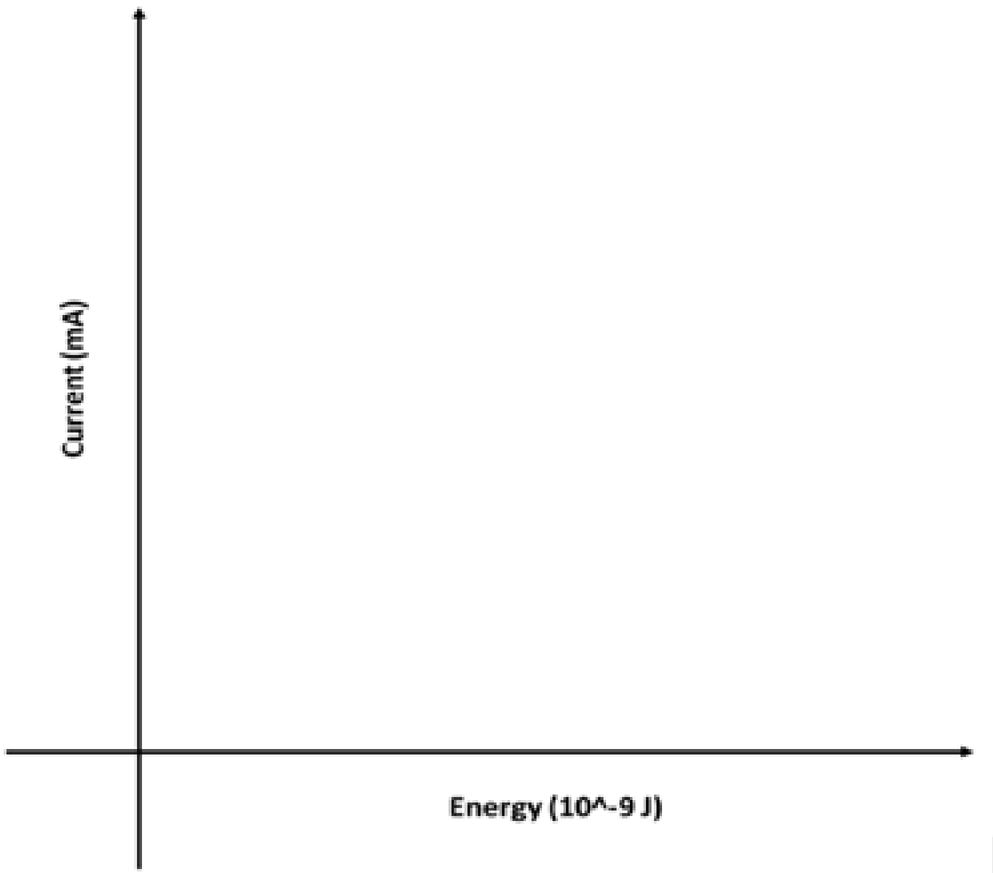
1. Connect the multimeter in series with the DC motor and the resistor to measure the current. Switch the multimeter in the milliamperes section (mA). Use the following diagram as a guide:
The values depend a lot on the students' set up.



Cellophane Color	Energy (J)	Current (mA)
Red	2.8×10^{-19} J	
Orange	3.3×10^{-19} J	
Yellow	3.4×10^{-19} J	
Green	3.9×10^{-19} J	
Blue	4.4×10^{-19}J	
Indigo	4.9×10^{-19}J	
Violet	5.2×10^{-19}J	

5.b. Worksheet Answers

4. Plot a graph comparing speed of the wind and the wind turbine power (which is proportional to the kinetic energy) based on the previous table results.



3. What is the relationship between the energy being absorbed from the wavelength and the amount of current being produced?
There may be different results depending on the solar panel, the position of the light bulb, and the cellophane. Ideally, the cellophane with colors of high energy (blue, indigo, violet) will allow the solar panel to generate higher electrical current than cellophane with colors of low energy (red, orange, yellow). However, depending on the solar panel manufacturing, there may not be any trend. Namely, there is not a clear relationship between the energy and the current. You can discuss this result with the students explaining that scientists have improved the solar panels to respond efficiently to different light wavelengths.

4. How do these scientific concepts help us to improve the design of our electrical power generating system?
Higher radiant energy from the sun produces more electrical current and power. The solar panels should be in places where there are not shade and the radiant energy is maximum. The area available for the electrical power generating system is too small to have significant changes in radiant energy from the sun. Overall, students should try to avoid places with shade.

LESSON 6 Environmental Impact of the Power Generation System

LESSON OBJECTIVES

Students will be able to:

- Evaluate their electric power generating systems according to the physical and biological impacts upon the biodiversity of nearby ecosystems.
- Use a model to test their electrical power generating system and determine how well it meets criteria and constraints.
- Reflect on how the engineering and their own decisions impact the environment.

TIME REQUIRED

Two 50-minute periods

MATERIALS

Per classroom:

- 1 Engineering Design Process Poster
- Digital technologies for picture (ideal 1 per team)

Per team:

- Materials for the prototype (maps, models)

Per student:

- 1 Engineering Design Process slider

Lesson Summary

Students will gain an understanding and reflect about the environmental impacts from electrical power generating plants upon the ecosystems. Students will evaluate and modify their previous prototype based on minimizing their environmental impact to meet the client's requirement.

Background

Teacher Background

The construction and operation of any electrical generating power plant is not without impacts on the environment, ecosystem, and citizens of the area. Consideration of trade studies when contemplating such a solution needs to be a part of the planning and development process. There are many examples of how the need for energy drastically altered the landscape and thus overall ecosystem. These impacts tend to be permanent in nature and can result in causing real distress for life depending upon the fragile balance in the region.

Here are videos that address the environmental impacts from hydro, electric, and solar power plants:

https://www.youtube.com/watch?v=znEA8VjzzIU
https://www.youtube.com/watch?v=ynN39sfqT8w
https://www.youtube.com/watch?v=G3Dd5eBh7N4

Vocabulary:

Word	Definition
Ecosystem	Geographic area where biotic factors (living beings) work together as a system with abiotic factors (non-living beings).
Biodiversity	Biodiversity describes the variety of species living on the earth and in the water. Healthy ecosystems maintain the integrity of its biodiversity.
Physical component	Non-living elements of ecosystems such as the temperature, rocks, humidity, etc.
Biological component	Living elements of ecosystems such as animal, plants, and other organisms.

Before the Activity

Documents to print:

- Worksheet 6.a.
- Worksheet 6.b. Environmental impact assessment sheet
- Environment impact rubric

Videos to prepare:

For the teacher:

- Negative effects of solar energy sites (https://www.youtube.com/watch?v=znEA8VjzzIU)
- Coal mining's environmental impact (https://www.youtube.com/watch?v=ynN39sfqT8w)
- Pros and Cons of Hydro Power (https://www.youtube.com/

watch?v=G3Dd5eBh7N4)

Informative links:

- Life cycle of trash (https://www.advanceddisposal.com/for-mother-earth/education-zone/life-cycle-of-trash.aspx)
- The world's recycling is in chaos (https://www.wired.com/story/the-worlds-recycling-is-in-chaos-heres-what-has-to-happen/)

Classroom Instruction`

Introduction

1. **Tie in to the engineering problem.** Say/Ask: We have been working as engineers during this unit. Sometimes, engineers need to work as scientists to better understand the problem. Can anyone tell me what is the difference between working as an engineer and working as a scientist? Engineers tend to focus on solving problems for a client and considering an end user. In contrast, scientists tend to focus on understanding the world producing discoveries that may or may not have direct applications. So far, we have focused on the engineering problem, but today you will begin to think about designing a solution to the engineering problem. Can anyone tell me what our engineering problem is?
2. **Identify where they are in the engineering design process. (Plan, Try, Test).** Use the Engineering Design Process poster and students' Engineering Design Process sliders to help students identify what they have done so far and what step they are currently on. Say: We learned about the scientific principles of four power generating plants that we can use in our system. What are the types of plants? Now that we have defined our problem and learned background information about the types of electrical generators, we are ready to start designing solutions to the problem. We can always go back to define and learn more (point to arrows on posters that show going back to previous steps) about the problem or background information. For now, we will move on to the next steps of, plan, try, and test.
3. **Introduction to the minimum environmental impact constraint.** Say: We began planning our electric power generating system in Lesson Two. Today, we are going to continue working on our prototype making sure it accomplishes the criteria (remind the criteria of the project to the students). So, we are going to plan, try, and test based upon the criteria of minimizing environmental impact. What did our client say about the environmental impact of our electrical power generating system?

Activity

4. **Review the concepts of ecosystems, physical components, and biological components.** Ask: How do you know if your design negatively affects the environment? Use their responses to remind the students the concepts of what an ecosystem is and its relationship with physical and biological components. At the end, students should recognize that we identify the impact of our electrical power generating system in the environment by studying how much the system disrupts the physical and biological components.

STANDARDS ADDRESSED

Next Generation Science Standards:

MS-LS2-5. Evaluate competing design solutions for maintaining biodiversity and ecosystem services.

MS-ETS1-2. Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.

MS-ETS1-4. Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.

Common Core Mathematics:
None

EDUCATOR RESOURCES

- Life Cycle of Trash extracted from advanceddisposal.com and wired.com (https://www.advanceddisposal.com/for-mother-earth/education-zone/life-cycle-of-trash.aspx) (https://www.wired.com/story/the-worlds-recycling-is-in-chaos-heres-what-has-to-happen)

5. **Review the concept of biodiversity.** Connect the previous discussion with the concept of biodiversity. Remind the students that any disruption on the ecosystem has an impact on its biodiversity, even if the disruption is small. Point out to the students that we as humans are also part of the ecosystem and help them to reflect on the people who can be impacted by constructing each plant. For example, who are the people of New Albany? Are there rural areas where the solar panels will be placed? How should we contact and negotiate with them? Why are there movements such as “Not In My Back Yard” (NIMB)?
   Note. (Optional) You can emphasize the impact of people on the environment. Say: We all are part of the environment. This is a big system in which we are one component and one small part of our actions might cause large changes in other parts of the system. Provide or ask students about examples of how small actions can impact the environment. For example:
   You buy a plastic bottle of juice because you are thirsty. You throw the bottle into the garbage can and the garbage truck takes it to the transfer station. The bottle continues to the recycling center and is sold to a manufacturing facility so it can be reprocessed. However, there are not enough manufacturing facilities so the recycling center exports the bottle to another country, such as Vietnam. However, Vietnam does not have any more capability to process all the plastic, so they start throwing the plastic into the rivers or near small towns. Sadly, your plastic bottle ends up in a river where people used to fish, but due to the plastic wasting, the fish begin

to die off. In summary, you just drank some juice in a plastic bottle, but after some time, it negatively impacts the life of people in Vietnam who are dying due to the unintended consequences of your plastic bottle. (**https://www.advanceddisposal.com/for-mother-earth/education-zone/life-cycle-of-trash.aspx**) (**https://www.wired.com/story/the-worlds-recycling-is-in-chaos-heres-what-has-to-happen/**)

6. **Discuss the impact of the power generators on the ecosystems and biodiversity.** Say: Each generating plant has an impact upon the ecosystem. In the generating plants' information sheets, we have information about how they can negatively impact upon nearby ecosystems. Let's read that information. Have students read in teams the environment impact information of each sheet (available size and environmental impact). Ask students questions about the information and point out that the land occupation (the size of each plant) is also a factor that affects the environment.
   Note: The information sheets are the same from Lesson 2.
7. **Set the prototype and verify the generated electrical power.** Distribute the maps and the models of the generating plants to replicate the prototype that students proposed in Lesson Two. Pass around the worksheet 6.a. and ask the students to calculate the total power generated by their design. It should be higher than 280 MW.
8. **Reflect on the impact of the power generation system.** Have students review the location of each power generating plant (fossil-fuel power plants, small hydro power plants, wind turbines, and solar panels) to determine how to reduce the impact on the environment. Some examples of ways to reduce the negative impact of the plants include:

- Eliminate fossil-fuel plants for other alternative renewable sources of energy.
- Change some solar panels for wind turbines to reduce the impact on the shadow on the area.
- Place the wind turbines far from populated areas to reduce their impact on people.
- Place the solar panels on the roofs of houses to avoid the usage of soil where insects and plants live.
- Change fossil-fuel plants for small hydro power plants. However, you would need to assure the river is moving strong enough to generate electricity and there are no populations downstream who could have been affected by disrupting the river.

9. **Self-Assessment of the environmental impact.** After students have reflected about the impact on the ecosystems and modified their prototype, pass around the Environmental Impact Assessment Sheet. Say: Sometimes it is hard to minimize the environmental impact of engineering designs. This assessment sheet provides recommendations to help us reduce the negative impact of the power generating plants upon the environment. Ask students to complete the Environmental Impact Assessment Sheet.
   Note: The students do not need to include all the design

ASSESSMENTS

Pre-Activity Assessment
Check students' verbal responses during numeral 4 and 5 of the activities section. Look for their previous knowledge about ecosystems, biotic and abiotic factors, and biodiversity.

Activity Embedded Assessment
Walk around as teams are discussing the impact of their electrical power generating systems upon the ecosystems. Check students' usage of the vocabulary and encourage them to justify all their design decisions.

Post-Activity Assessment
Use the Environmental Impact Rubric to assess students' reflection and knowledge about the environmental impact of their designs upon nearby ecosystems.

DUPLICATION MASTERS

- Worksheet 6.a.
- Worksheet 6.b. Environmental Impact Assessment Sheet

recommendations. However, encourage students to think about the negative environmental impact of their designs upon the soil, water, air, living beings, humans, etc.

10. **Evaluate the students' reflection about their designs' environmental impact upon nearby ecosystems.** Use the Environment Impact Rubric to evaluate the students reflection based on your conversations with them and their responses in the Environmental Impact Assessment Sheet.

Closure

11. **Conclude the activity and take pictures of the model.** Conclude the activity asking why it is important to reduce the environmental impact of our system and how we determine the impact. Have students take a picture of their second prototype and keep the final worksheet 6.a. for the next lessons.
12. **Review the concepts and final reflection.** Say: Today we learned about the environmental impact of our electric power generating system. What did you learn today? How could you apply what you learn in your daily life? What else do we need to do to complete our design? What do you need to improve your design?

LESSON 6

Name________________________________ Date____________ Period _____

6.a. Worksheet

Use the following table to verify that your design meets the power needs of the grid. Hint. To get the total power, multiply the power of each unit times the number of generators that you have placed in your prototype. Then, add all the individual total power to have the Total Electrical Power of your system.

Generating Plants	Power per Unit (MW)	Number of generators	Total Power (MW)
Fossil-fuel Power Plants	50		
	150		
	300		
Small Hydro power Plant	5		
	10		
	30		
Wind Turbines	1		
	10		
	30		
Solar Panels	1		
	5		
	10		
Total Electrical Power of the Generating System			

Name________________________________ Date___________ Period _____

LESSON 6

6.b. Worksheet - Environmental Impact Assessment Sheet

Fill the below table with the information about how you integrated each design recommendations in your design.

Design recommendations	Did you consider it?	How did your team consider the design recommendations in your prototype?
Land: Land occupation should be kept at minimum to reduce the habitat disruption of the wildlife.	Yes or No	
Air: The emission of the greenhouse gases should be kept at minimum.	Yes or No	
Water: Provide ways to keep nearby water sources clean.	Yes or No	
Solid waste: The construction, running, and end disposal of the generator should not produce much solid waste.	Yes or No	
Biodiversity: The generation system should minimize the disruption of the biological components of the area.	Yes or No	
People: The generators should have a minimal impact on people's lives.	Yes or No	
Energy source: Renewable energy resources are preferable over nonrenewable.	Yes or No	
Other considerations	Yes or No	
Teacher/Expert Evaluation		

LESSON 6

Name______________________________ Date____________ Period _____

6.b. Environmental Impact Rubric

Criteria	Level 1	Level 2	Level 3
Contamination of soil (solid waste) and minimize land occupation (3 points)	The team showed minimum reflection in their discussions and written reports about their designs' impact upon the soil and land occupation.	The team showed some reflection in their discussions and written reports about their designs' impact upon the soil and land occupation.	The team showed deep reflection in their discussions and written reports about their designs' impact upon the soil and land occupation.
Contamination of water (3 points)	The team showed minimum reflection in their discussions and written reports about their designs' impact upon the water sources.	The team showed some reflection in their discussions and written reports about their designs' impact upon the water sources.	The team showed deep reflection in their discussions and written reports about their designs' impact upon the water sources.
Contamination of air (3 points)	The team showed minimum reflection in their discussions and written reports about their designs' impact upon the air quality.	The team showed some reflection in their discussions and written reports about their designs' impact upon the air quality.	The team showed deep reflection in their discussions and written reports about their designs' impact upon the air quality.
Considerations of the biodiversity (3 points)	The team showed minimum reflection in their discussions and written reports about their designs' impact upon the life of animals, plants, and other organisms.	The team showed some reflection in their discussions and written reports about their designs' impact upon the life of animals, plants, and other organisms.	The team showed deep reflection in their discussions and written reports about their designs' impact upon the life of animals, plants, and other organisms.
Consideration of human populations (3 points)	The team showed minimum reflection in their discussions and written reports about their designs' impact upon the life of human populations.	The team showed some reflection in their discussions and written reports about their designs' impact upon the life of human populations.	The team showed deep reflection in their discussions and written reports about their designs' impact upon the life of human populations.
Consideration of renewable resources (3 points)	The team showed minimum reflection in their discussions and written reports about the nature of the fuel required for the generating power plant (wind, water, coal, natural gas, sun radiation).	The team showed some reflection in their discussions and written reports about the nature of the fuel required for the generating power plant (wind, water, coal, natural gas, sun radiation).	The team showed deep reflection in their discussions and written reports about the nature of the fuel required for the generating power plant (wind, water, coal, natural gas, sun radiation).
Total points per team			

Name________________________________ Date___________ Period _____

LESSON 6

6.a. Worksheet - Possible Answers

Use the following table to verify that your design meets the power needs of the grid. Hint. To get the total power, multiply the power of each unit times the number of generators that you have placed in your prototype. Then, add all the individual total power to have the Total Electrical Power of your system.

Generating Plants	Power per Unit (MW)	Number of generators	Total Power (MW)
Fossil-fuel Power Plants	50	1	50
	150		
	300		
Small Hydro power Plant	5		
	10		
	30	1	30
Wind Turbines	1		
	10		
	30	6	180
Solar Panels	1		
	5		
	10	2	20
Total Electrical Power of the Generating System			280

LESSON 6

Name_______________________________ Date___________ Period _____

6.b. Worksheet - Possible Answers

Fill the below table with the information about how you integrated each design recommendations in your design.

Design recommendations	Did you consider it?	How did your team consider the design recommendations in your prototype?
Land: Land occupation should be kept at minimum to reduce the habitat disruption of the wildlife.	Yes or ~~No~~	We are going to promote the usage of solar panels on the roofs of buildings.
Air: The emission of the greenhouse gases should be kept at minimum.	Yes or ~~No~~	We are using only one fossil-fuel power plant with a almost clean technology. We will make the plant producing less electrical energy (instead of power) to reduce the emissions.
Water: Provide ways to keep nearby water sources clean.	Yes or ~~No~~	We are going to implement filters and check the purity of the water that we use in the construction and operation process.
Solid waste: The construction, running, and end disposal of the generator should not produce much solid waste.	Yes or ~~No~~	We try to use more wind turbines than solar panels and recycled materials as much as possible.
Biodiversity: The generation system should minimize the disruption of the biological components of the area.	Yes or ~~No~~	We are going to construct the facilities near already occupied places avoiding wild areas.
People: The generators should have a minimal impact on people's lives.	Yes or ~~No~~	We are not placing any plant in the middle of the city.
Energy source: Renewable energy resources are preferable over nonrenewable.	Yes or ~~No~~	We did not include fossil-fuel power plants.
Other considerations	Yes or No	
Teacher/Expert Evaluation		

LESSON 7

Cost Analysis and First Prototype

LESSON OBJECTIVES

Students will be able to:

- Use ratio and rate reasoning to calculate the construction and operation cost of their electrical power generating system.
- Develop a model to compute the total construction and operation cost of their electrical power generating system.
- Evaluate how their system meets the criteria and constraints of the engineering problem.

TIME REQUIRED

Two 50-minute periods

MATERIALS

Per classroom:

- 1 Engineering Design Process Poster
- Optional - 1 printer (to print pictures of teams' prototypes)
- Digital technologies to take pictures (of the prototype)

Per team:

- Materials for the prototype (maps, models,...)

Per student:

- 1 Engineering Design Process slider
- Engineering Notebook

Lesson Summary

Students will finalize their first full electric power generating plant prototype that meets all criteria and constraints. They will continue working on their prototype from Lesson 6 to meet the criterion of cost. Students will establish construction and operating costs to build and sustain an electrical power generating plant. They will use proportions and rate reasoning to analyze their costs and will use an Excel platform to calculate the specific values.

Background

Teacher Background

Cost benefit analysis is an aspect of engineering that allows for a comparison of different systems. This also establishes a baseline cost of a system proposal for a customer to refer to as the design is being implemented. The first prototype allows engineers to see their designs built and measure them for cost and operation. If adjustments or updates are made the prototype allows for testing and evaluation of these choices.

Here is a video giving details and examples of Cost benefit Analysis: https://www.youtube.com/watch?v=7tdKkeNCIPE

Students need to be aware that in the United States, there exists a federal agency that was established to protect the lands, water, and air. This is the mandate of The Environmental Protection Agency (EPA) that was established in 1970. The agency protects people and the environment from significant health risks, sponsors and conducts research, and develops and enforces environmental regulations and national pollution-control standards.

Here is a video on the EPA: https://www.youtube.com/watch?v=0obuD-yqq80

Here is a video explaining the fees associated to greenhouse gases (GHG): https://www.youtube.com/watch?v=4hTHbcsfWEg

Doing the cost analysis is more than a mathematics activity. By doing it, students work on important cognitive skills for other disciplines and their daily life. For example, in this lesson, students will look at the electrical energy output and costs for different types of power generation units. To compare the plants, students will have to use rate and proportions reasoning to analyze how much the costs change per unit of energy produced as they choose among the power generating plants. This skill is particularly important in other areas such as chemistry where students need to understand how the changes in chemical reactions are proportional to the reaction's stoichiometry. We encourage teachers to take any opportunity to also help students develop the mathematical way of thinking.

Vocabulary:

Word	Definition

Construction cost	Amount paid to a contractor for building the generating plant. It includes the cost for the labor, materials, and the land preparation.
Operating cost	Cost associated with running the plant. It includes the Operation and Maintenance cost, the fuel cost, and additional fees for running the plant.
Operation and maintenance cost (O&M)	One of the values of the operating cost. It includes payment of workers, cleaning up the building, and eventual replacement of the equipment.

Before the Activity

Documents to print:

- Worksheet 7.a. Cost Analysis Design
- Worksheet 7.b. Evidence-Based Reasoning

Videos to prepare:
For the teacher:

- Intro to Cost-Benefit Analysis (https://www.youtube.com/watch?v=7tdKkeNCIPE)
- What is the EPA (https://www.youtube.com/watch?v=0obuD-yqq80)
- What is Carbon Emissions Trading? (https://www.youtube.com/watch?v=4hTHbcsfWEg)

Classroom Instruction`

Introduction

1. **Tie in to the engineering problem.** Say/Ask: In the last lesson, we worked on addressing one of the criteria of the client. Does anyone remember it? Today we need to continue testing for the other criterion which is the costs of our electric power generating system. Remind the students that the total construction cost should be less than 510 million dollars and the total operating cost per year should be less than 20 Million dollars.
2. **Identify where they are in the engineering design process. (Plan, Try, Test).** Use the Engineering Design Process poster and students' Engineering Design Process sliders to help students identify what they have done so far and what step they are currently on. Say/Ask: We are going to work on trying and test for the cost criterion of our engineering design.
3. **Identify what students still need to learn about.** Say/Ask: What do you all think we need to learn to calculate the costs? How would you calculate them?

Activity

4. **Setting up the previous prototype.** Give each group the materials they used in the previous lesson for making their electric power generation system. Ask students to set up the prototype as it was for the environmental impacts lesson.
   Note: Depending on your own objective goal and time, you can ask the

STANDARDS ADDRESSED

Next Generation Science Standards:

MS-ETS1-4. Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.

MS-ETS1-2. Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.

Common Core Mathematics:

6.RP.A.1 Understand the concept of a ratio and use ratio language to describe a ratio relationship between two quantities.

6.RP.A.3 Use ratio and rate reasoning to solve real-world and mathematical problems.

EDUCATOR RESOURCES

- Mandate of The Environmental Protection Agency (EPA) information extracted from usa.gov (https://www.usa.gov/federal-agencies/environmental-protection-agency#:~:text=The%20Environmental%20Protection%20Agency%20protects,develops%20and%20enforces%20environmental%20regulations)

DUPLICATION MASTERS

- Worksheet 7.a. Cost Analysis Design
- Worksheet 7.b. Evidence-Based Reasoning

students to compute the Analysis Cost by hand using the Worksheet 7.a. or you can share the Excel File "Cost_Analysis.xlsx" where the students only need to introduce the number of employed units for each generating plant. The following explanation is based on the worksheet, but the steps can be adapted to use the Excel file.

5. **Introducing the cost analysis of the project.** Pass around the worksheets 7.a. and ask students to determine what are the costs the client is asking for. Assist them to look for the total construction costs and the total operating costs in the client letter. These values are the results of our cost analysis.
6. **Computing the total construction cost.** Say: We are going to start the cost analysis by computing the total construction cost. There may be additional costs that we are not considering such as the cost of batteries to store the energy from the small hydro power plants, wind turbines, and solar panels. The batteries represent an additional discussion that is over the scope of this unit; you can assume that the batteries were already bought. The following algorithm helps to compute the total construction cost. You can use the more convenient strategy to teach them to your students.

- Count the number of employed units for each power generation source in the map
- Total power per set of employed units = Power per unit * Number of employed units
- Total power per generation source = Summation of the three power per set of employed units
- Total construction cost per generation source = Total power per generation source * construction cost per megawatt
- Total construction cost = Summation of the four-construction cost per generation source

7. **Compute the total operation cost per year**. Say: The second value that we need to compute for the cost analysis is the total operation cost per year. This value is also directly proportional to the "Total power per generation source" that we calculated previously. However, for the fossil-fuel power plants, we need to include the cost of buying the fuel, and the fees for greenhouse gases (GHG) contamination. Usually, engineers use the term Operation and Maintenance (O&M) cost to set the payment of workers, cleaning up the building, and eventual replacement of the equipment in one value. Like in step 6, the following algorithm helps to compute the total operation cost per year, you can use the more convenient strategy to teach them to the students:

- Operation and Maintenance (O&M) cost per generation source = Total power per generation source * O&M cost per megawatt
- Total fuel cost per year= Fuel cost * Total Energy from the Plant per year
- Total GHG emissions = GHG emissions * Energy consumed per year
- Total environmental fee per year = Total GHG emissions * EPA fee for GHG emissions
- Total operating cost per year = Add up the four O&M costs per generation source + Total fuel cost per year + total environmental fee per year

Note: If the students include fossil-fuel power plants, they need to include the cost of fuel, and the cost of the EPA fees for emissions of GHG. These two costs are directly proportional to the amount of energy produced by the plant per year (in contrast to the total construction cost, and O&M cost which are proportional to the power produced by the generators). To simplify the problem, we are assuming that the 25% of the energy will be produced by the Fossil-Fuel Power Plant. The students could suggest generating less energy to reduce the emission of GHG and, consequently, the EPA fees.

Note: Ask students questions to encourage deep reasoning about the relationship of variables. For example, what is the variable that more impacts the construction cost? How could you reduce the operating cost?

8. **Complete the Evidence-Based Reasoning worksheet**. Say: This is the final first prototype of our electric power generating system. We are going to summarize all the information for our client in the Evidence-Based Reasoning worksheet 7.b. Pass around the worksheet and ask the students to complete one form per team. The students can print pictures of their prototypes or draw their map in the drawing section. Make sure that students include information about the land occupation, power production, environmental impact, and cost analysis of their power system in the Data/ Evidence section.

Closure

9. **Take a picture and evaluate the results.** Take pictures of students' final prototype and excel files or save the files in a flash drive. The students will need the picture and the worksheet 7.a. (Excel file) and 7.b. for the next lesson. Use the Evidence-Based Reasoning Rubric to assess the students performance of worksheet 7.b. and overall their learning of the lesson goals.
10. **Conclude the activity.** Review with the full class what they did in their lesson. Ask: Can you tell me how we solve our engineering problem? (Encourage students to be specific about learning activities and their purpose) What concepts are still confusing for you? Is it a final solution or you could improve your design? What did you do well and what did you need to improve about teamwork? Engineers usually have to redesign their solutions looking for improving them or depending on new constraints of the problem. We will work on that in our next lesson.

ASSESSMENTS

Pre-Activity Assessment
Check students' previous knowledge about cost analysis as you explain the numerals 5, 6, and 7 of the activities' section.

Activity Embedded Assessment
Walk around as teams are figuring out the Excel file and computing the total costs. Ask students questions to encourage deep reasoning about the relationship of variables. For example, what is the variable that more impacts the construction cost? How could you reduce the operating cost?

Post-Activity Assessment
Use the Evidence-Based Reasoning Rubric to evaluate the Worksheet 7.b. and determine students' understanding of the concepts.

Name_________________________________ Date____________ Period _____

7.a. Worksheet - Cost Analysis of Design (1/2)

According to your design and considering the information in Table 1, calculate the costs by filling in the following tables.

Table 1:Technical Information

Variable	Value
Power (MW)	280
Energy Consumed per Year (kWh/yr)	265000000

Guidelines

The following steps are the sequence to compute the total construction cost:

1. Count the number of employed units for each power generation source in the map
2. Total power per set of employed units = Power per unit * Number of employed units
3. Total power per generation source = Add up the three power per set of employed units
4. Total construction cost per generation source = Total power per generation source * construction cost per mega Watt
5. Total construction cost = Add up the four construction cost per generation source

The following steps are the sequence to compute the total operation cost per year:

1. O&M cost per generation source = Total power per generation source * O&M cost per mega Watt
2. Total fuel cost per year= Fuel cost * Total Energy from the Plant per year
3. Total GHG emissions = GHG emissions * Energy consumed per year
4. Total environmental fee per year = Total GHG emissions * EPA fee for GHG emissions
5. Total operation cost per year = Add up the four O&M costs per generation source + Total fuel cost per year + total environmental fee per year

Table 2: Construction Cost and Operation & Maintenance Cost per year

Power Generation Source	Construction Cost per Megawatt (USD/MW)	O&M Cost per Megawatt (USD/MW)
Fossil-Fuel Power Plants	$1,800,000	$27,000
Hydro power Plant	$1,500,000	$52,000
Wind Turbines	$1,400,000	$26,000
Solar Panels	$2,300,000	$15,000

Name_________________________________ Date____________ Period _____

LESSON 7

(2/2) 7.a. Worksheet - Cost Analysis of Design

Table 3: Cost Analysis

Generating Plants	Power / Unit (MW)	Max. Energy per year (MW h)	Number of employed units	Total Power per Set of Employed Units (MW)	Total Power per Generation Source (MW)	Total construction cost per Generation Source (USD)	O&M Cost per Generation Source (USD)
Fossil-fuel Power Plants	50	438,000					
	150	1,314,000					
	300	2,628,000					
Small Hydro power Plant	5	43,800					
	10	87,600					
	30	262,800					
Wind Turbines	1	8,760					
	10	87,600					
	30	262,800					
Solar Panels	1	8,760					
	5	43,800					
	10	87,600					

Table 4: Environmental Data Table for Fossil Fuel Power Plants

Variable	Value
Fuel Cost (USD/kWh)	
Percentage of energy from the Plant	
Total Energy from the Plant per year (kWh)	
Total Fuel Cost per Year (USD)	
GHG* Emissions (ton/kWh)	
Total GHG* Emissions (ton)	
EPA Fee for GHG* Emissions (USD/ton)	
Total Environmental Fee per Year (USD)	
* Greenhouse Gases (GHG)	

Table 5: Summary table for Fossil-Fuel Power Plants

Variable	Value (USD)
Total Power Produced (MW)	
Total Construction Cost (USD)	
Total Operation Cost per year (O&M, fuel, and fees) (USD)	

LESSON 7

Name____ Date_____________ Period _____

7.b. Worksheet - Evidence-Based Reasoning

Problem with Criteria & Constraints • Explain the client's problem that needs a solution and why it is important to solve. • List criteria and constraints that you will use to decide if your solution is working.
Problem: Criteria: Constraints:
Simplifying Assumptions • List things that might be important, but you have decided not to worry about.

Design Idea #______ • Plan including drawing or picture of the map.	Data/Evidence • List science/mathematics learned and/or results of tests that support your design idea.

Justification - Why do you think this design idea will work? Explain how your data and evidence support your design idea in order to meet criteria/constraints.

Name________________________________ Date___________ Period _____

LESSON 7

Evidence-Based Reasoning Rubric

Section	Learning Objective	Rubric	
Problem	Explain the problem based on a synthesis of information. Explain why the problem is important to solve based on evidence that is relevant to the problem.	Yes or No	Identified problem
		Yes or No	Explained why the problem is important
Criteria	Explain criteria based on given information.	Yes or No	Identified at least 1 criterion
Constraints	Explain constraints based on information.	Yes or No	Identified at least 1 constraint
Simplifying Assumptions	Explain assumptions they have made in order to make solving the problem more manageable.	Yes or No	Identified at least 1 simplifying assumption
Design Idea	Communicate design ideas through drawing, including pieces for materials and the map.	Yes or No	Included drawing to represent design idea
		Yes or No	Included the map with the respective representations
Data/Evidence (List math/ science learned and/or results of tests that support your design idea)	Apply evidence gathered from testing to choose a solution. Apply math/ science concepts to choose a solution.	Yes or No	Listed at least 1 piece of valid evidence
		Yes or No	Evidence is from mathematics/science they have learned or from the results of the tests
Justification (Explain how your data/ evidence supports your design idea in order to meet criteria/constraints. Why do you think this will work?)	Justify why their design solution is appropriate based on application of core science/mathematics concepts. Justify why their design solution is appropriate based on information obtained in problem scoping.	Yes or No	Included explanation of how their data/evidence supports their design idea
		Yes or No	Explained why this will work
		Yes or No	Explained how design idea will meet criteria/ constraints
Notes:			

LESSON 7

Name______________________________ Date____________ Period _____

7.a. Worksheet - Possible Answers

Table 3: Cost Analysis

Generating Plants	Power / Unit (MW)	Max. Energy per year (MW h)	Number of employed units	Total Power per Set of Employed Units (MW)	Total Power per Generation Source (MW)	Total construction cost per Generation Source (USD)	O&M Cost per Generation Source (USD)
Fossil-fuel Power Plants	50	438,000	1	50	50	$ 90,000,000	$ 1,350,000
	150	1,314,000	0	0			
	300	2,628,000	0	0			
Small Hydro power Plant	5	43,800	0	0	30	$ 45,000,000	$ 1,560,000
	10	87,600	0	0			
	30	262,800	1	30			
Wind Turbines	1	8,760	0	0	180	$ 252,000,000	$ 4,680,000
	10	87,600	0	0			
	30	262,800	6	180			
Solar Panels	1	8,760	0	0	20	$ 46,000,000	$ 300,000
	5	43,800	0	0			
	10	87,600	2	20			

Table 4: Environmental Data Table for Fossil Fuel Power Plants

Variable	Value
Fuel Cost (USD/kWh)	0.03
Percentage of energy from the Plant	0.25
Total Energy from the Plant per year (kWh)	66250000
Total Fuel Cost per Year (USD)	$ 7,950,000
GHG* Emissions (ton/kWh)	0.000440924
Total GHG* Emissions (ton)	116844.86
EPA Fee for GHG* Emissions (USD/ton)	20
Total Environmental Fee per Year (USD)	2,336,897.20
* Greenhouse Gases (GHG)	

Table 5: Summary table for Fossil-Fuel Power Plants

Variable	Value (USD)
Total Power Produced (MW)	280
Total Construction Cost (USD)	$ 433,000,000
Total Operation Cost per year (O&M, fuel, and fees) (USD)	$12,214,397.20

Name___________________________________ Date____________ Period _____

LESSON 7

7.b. Worksheet - Possible Answers

Problem with Criteria & Constraints
• Explain the client's problem that needs a solution and why it is important to solve.
• List criteria and constraints that you will use to decide if your solution is working.

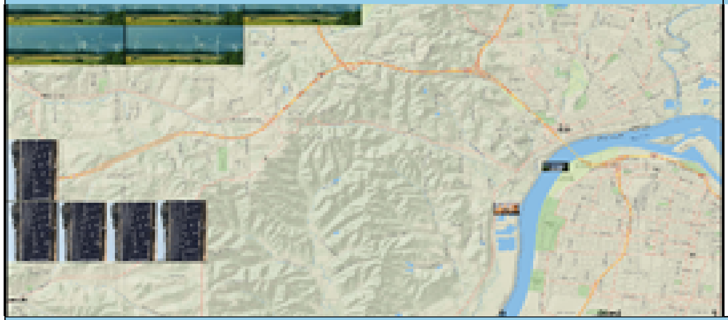
Problem: The members of the Indiana Office of Energy Development want to replace the Gallagher Station, an old power station, with a new electric power generating system that utilizes sustainable technologies. This replacement is crucial to minimize hazardous emissions in the environment around that may affect the local population in a negative way.

Criteria: The electrical power generating system should provide at least 280 MW of power. The generating plants should be located near the energy source. The electrical power generating system should look to minimize the environmental impact.

Constraints: The total construction cost should be less than 510 Million dollars and the total operating cost per year should be less than 20 Million dollars.

Simplifying Assumptions
• List things that might be important, but you have decided not to worry about.

We don't need to worry about the cost of batteries that are needed to store the energy produced by the solar panels or wind turbines.
We don't need to worry about which places have more radiation from the sun; we are assuming the radiation is homogeneous across this region.
We are assuming the average radiation and wind speed of this area is good enough to place solar panels and wind turbines.
We are not considering the costs associated to the construction of electrical distribution lines from the place of the plant to the station.

Design Idea #______ • Plan including drawing or picture of the map.	Data/Evidence • List science/mathematics learned and/or results of tests that support your design idea.
	1 Fossil-fuel power plant (50 MW); 1 small hydro power plant (30 MW); 5 Wind turbines of 30 MW (150 MW); 5 Solar panels of 10 MW (50 MW). Total construction cost: $ 460 million dollars. Total operating cost: $11.9 million dollars.

Justification - Why do you think this design idea will work?
Explain how your data and evidence support your design idea in order to meet criteria/constraints.

The design fits the design criteria and constraints. We assess the design based on the recommendations for minimizing environmental impact. The computed construction and operating cost fit with the available budget. The small hydro power plants and the fossil-fuel power plant are located near the available resources (water and fossil fuels).

LESSON 8 Redesigning the Electrical Power Generating System

LESSON OBJECTIVES
Students will be able to:
- Use evidence from problem scoping, core science/ mathematics concepts, and initial design test analysis to plan an improved design.
- Plan, try, and test a new power generation system based on a set of criteria and constraints.
- Evaluate competing electrical power generating designs to determine how much they fill the criteria and choose the one that better solves the problem.

TIME REQUIRED
Two 50-minute periods

MATERIALS
Per team:
- Materials for the prototype (maps, models,...)

Per student:
- Engineering Notebook

Lesson Summary
Students take the lessons learned from their prototypes, cost analysis, and operating procedures of their electrical generator plants to improve them. The project is examined for potential increases in efficiency, return rates, and decreases in environmental impacts, and cost. Students will come to realize the project is never completely done, just simply initial design specifications are met.

Background
Teacher Background
Traditionally, all designs are updated, refined, or re-purposed at some point. This update to an initial system is what is considered as a redesign. There are many reasons that redesign could be warranted for a system. New technology that was not present during the initial design may come into use forcing a desire to leverage the latest technology. A requirement to reduce operating cost can cause a re-evaluation of the system to determine which sub-system is causing cost to increase.

Here is a video giving more details on the engineering design process: https://www.youtube.com/watch?v=MAhpfFt_mWM

Vocabulary:

Word	Definition
Redesign	The act or process of changing the way something looks, is made, or how it works.
Evidence-based reasoning	The engineering practice of providing proof for design ideas and decisions.

Before the Activity
Documents to print:
- Handout: The Client's Email
- Worksheet 7.a.
- Worksheet 8.a.
- Evidence Based Reasoning Rubric

Videos to prepare:
For the teacher:
- Engineering Design process (https://www.youtube.com/watch?v=MAhpfFt_mWM)
- CISTAR Introduction Video (https://www.youtube.com/watch?v=IEZEPE9rdR0&feature=youtu.be)

Classroom Instruction`
Introduction
1. **Tie in to the engineering problem.** Say/Ask: Have students explain the engineering problem that they have been trying to solve, including its criteria and constraints, as well as any modifications they would make to the problem based on what they learned from initial prototype testing.

2. **Identify where they are in the engineering design process.** Direct students' attention to the Engineering Design Process poster and their Engineering Design Process sliders. Say/Ask: What did you all do in the previous class? (Decide.) Say: Now, we will be doing a redesign, so we will need to go through the solution generation (plan, try, test, and decide) again to create a second, better prototype.
3. **Introduce redesign.** Explain that engineers often redesign as new criteria and constraints arise, and students must also complete a redesign. Say/Ask: We have received new information from the client that may make us change our Electric Power Generating System.

Activity

4. **Introduce the new client information.** Read the client's email about the new technology that the client wants to be included (Handout: The Client's Email).
5. **Introduce the new constraint.** Discuss with the students the new information from the email and guide them to identify the new constraints of the problem: The students should identify as a constraint the inclusion of at least one fossil-fuel power plant that uses the CISTAR technology.
6. **Provide background information about CISTAR.** Say/ask: Let's learn a little more about this research group CISTAR. Present the following video to the students: CISTAR Overview. Can someone tell me what CISTAR does? CISTAR is a research group of several universities with the purpose of transforming shale gas (natural gas) into other fuels. They use chemical reactions to transform natural gas in fuels such as gasoline or other chemical substances. This reaction is very hard to happen, so they develop new catalysts. Can someone remind me what catalysts are? In CISTAR, engineers and scientists work in collaboration to develop these new catalysts among other technologies. Thus, we will be able to use another fossil-fuel for our electrical power generating plants. What do you think about the idea of CISTAR?
7. **Redesign the power generation system.** Provide the students with the materials for the last prototype of the system that they proposed in the last lesson. Explain to the students that redesign is also an opportunity for improving the previous design. Ask: How do you think your previous design could be better? How could you make it cheaper? How could you make it less contaminant?
8. **Plan and try the power generation system. All students should include a fossil-fuel power plant in their redesign. If they already had this plant in their design, you could ask the students to include another change to improve their design (e.g. Using less land with solar panels by putting more wind turbines). At this moment, the students can focus on computing the total power produced by the generators.**
9. **Test for environmental impact and cost analysis of the redesign.** Once the team agrees with the new design of the power system, they need to create a new cost analysis (Worksheet 7.a. or the Second spreadsheet in the Excel file). Revise the students design and ask questions to

STANDARDS ADDRESSED

Next Generation Science Standards:

MS-ETS1-1. Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, considering relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.

MS-ETS1-2. Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.

MS-ETS1-4. Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.

MS-PS1-2. Analyze and interpret data on the properties of substances before and after the substances interact to determine if a chemical reaction has occurred.

MS-LS2-5. Evaluate competing design solutions for maintaining biodiversity and ecosystem services.

Common Core Mathematics:

6.RP.A.1 Understand the concept of a ratio and use ratio language to describe a ratio relationship between two quantities.

6.RP.A.3 Use ratio and rate reasoning to solve real-world and mathematical problems.

EDUCATOR RESOURCES

- Mandate of The Environmental Protection Agency (EPA) information extracted from usa.gov (https://www.usa.gov/federal-agencies/environmental-protection-agency#:~:text=The%20Environmental%20Protection%20Agency%20protects,develops%20and%20enforces%20environmental%20regulations)

DUPLICATION MASTERS

- Handout: The Client's Email
- Worksheet 7.a.
- Worksheet 8.a.

evaluate if they are still considering the environmental impact. Ask: Did you generate new negative impacts upon the ecosystems with this design? How are you still minimizing the environmental impact? If you see necessary, ask students to write down how they are minimizing the impact of the new design.
Note: To compute the new the total operating cost per year and the total construction cost. You can take values obtained from the Excel and add or subtract the corresponding percentage. You can create in advance the formula for the students or teach them how to introduce the formula.

10. **Fill the Evidence-Based Reasoning form.** Similar to the previous lesson, ask students to complete worksheet 8.a. to summarize their redesign information.

Closure

11. Choose between the design and redesign. Have students consider each electrical power generating system that they developed. Instruct students to list pros and cons of each process in their engineering notebooks (Worksheet 8.b.). Then, ask each team to decide on their final solution. When students have settled on their best option, have them answer the notebook prompt: Which solution did your team choose and why? Say: The design that you choose is the one that we are going to present to our client; be sure that it addresses all the criteria and constraints:

- The electrical power generating system provides at least 280 MW of power.
- The generating plants (fossil-fuel plants, small hydro power plants, wind turbines, and solar panels) are located near the energy source.
- The electrical power Generation system aims to minimize the environmental impact.
- The total construction cost should be less than 510 Million dollars.
- The total operating cost per year should be less than 20 Million dollars.

ASSESSMENTS

Pre-Activity Assessment
Check students' previous knowledge about the client, criteria, and constraints during the numerals 4 and 5 of the lesson. Provide feedback about their last Evidence-Based Reasoning worksheet 7.b.

Activity Embedded Assessment
Walk around as teams are modifying their design based on the new criteria. Ask questions about the engineering design process as a whole, check students' learning of the scientific concepts, the environmental analysis of the system, and costs.

Post-Activity Assessment
Use again the Evidence-Based Reasoning Rubric to evaluate the new Evidence-Based Reasoning Worksheet 8.a. Additionally, check the students' responses in Worksheet 8.b. to evaluate their comparison of both designs.

LESSON 8

Redesigning the Electrical Power Generating System

Handout - The Client's Letter

Subject: Implementation of new technology

Dear Students Engineers,

We held a meeting with a research group from Purdue University called CISTAR. They have developed a new catalyst to produce a powerful fuel based on natural gas. This new fuel can be used in a fossil-fuel power plant and will diminish the amount of fuel, the emissions of greenhouse gases, and the O&M cost. Thus, the total operating cost per year will be 5% less. However, the installation of the equipment and the set of catalysts will increase the construction cost of the plant by 2%.

We want your team to consider the inclusion of a fossil-fuel power plant with this technology in your electrical power generating system design. Please, let us know your final design. If you decide for a design without fossil-fuel plants, please also share with us why you did not include the new technology of CISTAR.

Sincerely,

Members of Indiana Office of Energy Development

LESSON 8

Name________________________________ Date___________ Period _____

8.a. Worksheet - Evidence-Based Reasoning

Problem with Criteria & Constraints • Explain the client's problem that needs a solution and why it is important to solve. • List criteria and constraints that you will use to decide if your solution is working.	
Problem: Criteria: Constraints:	
Simplifying Assumptions • List things that might be important, but you have decided not to worry about.	
Design Idea #______ • Plan including drawing or picture of the map.	Data/Evidence • List science/mathematics learned and/or results of tests that support your design idea.
Justification - Which solution did your team choose and why? • Explain how your data and evidence support your design idea in order to meet criteria/constraints. • Cite the pros and cons of each of your own solution ideas.	

Name________________________________ Date___________ Period _____

LESSON 8

Evidence-Based Reasoning Rubric

Section	Learning Objective	Rubric	
Problem	Explain the problem based on a synthesis of information. Explain why the problem is important to solve based on evidence that is relevant to the problem.	Yes or No	Identified problem
		Yes or No	Explained why the problem is important
Criteria	Explain criteria based on given information.	Yes or No	Identified at least 1 criterion
Constraints	Explain constraints based on information.	Yes or No	Identified at least 1 constraint
Simplifying Assumptions	Explain assumptions they have made in order to make solving the problem more manageable.	Yes or No	Identified at least 1 simplifying assumption
Design Idea	Communicate design ideas through drawing, including pieces for materials and the map.	Yes or No	Included drawing to represent design idea
		Yes or No	Included the map with the respective representations
Data/Evidence (List math/ science learned and/or results of tests that support your design idea)	Apply evidence gathered from testing to choose a solution. Apply math/ science concepts to choose a solution.	Yes or No	Listed at least 1 piece of valid evidence
		Yes or No	Evidence is from mathematics/science they have learned or from the results of the tests
Justification (Explain how your data/ evidence supports your design idea in order to meet criteria/constraints. Why do you think this will work?)	Justify why their design solution is appropriate based on application of core science/mathematics concepts. Justify why their design solution is appropriate based on information obtained in problem scoping.	Yes or No	Included explanation of how their data/evidence supports their design idea
		Yes or No	Explained why this will work
		Yes or No	Explained how design idea will meet criteria/ constraints
Notes:			

LESSON 9 Decision and Communication with the Client

LESSON OBJECTIVES
Students will be able to:
- Evaluate the alignment between their proposed solution and the problem.
- Communicate their design solution using evidence-based reasoning.
- Justify why their design solution is appropriate based on application of core science/mathematics concepts, information obtained in problem scoping, and interpretation of acquired or gathered evidence.

TIME REQUIRED
Two 50-minute periods

MATERIALS
Per class:
- One Engineering Design Process Poster

Per student:
- Engineering Notebook
- 1 Engineering Design Process Slider

Lesson Summary
Students will utilize presentation skills to communicate rationale for their electric power generation system. They will use multiple forms of communication to present graphs, numerics, and policies that influenced their recommendations and design solutions.

Background
Teacher Background
The fundamental need to communicate results is essential for all engineers. If the engineer is unable to tell you why a design is the most efficient, or the most optimal then it will introduce a lack of trust or confidence by the customer in the solution. This skill set also enables the engineer to provide feedback to the customer that their desires and requirements were received, understood, and taken into account for a solution.

Here is a video describing the importance of communication for engineers:
https://www.youtube.com/watch?v=_swfjbiZ3N0

Vocabulary:

Word	Definition
Client	Person or team who asks engineers to design something to solve a problem.
Evidence-based reasoning	Refers to the engineering practice of providing proof for design ideas and decisions.
Criteria	Criteria are the things required for a successful design, or goals of the designed solutions. They help engineers decide whether the solution has solved the problem.
Constraints	Constraints are a specific type of criteria; they are those criteria that limit design possibilities, or the ways that the problem can be solved. If constraints are not met, the design solution is by default not a viable solution to the problem.

Before the Activity
Documents to print:
- Worksheet 9.a. -Reflect About Engineering Design

Documents for reference
- Worksheet 7a. Evidence-Based Reasoning sheet
- “Reflect about engineering design” Rubric

Videos to prepare:
For the teacher:
- Keys to a successful Engineering career

Classroom Instruction`
Introduction

Decision and Communication with the Client

LESSON 9

1. **Tie in to the engineering problem.** Say/Ask: We are almost done with solving this engineering design problem! Can anyone tell me about that problem? Who was our client? What problem did they want us to solve? What were the criteria and constraints of the problem?
2. **Identify where they are in the engineering design process.** Draw students' attention to the Engineering Design Process poster and their Engineering Design Process sliders. Ask: What did you do in the previous class? Point out the iterative nature of the engineering design process, specifically how students went through the process twice to improve their solutions. Remind students of the "Communication and Teamwork" section that has arrows pointing to every step of the engineering design process. Say: Throughout the entire engineering design process, we have been working in teams and communicating within your teams and with other teams. Now you need to communicate to the client, The Indiana Office of Energy Development (OED), so that they know about your design and why it meets their needs.

Activity

3. **Review the client letter.** Have students review the Worksheet 1.a. Client Letter that they received in Lesson 1. Emphasize the last paragraph of the letter. Say/Ask: In the letter we received from The Indiana Office of Energy Development (OED), they stated that they want us to communicate our designs to them. What else did they say we need to include in that communication? We need to justify the designs with evidence.
4. **Explain what needs to be included in the letter or poster.** Use the Evidence-Based Reasoning sheet of your chosen design to review what it means to justify a design with evidence. Instruct students to use these pieces of evidence (i.e., solution, data/evidence, explanation/reasoning/justification) in their communication to the client. Additionally, students should start their letter or poster with a review of the problem including criteria and constraints, as well as the simplifying assumptions. If students want a blank copy of the Evidence-Based Reasoning worksheet to fill out to help them create their communication to the client, that is fine; however, they still need to write a letter or poster separately from the Evidence-Based Reasoning template.
   Note: If a specific letter-writing format needs to be followed, introduce that format here as well.
5. **Write the letter, poster, or slides.** Allow students plenty of time to write their materials. Circulate the room to answer questions, help students who are struggling, and remind students that they need to include their chosen solution (with written description and drawing), evidence defending that solution, and explanations connecting the evidence to the solution in the letter or poster.
   Note: Encourage students to use information from their engineering notebooks, including all the information from the problem scoping, science lessons and labs, and engineering design results.
6. **Evaluation of students' designs.** Use the Criteria and Constraints Checklist to evaluate the students prototypes. You can compare the

STANDARDS ADDRESSED

Next Generation Science Standards:

MS-ETS1-1. Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, considering relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.

MS-ETS1-2. Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.

MS-ETS1-3. Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.

MS-ETS1-4. Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.

Common Core Mathematics:
None

Decision and Communication with the Client

EDUCATOR RESOURCES

- Mandate of The Environmental Protection Agency (EPA) information extracted from usa.gov (https://www.usa.gov/federal-agencies/environmental-protection-agency#:~:text=The%20Environmental%20Protection%20Agency%20protects,develops%20and%20enforces%20environmental%20regulations)

DUPLICATION MASTERS

- Worksheet 9.a. - Reflect About Engineering Design

designs to see which one has less operating cost, less construction cost, has alternative ways to minimize the environmental impact, etc. Use the Client Communication Requirements Checklist to evaluate the students' letter, poster or presentation to the client.

Closure

7. **Share letters/posters to the client**.(Optional) If time permits, have the students share their letters/posters with the rest of the class. This could be done as a whole class, with the students presenting their letters/posters/slides to everyone, or in smaller teams, with students reading/viewing the letters/ posters of others. Let students ask each other questions about their designs and why they made their choices about which one was better. You can also invite a person or panel of people to come and listen to the products being pitched by the teams for a more authentic experience.
8. **Reflect on the engineering design process.** Pass out "Reflect About Engineering Design" worksheet or have students answer the 2 questions from the worksheet in their engineering notebooks, both individually and in their team.

Criteria and Constraints Checklist

- ☐ The electrical power generating system provides at least 280 MW of power.
- ☐ The generating plants (fossil-fuel plants, small hydro power plants, wind turbines, and solar panels) are located near the energy source.
- ☐ The electrical power Generation system aims to minimize the environmental impact.
- ☐ The total construction cost is less than 510 Million dollars.
- ☐ The total operating cost per year is less than 20 Million dollars.

Client Communication Requirements Checklist

- ☐ Students introduce themselves
- ☐ Students summarize the client's problem including criteria and constraints.
- ☐ Students explain how the engineering design process was used to develop their prototype.
- ☐ Students describe how they chose their final design using evidence.
- ☐ Students show an image of their prototype.
- ☐ Students describe how their prototype avoids negative environmental impacts.
- ☐ Students specify the amount of electrical power generated by their system.
- ☐ Students present the results of their cost analysis: total construction cost and total operating cost per year.
- ☐ Students use appropriate scientific vocabulary to justify their decisions and present their results.
- ☐ Students answer adequately to questions related to the scientific principles of each generating plant.
- ☐ All students participating in the development of the letter, poster or presentation.

ASSESSMENTS

Pre-Activity Assessment
Check students' understanding of the criteria and constraints of the challenge based on their responses to the questions in the introduction.

Activity Embedded Assessment
In students' client letters or posters, look for sufficient detail related to the engineering problem (description of the problem, assumptions, prototype, justification of the solution, etc.). Examine students response to the client, poster, or presentation to evidence that they are including all the information of the Criteria and Constraints Checklist and Client Communication Requirements Checklist.

Post-Activity Assessment
Use Criteria and Constraints Checklist and Client Communication Requirements Checklist to evaluate the students' comprehension of the science, technology, engineering, and math concepts. Additionally, use the Reflect About Engineering Design Rubric to evaluate the Worksheet 9 and check students' reflection about their learning during the engineering design process.

LESSON 9

Name___________________________________ Date____________ Period _____

9.a. Worksheet - Reflect about Engineering

Directions: First, on your own, answer each of the following questions beside the "My Response" space. Then, in your teams, each person is to share their response and discuss. In the space, "Team Response" write your revised answer to the question, based on discussion with your team. You may use a different color writing utensil to distinguish your answer and how it changed after talking with teammates.

1. How has your understanding of the problem changed during the design process?
• Look back to the places where you defined the problem in your Engineering Notebook.
•Think about client needs, criteria/constraints, and science/mathematics needed to solve the problem.

My response:

Team response:

2. How has your understanding of how to design a solution changed during the design process?
• Look back in your Engineering Notebook to see how you developed your solution throughout solving the problem.
• Think about what you did and how you made decisions to solve the problem.

My response:

Team response:

Name________________________________ Date___________ Period _____

LESSON 9

9.a. Worksheet - Possible Answers

Directions: First, on your own, answer each of the following questions beside the "My Response" space. Then, in your teams, each person is to share their response and discuss. In the space, "Team Response" write your revised answer to the question, based on discussion with your team. You may use a different color writing utensil to distinguish your answer and how it changed after talking with teammates.

1. How has your understanding of the problem changed during the design process?
• Look back to the places where you defined the problem in your Engineering Notebook.
•Think about client needs, criteria/constraints, and science/mathematics needed to solve the problem.

My response:

Team response: Responses may vary according to their personal understanding about the problem.

2. How has your understanding of how to design a solution changed during the design process?
• Look back in your Engineering Notebook to see how you developed your solution throughout solving the problem.
• Think about what you did and how you made decisions to solve the problem.

My response:

Team response: Responses may vary according to their first design solution.

LESSON 9

Name________________________________ Date____________ Period _____

Reflect on Engineering Rubric

Question	Learning Objective	Rubric	
How has your understanding of the problem changed during the design process? • Look back to the places where you defined the problem in your engineering notebook. • Think about client needs, criteria/constraints, and science/mathematics needed to solve the problem.	Communicate how their understanding of the problem deepened through the design process.	Yes or No	Explained how their understanding of the problem has changed
		Yes or No	Included at least 1 of client needs, criteria/constraints, and science/mathematics in their explanation
How has your understanding of how to design a solution changed during the design process? • Look back in your engineering notebook to see how you developed your solution throughout solving the problem. • Think about what you did and how you made decisions to solve the problem.	Communicate how their understanding of how to design solutions changed through the design process.	Yes or No	Explained how their understanding of the how to design a solution has changed
		Yes or No	Included at least 1 example from their experience or how they made decisions in their explanation
Notes:			