EngrTEAMS

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

Ecuadorian Fishermen

Grades 6-8

University of Minnesota
STEM Education Center
NSF
INSPIRE Research Institute for Pre-College Engineering
Purdue University

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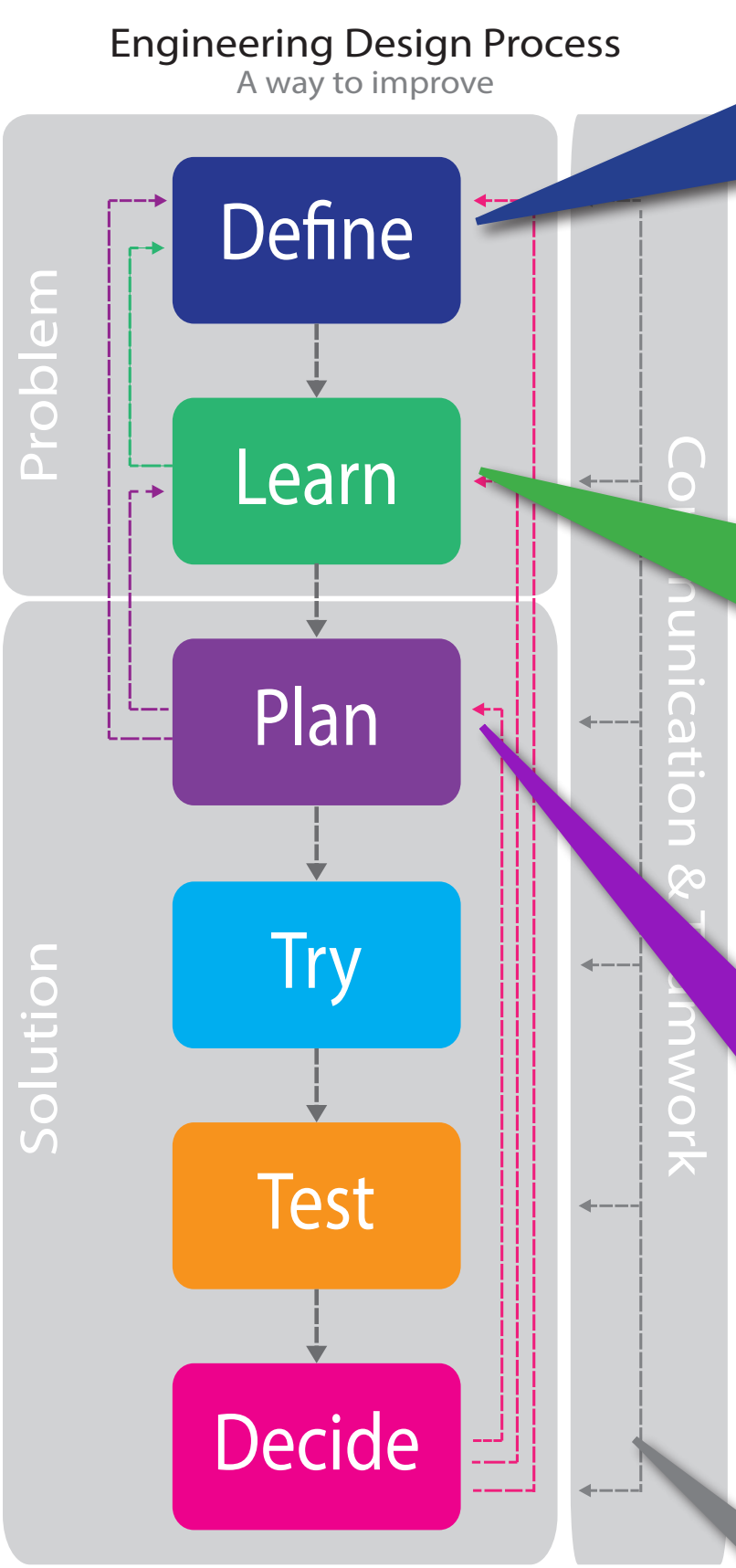
About EngrTEAMS

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.

Overview: Engineering Design Process



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 and constraints 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

Overview: 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

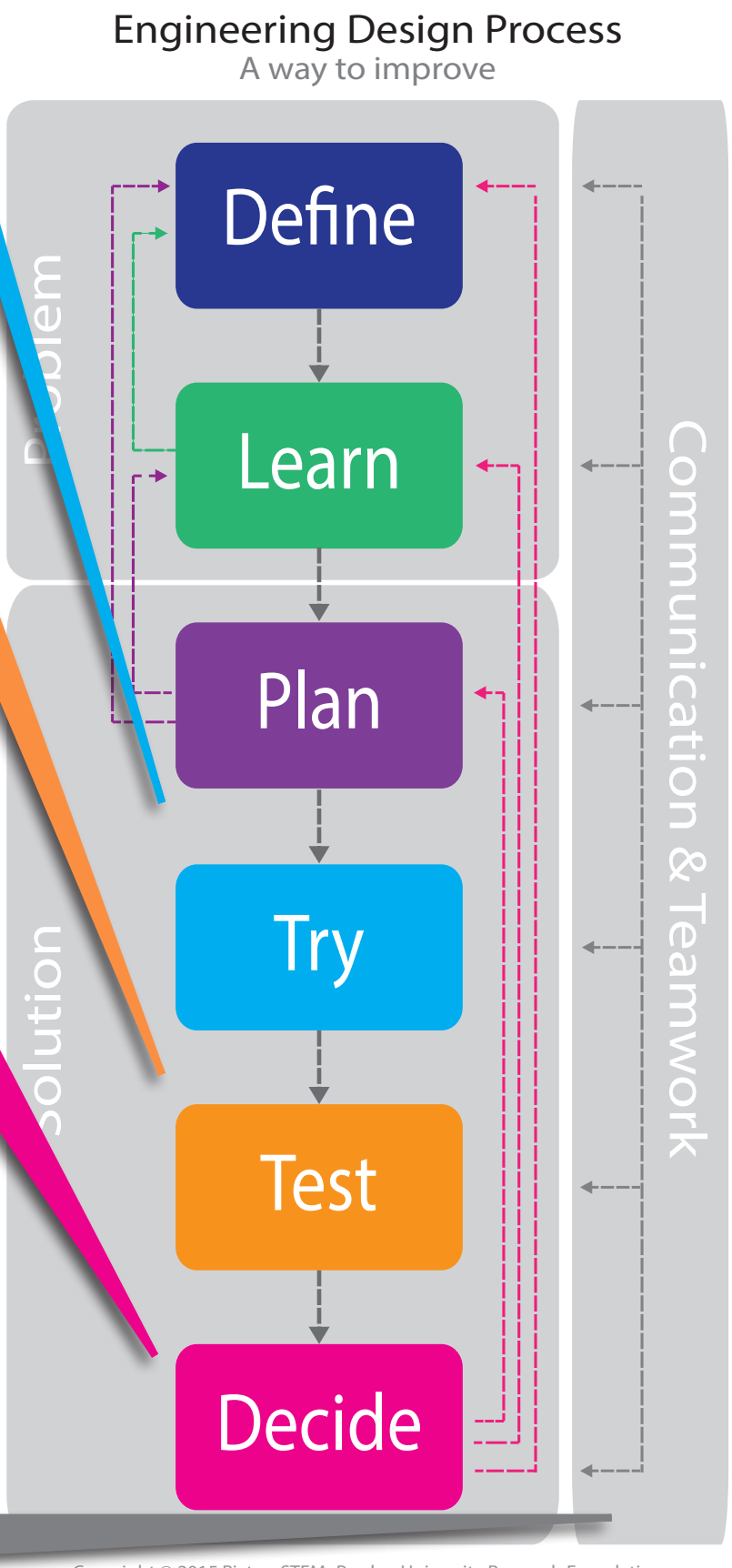
DECIDE IF THE SOLUTION IS GOOD ENOUGH

- 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



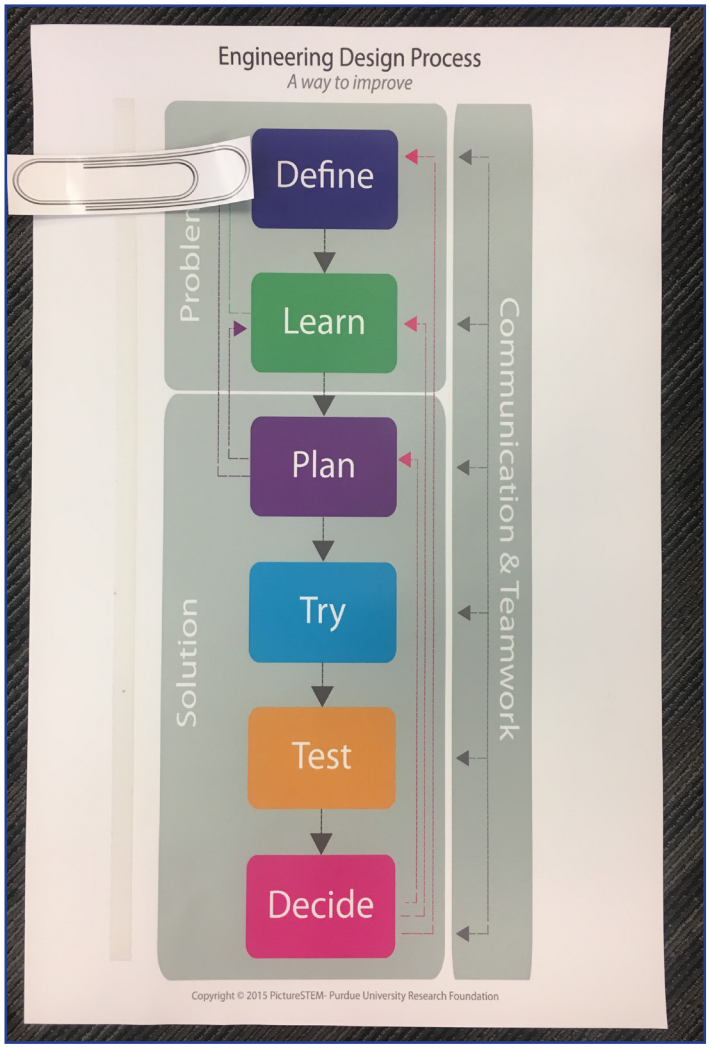
Overview: How to make EDP sliders

HOW TO CREATE THE POSTER

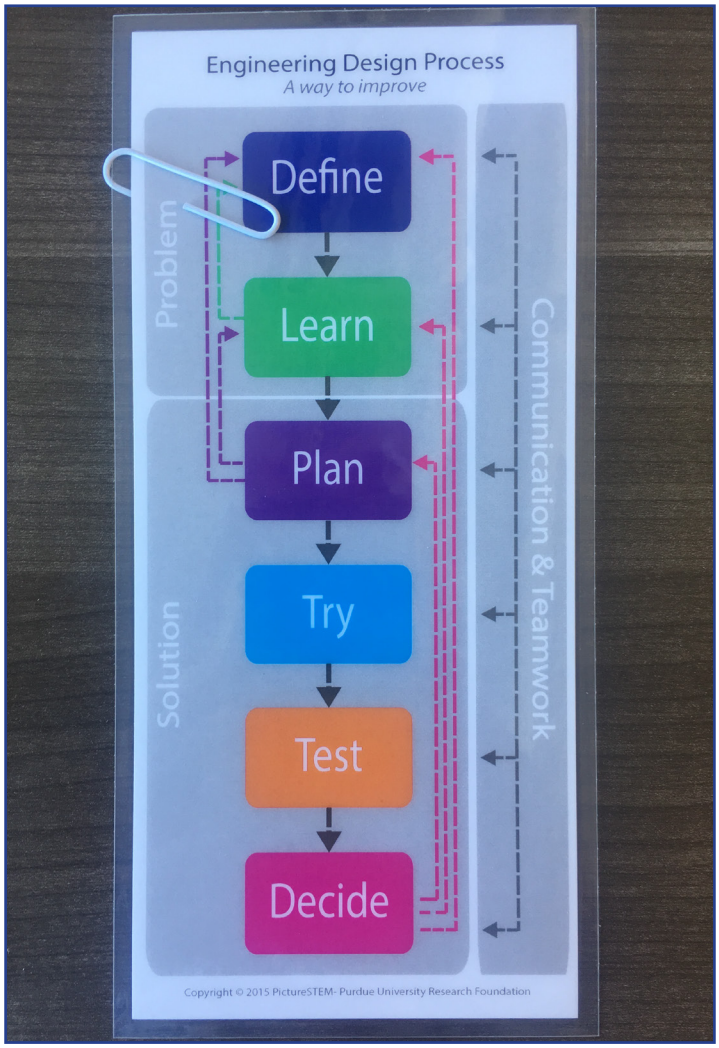
1. Download the high-quality PictureSTEM Slider Poster and the paper clip images from PictureSTEM.org.
2. Print the poster and the paper clip on poster-sized paper and cut to size. High-gloss or semi-gloss paper is the best choice.
3. Use self-sticking Velcro on the back of the paper clip and down the 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.



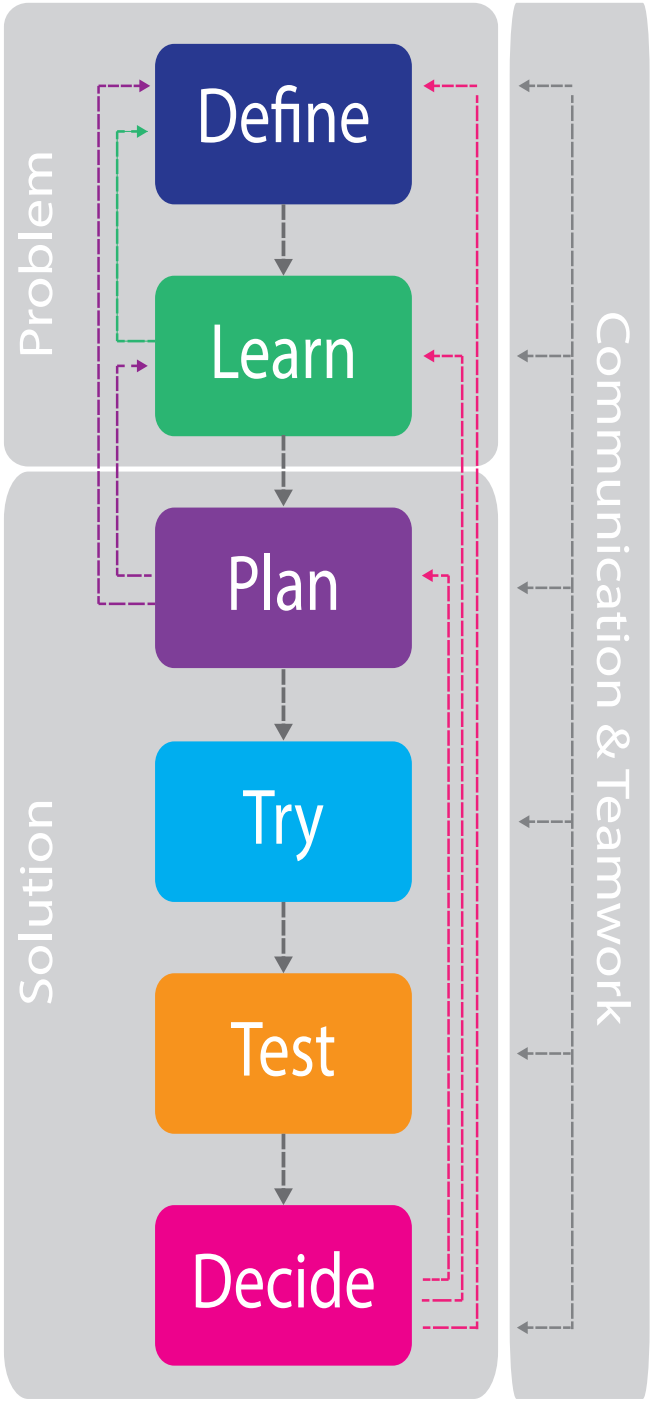
Poster



Individual slider

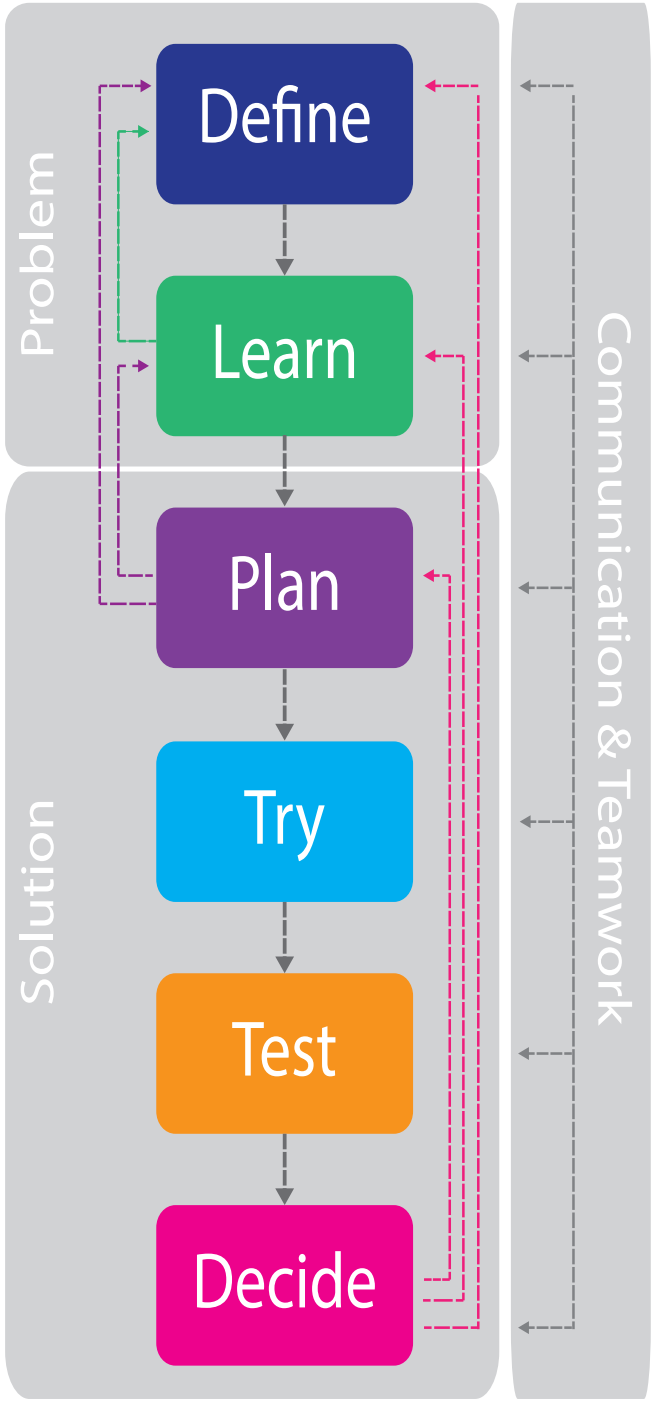
Engineering Design Process

A way to improve



Engineering Design Process

A way to improve



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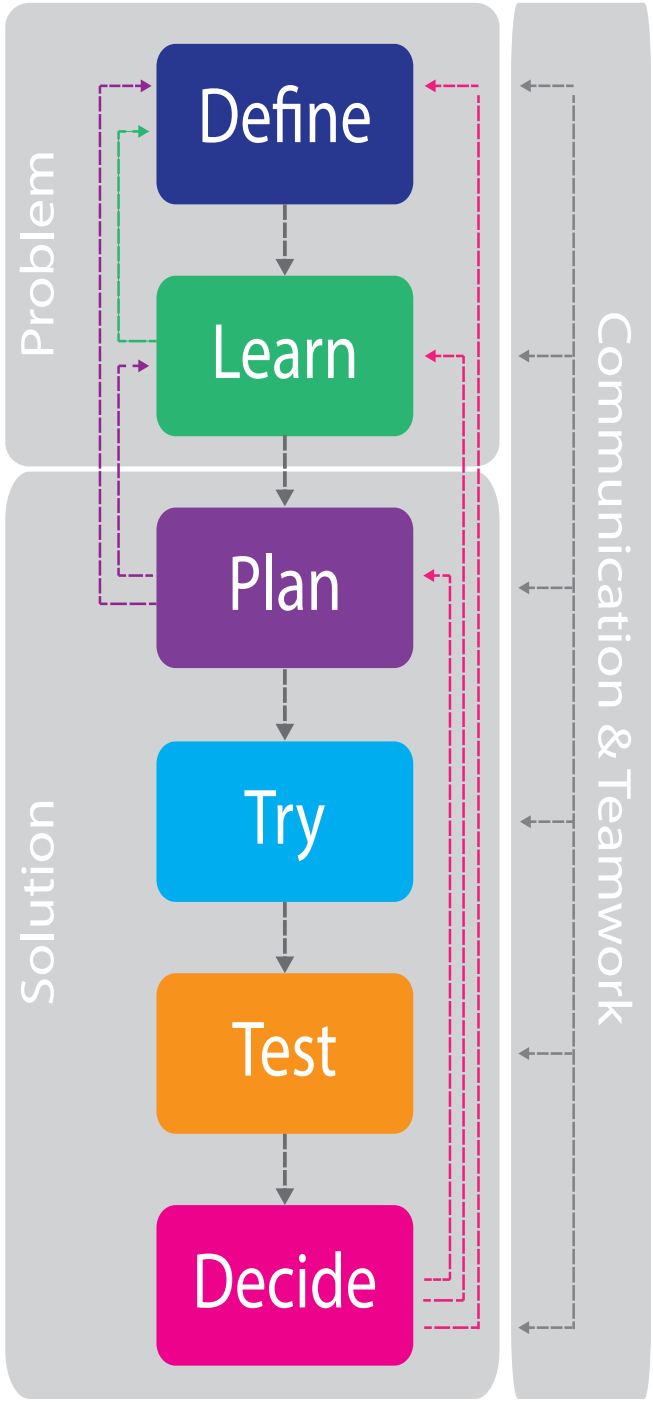
Engineering Design Process

A way to improve



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Overview: Unit Description

Grade Levels

6-8

Approximate Time Needed to Complete Unit

Fourteen-seventeen 50-minute class periods

Unit Summary

A team that works with small businesses in Ecuador has discovered that some of the Ecuadorian fishermen need help. Once the fishermen return to the fish markets, they need a small cooker container to cook the fish in so they can be sold. Students are tasked with designing this cooker container device. Before designing solutions, students learn about the science of heat transfer, including conduction, convection, and radiation. They also analyze data by creating temperature vs. time graphs and comparing different line graphs qualitatively. Students then plan (design), try (build), test, and decide whether their solution is successful (evaluate) twice, an initial design and a redesign. Finally, students communicate to the client their cooker container solutions, justifying them with evidence.

Science Connections	Technology & Engineering Connections	Mathematics Connections
Heat transfer (convection, conduction, radiation); temperature, thermal energy, and heat	Use of thermometers, 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	collecting data, plugging points in the Coordinate system, making interpretations from graphs, measuring temperature, and using data tables

Unit Standards

Next Generation Science Standards

- **MS-PS1-4:** Develop a model that predicts and describes changes in particle motion, temperature, and state of a pure substance when thermal energy is added or removed.
- **MS-PS3-3:** Apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer.
- **MS-PS3-4:** Plan an investigation to determine the relationships among the energy transferred, the type of matter, the mass, and the change in the average kinetic energy of the particles as measured by the temperature of the sample.
- **MS-PS3-5:** Construct, use, and present arguments to support the claim that when the kinetic energy of an object changes, energy is transferred to or from the object.
- **MS-PS4-2:** Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials.
- **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.

Overview: Unit Description

Unit Standards

- **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 State Standards - Mathematics

- **5.G.A.1:** Graph points on the coordinate plane to solve real-world and mathematical problems.
- **6.EE.C.9:** Represent and analyze quantitative relationships between dependent and independent variables.
- **8.F.B.5.** Describe qualitatively the functional relationship between two quantities by analyzing a graph (e.g., where the function is increasing or decreasing, linear or nonlinear). Sketch a graph that exhibits the qualitative features of a function that has been described verbally.

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 the students printed versions (included as duplication masters in each applicable lesson) to tape into their notebooks. Students use their notebooks as a reference – a place to maintain the information they are learning through design. Additionally, students reflect on their work throughout the design process. This 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 to the client recommending a design and justifying its success as a solution to the engineering problem.

Overview: Lesson Summaries

Lesson 1: Defining the Engineering Problem

Students learn about the characteristics of San Cristobal Island, which is part of San Cristobal Canton, Ecuador, and is an island in the Galápagos archipelago. This island is the setting for the engineering problem. Students receive the letter from the client, read it, and ask questions to the client. Students then receive the answers for their questions to the client and identify the engineering design challenge, which is to construct a cheap cooker container for the Ecuadorian fishermen so that they can quickly cook their fish in the market. Students also define the specifics of the engineering problem: client, end users, criteria, constraints, and why the problem is important. Finally, they identify topics or properties of materials that they would like to learn about.

Lesson 2: Temperature and Heat Transfer & Convection

Students learn about temperature, thermal energy, and heat. Temperature is the measure of how fast the particles in a substance are moving, on average. Thermal energy is the total amount of particle kinetic energy, so it depends on the temperature and number of particles. Heat is the thermal energy that passes from one system to another by virtue of a temperature difference. Students also observe a demonstration about heat transfer through convection.

Lesson 3: Heat Transfer Through Conduction

Students learn about heat transfer through conduction. They complete an ice cube experiment in which they place ice cubes on top of different materials and then observe and record which ice melted faster. Students are introduced to the concept of specific heat and tie this concept to their previous knowledge about conductors and insulators.

Lesson 4: Heat Transfer Through Radiation

Students learn about heat transfer through radiation and that materials can absorb, reflect, or transmit light. Students collect temperature data of the air inside cups that have lids made of materials such as black and white construction paper and felt, aluminum foil, transparency sheet, and wooden craft sticks.

Lesson 5: Analyzing the Absorption Property of Materials

Students create temperature vs. time graphs using the data they collected during the radiation lab. By drawing line graphs, they make interpretations about how well different materials absorb, reflect, or transmit radiation.

Lesson 6: Getting to Know the Context

The teacher presents the classroom oven, which is a solar oven, and the agar fish. Students describe the reasons for its structure and materials: black bottom, sides covered with aluminum foil, heating pad located in the bottom part of the oven, and lamps hanging in the top part of the oven. Students describe the types of heat transfer present in the classroom solar oven.

Overview: Lesson Summaries

Lesson 7: Exploring Materials and Planning: Idea Generation

Students review the engineering design challenge and explore the materials available for the final design. Students write their ideas for the first prototype individually. Students use a list of materials with their costs, as well as what they learned about heat transfer, to design a cooker container.

Lesson 8: Planning: Idea Selection and Evidence-Based Reasoning

Students share their individual ideas with other members of the team. Using one of these ideas or components of several design ideas, the team decides upon an idea for their first design. Students also use evidence-based reasoning to write justifications for every part of the design, including the cost amounts calculated for their first prototype.

Lesson 9: Trying/Building the First Prototype

Students implement their planned design and build a cooker container.

Lesson 10: Testing and Deciding about the First Prototype

Students test their cooker container prototypes' performance by placing them in the classroom oven for 10 minutes. They measure the initial and final temperature and calculate the temperature change. Student teams share their design's cost, temperature change, and additional characteristics with the whole class to determine what features made some designs successful. Students decide how well their design met each of the criteria and as a prompt for them to begin thinking about redesign.

Lesson 11: Redesigning a Second Prototype

Based on the discussion and analysis of the initial design test results, students work to improve their cooker container. Student teams redesign and rebuild prototype cooker containers. They then retest and reevaluate their second design. Students compare and contrast their results with the results of their initial design. By evaluating both designs, student teams decide which design to suggest to the client as the better solution to the engineering problem.

Lesson 12: Communicating with the Client

Students write a letter or create a poster for the client, members of The Pescadores Foundation, about their design. The letter or poster explains the chosen design solution with text and drawings and justifies it with evidence and explanations.

Overview: Unit Overview

Lesson	Time Needed	Objectives The student will be able to:
1: Defining the Engineering Problem	One-two 50-minute class periods	• describe important features of an engineering design process. • define an engineering problem from the perspective of stakeholders. • engage in problem scoping (i.e., define the problem and client and end user needs, and then identify the knowledge, criteria, and constraints required for a desirable solution).
2: Temperature and Heat Transfer & Convection	One 50-minute class period	• describe the relationship between the motion of particles and temperature in a solid, liquid, and gas. • define temperature as a measure of the average kinetic energy of particles of matter. • define thermal energy as the total amount, or sum, of kinetic energy in a substance; it depends on the temperature and the total number of particles. • define heat as the thermal energy transferred from one object to another due to the temperature difference between the objects; energy is transferred from hotter objects to colder ones. • define convection as how heat transfers in liquids and gases; cold matter sinks because it is more dense, which pushes the hotter matter up.
3: Heat Transfer Through Conduction	One 50-minute class period	• define conduction as the transfer of energy through a solid or from a solid to another solid, a liquid, or a gas. • identify which kinds of materials are conductors (i.e., transfer heat by the process of conduction easily and quickly) or insulators (i.e., slow down the transfer of heat by the process of conduction).
4: Heat Transfer Through Radiation	One 50-minute class period	• define radiation as the transfer of thermal energy across space in the form of light waves called electromagnetic radiation. • explain that electromagnetic radiation (i.e., light) can be reflected, absorbed, or transmitted by objects depending on the object's material.

Overview: Unit Overview

Materials	Duplication Masters & Educator Resources
• **Per classroom:** 1 *Engineering Design Process* poster, digital technologies to display videos, 1 poster size sticky note paper labeled "Questions for Client", markers • **Per student:** 2 different colors or types of writing utensils, 1 engineering notebook, 1 *Engineering Design Process* slider	**DUPLICATION MASTERS** • 1.a. What Do You Know About Engineers? • 1.b. Client Letter • 1.c. Questions for the Client • 1.d. Define the Problem **EDUCATOR RESOURCES** • 1.e. Problem Scoping Rubric • 1.f. Define the Problem Possible Answers
• **Per classroom:** 1 *Engineering Design Process* poster, digital technologies to display video and online simulation, 1 clear plastic container with a minimum height of 4", 1 gel food coloring (not yellow), 5 Styrofoam cups of the same size, hot water (at or near boiling), room temperature water • **Per student:** 2 different colors or types of writing utensils, 1 engineering notebook, 1 *Engineering Design Process* slider	**DUPLICATION MASTERS** • 2.a. Temperature, Thermal Energy, and Heat • 2.c. Convection **EDUCATOR RESOURCES** • 2.b. Temperature, Thermal Energy, and Heat Answers • 2.d. Convection Answers • 2.e. Convection Demonstration
• **Per classroom:** 1 *Engineering Design Process* poster, digital technologies to display videos, 1 laser infrared thermometer • **Per team:** 2 ice cubes of approximately the same mass, 1 wood or plastic cube, 1 metal cube, (Optional) 1 paper plate or several paper towels • **Per student:** 2 different colors or types of writing utensils, 1 engineering notebook, 1 *Engineering Design Process* slider	**DUPLICATION MASTERS** • 3.a. Conduction **EDUCATOR RESOURCES** • 3.b. Conduction Answers
• **Per classroom:** 1 *Engineering Design Process* poster, digital technologies to display videos, (Optional) 1 poster size of sticky note paper, (Optional) markers, materials for radiation lab: 1 piece of black construction paper, ~4.5"x4.5"; 1 piece of white construction paper, ~4.5"x4.5"; 1 piece of black felt, ~4.5"x4.5"; 1 piece of white felt, ~4.5"x4.5"; 1 piece of aluminum foil, ~4.5"x4.5"; 1 piece of transparency sheet, ~4.5"x4.5"; 8-12 craft sticks taped together in a flat row; 8 heat lamps with clamps; 8 incandescent light bulbs; 8 plastic cups, 16 oz.; 8 ring stands; 8 digital thermometers; masking tape; 2 outlet power strips • **Per student:** 2 different colors or types of writing utensils, 1 engineering notebook, 1 *Engineering Design Process* slider	**DUPLICATION MASTERS** • 4.a. Radiation **EDUCATOR RESOURCES** • 4.b. Radiation Answers • 4.c. Radiation Lab Set-up

Overview: Unit Overview

Lesson	Time Needed	Objectives The student will be able to:
5: Analyzing the Absorption Property of Materials	One-two 50-minute class periods	• graph points in the Cartesian system. • draw line graphs from coordinate points. • analyze data by qualitatively comparing multiple line graphs. • identify materials that absorb, reflect, or transmit radiation based on the data analyzed.
6: Getting to Know the Context	One 50-minute class period	• describe how the three processes of heat transfer are present in the classroom solar oven. • identify the process of heat transfer represented in various scenarios. • explain similarities and differences between conduction, convection, and radiation.
7: Exploring Materials and Planning: Idea Generation	One 50-minute class period	• identify whether materials conduct or insulate against heat transfer via conduction and absorb or reflect heat transfer via radiation. • use evidence from problem scoping to generate multiple initial ideas for a design solution.
8: Planning: Idea Selection and Evidence-Based Reasoning	One 50-minute class period	• systematically evaluate various solutions based on the problem to narrow to one design solution. • justify why their proposed design solution is appropriate based on the application of core science/mathematics concepts, and information obtained in problem scoping.

Overview: Unit Overview

Materials	Duplication Masters & Educator Resources
• **Per classroom:** 1 *Engineering Design Process* poster; computer or laptop; projector, document camera, or interactive whiteboard • **Per student:** 2 different colors or types of writing utensils, 1 engineering notebook, 1 *Engineering Design Process* slider, 1 ruler	**DUPLICATION MASTERS** • 5.a. Graphing Data Points • 5.b. Radiation Lab Data Analysis **EDUCATOR RESOURCES** • 5.c. Radiation Lab Data Analysis Answers
• **Per classroom:** 1 *Engineering Design Process* poster, solar oven materials: 1 large storage container, aluminum foil, 1 ~12”x24” heating pad, Pieces of black construction paper, 4 heat lamps with clamps, 4 incandescent light bulbs, 1 outlet power strip, scissors, tape, materials to make agar fish: 1 silicone mold w/ fishshaped wells; 1 glass beaker, 600 mL; 2 tbsp. agar powder; water • **Per student:** 2 different colors or types of writing utensils, 1 engineering notebook, 1 *Engineering Design Process* slider	**DUPLICATION MASTERS** • 6.c.Types of Heat Transfer in the Solar Oven • 6.e. Heat Transfer Review **EDUCATOR RESOURCES** • 6.a. Making Agar Fish • 6.b. Making the Solar Oven • 6.d. Types of Heat Transfer in the Solar Oven Answers • 6.f. Heat Transfer Review Answers
• **Per classroom:** 1 *Engineering Design Process* poster • **Per team:** 1 ~6”x6” piece of aluminum foil, 1 12” piece of 16 gauge copper wire; 1 steel washer (suggested size: 7/8” OD x 3/8” ID), 1 jumbo paper clip, 1 pipe cleaner, 1 ~4.5”x6” piece of white construction paper, 1 ~4.5”x6” piece of black construction paper, 1 ~6”x5” piece of black felt, 1 ~6”x5” piece of white felt, 1 ~4.25”x5.5” piece of transparency sheet, 1 craft stick, 1 ruler, (optional) 1 agar fish • **Per student:** 2 different colors or types of writing utensils, 1 engineering notebook, 1 *Engineering Design Process* slider	**DUPLICATION MASTERS** • 7.a. Thermal Properties of Design Materials • 7.c. Materials Cost List • 7.d. Individual Design Ideas **EDUCATOR RESOURCES** • 7.b. Thermal Properties of Design Materials Answers
• **Per classroom:** 1 *Engineering Design Process* poster, 1 poster-sized sheet of sticky note paper, markers, ~6”x6” aluminum foil, 12” pieces of 16 gauge copper wire, steel washers (suggested size: 7/8” OD x 3/8” ID), jumbo paper clips, pipe cleaners, ~4.5”x6” pieces of white construction paper, ~4.5”x6” pieces of black construction paper, ~6”x5” pieces of black felt, ~6”x5” pieces of white felt, ~4.25”x5.5” pieces of transparency sheet, craft sticks • **Per team:** 1 ruler, (optional) 1 agar fish • **Per student:** 2 different colors or types of writing utensils, 1 engineering notebook, 1 *Engineering Design Process* slider	**DUPLICATION MASTERS** • 8.a. Evidence-Based Reasoning • 8.d. Planning Reflection Questions **EDUCATOR RESOURCES** • 8.b. Evidence-Based Reasoning Rubric • 8.c. Evidence-Based Reasoning Instructions • 8.e. Planning Reflection Questions Rubric

Overview: Unit Overview

Lesson	Time Needed	Objectives The student will be able to:
9: Trying/Building the First Prototype	One 50-minute class period	• implement a design and create a prototype cooker container.
10: Testing and Deciding About the First Prototype	One-two 50-minute class periods	• test the cooker container prototypes. • compare design's performance with the performance of their peer's designs to determine the characteristics of the best performing cooker container prototypes. • analyze the performance of their first prototype.
11: Redesigning a Second Prototype	Two-three 50-minute class periods	• use evidence from problem scoping, core science/mathematics concepts, and initial design test analysis to plan an improved design. • implement a design and create a prototype cooker container. • test the performance of the improved solution. • compare their second design's performance with the performance of their first design. • evaluate the alignment between their proposed solution and the problem.
12: Communicating with the Client	One 50-minute class period	• evaluate the alignment between their proposed solution and the problem. • communicate their design solution through the use of 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.

Overview: Unit Overview

Materials	Duplication Masters & Educator Resources
• **Per classroom:** 1 *Engineering Design Process* poster, (Optional) solar oven built in lesson 6 • **Per team:** scissors, 1 ruler, 1 agar fish, 2-3 ~6”x6” aluminum foil, 2-3 12” pieces of 16 gauge copper wire, 6-8 steel washers (suggested size: 7/8” OD x 3/8” ID), 10 jumbo paper clips, 5 pipe cleaners, 2-3 ~4.5”x6” pieces of white construction paper, 2-3 ~4.5”x6” pieces of black construction paper, 2-3 ~6”x5” pieces of black felt, 2-3 ~6”x5” pieces of white felt, 2-3 ~4.25”x5.5” pieces of transparency sheet, 8-10 craft sticks • **Per student:** 2 different colors or types of writing utensils, 1 engineering notebook, 1 *Engineering Design Process* slider	**DUPLICATION MASTERS** • NONE **EDUCATOR RESOURCES** • 9.a. Teacher Observation Protocol: Try
• **Per classroom:** 1 *Engineering Design Process* poster, 1 poster size sticky note paper, markers, (optional) sticky notes, solar oven built in lesson 6: 1 large storage container, aluminum foil, 1 ~12”x24” heating pad, pieces of black construction paper, 4 heat lamps with clamps, 4 incandescent light bulbs, 1 outlet power strip • **Per team:** 1 digital thermometer, 1 agar fish • **Per student:** 2 different colors or types of writing utensils, 1 engineering notebook, 1 *Engineering Design Process* slider	**DUPLICATION MASTERS** • 10.b. Test Results • 10.c. Think About Results **EDUCATOR RESOURCES** • 10.a. Teacher Observation Protocol: Test • 10.d. Think About Results Rubric
• **Per classroom:** 1 *Engineering Design Process* poster, solar oven built in lesson 6: 1 large storage container, aluminum foil, 1 ~12”x24” heating pad, pieces of black construction paper, 4 heat lamps with clamps, 4 incandescent light bulbs, 1 outlet power strip • **Per team:** 1 pair of scissors, 1 ruler, 1 agar fish, 1 digital thermometer, materials available for design: 2-3 ~6”x6” aluminum foil, 2-3 12” pieces of 16 gauge copper wire, 6-8 steel washers (suggested size: 7/8” OD x 3/8” ID), 10 jumbo paper clips, 4-5 pipe cleaners, 2-3 ~4.5”x6” pieces of white construction paper, 2-3 ~4.5”x6” pieces of black construction paper, 2-3 ~6”x5” pieces of black felt, 2-3 ~6”x5” pieces of white felt, 2-3 ~4.25”x5.5” pieces of transparency sheet, 8-10 craft sticks • **Per student:** 2 different colors or types of writing utensils, 1 engineering notebook, 1 *Engineering Design Process* slider	**DUPLICATION MASTERS** • 11.a. Redesign Plan • 11.b. Redesign Materials Cost List • 11.c. Redesign Test and Decide **EDUCATOR RESOURCES** • 11.d. Redesign Test and Decide Rubric • 11.e. Teacher Observation Protocol: Redesign
• **Per classroom:** 1 *Engineering Design Process* poster, 1 poster size sticky note paper with Evidence-Based Reasoning template • **Per team:** If students are creating a poster, each team will need: 1 poster size sheet of paper, markers • **Per student:** 2 different colors or types of writing utensils, 1 engineering notebook, 1 *Engineering Design Process* slider	**DUPLICATION MASTERS** • 12.a. Reflect About Engineering Design • (optional) 8.a. Evidence-Based Reasoning **EDUCATOR RESOURCES** • 12.b. Reflect About Engineering Design Rubric

Master Material List

	Material	Lessons Where Material is Used
Per classroom	1 *Engineering Design Process* poster*	All
	digital technologies to display videos, simulations, and other online resources (i.e., computer/laptop; interactive whiteboard or other projector)*	1, 2, 3, 4, 5
	poster size sticky note paper*	1, 4, 8, 10, 12
	1 set of markers*	1, 4, 8, 10, 12
	1 clear plastic container, minimum height of 4”	2
	1 gel food coloring (not yellow)	2
	5 Styrofoam cups of the same size	2
	hot water (at or near boiling)*	2
	room temperature tap water*	2, 6
	1 laser infrared thermometer*	3
	10-12 craft sticks	4
	8 plastic cups, 16 oz	4
	8 ring stands	4
	8 heat lamps with clamps (8 for lesson 4; 4 for others)	4, 6, 10, 11
	8 incandescent light bulbs (8 for lesson 4; 4 for others)	4, 6, 10, 11
	2 outlet power strips*	4, 6, 10, 11
	1 large storage container	6, 10, 11
	aluminum foil, 10’-20’ to line solar oven sides	6, 10, 11
	~four 9”x12” sheets of black construction paper to line solar oven bottom	6, 10, 11
	1 ~12”x24” heating pad*	6, 10, 11
	scissors*	4, 6, 7, 8, 9, 11
	2 rolls masking tape	4, 6, 7, 8, 9, 10, 12
	1 silicone mold w/ fish-shaped wells*	6
	1 glass beaker, 600 mL	6
	4 tbsp. agar powder	6
	(optional) sticky notes*	10
Per team (assuming 3 students per team)	2 ice cubes of approximately the same mass*	3
	1 wood or plastic cube	3
	1 metal cube	3
	(optional) 1 paper plate or several paper towels*	3
	1 digital thermometer (8 total needed for Lesson 4)	4, 10, 11
	1 ruler*	5, 7, 8, 9, 11
	5-7 black construction paper pieces, ~4.5”x6”	4, 7, 8, 9, 11
	5-7 white construction paper pieces, ~4.5”x6”	4, 7, 8, 9, 11

Master Material List

	Material	Lessons Where Material is Used
	5-7 transparency sheets pieces, ~4.25”x5.5”	4, 7, 8, 9, 11
	5-7 black felt pieces, ~5”x6”	4, 7, 8, 9, 11
	5-7 white felt pieces, ~5”x6”	4, 7, 8, 9, 11
	5-7 aluminum foil pieces, ~6”x6”	4, 7, 8, 9, 11
	4-6 pieces of 16 gauge copper wire, 12” long	7, 8, 9, 11
	6-8 steel washers (suggested size: 7/8” OD x 3/8” IN)	7, 8, 9, 11
	10-12 jumbo paper clips	7, 8, 9, 11
	10-15 craft sticks	7, 8, 9, 11
	8-10 pipe cleaners	7, 8, 9, 11
	scissors*	9, 11
	1 agar fish (made from supplies in Lesson 6)	6, 7, 8, 9, 11
Per student	2 different colors or types of writing utensils*	All
	1 engineering notebook*	All
	1 *Engineering Design Process* slider*	All

*required materials not included in the kit

LESSON 1 Defining the Engineering Problem

Lesson Objectives

Students will be able to:

- describe important features of an engineering design process.
- define an engineering problem from the perspective of stakeholders.
- engage in problem scoping (i.e., define the problem and client and end user needs, and then identify the knowledge, criteria, and constraints required for a desirable solution).

Time Required

One-two 50-minute class periods

Materials

Per classroom:

- 1 *Engineering Design Process* poster
- digital technologies for videos
- 1 poster size sticky note paper labeled "Questions for Client"
- markers

Per student:

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

Standards Addressed

Next Generation Science Standards: MS-ETS1-1, MS-PS3-3

Key Terms

engineering design process, client, end user, criteria, constraints, prototype

Lesson Summary

Students learn about the characteristics of San Cristobal Island, which is part of San Cristobal Canton, Ecuador, and is an island in the Galápagos archipelago. This island is the setting for the engineering problem. Students receive the letter from the client, read it, and ask questions to the client. Students then receive the answers for their questions to the client and identify the engineering design challenge, which is to construct a cheap cooker container for the Ecuadorian fishermen so that they can quickly cook their fish in the market. Students also define the specifics of the engineering problem: client, end users, criteria, constraints, and why the problem is important. Finally, they identify topics or properties of materials that they would like to learn about.

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.

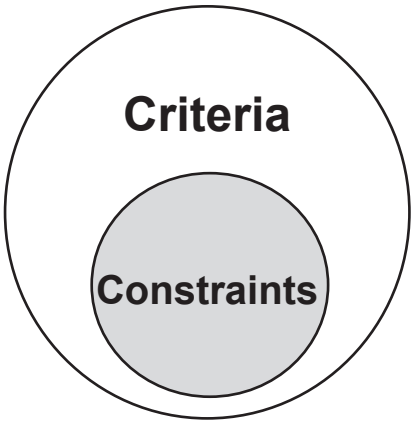
Engineering Design Process: Students should have some familiarity with the engineering design process before beginning the unit. If they do not, the teacher will need to spend additional time explaining it, so this lesson may take more than one day. The engineering design process (EDP) is an iterative, 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, the 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 a 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 about it.

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 continually learn throughout their lives.
- 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.

Defining the Engineering Problem

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 are 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 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. 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 common 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 combine to make Problem Scoping. In this stage, students will be first introduced to the engineering problem through a client letter and then be given a chance to ask questions to 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 as a means to continually improve their solution, reflect back on the problem definition and what they have learned about the problem, and consider criteria, constraints,

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 *1.d. Define the Problem* activity and discussions. This is particularly important when students are answering the *1.d. Define the Problem* worksheet questions, since they are doing so individually and in teams; circulate during this part of the activity and check their understandings 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 the *1.d. Define the Problem* questions. Use the *1.e. Problem Scoping Rubric* to provide feedback to students for their responses to *1.c. Questions for the Client* and *1.d. Define the Problem.*

DUPLICATION MASTERS

- 1.a. What Do You Know About Engineers?
- 1.b. Client Letter
- 1.c. Questions for the Client
- 1.d. Define the Problem

EDUCATOR RESOURCES

- 1.e. Problem Scoping Rubric
- 1.f. Define the Problem Possible Answers

and trade-offs. Trade-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, 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. A number of 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.

If this lesson needs to take two days instead of one, a recommended stopping point is after the students have shared their Questions for the Client with the whole class but before the client responds with answers.

Before the Activity

Assemble the *Engineering Design Process* sliders and post an EDP poster in the classroom (see the front matter for how to assemble them).

If using the duplication masters, print and make copies of the following worksheets in the labeled amounts:

- *1.a. What Do You Know About Engineers* (1 per student)
- *1.b. Client Letter* (1 per student)
- *1.c. Questions for the Client* (1 per student)
- *1.d. Define the Problem* (1 per student)

If students are writing question prompts directly into their engineering notebooks, it is still recommended to make copies in the specified amounts for *1.b.*

Cue up this video about the Galapagos island (Galapagos Islands Tour): https://www.youtube.com/watch?v=bq0FO7QUGYs

Cue up a video about markets in Ecuador. Here are two possibilities:

- **Most recommended:** https://www.youtube.com/watch?v=KHzPZWPTcXY
- **Another recommendation:** https://www.youtube.com/watch?v=U92ewvzahOM

Create a poster titled "Questions for Client". It is recommended to make two columns, one for the students' questions and one for the answers from the client. This could also be done on a white board or digitally projected. However, since the students may refer to the client's answers throughout the unit, it would be useful to have them visible for the duration of the unit.

Defining the Engineering Problem

Classroom Instruction

Introduction to the Unit

1. **Introduce the unit. Say:** *We will be working on an engineering project to solve a problem for some fishermen in Ecuador.*

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'll use the notebooks to take notes and record what you are learning. In addition, there are questions that you'll be asked to answer. Sometimes you'll answer the questions on your own, then in your teams. Each day, turn in your engineering notebooks before you leave class.* NOTE: You can have your students write in their notebooks in two different colors – one for thoughts and prompts that are individual and one for thoughts and prompts that they discuss in their teams. This will help you assess the students' individual contributions and help the students recognize their contribution of ideas. You also may want to have students complete a notebook cover and start a Table of Contents page. You may choose to have students tape/ glue copies of the notebook prompts and/or the duplication masters into their notebooks.

3. **Complete notebook prompts about engineering.** Pass out *1.a. What Do You Know About Engineers* or have students individually answer the two prompts in their notebooks prior to teaching them anything else about the unit or about engineering. Make sure to let them know that it is okay if they do not know very much about engineers or engineering – just have them answer the questions to the best of their ability. NOTE: See pages 146-148 for instructions for using notebooks rather than duplication masters.

Introduction to the Lesson

4. **Introduce engineering. Say/Ask:** *In order to create solutions to our problem, we will be working as engineers. What do you know about engineers?* Take student 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 objects or processes.*

5. **Introduce the engineering design process.** Display the *Engineering Design Process* poster and pass out *Engineering Design Process* sliders to each student. **Say:** *Engineers use an engineering design process, along with mathematics, science, and creativity, to understand a problem and come up with a solution. Since we are working as engineers during this unit, we will be using this engineering design process as a guide while we come up with a solution for our engineering problem.*

6. **Unpack the engineering design process.** Ask students to make observations about their *Engineering Design Process* sliders and then to share what they think the different parts mean. Guide discussion so that the following key points are noted:

- The process can be broken down into two overall pieces: the Problem and the Solution (two gray boxes on the left).
- Communication and teamwork are important to the entire engineering design process (gray box on the right side).
- The process is broken down into six steps: define (the problem), learn (about the problem), plan (the solution), try (the solution), test (the solution), and decide (whether the solution is good enough).
- Often, you go through the steps from one to the next one down (arrows in the middle).
- The process is iterative, or repeatable, meaning that you don't have to go exactly in order only one time (arrows along the sides).

NOTE: While this is not evident on the slider, it important to inform students that there is not one single engineering design process. There are others, some with more steps, and some with fewer steps. They all have similar parts, though, such as iterating between the problem and solution, needing communication and teamwork throughout, and being repeatable.

7. **Identify where they are in the engineering design process. (Define)**
   Say: *Engineers need to first define the problem in detail before they can learn more about the problem and design a solution. This is what we will be doing today.*

Activity

8. **Make a personal connection to students' lives. Ask:** *Has anyone been to an island or to the Caribbean or Galápagos islands? Has anyone been to a fish market? Has anyone caught or cooked fish?* Take student answers after each question. Tell students that today they are going to learn about the Galápagos archipelago and one of the main living activities there.

9. **Watch a short video about the Galápagos Islands.** This 2 minute, 43 second long video provides students with a familiarity of the region in which their engineering problem is based. The island of San Cristobal will be their main focus and is featured from 1:08-1:18 on the video.
   - Link to Galapagos Islands Tour: https://www.youtube.com/watch?v=bq0FO7QUGYs

10. **Watch a video about fish markets.** Show one video of a fish market in Ecuador. Point out to students that they will be working with fishermen for the engineering design challenge.
    - Most recommended link, Traveling in the Galapagos – Local Fish market: https://www.youtube.com/watch?v=KHzPZWPTcXY
    - Another recommendation, Manta Ecuador Fish Market at the Beach: https://www.youtube.com/watch?v=U92ewvzahOM

    NOTE: It is not necessary to watch both of these videos; one is sufficient. Similarly, each video is approximately five minutes long, so only a portion of the video can be viewed if there is not enough time.

11. **Introduce the engineering problem.** Pass out the *1.b. Client Letter* 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).

12. **Introduce the concept of prototype.** Point out that the student engineers have been asked to create a "cooker container prototype." 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 be creating cooker containers large enough to cook large fish; instead, they will build a prototype, which is a smaller version made out of easily available materials.

13. **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 actually using the design solution. The client and end users are both important to the engineering problem. According to this letter, who is our client? Who are the end users?* NOTE: The clients are the members of The Pescadores Foundation; they are asking the student engineers to solve the engineering problem. The end users are the fishermen who want to sell fresh cooked fish; they will actually use the cooker container.

14. **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.* Pass out *1.c. Questions for the Client*. Have students think of possible questions individually at first and record them on the *1.c.* sheet or in their notebooks. Then give them time to share their list with their team and develop a team set of questions. Students can use different color pens for their response and their team's response.

15. **Share questions.** As a whole team, share these questions. Record students' questions for the client on chart paper labeled "Questions for Client". Leave space near each question for its 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 that the limited materials and money, as well as how the fish need to cook, are addressed at this time. If the class has not thought of these three possibilities, guide them toward asking questions about supplies available and cost. Students may also ask questions not on this list. Use your judgment to answer them. Possible questions and appropriate responses (*Client answer in italics*):
    - What materials can we use? *Your teacher has a list of materials that you can use for your prototype. We ask that you stick to these materials.*
    - How much money can we spend? *The list of materials that your teacher has also has prices. The less money you spend, the better.*
    - How do we know when the fish are cooked? (Or, what temperature do we need to reach to make sure the fish are cooked?) *Fish usually need to reach an internal temperature of 145°F (63°C) to*

be considered cooked. However, we do not expect the fish in the prototypes to reach that temperature. We will adjust your cooker container prototype designs to work exactly for the solar ovens the fishermen have and the types of fish they will cook. For now, your goal is to increase the temperature of the model fish that will be placed in your cooker container prototypes as much as possible during the 10 minutes that it will be placed in your teacher's solar oven.

- What is a solar oven? *It is a box that utilizes different types of heat transfer, including radiation from the sun and heat transferred from warm coals, to heat and cook anything inside it. Your teacher will show you a solar oven later in the unit.*
- Does it need to be reusable? *Yes, the cooker container prototype must be able to be re-used; this means that a model fish can be placed inside it and then later removed without destroying the cooker container.*
- Does the cooker container need to look nice? *No. Appearance doesn't matter to us.*
- What size should the cooker containers be? *The cooker container prototypes need to be large enough to hold a model agar fish; your teacher will show you examples of these fish later. However, your cooker container should not be too big either, since we want to fit as many cooker containers into the solar oven as possible.*
- What shape does the cooker container need to be? *It is up to you.*
- Does it matter how easy the cooker container is to make? *The easier the cooker container is to create, the better, but this is not a huge factor in our decision.*

16. **Provide answers to students' 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.

17. **Record the client's answers.** Record the answers to the questions on the chart paper labeled "Questions for Client", preferably in a different color than the questions. NOTE: If students continue to ask questions about the problem in later lessons, write the questions and answers on the "Questions for Client" chart paper. Keep this chart on display as a reminder to students about the criteria and constraints of the problem.

18. **Define the problem, including identifying the client and end users.** Pass out the *1.d. Define the Problem* worksheet and have students attach them in their notebooks or provide students with the prompts to answer in their notebooks. **Say:** *Let's 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 *1.d. 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 that possibly revised answer on the *1.d. Define the Problem* worksheet or directly in the students' engineering notebooks. **(Optional)** If student teams seem to be struggling with a question, address it as a whole class.

19. **Describe the criteria and constraints of the problem. Say:** *The "criteria" of an engineering problem are the requirements, or goals, of the designed solutions. 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.* Ask students to individually answer the questions about criteria and constraints on the *1.d. 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 possibly revised answer on the *1.d. Define the Problem* worksheet or directly in the engineering notebooks. **(Optional)** Determine one criterion and one constraint as a whole class so students have an example to clarify what criteria and constraints are.

20. **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 start designing solutions to the problem. What else do you think we need to learn in order to create a successful cooker container design?* Ask students to individually answer the final question on the *1.d. Define the Problem* worksheet, generating ideas about the kinds of information they still need to learn. 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 possibly revised answer on the *1.d. Define the Problem* worksheet or directly in their engineering notebooks. **(Optional)** As a whole class, have teams share ideas about what background information they think they need to learn in order to create a successful cooker container.

Closure

21. **Review the problem.** As a whole class, discuss the answers students have provided in *1.d. Define the Problem* worksheet or directly in their engineering notebooks. Emphasize that in order to engineering a solution to a problem, they need to deeply understand the problem first. Defining the problem is critical to the work of engineers. NOTE: Determining the criteria and constraints will likely be the most difficult aspect of defining the problem, so this is an opportunity to spend more time on that concept.

LESSON 1

Name_____ Date_____ Period _____

1.a. What Do You Know About Engineers?

Answer these questions the best you can.

1. What do engineers do?

2. How do engineers solve problems?

LESSON 1

Name_____ Date_____ Period _____

1.c. Questions for the Client

1. What are at least 3 questions that you want to ask the client that will help you understand the problem better? Make sure to ask about all important aspects of the problem.

LESSON 1

Name_____ Date_____ Period _____

1.b. Client Letter

The Pescadores Foundation
Corporación de Investigaciones Marina
Province of Esmeralda, Ecuador

Dear Student Engineers,

We are contacting you in hopes that you will help us find a solution for a problem here in the Province of Esmeralda. As members of The Pescadores Foundation, our job is to help villages around the world by promoting and teaching new methods in harvesting, preparing, and marketing food. Our latest project is assisting fishermen in villages on the coast of Ecuador with proper cooking of fish while at the fish market.

Fishermen travel several hundred miles to San Cristobal Island in the Galápagos to catch the best fish the area has to offer. Now those fishermen have come to us and said that they are interested in selling cooked fish at the fish market in addition to the raw fish they already sell, but they do not have a good way to cook them in the solar ovens that are available to them. They are in need of a small cooker container to hold each fish as it cooks in a solar oven. Since fishing is the number one occupation in the Province of Esmeralda, it is important for us to assist them by designing a cheap cooker container to hold and help cook the fresh fish in a solar oven while the fishermen are at the market. This way, the fishermen can earn more money in the fish market, which will improve their quality of life and also help benefit their families and villages.

We are asking you to design a successful cooker container prototype to assist the fishermen. 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 cooker container prototype design, including the specific materials used and a drawing with the parts labeled
- evidence that supports the success of your design
- an explanation of why this design works well to solve the engineering problem

We appreciate your willingness to help us assist these fishermen and join us in our project. We look forward to hearing about your engineering design solution.

Sincerely,

Members of The Pescadores Foundation

LESSON 1

Name_____ Date_____ Period _____

1.d. Define the Problem

Directions: Please answer these questions after you have been able to ask questions about the challenge.

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:

LESSON 1

Name_____ Date_____ Period _____

1.d. Define the Problem

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. **Think about the problem of cooking fish in a solar oven. In terms of being able to properly cook a fish using a cooker container in a solar oven, what are at least 2 things you need to learn in order to design a successful cooker container prototype? Make sure to consider all important aspects of the problem. Be specific.**
   My response:

   Team response:

LESSON 1

Student Name_____ Date_____ Period _____

1.e. 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. Explain why the problem is important to solve based on evidence that is relevant to the problem.	yes no	**Identified 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 1

Student Name_____ Date_____ Period _____

1.e. Problem Scoping Rubric

Problem	Question	Learning Objectives	Rubric	
1.d.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**
1.d.6	Think about the problem of cooking fish in a solar oven. In terms of being able to properly cook a fish using a cooker container in a solar oven, what are at least 2 things you need to learn in order to design a successful cooker container prototype? 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:

1.f. Define the Problem Possible Answers

1. **Who is the client?**

   The clients are the members of The Pescadores Foundation.

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 answers.**

   The fishermen want to properly cook and sell fish at the fish market. If the fishermen are able to earn more money at the fish market, it will benefit their families and villages.

3. **Who are the end users?**

   The end users are the Ecuadorian Fishermen who will use the cooker containers to cook fish in their solar ovens at the fish market.

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

   (Main) The model fish needs to be cooked in the cooker container, which means that it needs to reach as high of a temperature as possible when it is placed in the solar oven. Also, a cheaper cooker container prototype is better.

   (Possible others) It also needs to be re-usable.

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

   We can only use materials on the list. The cooker container prototypes must be large enough to hold one model agar fish but still relatively small so multiple can fit into a solar oven. Specific maximum dimensions may be included.

6. **Think about the problem of cooking fish in a solar oven. In terms of being able to properly cook a fish using a cooker container in a solar oven, what are at least 2 things you need to learn in order to design a successful cooker container prototype? 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: how to transfer heat, types of heat transfer, etc.

LESSON 2 Temperature and Heat Transfer & Convection

Lesson Objectives

Students will be able to:

- describe the relationship between the motion of particles and temperature in a solid, liquid, and gas.
- define temperature as a measure of the average kinetic energy of particles of matter.
- define thermal energy as the total amount, or sum, of kinetic energy in a substance; it depends on the temperature and the total number of particles.
- define heat as the thermal energy transferred from one object to another due to the temperature difference between the objects; energy is transferred from hotter objects to colder ones.
- define convection as how heat transfers in liquids and gases; cold matter sinks because it is more dense, which pushes the hotter matter up.

Time Required

One 50-minute class period

Materials

Per classroom:

- 1 *Engineering Design Process* poster
- digital technologies to display video and online simulation
- 1 clear plastic container with a minimum height of 4”
- 1 gel food coloring (not yellow)
- 5 Styrofoam cups of the same size
- hot water (at or near boiling)
- room temperature water

Per student:

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

Lesson Summary

Students learn about temperature, thermal energy, and heat. Temperature is the measure of how fast the particles in a substance are moving, on average. Thermal energy is the total amount of particle kinetic energy, so it depends on the temperature and number of particles. Heat is the thermal energy that passes from one system to another by virtue of a temperature difference. Students also observe a demonstration about heat transfer through convection.

Background

Teacher Background

A simultaneous advantage and disadvantage in science education is that students bring many prior conceptions and experiences about natural phenomena to the classroom. This can be an advantage when standards-based science concepts align well with students’ intuition. However, this alignment does not always happen, leading to students having various misconceptions about science content knowledge. One area in which teachers typically deal with many misconceptions is heat transfer. Students have experience touching hot and cold items, cooking, being near fireplaces or campfires, to name of few. This causes them to have intuitions about temperature and heat that are often incomplete or incorrect. This unit will attempt to address several, though not all, common misconceptions related to temperature, thermal energy, and heat transfer. This background section will define several terms and then address misconceptions students might have.

Background Information: This unit assumes that students have at least partially mastered certain science concepts. First, students should already know that *matter* is any physical substance that had mass and takes up space. *Matter* is made up of smaller *particles*; these *particles* can be atoms or molecules. (In this unit, the term *particle* is mostly used, but *atom* and *molecule* would also work in most situations.) Matter can occur in three *states*: solid, liquid, and gas. (Other states, such as plasma, also exist, but discussing only three states is appropriate for this level.) These concepts are needed for the first part of the lesson, which involves a simulation that shows how *particles* look and move in each *state of matter*, as well as the effect a change in *temperature* has on the motion of particles. This unit does not address changes in state (e.g., melting, freezing, vaporization, condensation).

Second, students should already know that *kinetic energy* is the energy due to motion. They don’t need to have a detailed understanding of the mathematical definition of *kinetic energy*, nor do they need to understand that kinetic energy depends on the mass of an object. However, they need to know that the speed (or velocity) of an object relates to its *kinetic energy*; the faster something moves, the more *kinetic energy* it has. (Again, the mathematical relationship between speed and kinetic energy, i.e., that kinetic energy is proportional to the square of the velocity, is not necessary.)

Third, it would be helpful if students had a general idea about the meanings of the terms *average* and *sum*. An exact mathematical definition is not necessary. It’s enough to think about *sum* as the total and *average* as the central/typical value of a set of data.

Temperature and Heat Transfer & Convection

Finally, students should know how density affects whether something floats or sinks. If object/fluid 1 is more dense than object/fluid 2, then object/fluid 1 will sink when mixed with object/fluid 2. It would also be helpful if students understood the relationship between particle packing and density: generally speaking, the more closely packed the particles of an object/fluid are, the more dense it is. These concepts will be helpful for understanding convection.

More information about heat transfer concepts:
Temperature is a measure of the average kinetic energy of particles of matter. The faster the particles are moving (on average), the hotter the temperature. Temperature is sometimes referred to as the degree of hotness of a system. Temperature can be measured using a thermometer, thermocouple, or temperature probe. Note that these measurement tools measure the average kinetic energy indirectly and so no mathematical definition of average is needed. There are three units used to measure temperature: degrees Fahrenheit (°F), degrees Celsius (°C), and Kelvin (K). Celsius and Kelvin are generally preferred for scientific investigation. At this level and in this unit, it is appropriate to use degrees Celsius.

Thermal energy is the total amount, or sum, of kinetic energy in a substance; it can also be stated that it is the motion of particles within a substance. This means that the thermal energy of a system depends on the temperature of the system, the total number of particles of the system, and the state of materials in the system. For the purposes of this unit, we only discuss the impact of temperature and total number of particles. In more advanced thermodynamics, thermal energy is called total internal energy.

Heat is the thermal energy transferred from one object to another due to the temperature difference between the objects. Heat transfers from hotter (i.e., higher temperature) regions or objects to colder (i.e., lower temperature) regions or objects. One confusing aspect about heat is that it is used differently in everyday language and in scientific language. In everyday language, heat can mean the thermal energy of an object and also the transfer of thermal energy between objects. However, in science, heat only refers to the transfer of thermal energy. However, science education still frequently uses “heat transfer” synonymously with “thermal energy transfer,” even though the scientific term “heat” automatically means transferred energy. For most of this unit, we use both “heat transfer” and “thermal energy transfer” interchangeably, even though “heat” and “thermal energy” have different meanings.

We will use an example to clarify the terms. Imagine that there is a bucket of water. If a cup of water is removed from the bucket, the *temperature* of the water in the bucket and cup is the same. (The average kinetic energy of the molecules in each container is the same.) However, the *thermal energy* of the water in the bucket is greater than the *thermal energy* of the water in the cup, since the water in the bucket has more particles (and thus a greater total kinetic energy of molecules) than the water in the cup. Now, two ice cubes are dumped into the cup and two into the bucket. For both containers,

Standards Addressed
Next Generation Science Standards: MS-PS1-4, MS-PS3-3, MS-PS3-5

Key Terms
- Primary: temperature, thermal energy, heat, convection
- Secondary (review): particle, kinetic energy, Celsius, average, dense

Assessments
Pre-Activity Assessment
Students should have their engineering notebooks and/or worksheets from the previous lesson. Check that students can state the defined engineering problem.

Activity Embedded Assessment
Check students’ progressive understanding through their verbal and written responses during activities and discussions, especially their explanations about temperature vs. thermal energy vs. heat.

Post-Activity Assessment
At the end of the lesson, check that students describe the difference between temperature, thermal energy, and heat, and describe heat transfer through convection.

DUPLICATION MASTERS
- 2.a. Temperature, Thermal Energy, and Heat
- 2.c. Convection

EDUCATOR RESOURCES
- 2.b. Temperature, Thermal Energy, and Heat Answers
- 2.d. Convection Answers
- 2.e. Convection Demonstration

thermal energy will transfer from the water to the ice cubes, since *heat* transfers from materials with higher temperatures to those with lower temperatures. At the molecular level, the liquid water molecules next to the ice interact with the solid water molecules in the ice, transferring some of their energy (i.e., *heat transfer by conduction*). This means that the liquid water molecules lose a little kinetic energy, while the energy gained by the solid water molecules is used to melt the ice. The ice in the bucket will melt more quickly than the ice in the cup because of its greater total kinetic energy of molecules (i.e., thermal energy). Each water molecule in the cup has to transfer more of its kinetic energy to the ice in order to melt it as compared to each water molecule in the bucket, since there are fewer molecules in the cup. Since the liquid molecules in the cup lose more kinetic energy than those in the bucket, this means that the average kinetic energy of the molecules in the cup lowers more than in the bucket. In other words, the temperature of the water in the cup decreases more during the melting process than the water in the bucket. The rate of melting correlates to the temperature difference between the objects. The temperature of the water in the bucket and cup lowers as the ice melts, but the water temperature in the cup lowers more, becoming closer to the melting temperature of the ice. Since the temperature difference in the cup is smaller, melting occurs at a slower rate.

Temperature is a property of materials; an object/fluid can *have* a temperature. *Thermal energy* is also a property of materials. Similar to other kinds of energy such as kinetic energy or potential energy, thermal energy is used to describe a kind of energy that an object/fluid *has*. However, some energy can only be transferred between objects/fluids, such as work or *heat*. An object/fluid does not *have* work or *heat*. Objects/fluids *do* work or have work *done* on them. *Heat* can transfer into or out of a system, but we would not say that the system "has a heat." An object/fluid *has* a *thermal energy*; when thermal energy is transferred, this is *heat* or *thermal energy transfer*. As stated before, this process is also commonly called *heat transfer*, even though this is a bit misleading since *heat* implies *transfer*. We will use *heat transfer* and *thermal energy transfer*, since both are commonly used at this level.

There are three processes by which heat transfers from hotter objects/fluids into colder objects/fluids: *conduction* (within solids or between solids and a fluid), *convection* (by the flow of a fluid), and *radiation* (which travels across space). In this lesson, students will observe a demonstration of convection. Fluids, which are liquids and gases, transfer heat through convection. In a fluid that has different regions with different temperatures, the particles of the fluid with a colder temperature are more dense than the particles of the fluid with the higher temperature, since particles with higher temperatures have more average kinetic energy (i.e., move more) and thus take up more space. The colder fluid particles sink, pushing the hotter fluid particles up. This creates a *convection current*. Photos of this phenomenon can be seen in *2.c. Convection Demonstration.*

There are several common misconceptions related to the heat transfer topics explained above. Try to watch for and address them as needed during this lesson and the rest of the unit.

- **Misconception:** Heat is a "thing", a "substance", or matter. In everyday

language, we say things like, “Heat moves,” “Heat flows”, or “Heat rises”, which all imply that heat is a substance made of particles. **Correct conception:** Heat is the *transfer of thermal energy* between matter, not the matter itself. In convection, it is not “heat” that rises; rather, the higher-temperature particles of fluid rise because they have been pushed up as the colder-temperature particles sink (due to differences in density).

- **Misconception:** Temperature “transfers”. **Correct conception:** Since temperature is a measure of an average kinetic energy of molecules, it cannot transfer from one object to another. Thermal energy transfers between objects (i.e., heat), which changes the temperature of each object. Temperatures “change”; energy “transfers”.
- **Misconception:** If you place an object in a colder temperature environment, it will gain or absorb “coldness.” For example, when water in an ice cube tray is placed into a freezer, people will say the water “absorbs the coldness” from the freezer air. Cold is a kind of “negative energy.” **Correct conception:** Thermal energy always transfers from regions or objects that are higher in temperature to regions or objects that are lower in temperature; this transfer is called *heat*. “Cold” does not transfer. When water in an ice cube tray is placed into a freezer, energy transfers from the warmer water to the cooler air in the freezer (i.e., the freezer air absorbs heat from the water).

Before the Activity

If using the duplication masters, print and make copies of the following worksheets in the labeled amounts:

- *2.a. Temperature, Thermal Energy, and Heat* (1 per student)
- *2.c. Convection* (1 per student)

If students are writing question prompts directly into their engineering notebooks, it may still be helpful for students to have copies of *2.a.* since there are diagrams on this worksheet.

Cue up the online PhET simulation, “States of Matter: Basics.” This can be downloaded from the link: https://phet.colorado.edu/en/simulation/states-of-matter-basics

Cue up a video about temperature and either thermal energy or heat.
Most recommended: *Temperature vs. Heat (Eureka!)*

- https://www.youtube.com/watch?v=wTi3Hn09OBs

Alternate version of that video: (only use 0:43-4:33 of *Eureka! Episode 21 Temperature vs Heat*)

- https://www.youtube.com/watch?v=yxBTEMnrZZk

Another recommendation: (only use 7:46-9:43 of *Heat Temperature and Energy*)

- https://www.youtube.com/watch?v=maPt__CZ1cY

NOTE: Both of the recommended videos have two drawbacks: they are old and a bit corny, and they both use “heat” to mean “thermal energy” and “thermal energy transfer.” The lesson is written to take that into account. However, it was difficult to find concise and interesting videos on the subject. Other videos can be used instead of this.

(Optional) Cue up a video about convection.
Recommended: *eureka 27 convection*
- https://www.youtube.com/watch?v=IfeRaOb_E-s

Set up the Convection Demonstration based on the information in *2.c. Convection Demonstration.*

Classroom Instruction

Introduction

1. **Tie to the engineering problem. Ask:** *What is our engineering design problem?*

2. **Identify where they are in the engineering design process. (Learn) Say/Ask:** *So far, we have defined the problem in detail with help from our client.* Point out the "Define" block on engineering design process, and have students look at their *Engineering Design Process* sliders. *Before we can start designing solutions, though, we need more information. What step of the engineering design process do we need to do next?*

3. **Identify what students need to learn about. Say/Ask:** *In the previous lesson, you all identified what we need to learn about. What were some of those ideas we need to learn?* Remind students to refer to their notes from the previous lesson, specifically the last question in *1.d. Define the Problem*. Students should say something about how to best transfer heat, learning about types of heat transfer, etc.

Activity Part 1: Temperature and Particles of Matter

4. **Review background information. Say/Ask:** *Today we are going to learn about temperature, thermal energy, and heat. Before we do that, though, we need to review some other science concepts.* Lead a whole class discussion in which students answer the following questions:
   - What is matter? (*a physical substance that has mass and takes up space*)
   - What is matter made up of? (*particles; or atoms and molecules*)
   - What are the three main states of matter? (*solid, liquid, gas*)

5. **Introduce the simulation activity.** Pass out *2.a. Temperature, Thermal Energy, and Heat* or have students write the answers to the prompts in their engineering notebooks next to the number of that prompt. Tell students that they will be observing a simulation about what happens to particles in different states of matter when temperature is applied. NOTE: The remainder of Activity Part 1 is a teacher demonstration with a whole class discussion. However, this simulation could also be done by individual or paired students if enough digital technologies are available.

6. **Show the states of matter.** In the "States of Matter: Basics" online simulation, show students one or two types of particle in their solid, liquid, and gas forms by clicking the buttons on the right side of the simulation screen. NOTE: It is recommended to use Neon, Argon, and/or Oxygen instead of Water. (The packing of molecules in solid form is most

straightforward with the first three types of particles; water is much more difficult due to its shape and the importance of hydrogen bonding.)

7. **Draw particles in different states.** Have students draw the arrangement of particles in a solid, liquid, and gas state.

8. **Describe how particles move.** Discuss how the particles move in each state. Point out that even in the solid state, the particles are moving through vibration, even though they are not moving past each other. Have students record descriptions of how particles move in *2.a. Temperature, Thermal Energy, and Heat* or in their engineering notebooks. NOTE: Vibrational and translational motion is visible regardless of which particle is chosen. Rotational motion is only visible for Oxygen, however. It is not important that students know all three of these types of motion at this level, but if Oxygen is chosen as the particle to demonstrate with, students may point out the spinning motion of the molecules.

9. **Predict the effect of temperature. Ask:** *What do you think will happen to the particles when I increase the temperature of each state?* NOTE: Students may mention changes of state (e.g., melting, boiling, evaporation) as a possible answer. Acknowledge this as a correct answer, but also tell them that their primary focus is not about phase changes but rather about what happens to particle motion as temperature changes **(Optional)** Point out that the simulation uses two different units of temperature: degrees Celsius and Kelvin. These are the two units used in science, as opposed to degrees Fahrenheit which is used in everyday life. For this unit, students will be used degrees Celsius.

10. **Demonstrate the effect of temperature.** Use the heat button at the bottom of the simulation to change the temperature. Heat each phase enough so that there's a visible difference in the motion of particles, but not so much that it starts a change of state.

11. **Discuss and record the effect of temperature. Ask:** *What happened to the particles when the temperature increased?* Students should note that the motion of the particles increased in all three states of matter (i.e., more vibrations, faster flow). Have them record their observations.

Activity Part 2: Temperature, Thermal Energy, and Heat

12. **Preface the video. Say:** *In order to understand heat transfer better, we need to understand the difference between three key terms: temperature, thermal energy, and heat.* Tell students that in everyday language, "heat" means two different things. Sometimes it means a transfer of energy from higher temperature (hotter) objects to lower temperature (colder) ones, which is the proper definition in science. Sometimes, though, we use the word "heat" when we really mean "thermal energy." If using the videos suggested, **say:** *In the video, the narrators often use heat when they actually should be using the scientific term thermal energy. When we are watching the video, I will point out when this happens.*

13. **Watch the video.** Show a video about temperature vs. heat (or thermal energy, depending on the video). Whenever the video uses the word "heat" when they should be using "thermal energy", point this out to the students. **(Optional)** Stop the video before certain demonstrations and ask for predictions of what will happen.

14. **Discuss the video.** Ask students what they learned from the video. Clarify that temperature is different from thermal energy, since temperature only depends on the motion of particles, while thermal energy depends on the temperature and number/quantity/amount of particles.

15. **Define temperature, thermal energy, and heat.** Present the students with definitions of temperature, thermal energy, and heat. Discuss each one, including any confusing words within the definition, and have them record the definitions.
    - *Temperature* is a measure of the average kinetic energy of particles of matter
    - *Thermal energy* is the total amount, or sum, of kinetic energy in a substance; it depends on the temperature and the total number of particles.
    - *Heat* is the thermal energy transferred from one object to another due to the temperature difference between the objects; energy is transferred from hotter objects to colder ones.

    NOTE: Students may need to be reminded about the meanings of the terms kinetic energy, average, and sum. Another method of defining vocabulary (e.g., the Frayer model) may be used here.

16. **Highlight "heat transfer" and "thermal energy transfer." Say:** *In science, "heat" means the transfer of thermal energy from a higher temperature to a lower temperature; this can also be called "thermal energy transfer." However, rather than just saying "heat", we often say "heat transfer" to emphasize that heat is the transfer of energy.*

17. **Introduce the block example. Say:** *These are difficult scientific terms to understand the difference between. Let's think about them in another way, using an example.* Have students look at the two blocks in *2.a. Temperature, Thermal Energy, and Heat*.

18. **Use the key terms.** Have students answer the questions about the blocks in *2.a. Temperature, Thermal Energy, and Heat* or in their engineering notebooks. This can be done individually, in small teams, or as a whole class. If done individually or in small teams, it is recommended to reteam as a whole class to review answers.

Activity Part 3: Convection

19. **Introduce convection. Say:** *Today we are going to learn about one of the three main types of heat transfer. This is called convection.*

20. **(Optional) Watch a video about convection.** Show the recommended video about convection, which ties to the real-world situation of using

convection to heat a house.

21. **Introduce the demonstration.** Pass out *2.c. Convection* or have students write the answers to the prompts in their engineering notebooks next to the number of that prompt. Display the convection demonstration set up so that all students can see it.

22. **Make a prediction.** Explain to students what will happen next: gel food coloring will be placed in the bottom of the tub, and a cup of very hot water will be placed underneath the tub. Have students discuss and record their predictions for what they think will happen inside the tub.

23. **Complete the demonstration.** Follow the directions on *2.e. Convection Demonstration*. Once the convection current starts (i.e., the food coloring and water circulates), have students record observations in *2.c. Convection* or directly in their engineering notebooks.

24. **Explain the demonstration. Ask:** *Why do you think this happened?* Guide student discussion so that they make connections between the temperature and density of water (i.e., hotter temperatures have faster particles which expand more and thus are less dense). NOTE: This is a good time to address two misconceptions. First, it is the hot and cold water that is moving, not "heat" itself. Second, the cold water sinks due to its greater density, which pushes the hot water up.

Closure

25. **Review the terms.** Lead a whole class discussion about the difference between temperature, thermal energy, and heat, as well as what the heat transfer process of conduction is. Address any misconceptions that came up during the lessons' discussions.

LESSON 2

Name_____ Date_____ Period _____

2.a. Temperature, Thermal Energy, and Heat

Temperature and Particles of Matter

1. Draw particles in different states of matter.

Particles in a solid	Particles in a liquid	Particles in a gas

2. Describe how particles move:

   - in a solid: _____
   - in a liquid: _____
   - in a gas: _____

3. What happens to the particles when the temperature increases?

Key Terms

4. Define "temperature." (You may use drawings in addition to words.)

5. Define "thermal energy." (You may use drawings in addition to words.)

6. Define "heat." (You may use drawings in addition to words.)

LESSON 2

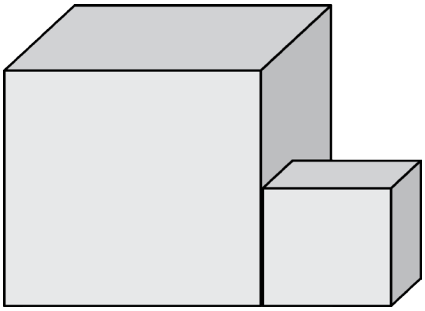
Name_____ Date_____ Period _____

2.a. Temperature, Thermal Energy, and Heat

Using the Key Terms

In the drawing below, there are two metal blocks that are touching. They are made out of the same materials, but they have different temperatures and sizes.

Block 1:
Temperature = 25°C



Block 2:
Temperature = 30°C

7. Which block has the higher temperature? Why do you think so?

8. Which block has more thermal energy? Why do you think so?

9. Since the blocks are touching, there will be a transfer of thermal energy, or heat, from one to the other. Which direction will the heat transfer occur? Why do you think so?

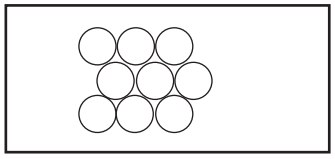
10. Describe the heat transfer that would occur if you put Block 2 into a freezer, which has a temperature of 0°C. Why do you think so?

2.b. Temperature, Thermal Energy, and Heat Answers

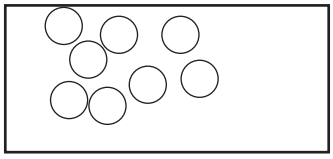
Temperature and Particles of Matter

1. Draw particles in different states of matter.

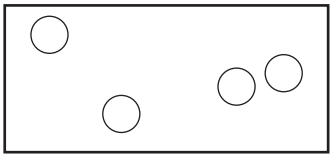
Particles in a solid



Particles in a liquid



Particles in a gas



2. Describe how particles move:
   - in a solid: The particles vibrate, but they don't move past each other.
   - in a liquid: The particles vibrate and slowly flow past each other.
   - in a gas: The particles move around in space, sometimes hitting each other.
3. What happens to the particles when the temperature increases?
   As the temperature increases, the particles move more and/or faster. (They vibrate more, flow past each other faster, and zoom around space in the gas faster.)

Key Terms

4. Define "temperature." (You may use drawings in addition to words.)
   Temperature is a measure of the average kinetic energy of particles of matter. (Temperature measures how fast the particles in matter are moving, on average.)
5. Define "thermal energy." (You may use drawings in addition to words.)
   Thermal energy is the total amount of kinetic energy in a substance; it depends on the temperature and the total number of particles.
6. Define "heat." (You may use drawings in addition to words.)
   Heat is the transfer of thermal energy from one object to another due to the temperature difference between the objects. Energy is transferred from hotter objects (higher temperature) to colder objects (lower temperature).

Using the Key Terms

7. Which block has the higher temperature? Why do you think so?
   Block 2 has a higher temperature. The temperature is given to us, and 30°C is higher than 25°C.
8. Which block has more thermal energy? Why do you think so?
   Block 1 probably has more thermal energy because it has more particles. Thermal energy depends on the temperature and the number of particles. Even though Block 2 has a higher temperature, Block 1 has many more particles, so it probably has a higher thermal energy.
9. Since the blocks are touching, there will be a transfer of thermal energy, or heat, from one to the other. Which direction will the heat transfer occur? Why do you think so?
   The thermal energy will transfer (heat transfer will occur) from Block 2 to Block 1, since heat transfers from an object at a higher temperature to an object at a lower temperature.
10. Describe the heat transfer that would occur if you put Block 2 into a freezer, which has a temperature of 0°C. Why do you think so?
    Heat transfer would occur from Block 2 to the air of the freezer, since Block 2 has a higher temperature (30°C) than the freezer air (0°C) and energy transfers from hotter substances to colder substances.

LESSON 2

Name_____ Date_____ Period _____

2.c. Convection

1. **Predict:** What do you think will happen to the water and food coloring inside the plastic tub when the cup of boiling water is placed underneath?

2. **Observe:** What happens to the water and food coloring? Describe and/or draw your observations.

3. **Explain:** Why did this happen?

4. **Identify:** The process of heat transfer this represents is: _____

LESSON 2

Name_____ Date_____ Period _____

2.c. Convection

1. **Predict:** What do you think will happen to the water and food coloring inside the plastic tub when the cup of boiling water is placed underneath?

2. **Observe:** What happens to the water and food coloring? Describe and/or draw your observations.

3. **Explain:** Why did this happen?

4. **Identify:** The process of heat transfer this represents is: _____

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2.d. Convection Answers

1. **Predict:** What do you think will happen to the water and food coloring inside the plastic tub when the cup of boiling water is placed underneath?

   Answers will vary

2. **Observe:** What happens to the water and food coloring? Describe and/or draw your observations.

   They should show/write about the food coloring flowing in a somewhat circular patter (see *2.c. Convection Demonstration* for a photo). They do not need to use the term convection current, but they can.

3. **Explain:** Why did this happen?

   The hot water in the Styrofoam cup transferred heat energy to the water molecules in the bottom of the plastic tub. This energy transfer made the particles increase in temperature, move more, and expand, making them less dense. The cold temperature, more dense water particles sunk to the bottom of the tub, pushing up the higher temperature, less dense water particles.

4. The process of heat transfer this represents is: _convection._

2.e. Convection Demonstration

Supplies: 1 clear rectangular plastic tub at least 4” tall; 1 gel food coloring (dark color preferable, definitely not yellow); 5 Styrofoam cups of the same size; room temperature water (enough to fill the tub at least halfway if not more); hot water (at or near boiling)

Directions:

Before the demonstration:

1. Pour room temperature water into the clear plastic tub to fill it at least halfway if not more. Tap water works fine.
2. Place the tub of water on top of four upside-down Styrofoam cups. (See Figure 1.)
3. The demonstration will require at or near boiling-temperature water. The water can be heated beforehand and put into a thermos until the demo, or it can be heated immediately prior to the demo.

During the demonstration:

4. Place one large blob of the gel food coloring onto the bottom of the plastic tub near the middle. (See Figure 2 for a top view.)
5. Pour the hot water into the fifth Styrofoam cup. Place the cup underneath the plastic tub, directly underneath the blob of food coloring. (See Figure 3.)
6. Wait and watch as the convection current starts. (See Figure 4.) This will take a few minutes.

Figure 1

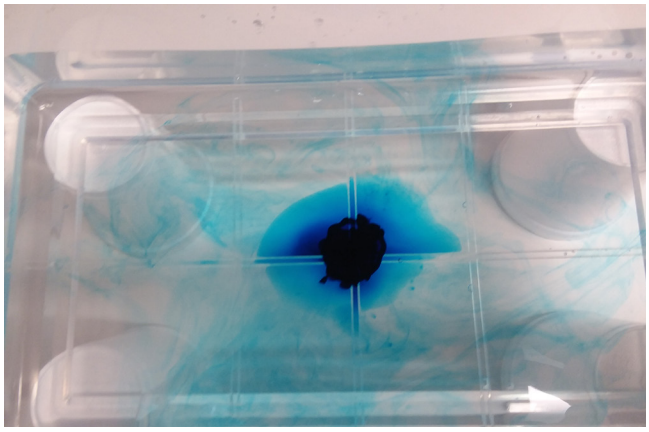


Figure 2

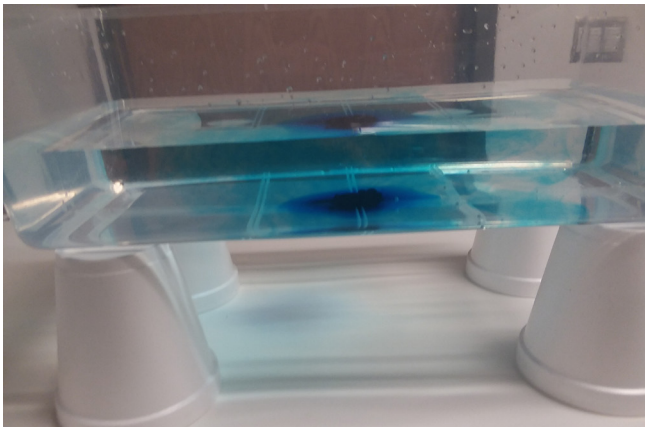


Figure 3

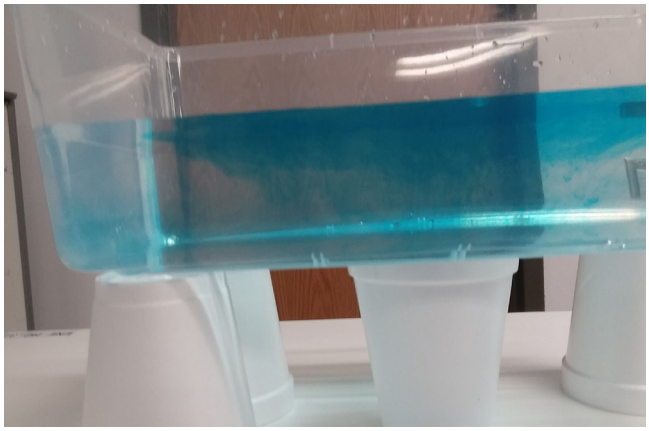


Figure 4

LESSON 3

Heat Transfer through Conduction

Lesson Objectives

Students will be able to:

- define conduction as the transfer of energy through a solid or from a solid to another solid, a liquid, or a gas.
- identify which kinds of materials are conductors (i.e., transfer heat by the process of conduction easily and quickly) or insulators (i.e., slow down the transfer of heat by the process of conduction).

Time Required

One 50-minute class period

Materials

Per classroom:

- 1 *Engineering Design Process* poster
- digital technologies for videos
- 1 laser infrared thermometer

Per team:

- 2 ice cubes of approximately the same mass
- 1 wood or plastic cube
- 1 metal cube
- **(Optional)** 1 paper plate or several paper towels

Per student:

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

Standards Addressed

Next Generation Science Standards: MS-PS1-4, MS-PS3-3, MS-PS3-4, MS-PS3-5

Key Terms

heat transfer, conduction, conductor, insulator

Lesson Summary

Students learn about heat transfer through conduction. They complete an ice cube experiment in which they place ice cubes on top of different materials and then observe and record which ice melted faster. Students tie the concept of conduction to their previous knowledge about conductors and insulators.

Background

Teacher Background

Conduction is the second of three types of heat transfer, or thermal energy transfer, that students will learn about in this unit. On a macroscopic scale, conduction is defined as the transfer of energy through a solid or from a solid to a fluid (liquid or gas). This is the definition students will need to know for mastery. However, they will also be exposed to how this happens on the microscopic level. Vibrating particles collide, transferring kinetic energy. When a particle with a higher kinetic energy collides with a particle with less kinetic energy, some of the kinetic energy transfers from the high kinetic energy particle to the low kinetic energy particle. This decreases the kinetic energy in the first particle and increases the kinetic energy of the second particle. When this happens on a large scale, these changes in kinetic energy of particles mean that the object that originally had a higher temperature (i.e., higher average kinetic energy of particles) will decrease in temperature as the particles transfer kinetic energy away; the opposite will happen to the object that originally had a lower temperature.

Materials that transfer heat via the process of conduction quickly and easily are called conductors, and those that don't are insulators. These terms should be review for students. They should also know that metals tend to be good conductors, and materials such as polymers, paper, and wood are good insulators. Why this occurs at a microscopic level is not required for this lesson, but it is an option to teach. Materials that are good insulators tend to have particles that are farther apart, especially if there are small pockets of trapped air in the material (e.g., paper and wood contain hollow, dried-up plant cells, each of which is a tiny air pocket). This makes it difficult for particles to collide with each other, which is how the transfer of kinetic energy that leads to conduction occurs. On the other hand, metals have free electrons, which means that there are even more particles colliding with each other. The high number of collisions means that energy is transferred quickly through metals.

One common misconception related to temperature can be explained in terms of conduction, and this is addressed in this lesson. Specifically, many people rely on their sense of touch to determine the temperature of materials, which can be misleading. Two materials (e.g., a piece of metal and a piece of paper, wood, or plastic) can be at the same temperature (e.g., room temperature) but feel different. At room temperature and other temperature points below body temperature, metals feel colder than paper, wood, or polymers. At temperatures above body temperature, metals feel hotter than paper, wood, or plastic. This difference is due to how well the materials conduct thermal energy. Metals are good conductors, and thus they transfer heat from your body into the metal quickly and easily. Materials that are good insulators conduct heat poorly, and thus the rate of heat transfer away from your body is much slower. Because

Heat Transfer through Conduction

metals transfer heat away from your body faster than insulators, it feels like metals are colder even though they aren't. The same argument works for temperature above body temperature (e.g., grabbing a hot ladle), though in this case the heat transfers from the hot temperature object into the cooler temperature body.

Before the Activity

If using the duplication masters, print and make copies of the following worksheets in the labeled amounts:

- *3.a. Conduction* (1 per student)

(Optional) Cue up a video about adults working through misconceptions related to temperature and heat transfer. Both recommended videos are made by the YouTube channel Veritasium. They are very similar, so only one should be shown.

- **Recommended:** Misconceptions About Heat (from August 2012): https://www.youtube.com/watch?v=vqDbMEdLiCs
- **Recommended:** Misconceptions About Heat (from June 2011): https://www.youtube.com/watch?v=hNGJ0WHXMyE

Preparing student materials for the Conduction Lab:

1. Collect the following materials:
   - 4 sets of a PVC and acrylic density cubes (or other polymers)
   - 4 sets of a pine and oak density cubes (or other wood)
   - 2 sets of the following density cubes: silver, cooper, bronze, and aluminum
   - 2 ice cubes per student team
   - **(optional)** 1 paper plate or several paper towels per student team
2. Organize the materials for each team in the following way:

Team 1	Team 2	Team 3	Team 4	Team 5	Team 6	Team 7	Team 8
2 ice cubes	2 ice cubes	2 ice cubes	2 ice cubes	2 ice cubes	2 ice cubes	2 ice cubes	2 ice cubes
1 pine cube	1 oak cube	1 pine cube	1 oak cube	1 PVC cube	1 acrylic cube	1 PVC cube	1 acrylic cube
1 copper cube	1 aluminum cube	1 silver cube	1 bronze cube	1 copper cube	1 aluminum cube	1 silver cube	1 bronze cube

NOTE: The lab is written to use density cubes because they usually provide different kinds of materials in a single set. However, a collection of various materials (conductors and insulators) that are different sizes would also work for this lab. While the rate of heat transfer via conduction does depend on the mass of the material used, this should not make that much of a difference since this is a mostly qualitative lab. Adjust as needed if there are more or fewer student teams.

Cue up a video about conduction.

- **Recommended:** eureka 24 conduction (definitely watch 0:38-2:17): https://www.youtube.com/watch?v=Yitiw6Y7xZg

NOTE: Watching the entire video is optional; part of the video describes subatomic particles of the atom, which is advanced for middle school.

Assessments

Pre-Activity Assessment
Check students' ability to explain the engineering problem and identify where they are in the engineering design process. Students should be able to move the paper clip on their sliders to the appropriate step.

Activity Embedded Assessment
Check students' progressive understanding through their verbal and written responses when implementing the conduction lab. This is especially important because students will need to use this information later to select better conductors for the bottom part of the cooker container.

Post-Activity Assessment
Check students' suggestions for which materials they would choose to use for their cooker container prototypes to see if they are conductors.

DUPLICATION MASTERS

- 3.a. Conduction

EDUCATOR RESOURCES

- 3.b. Conduction Answers

LESSON 3

Heat Transfer through Conduction

Classroom Instruction

Introduction

1. **Tie to the engineering problem. Ask:** *Why do we need to know about temperature and heat transfer?* Take student answers. Guide the discussion so that it reviews the engineering problem, 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 far and what step they are currently on.

3. **Identify what students still need to learn about. Say/Ask:** *We have already started learning about some science concepts that will help us design a solution to the engineering challenge. What have we already learned about?* Take this time to review temperature, thermal energy, heat, and convection. **Ask:** *What other science do you think we need to learn about?*

Activity Part 1: Feeling the Temperature of Everyday Objects

4. **Introduce the activity. Say:** We are going to review what we learned about temperature and heat transfer and then connect that to what we are going to learn about in this lesson.

5. **Feel classroom materials.** Have students put on hand on a metal surface and the other hand on a wood or paper surface. (For example, if student desks are made of metal supports and wooden desktops, their desks would work for this activity. If not, identify other locations in the classroom where students can feel a piece of metal and a piece of wood or paper at the same time.) **Ask:** *Which surface is colder?* Take student answers; they will probably say the metal feels colder. If students moved around the classroom to feel two objects, have them return to their seats.

6. **Measure the temperature of the objects.** Use the infrared laser thermometer to measure the temperature of several objects in the room, some metal and some other materials. They should all have the same temperature.

7. **Discuss the results. Ask:** *Is this result surprising? Why do you think that might be?* Take student answers. Remind students to think about not just temperature, but also thermal energy transfer, or heat.

8. **Explain the results.** Tell students that for both surfaces, heat transfers away from a person's warm hand (about 37°C) to the cooler surface (both surfaces are at room temperature, usually about 25°C). However, the heat transfers from a hand to metal easily and quickly, and since some heat is leaving the hand, it cools off and feels cold. Heat doesn't transfer well or quickly from a hand to wood or paper, so the flow is blocked, and the hand doesn't feel as cold. **(Optional)** This result is also explained in the optional Misconceptions About Heat video by Veritasium. This video can be shown in lieu of an explanation from the teacher. An advantage of this video is

that is shows many adults being stumped by this experiment as well, so students realize that adults have misconceptions about heat transfer too. NOTE: Emphasize to students the direction of thermal energy transfer. Remind students that heat transfers from objects with higher temperature to objects with lower temperatures. Students will likely identify that thermal energy transferred from their hand to the metal surface, but they may struggle to identify that heat transferred from their hand to the paper or wood surface.

9. **Summarize the activity.** Pass out *3.a. Conduction* if students are using duplication masters; otherwise, have students write the answers to the prompts in their engineering notebooks next to the number of that prompt. Have students record answers to the first three questions: what objects they felt, what they felt like, and why metals feel colder than items such as plastic, wood, or paper.

Activity Part 2: Conduction Lab

10. **Hand out materials to student teams.** Each team should receive two blocks of different materials. Have students record the two materials they received on *3.a. Conduction* or directly in their engineering notebooks. **(Optional)** Also hand out one paper plate or several paper towels for each team. They can put their material blocks on top of the plate of paper towels in order to absorb the water as the ice cubes melt.

11. **Make predictions.** Tell students that one block of ice will be placed on top of each of their materials. Have student teams discuss and record their predictions of which ice cube will melt first.

12. **Start the experiment.** Hand out two ice cubes of approximately the same mass to each student team and have the students place them on top of their assigned material objects. Make sure students make observations of what happens, and have them record these observations in *3.a. Conduction* or in their engineering notebooks. **(Optional)** Students can time how long it takes each ice cube to melt, but this is not necessary. The important aspect is the qualitative comparison. NOTE: If time is an issue, it is not necessary to wait until one or both ice cubes have fully melted. Once one ice cube has melted a lot, enough data has been gathered during the experiment, since they only need to know which material melted the ice cube first.

13. **Draw the direction of heat transfer.** Before sharing results, have students draw diagrams of the material blocks and ice cubes in their notebooks or on *3.a. Conduction*. On these diagrams, they need to:
    a. draw the direction of heat transfer using arrows
    b. note which material transferred heat more quickly.

    NOTE: If students are struggling to identify that thermal energy is being transferred (heat) from the material blocks to the ice cubes, have a class discussion about this. Remind them about their definition of heat transfer from the previous lesson.

14. **(Optional) Create a data table.** If students are not using duplication masters, have them create a data table (as shown in *3.a. Conduction*) in their engineering notebooks by the appropriate number.

15. **Record and share data.** Have one member from each team share which of their materials melted first. All students should record this information in their data table. **(Optional)** The teacher can record and display the data table on a poster size sheet of paper, on a whiteboard, or by some other means.

16. **Analyze data.** Have students look at the whole class data. **Ask:** *What do you notice about the cubes that melted more quickly? Do they have anything in common?* (The data table will probably just have metal materials listed on it.) Discuss the results of the data, and have them record answers to this question.

17. **Discuss the results. Ask:** *Why did the ice melt faster on certain surfaces?* Discuss as a whole class or in small teams. Remind students about the previous discussion they had about why heat transferred from their hands to other objects at different rates. Have them record answers in their engineering notebooks or *3.a. Conduction*.

Activity Part 3: Conductors and Insulators

18. **Watch the video about conduction.** Show students the video about conduction. (Show at least 0:38-2:17.) NOTE: Before and after this time frame, the video talks about subatomic particles such as electrons, which might be too advanced for this level. It is up to the teacher.

19. **Define conduction.** Have students come up with a definition for conduction. Remind them to think about the video and the activities from the day. Have them record this in *3.a. Conduction* or in their engineering notebooks. NOTE: At minimum, students should be able to define conduction as the transfer of heat energy through a solid or from a solid to another solid or fluid (liquid or gas). However, students could also mention the microscopic means of vibrating atoms colliding and transferring kinetic energy (energy of motion) from higher temperature particles to lower temperature particles. For this step and step 20, another method of defining vocabulary (e.g., the Frayer model) may be used.

20. **Define conductors and insulators. Say/Ask:** *The video also talked about "good conductors" and "bad conductors." What do they mean by "conductor"? What is another name for a "bad conductor"?* Students should discuss the definitions of conductors and insulators and then record those definitions.

21. **(Optional) Discuss why materials are good conductors or good insulators.** If students viewed the entire video, lead a discussion about why materials such as metals are good conductors. Also, have them think about why materials might be good insulators. (It may help to talk about small air pockets and how lots of space between particles affects how often they can

collide and transfer kinetic energy.)

Closure

22. Apply their knowledge of conduction to the challenge. Say/Ask: *Think back to the challenge of designing a cooker container prototype. If you wanted the container to transfer heat through conduction, what are some materials you would choose? What materials would you avoid?* Have student teams discuss ideas.

LESSON 3

Name_____ Date_____ Period _____

3.a. Conduction

Feeling the Temperature of Everyday Objects

1. What two objects did you feel?

2. What did they feel like? (Which one felt colder and which felt warmer?)

3. Why do metals feel colder than items such as plastic, wood, or paper?

Conduction Lab

4. What are the two materials your team received?

5. **Predict:** Two ice cubes will be placed on top of the materials. Which ice cube will melt first?

6. **Observe:** Place one ice cube on top of each material. Record observations.

7. Draw a diagram showing each material with an ice cube on top. On the diagram, indicate the direction of heat transfer using arrows. Also, note which material transferred heat more quickly.

Name_____ Date_____ Period _____

3.a. Conduction

8. **Collect Data:** Fill out the data table with the whole class's data.

Team	Material on which ice melted first
1	
2	
3	
4	
5	
6	
7	
8	

9. **Analyze Data:** What do you notice about the cubes that melted ice more quickly?

10. **Explain:** Why did the ice melt faster on certain surfaces?

Key Terms

11. Define "conduction." (You may use drawings in addition to words.)

12. Define "conductor." (You may use drawings in addition to words.)

13. Define "insulator." (You may use drawings in addition to words.)

3.b. Conduction Answers

Feeling the Temperature of Everyday Objects

1. What two objects did you feel?
   Answers will vary, but one should be metal and the other paper or wood
2. What did they feel like? (Which one felt colder and which felt warmer?)
   The metal felt colder, and the paper/wood felt warmer.
3. Why do metals feel colder than items such as plastic, wood, or paper?
   Metals feel colder because they transfer heat well. When I touch the metal, the heat transfers from my hand to the metal quickly, so it feels cold. When I touch wood/paper, the heat does not transfer well from my hand to the wood/paper, so it feels warmer.

Conduction Lab

4. What are the two materials your team received?
   Answers will vary, but one should be wood and the other plastic
5. **Predict:** Two ice cubes will be placed on top of the materials. Which ice cube will melt first?
   Answers will vary
6. **Observe:** Place one ice cube on top of each material. Record observations.
   Answers will vary
7. Draw a diagram showing each material with an ice cube on top. On the diagram, indicate the direction of heat transfer using arrows. Also, note which material transferred heat more quickly.
   The diagrams should show heat transferring from the block of material (at higher temperature) to the ice cubes (at lower temperature). The metal transferred heat more quickly.
8. **Collect Data:** Fill out the data table with the whole class's data.
   The material that melted first should be metal for all teams.
9. **Analyze Data:** What do you notice about the cubes that melted ice more quickly?
   All of the cubes are metals.
10. **Explain:** Why did the ice melt faster on certain surfaces?
    The ice melted faster on the metal material because heat transfers quickly through metals. The thermal energy transferred from the metal to the ice cube quickly, melting it faster. The thermal energy did not transfer well from the wood/plastic to the ice cube, so it melted slowly.

Key Terms

11. Define "conduction." (You may use drawings in addition to words.)
    Conduction is the transfer of heat energy through a solid or from a solid to another solid, liquid, or gas. (Optional) It occurs because vibrating particles collide, and the ones at a higher temperature (with more kinetic energy) transfer some of their kinetic energy to the particles at a lower temperature (with less kinetic energy).
12. Define "conductor." (You may use drawings in addition to words.)
    A conductor is a material that transfers heat by the process of conduction easily and quickly. Metals are conductors.
13. Define "insulator." (You may use drawings in addition to words.)
    An insulator is a material that slows down the transfer of heat by the process of conduction. Materials such as plastics, paper, and wood are insulators.

LESSON 4 Heat Transfer through Radiation

Lesson Objectives

Students will be able to:

- define radiation as the transfer of thermal energy across space in the form of light waves called electromagnetic radiation.
- explain that electromagnetic radiation (i.e., light) can be reflected, absorbed, or transmitted by objects depending on the object's material.

Time Required

One 50-minute class period

Materials

Per classroom:

- 1 *Engineering Design Process* poster
- digital technologies for videos
- materials for radiation lab:
  - 1 piece of black construction paper, ~4.5"x4.5"
  - 1 piece of white construction paper, ~4.5"x4.5"
  - 1 piece of black felt, ~4.5"x4.5"
  - 1 piece of white felt, ~4.5"x4.5"
  - 1 piece of aluminum foil, ~4.5"x4.5"
  - 1 piece of 4.5"x4.5" transparency sheet
  - 8-12 craft sticks taped together in a flat row
  - 8 heat lamps with clamps
  - 8 incandescent light bulbs
  - 8 plastic cups, 16 oz.
  - 8 ring stands
  - 8 digital thermometers
  - masking tape
  - 2 outlet power strips
- **(Optional)** 1 poster size of sticky note paper
- **(Optional)** markers

Per student:

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

Lesson Summary

Students learn about heat transfer through radiation and that materials can absorb, reflect, or transmit light. Students collect temperature data of the air inside cups that have lids made of materials such as black and white construction paper and felt, aluminum foil, transparency sheet, and wooden craft sticks.

Background

Teacher Background

The third process of heat transfer is called radiation. Radiation is the transfer of energy across space in the form of light waves called electromagnetic radiation. The heat transfer processes of conduction and convection both involve the motion of particles of matter. In conduction, particles in a solid collide with neighboring particles (in a solid, liquid, or gas), transferring kinetic energy. In convection, particles in a fluid physically sink and rise, mixing higher and lower temperature regions of the fluid. However, radiation does not need to travel through particles; it can travel through empty space. When electromagnetic radiation, or light waves, reach matter, they transfer energy from the wave to the particles, increasing the kinetic energy of the particles (and thus also increasing the temperature and thermal energy).

Electromagnetic radiation, or light waves, includes many types of light waves that vary in frequency and wavelength. Students will not be expected to know about frequency, wavelength, the speed of light, or the types of electromagnetic radiation, but it may be helpful to discuss them if students are already familiar with those concepts. Electromagnetic radiation includes (in order from longest wavelength/lowest frequency to shortest wavelength/highest frequency): radio waves, microwaves, infrared, visible light, ultraviolet (UV), X-rays, and gamma rays. This is also called the electromagnetic spectrum. All of these types of radiation transfer heat energy. All objects emit some radiation, but not all objects emit all types of electromagnetic radiation. For example, while the sun technically emits the entire electromagnetic spectrum, almost all of the radiation emitted is in the form of infrared, visible light, or UV. Incandescent light bulbs emit mostly light waves that are infrared and visible light waves. Human bodies emit infrared radiation, which can be detected by infrared cameras.

Light (i.e., electromagnetic radiation) can be absorbed, reflected, or transmitted through an object depending on the object's material and the frequency of light (type of electromagnetic radiation). In this unit, the fact that the frequency of light affects the absorption, reflection, and transmission properties of materials will not be discussed. However, students should learn that darker colors absorb radiation well, and light colors and shiny materials reflect radiation. Transparent materials, i.e., those that are see-through, transmit light waves. When electromagnetic radiation is reflected or transmitted, there is very little energy transfer. When light waves are absorbed by a material, the light energy converts to thermal energy as the electromagnetic radiation interacts with the material's particles, causing them to move faster. Students should learn the above information; they do not need to have a deep understanding of how color works, but it is explained here in case they are interested. Our perception of the color of opaque materials depends on what the material reflects. Green

Heat Transfer through Radiation

objects absorb all visible light except green light, which is thus reflected from the object. This green light hits the eye, and our brain "sees" green. Black objects absorb all visible light; since no visible light is reflected into our eyes, we see "no light" which is black. White objects absorb almost no visible light, which means it all reflects into our eyes. In terms of light, a combination of the entire visible spectrum is white. Because light colored and shiny objects reflect almost all of the electromagnetic radiation that hits them, very little heat transfer by radiation occurs. However, dark objects absorb most of the visible spectrum, which means a large amount of heat transfer.

In this lesson, students will be near hot lamps during the radiation lab. Reinforce with the class safety rules about not touching the lamp or bulb.

Before the Activity

If using the duplication masters, print and make copies of the following worksheets in the labeled amounts:

- *4.a. Radiation* (1 per student)

Cue up a video about radiation.

- **Most recommended:** Radiation (Eureka!): https://www.youtube.com/watch?v=2JZciWtK6vc
- **Alternate version of that video:** (only use 0:38-4:40 of eureka 29 radiation waves): https://www.youtube.com/watch?v=TgvGC0yQ2Dg

Prepare the eight radiation stations as in *4.c. Radiation Lab Set-up.*

Prepare the master data table. This can be done using a poster size sheet of paper and markers, a white board, or be done on a computer and displayed electronically. Students will only record the data for their assigned material. However, they will need to be able to see the data from all materials for the post-experiment discussion. The master data table will need 9 rows and 11 columns. The top row is the time in minutes; it should be the same as the top row of the data table in *4.a. Radiation*, with the last column's heading as "Temperature increase." Each row will contain one material's temperature data. Therefore, the first column of the master data table is a list of the eight materials. The middle nine columns contain the raw temperature data. The last column is the overall temperature increase, or the temperature at 4 minutes minus the temperature at 0 minutes.

Classroom Instruction

Introduction

1. **Tie to the engineering problem. Ask:** *Why do we need to know about temperature and heat transfer?* Take student answers. Guide the discussion so that it reviews the engineering problem, 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 far and what step they are currently on.

Standards Addressed

Next Generation Science Standards: MS-PS1-4, MS-PS3-3, MS-PS3-5, MS-PS4-2

Key Terms

heat transfer, radiation, electromagnetic waves, absorb, reflect, transmit

Assessments

Pre-Activity Assessment
Check students' ability to explain the engineering problem and identify where they are in the engineering design process. Students should be able to move the paper clip on their sliders to the appropriate step.

Activity Embedded Assessment
Check students' progressive understanding through their verbal and written responses when introducing radiation and implementing the radiation lab. This is especially important because students will need to use this information later to select materials that absorb or transmit radiation for their cooker container prototypes

Post-Activity Assessment
Listen to students' discussion about the key terms to make sure they understand the difference between absorb, reflect, and transmit.

DUPLICATION MASTERS

- 4.a. Radiation

EDUCATOR RESOURCES

- 4.b. Radiation Answers
- 4.c. Radiation Lab Set-up

3. **Identify what students still need to learn about. Say/Ask:** *We have already started learning about some science concepts that will help us design a solution to the engineering challenge. What have we already learned about?* Take this time to review temperature, thermal energy, heat, convection, and conduction. **Ask:** *What other science do you think we need to learn about?*

Activity

4. **Introduce radiation. Say:** *In previous lessons, we learned about two processes of heat transfer: convection and conduction. Today, we are going to learn about the third type of heat transfer, radiation.*

5. **Watch the video.** Show students a video about radiation.

6. **Discuss the video.** Discuss the following questions based on the information in the video.
   - What is radiation?
   - How is radiation different from conduction and convection?
   - What are some sources of radiation?

7. **Refine the definition.** If students are using duplication masters, pass out *4.a. Radiation*. Otherwise, have students write the answers to the prompts in their engineering notebooks next to the number of that prompt. Tell students that while the video used the term "radiation waves," the scientific term for these are "electromagnetic radiation," or "light waves." Thus, radiation is the transfer of energy across space in the form of light waves, which are also called electromagnetic radiation. Have students record a definition for radiation. NOTE: If desired, this can also include a more detailed discussion about the different types of radiation in the electromagnetic spectrum (e.g., infrared, visible light, ultraviolet). Point out that infrared and visible light are particularly important for the heat transfer process of radiation. Another method of defining vocabulary (e.g., the Frayer model) may be used here and for the other vocabulary terms (i.e., absorb, reflect, transmit) in this lesson.

8. **Tie to conduction. Say:** *In the previous lesson, we learned about insulators and conductors, which are materials that are different in terms of transferring heat by the process of conduction. Similarly, different materials transfer heat by the process of radiation differently. Materials can absorb, reflect, or transmit electromagnetic radiation.*

9. **Link to students' personal lives.** Use an example that would be meaningful to students to demonstrate that different materials absorb or reflect light waves (electromagnetic radiation) differently. This could be wearing a dark shirt vs. a light shirt on a hot sunny day or sitting in a car with dark seat fabric vs. light seat fabric after the car has sat in the sun. Similarly, use an example about how a material would transmit light waves (electromagnetic radiation), such as sunlight passes through a window.

10. **Discuss the terms. Ask:** *What do think it means for an object to absorb, reflect, or transmit light (or electromagnetic radiation)?* Lead a discussion that connects students' previous knowledge about the terms and real-life examples with their new scientific understandings of electromagnetic radiation and heat transfer. In addition to the basic meaning of each term (i.e., transmit = passes through, reflect = bounces off, absorb = transfer energy), students should be aware heat transfer by the process of radiation occurs when materials absorb electromagnetic radiation. Very little energy transfer happens between electromagnetic radiation and a material when the light waves reflect off of or transmit through the material. NOTE: It may help to draw diagrams showing how rays of light interact with a material when light is absorbed, reflected, and transmitted.

11. **Record the terms.** Either on *4.a. Radiation* or in their engineering notebooks, have students describe and/or draw what happens when light waves (electromagnetic radiation) interact with a material that:
    a. absorbs light.
    b. reflects light.
    c. transmits light.

12. **Introduce the radiation lab. Say:** *In this lesson and the next, we are going to do an experiment and analyze the results to figure out what kinds of materials absorb, reflect, and transmit electromagnetic radiation.* Tell students that they will measure the temperature of the air inside cups that are covered by eight different materials over the course of four minutes. They will analyze the data in the next lesson.

13. **Make a prediction.** Tell students that the eight materials are: black construction paper, white construction paper, black felt, white felt, aluminum foil, clear transparency sheet, wooden sticks, and no material (control). **Ask:** *Which of these materials will absorb radiation? Which will reflect it? Which will transmit it? Why do you think so?* Have them record their predictions in *4.a. Radiation* or in their engineering notebooks.

14. **Assign cups to students.** Assign each student team one cup and have them move to that cup. NOTE: Teams may have to be rearranged if there are not exactly eight teams. It is not necessary that students work with their engineering design team for the data collection of this experiment.

15. **Measure the initial temperature.** Have students measure the initial temperature of the air inside their cups before the lamps are turned on. Have them record this information in their data tables as the temperature at 0 minutes. Also, have each student team read out their temperature value; this should be recorded in the master data table. NOTE: This is the first time students will use the digital thermometers in this unit, and they will need to use them again when they test their cooker container prototypes. Therefore, it may be helpful to demonstrate for students how to use the thermometer. This includes how to make it read Celsius instead of Fahrenheit.

16. **Start the experiment.** Have students turn on the lamps. Remind them that the lamps will get very hot, so do not touch them.

17. **Collect and record data.** Every 0.5 minutes, tell students to measure the temperature of the air inside their assigned cup and record this information in their data table (on *4.a.* or in their engineering notebooks).

18. **Complete data collection.** After students have finished measuring the temperature of the last data point, 4 minutes, tell them to carefully turn the heat lamps off and then return to their seats.

19. **Share data.** Have each team share their data for the master data table.

20. **Calculate the overall temperature difference.** Instruct student teams to calculate the overall temperature increase for their material's data. This means that they need to subtract the temperature at 0 minutes from the temperature at 4 minutes. When they have finished this calculation, they should record it themselves and also share it for the master data table.

21. **Prepare for the next lesson.** Inform students that they will be analyzing these data in more detail during the next lesson.

Closure

22. **Review key terms.** Review the key terms of the lesson: radiation, absorb, reflect, and transmit. Tell students that they will be using these terms when they analyze data during the next lesson.

LESSON 4

Name_____ Date_____ Period _____

4.a. Radiation

Introduction to Radiation

1. **Define radiation.** (You may use drawings in addition to words.)

2. **Describe and/or draw what happens when light waves (electromagnetic radiation) interact with a material that:**
   a. absorbs light.

   b. reflects light.

   c. transmits light.

Radiation Lab Data Collection

3. **Predict:** Which of the materials will absorb electromagnetic radiation? Which will reflect it? Which will transmit it? Why?

4. **What material is the lid of your assigned cup?** _____

5. **Collect data.**

Time (minutes)	0	0.5	1	1.5	2	2.5	3	3.5	4
Temperature (°C)									

6. **Analyze data.** What is the overall temperature increase of your material? _____
   (Use this space for the subtraction)

4.b. Radiation Answers

Introduction to Radiation

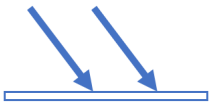
1. **Define radiation.** (You may use drawings in addition to words.)

Radiation is the transfer of thermal energy across space in the form of light waves, which are also called electromagnetic radiation. (Optional) When electromagnetic waves encounter particles, they vibrate the particles, making the particles' kinetic energy greater. This increases the temperature of the object, so a thermal energy transfer has occurred.

2. **Describe and/or draw what happens when light waves (electromagnetic radiation) interact with a material that:**

a. absorbs light.

When a material absorbs electromagnetic radiation, the light wave transfers energy to the particles in the material, causing the particles to move faster. (Light energy converts to thermal energy.) This means the temperature of the material increases.

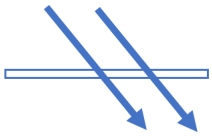


b. reflects light.

When a material reflects electromagnetic radiation, the light wave bounces off of the material, transferring very little energy to the material.

c. transmits light.

When a material transmits electromagnetic radiation, the light wave passes through the material, transferring very little energy to the material.



Radiation Lab Data Collection

3. **Predict:** Which of the materials will absorb electromagnetic radiation? Which will reflect it? Which will transmit it? Why?

Answers will vary. Students may predict that dark materials will absorb electromagnetic radiation and light and shiny materials will reflect it. Transparent materials will transmit radiation.

4. **What material is the lid of your assigned cup?** _____

5. **Collect data.**

Time (minutes)	0	0.5	1	1.5	2	2.5	3	3.5	4
Temperature (°C)									

6. **Analyze data.** What is the overall temperature increase of your material? _____
(Use this space for the subtraction)

4.c. Radiation Lab Set-up

Supplies: 1 piece of black construction paper, ~4.5”x4.5”; 1 piece of white construction paper, ~4.5”x4.5”; 1 piece of black felt, ~4.5”x4.5”; 1 piece of white felt, ~4.5”x4.5”; 1 piece of aluminum foil, ~4.5”x4.5”; 1 piece of transparency sheet, ~4.5”x4.5”; 8-12 wooden craft sticks taped together to make a flat surface; 8 heat lamps with clamps; 8 incandescent light bulbs; 8 plastic cups, 16 oz.; 8 ring stands; 8 digital thermometers; masking tape; 2 outlet power strips; (optional) bamboo skewer

Directions:

Making the cups

1. Carefully make a hole in the side of each cup, approximately in the middle from top to bottom (see Figure 1). If the thermometer tip is sharp enough, use this to make the hole. If not, use another device such as a bamboo skewer. The holes should be big enough to fit the probe of the digital thermometers through but small enough prevent warm air inside the cup from leaking out through the hole.
2. Cover the top of each of the seven cups with: a piece of black construction paper, a piece of white construction paper, a piece of black felt, a piece of white felt, a piece of aluminum foil, a piece of transparency sheet, or a flat panel of taped-together wooden craft sticks. (The eighth cup is a control and thus has no top covering material). Tape the edges of the materials firmly to the sides of the cups; there should be no leaks (see Figures 1 and 2).

Setting up the lab

3. Place one incandescent bulb into each heat lamp. Clip each heat lamp onto a ring stand.
4. Arrange the ring stand/heat lamps so that they are as spread out as possible but all eight can still be plugged in. Outlet power strips will most likely be needed.
5. Place one cup underneath each heat lamp. Adjust the heat lamps so that: a), they are pointing directly down, and b) the bulbs are ~3.5” from the top of the cups (see Figures 1 and 2).
6. (Optional) Tape the cups to the table to avoid cups being accidentally moved.
7. Place the probe of a digital thermometer into the side hole (made in step 1) in each cup. Students need to be able to read the temperature without touching or moving the cup. Also, try to position the probe so that the tip is pointed upward, possibly touching the underside of the top covering material. Use tape to secure it in place, if necessary.

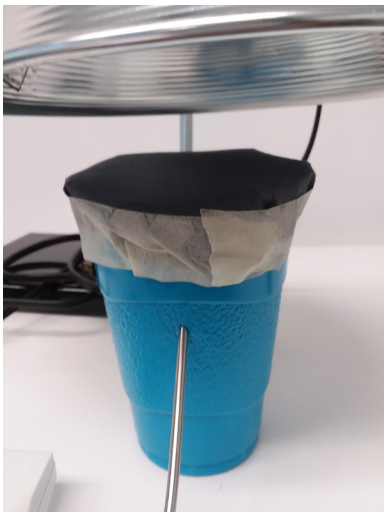


Figure 1

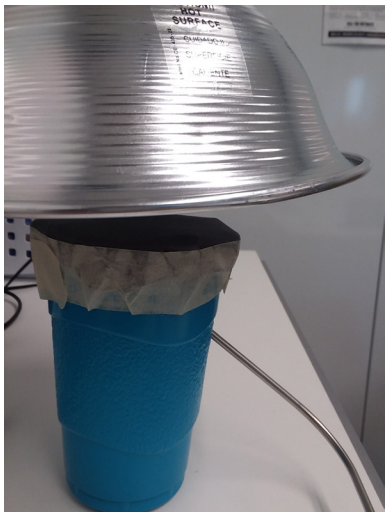


Figure 2

LESSON 5 Analyzing the Absorption Property of Materials

Lesson Objectives
Students will be able to:
- graph points in the Cartesian system.
- draw line graphs from coordinate points.
- analyze data by qualitatively comparing multiple line graphs.
- identify materials that absorb, reflect, or transmit radiation based upon the data analyzed.

Time Required
One-two 50-minute class periods

Materials
Per classroom:
- 1 *Engineering Design Process* poster
- computer or laptop
- projector, document camera, or interactive whiteboard

Per student:
- 2 different colors or types of writing utensils
- 1 engineering notebook
- 1 *Engineering Design Process* slider
- 1 ruler

Standards Addressed
- Next Generation Science Standards: MS-PS1-4, MS-PS3-3, MS-PS3-5, MS-PS4-2, MS-ETS1-3
- Common Core State Standards – Mathematics: 5.G.A.1, 6.EE.C.9, 8.F.B.5

Key Terms
data analysis, radiation, absorb, reflect, transmit

Lesson Summary
Students create temperature vs. time graphs using the data they collected during the radiation lab. By drawing line graphs, they make interpretations about how well different materials absorb, reflect, or transmit radiation.

Background
Teacher Background
This lesson may take two days, depending on students' comfort level with plotting points on a graph. It may take one full day for each team to make a plot of their assigned data and another to analyze and interpret the whole class's data.

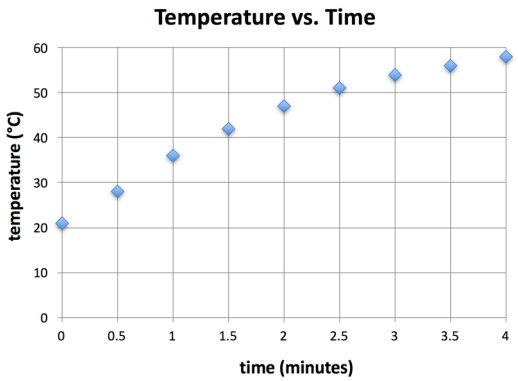
Even though plotting points in the Cartesian coordinate system is a fifth grade standard in Common Core State Standards – Mathematics, students might not remember how to do this. One way to address this is by asking students to graph points in a coordinate system presented in this online website: http://www.shodor.org/interactivate/activities/SimpleCoordinates/. This review activity might also be done by hand using the grid paper in *5.a. Graphing Data Points.*

In the first activity of this lesson, students plot points and draw temperature versus time line graphs of the data they collected during the radiation lab. This lesson could be implemented on paper using *5.a. Graphing Data Points*, or using any digital technology such as Desmos (https://www.desmos.com/calculator), Excel, or Shodor (http://www.shodor.org/interactivate/activities/SimplePlot/).

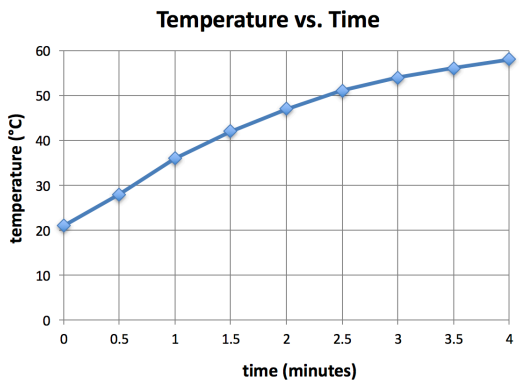
Students might need help with creating a graph. Some features that every graph should have are: title, axes, labels, intervals, and scale. The title should clearly describe the information presented in the graph. Axes should be drawn neat and straight. The axes should also be labeled; these labels indicate what variable is graphed, as well as the units of the variable in parentheses. The independent variable should be on the x-axis, and the dependent variable (i.e., the one which is measured) should be the y-axis. In the radiation lab, the x-axis/independent variable is time and the y-axis/dependent variable is temperature. For this lab's temperature vs. time data points, students need to identify that the time ranges from 0 to 4 minutes. This means that the x-axis on their graphs will range from 0 minutes to 4 minutes with half minute increments marked. The y-axes will vary depending on the material students were assigned to during the radiation lab. The range of temperature could be as small as 20°C-25°C or as large as 20°C-100°C. Students will need to identify an appropriate scale for the y-axis. The example below shows a temperature change from 21°C to 58°C. For both axes, there is no one correct answer for the appropriate scale. However, the scales chosen need to allow for accurate graphing and need to be consistent along the entire axis. The scale also needs to be clearly numbered, and the numbers need to use all or most of the space that the piece of paper, or screen, allows for. In other words, the graph of the data points should take up most of the piece of paper or screen; numbers should not be all crowded in the middle or in one extreme of the axes.

Analyzing the Absorption Property of Materials

time (minutes)	temperature (°C)
0	21
0.5	28
1	36
1.5	42
2	47
2.5	51
3	54
3.5	56
4	58



Once students have plotted the coordinate points, they will draw line graphs connecting the given points. The figure below shows how this step could look in Excel.



In the second activity of the lesson, students first do an initial analysis of the line graph that they graphed. No matter which material they were assigned, the line graphs have the same general curve. The slope of the line gets shallower (decreases) and flattens out as time passes. Given the variables of the radiation lab, this means that the rate of temperature increase per minute decreased as the lab progressed. (The temperature continues to increase, but the graph begins to flatten.) This effect tends to be more visible in materials for which the temperature of the air inside the cup increases significantly. This is a general feature of all three processes of heat transfer; the rate/speed of heat transfer (and thus the rate of temperature change) depends the temperature difference between objects. The greater the temperature difference between two objects, the faster heat transfers. At the beginning of the radiation lab, the materials on top of the cups were the lowest temperature they would be relative to the lamps; thus, the heat transfers relatively quickly. As the temperature of the air inside the cups increases, the temperature difference between the cups and the heat lamp decreases, which slows down the process of heat transfer. At some point, the temperature increase slows down to an essential stop, and the graph would reach a plateau.

In a second analysis in this part of the activity, the teacher shows the students the line graphs corresponding to white and black felt and asks them to compare them. Students should be able to describe two patterns in the graph: both line graphs get shallower and flatten out as time passes, and black felt has a higher temperature increase than white felt. This part of the second

Assessments

Pre-Activity Assessment
Check students' ability to explain the engineering problem and identify where they are in the engineering design process. Students should be able to move the paper clip on their sliders to the appropriate step.

Activity Embedded Assessment
Check students' progressive understanding through their verbal and written responses when graphing and analyzing the radiation lab data. This is especially important because students will need to use this information to select the material for the top part of the cooker container prototype.

Post-Activity Assessment
During the closure activity, check students' justifications for their chosen material to see if it makes sense with the science of heat transfer and radiation.

DUPLICATION MASTERS

- 5.a. Graphing Data Points
- 5.b. Radiation Lab Data Analysis

EDUCATOR RESOURCES

- 5.c. Radiation Lab Data Analysis Answers

activity is designed to act as a scaffold before students compare all eight line graphs.

In the third activity of the lesson, students qualitatively compare all eight line graphs and use this analysis to reach conclusions about how well the materials absorb, reflect, and transmit electromagnetic radiation. The first conclusion they should make is that for all eight materials (including the control), the rate of temperature increase per minute decreases with time. This is a review of what they learned from the previous activity's analysis.

The other major conclusion students can draw from the graph of all of the radiation lab data is to determine which materials absorb, reflect, and transmit radiation better than others. For the control, there is no absorption, reflection, or transmission through a material since there is no top material. However, the temperature inside the cup still increases because the radiation energy transfers some heat energy directly to the air inside the cup. Since the transparency sheet is the only transparent material, light rays pass through (i.e., transmit) the transparency sheet. This electromagnetic radiation transfers energy directly to the particles of air inside the cup. Since the transparency sheet also acts as an insulator, the warmed air is trapped inside the cup, which is why the temperature increases a great deal.

For the remaining six opaque (i.e., not see through) materials, there is a bit of interpretation involved, since it is assumed that the temperature of air inside the cup is a reliable measure of how well the lid material absorbed thermal energy through radiation. This is not exactly true, since there is also a conduction factor due to how well the lid material conducts its absorbed thermal energy to the air inside the cup. Also, convection plays a role, but this is minimized by placing the thermometer probe tips near the top of the cups, which is the highest temperature region inside the cups. Thus, the equivalence of temperature change with amount of absorption is not exact, but it is a close estimate given the limitations of the laboratory set-up.)

All of the other six opaque materials absorb some radiation, since the temperature inside the cups increases. However, certain materials reflect more electromagnetic radiation, and certain materials absorb more. Aluminum foil, wooden sticks, and white paper reflect more radiation (i.e., light rays bounce off), while black felt absorbs the most as evident by its temperature increasing the most. Generally speaking, darker materials absorb more electromagnetic radiation than their lighter (or shinier) counterparts. Black felt absorbs more light than white felt, and black construction paper absorbs more light than white construction paper. However, the materials may differ relative to each other. For example, white felt may absorb more electromagnetic radiation than black construction paper. It may be important to make this distinction for students depending on the results of the radiation lab.

Before the Activity

If using the duplication masters, print and make copies of the following worksheets in the labeled amounts:

- *5.a. Graphing Data Points* (1 per student)

Analyzing the Absorption Property of Materials

- *5.b. Radiation Lab Data Analysis* (1 per student)

If the engineering notebook pages are graph paper, then it is unnecessary to make copies of 5.a.

For the second part of the activity, the graph with the two data sets (i.e., black felt and white felt) will need to be made in advance. Also for the third part of the activity, the graph with all eight data sets will need to be made in advance, if possible. Use a digital software tool (e.g., Excel, Desmos) to draw line graphs for all eight materials: black felt, white felt, black construction paper, white construction paper, aluminum foil, wooden sticks, transparency sheet, and control (i.e., no covering).

(Optional) If using the review activity described in the Teacher Background, cue up the website:

- http://www.shodor.org/interactivate/activities/SimpleCoordinates/

(Optional) If using online applications to graph line graphs, cue up a website:

- Desmos: https://www.desmos.com/calculator
- Shodor: http://www.shodor.org/interactivate/activities/SimplePlot/

Classroom Instruction

Introduction

1. **Tie to the engineering problem. Say/Ask:** *We have spent several lessons learning about the science of heat transfer. What is the purpose of this?* Take student answers. Guide the discussion so that it reviews the engineering problem, 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 far and what step they are currently on.

3. **Identify what students still need to learn about. Say:** *In the previous lesson, we learned about the heat transfer process of radiation and collected data in the radiation lab. Today, we will analyze those data in a different way and see what this tells us about how materials absorb, reflect, or transmit electromagnetic radiation.*

4. **Highlight the importance of data analysis.** Remind students that they will eventually be communicating their cooker container prototypes to the client and also that the client wants them to justify their designs. **Ask:** *What kind of justification do you think the client would prefer: something along the lines of, "it worked for us," or actually showing the data you collected and your analysis of it?* Discuss the importance of collecting data and using a reliable method to analyze it.

Activity Part 1: Plot points and make a graph

5. **Assign students to data.** Students may work individually or in pairs to plot points and make a line graph using the data they collected and recorded in either *4.a. Radiation* or their engineering notebooks. They are only responsible for the one data set associated with the material they

were assigned during the radiation lab.

6. **(Optional) Review plotting points.** If students need a reminder about how to plot points in a Cartesian coordinate system, use the website addressed in the Teacher Background.

7. **Graph the data.** Instruct the students to graph the data, plotting the points either directly in their engineering notebooks or on *5.a. Graphing Data Points*. When starting a graph, students often have difficulty choosing appropriate axes and scales for the graph, labeling the axes and writing a title, clearly numbering the axes, and spreading out the numbered intervals so that the whole space in the axis is used. Thus, use the following step-by-step prompts to assist students:
   - Which variable we should graph on the X-axis? And Y-axis?
   - What label should we use for each axis? What are the units of each variable?
   - What is the range of time? How about the range of temperatures?
   - What scale should we use for the X-axis? What scale should you use on the Y-axis?
   - Are the numbers along the axes spread out so that they are using all the space available in the axes?
   - What is a title that describes the graph?

   NOTE: Students may figure out how to create the graph as a team (e.g., scale of axes, plotting points), but they are each expected to create a graph. It will be the same as their teammates', but it is required.

8. **Draw a line graph.** Have students draw a line graph by using a ruler to connect each point to its nearest neighbor.
   (Optional) If students have access to digital technology tools, they may plot their points and draw a line graph using a tool such as Desmos or Excel rather than hand drawing.

Activity Part 2: Analyzing simple line graphs

9. **Analyze a single line graph.** Pass out *5.b. Radiation Lab Data Analysis*, or have students write the answers to the prompts in their engineering notebooks next to the number of that prompt. **Ask:** *What patterns do you observe in your line graph?* Students may make and record various observations, but at minimum guide them toward the observation that the slope of the line gets shallower (decreases) and flattens out as time passes. In the context of this radiation lab, this means that the rate of temperature increase per minute decreased as the lab progressed. In other words, the temperature continued to increase throughout the lab, but it did so less quickly at the end than at the beginning.
   (Optional) Use this single line graph analysis activity to review what the line graph actually means: it documents the temperature change inside each cup over time. It may be helpful to have students compare actual data points.

10. **Compare two line graphs.** Show students the line graphs corresponding to the white and black felt in the same Cartesian system. **Ask:** *What*

comparisons can you make between these two line graphs? Students might repeat what they shared in previous part, which is that the slope of each line gets shallower (decreases) and flattens out as time passes (i.e., the rate of temperature increase per minute decreases). Direct their attention to also note that the black had a higher temperature increase than the white felt. Have them record their observations to question 2 on *5.b. Radiation Lab Data Analysis* or in their engineering notebooks next to the number of that prompt.

Activity Part 3: Analyze the whole class data

11. **Show all eight lines of whole class data.** Show students the eight lines from the eight sets of data points in the same Cartesian coordinate system using one of the websites described above, Excel, or any online spreadsheet such as Google Sheets. Point out which line represents which material. **Ask:** *What patterns do you observe in the lines on this graph?* Students may make various observations, but at minimum guide them toward two points:
    - The slopes of all of the lines get shallower (decrease) and flatten out as time passes (i.e., the rate of temperature increase per minute decreases).
    - Certain materials had greater temperature increases in four minutes than others. (Students may point out specific examples of this, such as "black felt had the highest temperature increase" or "aluminum foil and wooden sticks barely increased in temperature.")

12. **Compare the graph to overall temperature change.** Point out the "Temperature Increase" column of the Whole Class Data Table as compared to the eight lines on the whole class graph. **Ask:** *How is the graph of all eight lines similar to or different from the table of temperature increases?* Given that their initial temperatures should have been similar, they should notice that the materials with the highest values of "Temperature Increase" are also the materials that reach the highest temperatures on the graph.

13. **Tie back to radiation.** Guide students through a discussion to remind them how these data relate to heat transfer via the process of radiation. Possible step-by-step prompts are:
    - Given the variables on our axes, what does the slope represent? The rate of change of temperature over time, how quickly the temperature increased per minute.
    - What temperature did we measure? The temperature of the air inside the cups, near the top.
    - What does a temperature increase of the air inside the cups represent? The temperature change corresponds roughly to how much electromagnetic radiation was absorbed by the lid material (for opaque materials) of the cups and then transferred via conduction to the air inside the cups. The exception to this is the transparency sheet, which transmitted light waves, and the control, which had no covering and thus the air had heat directly transferred.

    Students should reach the conclusion that for the opaque materials, the

temperature increases of these data are approximations for how well the materials on the lids absorbed heat through radiation. Opaque materials with high temperature increases absorbed a lot of electromagnetic radiation, increasing the motion and kinetic energy of the particles, which meant a large temperature increase. Opaque materials with lower temperature increases still absorbed electromagnetic radiation, but the increases in the motion and kinetic energy of the particles, and therefore the temperature increase, was less. The lone transparent material, transparency sheet, had light transmitted through it, which then transferred heat to the air inside.

14. **Develop general rules for absorb, reflect, and transmit.** Have students discuss and record answers to question 3 on *5.b. Radiation Lab Data Analysis* or in their engineering notebooks next to the number of that prompt in order to make some generalizations about which materials absorb, reflect, and transmit light waves.

Closure

15. **Tie to the engineering challenge. Say/Ask:** *Think about your cooker container prototype. Based on the data analysis of the radiation lab, which material would you choose to use to transfer heat via radiation and why?* Have students discuss this within their engineering design student teams and then record their answer for question 4 on the *5.c. Radiation Lab Data Analysis* sheet or in their engineering notebooks.

LESSON 5

Name_____ Date_____ Period _____

5.a. Graphing Data Points

LESSON 5

Name_____ Date_____ Period _____

5.b. Radiation Lab Data Analysis

1. **Analyze one line graph.** What patterns do you observe in the lines of the graph?

2. **Compare two line graphs.** What do you observe about the line graph of the black felt compared to the line graph of the white felt?

3. **Compare eight line graphs.** Make conclusions about how well materials absorb, reflect, and transmit electromagnetic radiation.

- Which material(s) transmitted electromagnetic radiation? _____
- Compare the white felt and black felt. Which absorbed more radiation? _____
- Compare the white paper and black paper. Which absorbed more radiation? _____
- In general, what absorbs more light: dark-colored materials or light-colored materials?
- What kinds of materials reflected more light?

4. **Think about your cooker container prototype.** Based on the data analysis of the radiation lab, which material would you choose to use to transfer heat via radiation and why?

5.c. Radiation Lab Data Analysis Answers

1. **Analyze one line graph.** What patterns do you observe in the lines of the graph?

   The slope of the line gets shallower (decreases) and flatten out as time passes. This means that the rate of temperature increase per minute decreases.

2. **Compare two line graphs.** What do you observe about the line graph of the black felt compared to the line graph of the white felt?

   The black felt had a greater temperature increase in four minutes than the white felt.

3. **Compare eight line graphs.** Make conclusions about how well materials absorb, reflect, and transmit electromagnetic radiation.

- Which material(s) transmitted electromagnetic radiation? **transparency sheet**
- Compare the white felt and black felt. Which absorbed more radiation? **black felt**
- Compare the white paper and black paper. Which absorbed more radiation? **black paper**
- In general, what absorbs more light: dark-colored materials or light-colored materials?

  Dark-colored materials absorb more light than light-colored materials.

- What kinds of materials reflected more light?

  Light-colored and shiny materials reflect more light. (Students may reference specific materials such as aluminum foil, white paper, and wooden sticks.)

4. **Think about your cooker container prototype.** Based on the data analysis of the radiation lab, which material would you choose to use to transfer heat via radiation and why?

   Answers will vary, but should include a material that had a large temperature increase during the four minutes of the radiation lab and also a justification related to data from the radiation lab or science discussed during the lesson

LESSON 6 Getting to Know the Context

Lesson Objectives
Students will be able to:
- describe how the three processes of heat transfer are present in the classroom solar oven.
- identify the process of heat transfer represented in various scenarios.
- explain similarities and differences between conduction, convection, and radiation.

Time Required
One 50-minute class period

Materials
Per classroom:
- 1 *Engineering Design Process* poster
- materials to make solar oven: 1 large storage container, 10'-20' aluminum foil, 1 ~12"x24" heating pad, ~4 9"x12" pieces of black construction paper, 4 heat lamps with clamps, 4 incandescent light bulbs, 1 outlet power strip, scissors, tape
- materials to make agar fish: 1 silicone mold w/ fish-shaped wells, 1 glass beaker (600 mL), 4 tbsp. agar powder

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

Standards Addressed
Next Generation Science Standards: MS-PS1-4, MS-PS3-3, MSPS3-4, MS-PS3-5, MS-PS4-2, MS-ETS1-1

Key Terms
heat transfer, convection, conduction, radiation

Lesson Summary
The teacher presents the classroom oven, which is a solar oven, and the agar fish. Students describe the reasons for its structure and materials: black bottom, sides covered with aluminum foil, heating pad located in the bottom part of the oven, and lamps hanging in the top part of the oven. Students describe the types of heat transfer present in the classroom solar oven.

Background
Teacher Background
The goal of this lesson is to provide students with a concrete opportunity to use/apply what they have learned about heat transfer to the classroom solar oven. Students are expected to describe how each process of heat transfer will affect their cooker container prototypes when they are inside the solar oven. Electromagnetic radiation will come from the heat lamps and transfer directly to the cooker container. This represents radiation from the sun. The aluminum-lined sides of the solar oven will assist with this transfer of radiation, since they will reflect the light waves so more light reaches the cooker container prototypes. Heat transfer through the process of conduction will occur from the heating pad, through the black paper, and to the bottom of the prototypes. This heating pad represents warm coals. The black paper is more of an insulator than it is a conductor, but it will be used for two reasons. First, the black paper should absorb electromagnetic radiation. Second, any mess made by the slimy agar fish will land on the black construction paper instead of directly onto the heating pad; black paper can be easily replaced, but it is more difficult to clean the heating pad. Convection occurs in the solar box as convection currents form in the air within. Cooler air will enter the solar oven from outside the oven, sinking to the bottom. This will push the warmer air near the black construction paper up. From a cooker container design standpoint, students should recognize that there isn't much they can do to maximize convection heat transfer. However, they can design their cooker container to maximize conduction heat transfer from the floor and radiation heat transfer from the top and sides.

Students will also have the opportunity to learn about the agar fish so that they can consider that information for their cooker container designs. They will make observations about the fish, most importantly the size of the fish. Also, in case there is a concern about melting the fish, they will learn that the agar melts at 85°C (185°F), while the temperature in the classroom solar oven in not expected to be greater than 38°C (100°F) during the ten minutes of the test.

The Heat Transfer Review Activity can be done in various ways. It could be completed individually as an assessment of individual students' current understandings, or in student teams. It could also be implemented as some sort of review game. For example, the teacher could provide a scenario and then have each student team identify which process of heat transfer this represents; student teams earn points for correct answers.

Before the Activity
If using the duplication masters, print and make copies of the following worksheets in the labeled amounts:

Getting to Know the Context

- *6.c. Types of Heat Transfer in the Solar Oven* (1 per student)
- *6.e. Heat Transfer Review* (1 per student)

If students are writing question prompts directly into their engineering notebooks, it may still be helpful for students to have copies of *6.e.* since there are many questions on the worksheet.

Prepare the agar solution the day before. The instructions are in the Educator Resource *6.a. Making Agar Fish*.

Prepare the solar oven. The instructions are in the Educator Resource *6.b. Making the Solar Oven*.

Classroom Instruction

Introduction

1. **Tie to the engineering problem. Ask:** *Why do we need to know about temperature, thermal energy, and the three processes of heat transfer?* Guide the discussion so that it reviews the engineering problem, 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 far and what step they are currently on.

3. **Identify what students still need to learn about. Say/Ask:** *We have been learning about science concepts that will help us design a solution for the engineering challenge for several lessons. What have we already learned about?* Take this time to quickly review temperature, thermal energy, heat, convection, conduction, and radiation. **Say:** *In this lesson, you will learn more about the specific details of the engineering challenge and apply science concepts to better understand the challenge.*

Activity

4. **Refer back to the engineering challenge. Ask:** *How does the client want us to test our cooker container designs?* The students should say something about putting agar fish into their cooker containers and then placing those prototypes into a solar oven for ten minutes. However, they may not yet understand what a solar oven or agar fish are or what they look like. **Say:** *In this lesson, you will make observations about the solar oven and agar fish in order to help you design a better cooker container prototype.*

5. **Make observations about the agar fish.** Pass out one agar fish to each student team. Invite students to share their comments and questions about the agar fish. At minimum, there are two observations that students should make:
   - Students should observe the size of the fish. (They do not need to measure the fish during this lesson; they will have opportunities to measure the fish in later lessons.) Their cooker container prototypes need to be large enough fully contain the agar fish, but they will need

Assessments

Pre-Activity Assessment
Check students' ability to explain the engineering problem and identify where they are in the engineering design process. Students should be able to move the paper clip on their sliders to the appropriate step.

Activity Embedded Assessment
Check students' progressive understanding through their verbal and written responses during the lesson. This is especially important because students will need to understand how the solar oven works in order to justify their selection of materials for their cooker container.

Post-Activity Assessment
Check students' written and verbal responses during the heat transfer review, especially how they describe similarities and difference among the three processes of heat transfer.

DUPLICATION MASTERS

- 6.c.Types of Heat Transfer in the Solar Oven
- 6.e. Heat Transfer Review

EDUCATOR RESOURCES

- 6.a. Making Agar Fish
- 6.b. Making the Solar Oven
- 6.d. Types of Heat Transfer in the Solar Oven Answers
- 6.f. Heat Transfer Review Answers

to be small enough that all student teams' prototypes can fit into the classroom solar oven at one time.
- Students might want to know if the agar fish will melt. Agar solution melts at 85°C (185°F), while the temperature in the classroom solar oven in not expected to be greater than 38°C (100°F) during the ten minutes of the test. Therefore, students can assume that the agar fish will remain solid throughout testing. (The agar fish are somewhat slimy, but they shouldn't actually melt.)

6. **Introduce students to the solar oven.** Pass out one *6.c. Types of Heat Transfer in the Solar Oven* to each student, or have students write the answers to the prompts in their engineering notebooks next to the number of that prompt. Display the solar oven to students. Point out each of the components (but not their purpose) to students: the oven has heat lamps clamped to the top that shine down into the oven (which represent the sun), the sides are lined with aluminum foil, there is a heating pad on the bottom (which represents warm coals), and there are sheets of black construction paper on top of the heating pad. Have students observe how the cross-section diagram on *6.c. Types of Heat Transfer in the Solar Oven* represents the three-dimensional solar oven.

7. **Determine the types of heat transfer.** Have students discuss the solar oven in their student teams in order to determine how each of the three processes of heat transfer – convection, conduction, and radiation – would transfer heat to a cooker container prototype. Additionally, they should think about which of these heat transfer processes they will most need to consider when designing their cooker container prototypes. Instruct them to record their ideas in their engineering notebooks or in *6.c. Types of Heat Transfer in the Solar Oven*. Circulate during this discussion, asking students to explain their thinking and addressing any misunderstandings the students might have.

8. **(Optional) Discuss as a whole class.** When students have completed their discussions about the solar oven, review the answers as a whole class. Make sure to address common misconceptions at this time.

9. **Review processes of heat transfer.** Pass out one *6.e. Heat Transfer Review* to each student. Students will need to complete this worksheet as a review of heat transfer concepts, though there are multiple ways this could be implemented.
   - It could be completed by students individually, acting as a formative assessment of each student's current understandings related to heat transfer, conduction, convection, and radiation.
   - It could be completed by each student team, acting as a formative assessment of each student team's current understandings related to heat transfer, conduction, convection, and radiation.
   - It could also be treated like a game. For example, the teacher could pose a scenario to the class, and each team would state which process of heat transfer the scenario best represents. Teams earn points for correct answers.

Closure

10. Discuss the heat transfer review. As a whole class, discuss the last question in the review, which is about the similarities and differences between the three processes of heat transfer.

Sample similarities:

- All three transfer heat from hotter objects/fluids/regions (i.e., have a higher temperature) to colder objects/fluids/regions (i.e., have a lower temperature).
- All three increase the temperature, and thus the thermal energy, of the object to which the heat is being transferred.

Sample differences:

- Conduction and convection involve particles colliding with each other to transfer energy; radiation does not need to travel through matter since electromagnetic radiation can travel through space.
- In conduction, particles collide with their neighbors; in convection, particles flow in a current due to density differences; in radiation, electromagnetic radiation interacts with particles to increase their vibration.
- Conduction is the transfer of heat across a solid or from a solid to another solid or fluid. Convection is the transfer of heat within a fluid (liquid or gas). Radiation can transfer energy across space, and it can affect solids, liquids, and gases.

6.a. Making Agar Fish

Supplies: 1 silicone mold w/ fish-shaped wells; 1 glass beaker, 600 mL; 1 Tbs agar powder
Optional supplies: a measuring tool (see step 2); a scale or balance (see step 5)

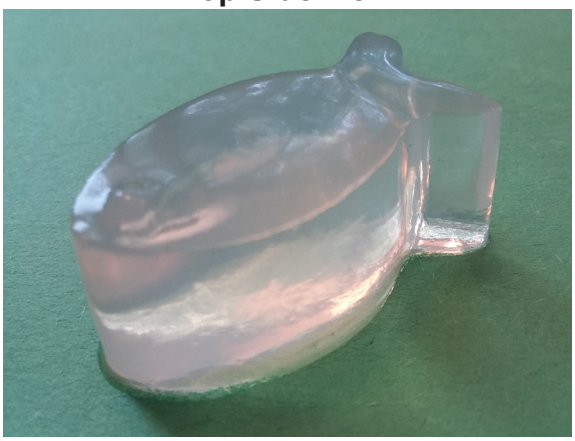
Directions:
1. Mix 250 mL of water and 1 tablespoon of agar powder in a glass beaker.
2. Microwave for 3 minutes or until it boils.
3. Pour into the silicone mold. It is recommended to have the same amount in each fish-shaped well. This can be done by filling each well to the top. To be even more precise, use some sort of measuring tool (e.g., a graduate cylinder, a syringe, a measuring spoon) to dispense the agar solution equally into each well.
4. Let the silicone mold and agar solution it at room temperature for the night.
(Optional) If the fish need to be created on the same day, the cooling process can be accelerating by placing the mold within a freezer for five minutes.
5. (Optional) In order to making sure the agar fish are of equal size for testing, weigh them all and select the ones that have approximately the same weight.

Storage: Agar fish should be kept in a sealed container (e.g. Ziploc bag, tupperware) in the refrigerator overnight and re-used from class to class until they break apart.

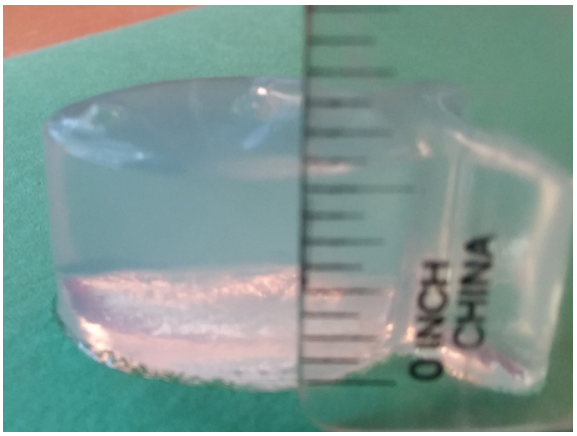
Pictures of the agar fish:

Top view

Top/Side view



Side view



Size of fish = ~1.5” long

LESSON 6

6.b. Making the Solar Oven

Supplies: 1 large storage container; aluminum foil; 1 heating pad that will cover most of the bottom of the storage container (usually ~12”x24”); ~4 pieces 9’x12’ of black construction paper, 4 heat lamps with clamps; 4 incandescent light bulbs, 1 outlet power strip, scissors, tape
Optional supplies: 2 extra heat lamps, 2 extra incandescent light bulbs

Directions:

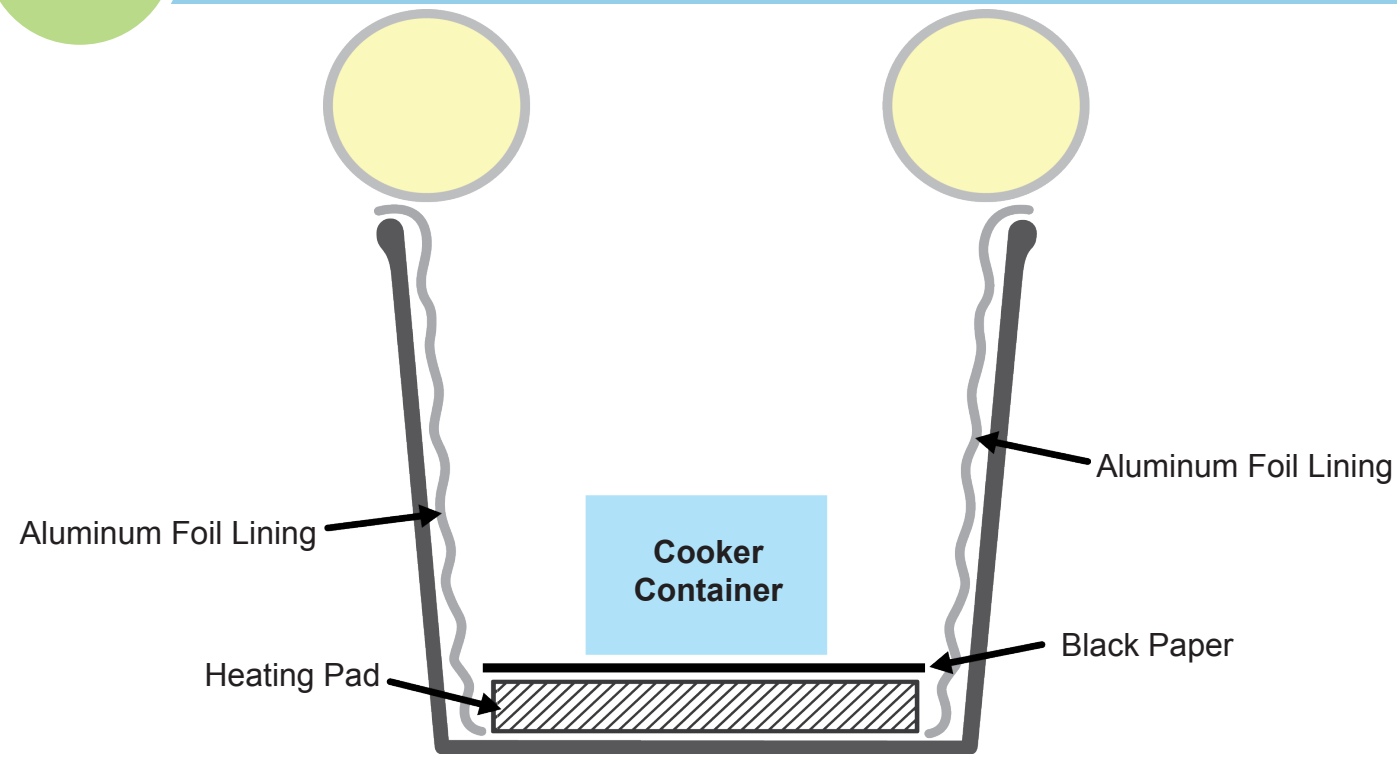
1. Cover the inner sides of the storage container with aluminum foil. When using the tape, try to make small loops and stick them on the back of the foil so that no tape is covering the visible surface of the foil. Also, try to keep the foil as smooth as possible.
2. Place the heating pad in the bottom of the storage container.
3. Cover the heating pad with one layer of black construction paper. Use scissors and tape to make one big sheet of black paper.
4. Screw the incandescent light bulbs into the heat lamps.
5. Place the four lamps on the upper ridge of the solar oven, one on each side (see picture). Try to make them as symmetrical as possible.
   (Optional) If the storage container is a bit large, use two extra lamps and bulbs so that each longer side of the container has two heat lamps and then each end has one heat lamp.
6. Since the angle of light is also important, try to tilt the heat lamps down as far as they will go, making sure the angle between the storage container side and the lamp are the same for all lamps.
7. Connect all of them to the same outlet power strip so that you just use the on-off button to turn on/off all of the lamps at the same time.

Storage: Keep the solar oven in the same way for lessons 6 through 11.

LESSON 6

Name_____ Date_____ Period _____

6.c. Types of Heat Transfer in the Solar Oven



The diagram above shows a cross-section of the classroom solar oven with one cooker container prototype inside. You may draw on this diagram to help you answer the following questions. You should reference all components of the solar oven (heat lamps, aluminum foil lined sides, heating pad on the bottom, black construction paper on top of heating pad) at least once below.

In the classroom solar oven, how would heat be transferred to the cooker container through:

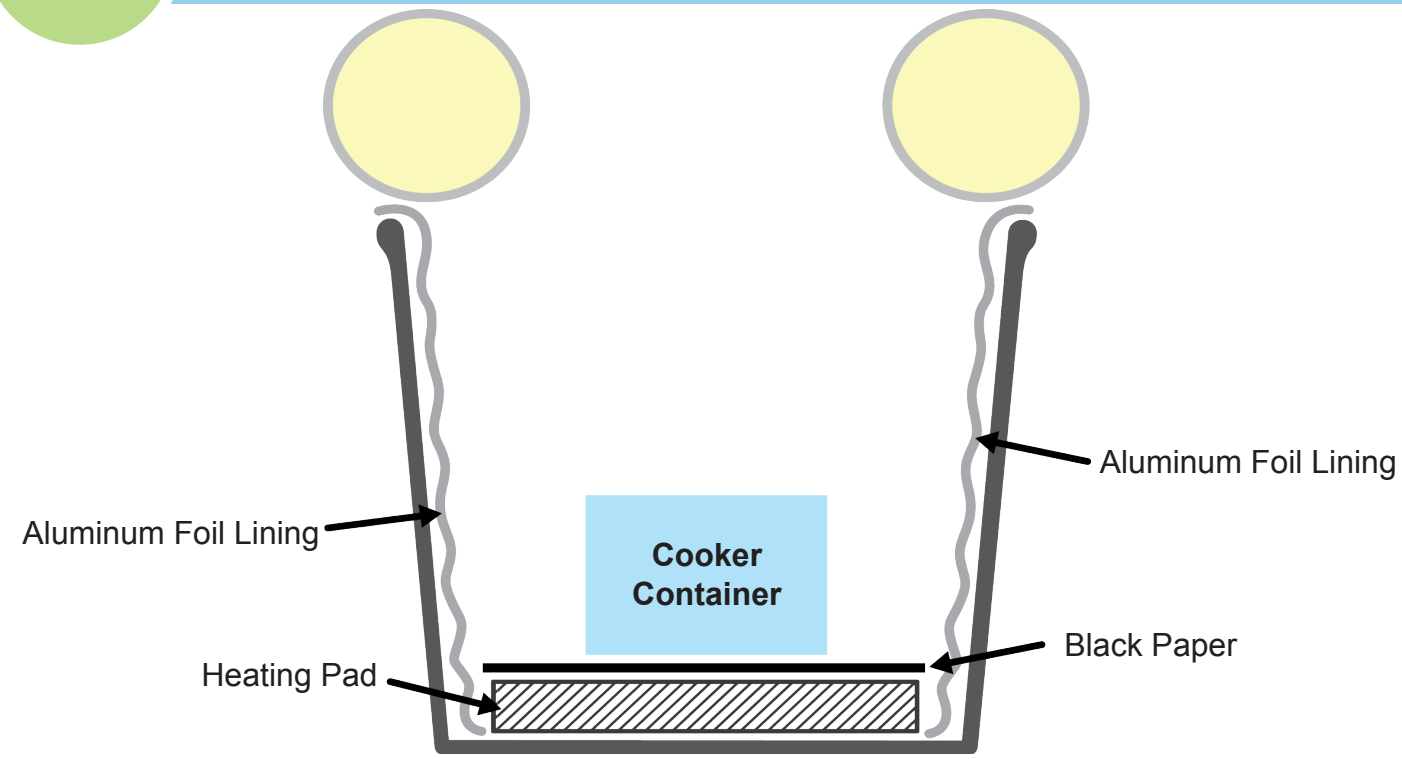
1. convection?

2. conduction?

3. radiation?

4. Which of these processes of heat transfer do you think you will need to most carefully consider when you design your cooker container prototypes?

6.d. Types of Heat Transfer in the Solar Oven Answers



The diagram above shows a cross-section of the classroom solar oven with one cooker container prototype inside. You may draw on this diagram to help you answer the following questions. You should reference all components of the solar oven (heat lamps, aluminum foil lined sides, heating pad on the bottom, black construction paper on top of heating pad) at least once below.

In the classroom solar oven, how would heat be transferred to the cooker container through:

1. convection?

Answers may vary, but could include: Convection occurs in the solar box as convection currents form in the air within. Cooler air will enter the solar oven from outside the oven, sinking to the bottom. This will push the warmer air near the black construction paper up.

2. conduction?

Answers may vary, but could include: Heat transfer through the process of conduction will occur from the heating pad, through the black paper, and to the bottom of the prototypes. The black paper is more of an insulator than it is a conductor, but it will still conduct some heat.

3. radiation?

Answers may vary, but could include: Electromagnetic radiation will come from the heat lamps and transfer directly to the cooker container. The aluminum-lined sides of the solar oven will assist with this transfer of radiation, since they will reflect the light waves so more light reaches the cooker container prototypes. The black paper should absorb electromagnetic radiation.

4. Which of these processes of heat transfer do you think you will need to most carefully consider when you design your cooker container prototypes?

From a cooker container design standpoint, students should recognize that there isn't much they can do to maximize convection heat transfer in the solar oven. They might think about convection inside the cooker container prototypes. However, they can design their cooker container to maximize conduction heat transfer from the floor and radiation heat transfer from the top and sides.

LESSON 6

Name_____ Date_____ Period _____

6.e. Heat Transfer Review

Directions: Label each of the following scenarios with the type of heat transfer that best describes it.	
1. Heat we feel from the sun.	
2. The heat you feel when you touch a hot stove.	
3. Heat you feel when you put your hands above a fire.	
4. My spoon is hot after leaving it on the pot that was on the stove.	
5. This is responsible for making macaroni rise and fall in a pot on the stove.	
6. The heat my snake feels from the heat lamp above him.	
7. Transfer of heat by the actual movement of the warmed matter (i.e., gas or liquid).	
8. The reason heating vents are usually placed on the floor of a home.	
9. Insulation is used to prevent this type of heat transfer.	
10. This type of heat transfer is trapped by green houses.	
11. Why the dog lays down next to the wood stove.	
12. Why the cat sits on a shelf above the stove.	
13. Why the kettle on the stove gets hot.	
14. Why you use a potholder/oven mitt when getting the cookie sheet out of the oven.	
15. Heat you feel when you sit next to a campfire.	
16. Heat you feel from your electric blanket.	

Directions: Answer the following question.

17. Describe the **similarities** and **differences** among the three processes of heat transfer: conduction, convection, and radiation

6.f. Heat Transfer Review Answers

Directions: Label each of the following scenarios with the type of heat transfer that best describes it.	
1. Heat we feel from the sun.	radiation
2. The heat you feel when you touch a hot stove.	conduction
3. Heat you feel when you put your hands above a fire.	radiation and/or convection
4. My spoon is hot after leaving it on the pot that was on the stove.	conduction
5. This is responsible for making macaroni rise and fall in a pot on the stove.	convection
6. The heat my snake feels from the heat lamp above him.	radiation
7. Transfer of heat by the actual movement of the warmed matter (i.e., gas or liquid).	convection
8. The reason heating vents are usually placed on the floor of a home.	convection
9. Insulation is used to prevent this type of heat transfer.	conduction
10. This type of heat transfer is trapped by green houses.	radiation
11. Why the dog lays down next to the wood stove.	radiation
12. Why the cat sits on a shelf above the stove.	radiation and/or convection
13. Why the kettle on the stove gets hot.	conduction (convection if referring to liquid inside)
14. Why you use a potholder/oven mitt when getting the cookie sheet out of the oven.	conduction
15. Heat you feel when you sit next to a campfire.	radiation
16. Heat you feel from your electric blanket.	conduction

Directions: Answer the following question.

17. Describe the **similarities** and **differences** among the three processes of heat transfer: conduction, convection, and radiation Answers may vary but could include:

Sample similarities:

- All three transfer heat from hotter objects/fluids/regions (i.e., have a higher temperature) to colder objects/fluids/regions (i.e., have a lower temperature).
- All three increase the temperature, and thus the thermal energy, of the object to which the heat is being transferred.

Sample differences:

- Conduction and convection involve particles colliding with each other to transfer energy; radiation does not need to travel through matter since electromagnetic radiation can travel through space.
- In conduction, particles collide with their neighbors; in convection, particles flow in a current due to density differences; in radiation, electromagnetic radiation interacts with particles to increase their vibration.
- Conduction is the transfer of heat across a solid or from a solid to another solid or fluid. Convection is the transfer of heat within a fluid. Radiation can transfer energy across space, and can affect solids, liquids, and gases.

LESSON 7 Exploring Materials and Planning: Idea Generation

Lesson Objectives

Students will be able to:

- identify whether materials conduct or insulate against heat transfer via conduction and absorb or reflect heat transfer via radiation.
- use evidence from problem scoping to generate multiple initial ideas for a design solution.

Time Required

One 50-minute class period

Materials

Per classroom:

- 1 *Engineering Design Process* poster

Per team:

- 1 piece of aluminum foil, ~6”x6”
- 1 piece of 16 gauge copper wire, 12”
- 1 steel washer (suggested size: 7/8” OD x 3/8” ID)
- 1 jumbo paper clip
- 1 pipe cleaner
- 1 piece of white construction paper, ~4.5”x6”
- 1 piece of black construction paper, ~4.5”x6”
- 1 piece of black felt, ~6”x5”
- 1 piece of white felt, ~6”x5”
- 1 piece of ~4.25”x5.5” transparency sheet
- 1 craft stick
- 1 ruler
- **(optional)** 1 agar fish

Per student:

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

Standards Addressed

Next Generation Science Standards: MS-PS1-4, MS-PS3-3, MS-PS3-4, MS-PS3-5, MS-PS4-2, MS-ETS1-1

Lesson Summary

Students review the engineering design challenge and explore the materials available for the final design. Students write their ideas for the first prototype individually. Students use a list of materials with their costs, as well as what they learned about heat transfer, to design a cooker container.

Background

Teacher Background

For the past six lessons, students have been in the Problem section of the engineering design process, which includes the steps define the problem and learn about the problem. In this lesson, students shift to the Solution section of the engineering process, which includes: plan (the solution), try (the plan of the solution), test (the solution), and decide (whether the solution successfully solves the problem). The focus of this lesson and the next is developing written plans; trying (i.e., implementing or building) the planned solution and testing and evaluating that implemented prototype solution will occur in later lessons. Students then will repeat the process and redesign. For more information about the engineering design process presented in this unit, see the front matter section about it.

Before the Activity

If using the duplication masters, print and make copies of the following worksheets in the labeled amounts:

- *7.a. Thermal Properties of Design Materials* (1 per student)
- *7.c. Materials Cost List* (1 per student)
- *7.d. Individual Design Ideas* (3 per student)

If students are writing question prompts directly into their engineering notebooks, it is still recommended to make copies in the specified amounts for *7.c.*

Prepare the materials that students will be able to purchase for their design. While they will not start trying/building during this lesson, they will be exploring the materials to determine their thermal properties. Therefore, create one set of design materials for each team. This set will need one of each item on *7.c. Materials Cost List* (with the exception of masking tape): 1 piece of ~6”x6” aluminum foil, 1 piece of 12” long copper wire, 1 steel washer, 1 jumbo paper clip, 1 pipe cleaner, 1 piece of white ~4.5”x6” construction paper, 1 piece of black ~4.5”x6” construction paper, 1 piece of white ~6”x5” felt, 1 piece of black ~6”x5” felt, 1 piece of ~4.25”x5.5” transparency sheet, and 1 craft stick. These items can be placed in piles or put in one folder for each team in order to keep them organized. Some of the materials (i.e., aluminum foil, copper wire, construction paper, felt) may need to be cut to the appropriate size. The copper wire should be thin enough to be able to be cut with normal scissors, but a wire cutter might be a better alternative.

(Optional) It may be helpful to provide one agar fish for each team while they individually generate initial design ideas for their cooker container prototype so that they can see the dimensions of the fish. However, it is recommended to not provide the agar fish during the first part of the activity. This first part of the lesson is intended for students to think deeply about the thermal properties of the materials they can use, rather than possible structural designs of the

Exploring Materials and Planning: Idea Generation

container. Providing the fish, along with the materials, may inadvertently encourage students to start focusing on structure rather than thermal properties.

Classroom Instruction

Introduction

1. **Tie to the engineering design problem. Say/Ask:** *We have been working as engineers in this unit. 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 students are in the engineering design process. (Plan)** Direct students' attention to the *Engineering Design Process* poster and their *Engineering Design Process* sliders. **Say/Ask:** *As engineers, we have been using an engineering design process to guide us. What steps have we done so far?* Students should say that they have Defined the problem and Learned some science/background knowledge that will help them solve the problem. **Say:** *Now that we have defined our problem and learned background information about types of heat transfer, we are ready start designing solutions to the problem. We can always go back to define and learn* (point to arrows on poster that show going back to previous steps) *if we need to learn more about the problem or background information. For now, we will move on to the next step, which is to plan a solution.*

3. **Discuss the importance of planning. Ask:** *Why do you think it is important for engineers to plan and create written designs before they create, test, and evaluate the designs?* Take student guesses. Guide discussion so students' realize that creating/building designs to test and evaluate (whether they are objects or processes) can be expensive, use a lot of materials, and take a lot of time, so engineers work hard and spend a lot of time on their written plans first.

Activity Part 1: Exploring Design Materials Available

4. **Introduce the activity. Say:** *Before you begin thinking about possible designs for a cooker container, you are going to have time to explore the materials available for the prototype solution in order to predict how well (or not) they might conduct or insulate against heat transfer by conduction and also absorb or reflect heat transfer by radiation.* If using duplication masters, pass out *7.a. Thermal Properties of Design Materials* to each student, or have students write the answers to the prompts in their engineering notebooks next to the number of that prompt.

5. **Distribute the materials.** Either pass out or have one student from each team come up to get one set of design materials. While the materials are being distributed, tell the students that these materials will need to be returned in their original state. The students can observe and feel the materials, but they should not alter (e.g., cut, bend) them in any way since they are not yet designing.

Key Terms
prototype, plan

Assessments

Pre-Activity Assessment
Check students' ability to explain the engineering problem and identify where they are in the engineering design process. Students should be able to move the paper clip on their sliders to the appropriate step.

Activity Embedded Assessment
Check students' progressive understanding through their verbal and written responses of the *7.a. Thermal Properties of Design Materials* worksheet. This is especially important because students will need to use information from the science previous lessons in this activity.

Post-Activity Assessment
At the end of the lesson, check the design ideas and justifications students wrote and/or drew in the *7.d. Individual Design Ideas* worksheets to see if they make sense within the context of the problem.

DUPLICATION MASTERS
- 7.a. Thermal Properties of Design Materials
- 7.c. Materials Cost List
- 7.d. Individual Design Ideas

EDUCATOR RESOURCES
- 7.b. Thermal Properties of Design Materials Answers

6. **Predict the thermal properties of the materials. Say:** *When you write about design ideas, you will need to justify why you choose to use each type of material. You will need to use what you have learned about heat transfer and thermal properties of materials to justify your choices.* Within student teams, have the students observe and feel the materials in order to answer the questions on *7.a. Thermal Properties of Design Materials* or in their engineering notebooks. Circulate during these discussions, listening and touching base with the materials. Remind students to look at information from previous lessons to help them answer the questions. NOTE: Students do not need to classify all of the design materials as either conductors/insulators or absorb/reflect. Two-three materials per question is sufficient.

7. **Collect materials.** When students have finished answering the questions, either collect the materials or have one student from each team return the materials.

8. **(Optional) Discuss thermal properties as a whole class.** Have each student team share one material that they talked about and whether they thought it would be a good conductor, insulator, absorb radiation, or reflect radiation.

Activity Part 2: Individual Design

9. **Transition to the design. Say:** *Now that your teams have predicted the thermal properties of the design materials, you can begin to think about planning designs for the cooker container prototype.*

10. **Review the engineering problem. Ask:** *What are the criteria and constraints of the engineering problem?* If students are having trouble remembering, remind them to look at: *1.b. Client Letter,* the questions for the client along with the answers, and/or the questions they answered during lesson one on the *1.d. Define the Problem* worksheet or in their engineering notebooks.

11. **Introduce the cost sheet.** Point out that one of the constraints of the problem is that the prototype should cost as little as possible, but students don't yet know how much each material costs. Pass out a *7.c. Materials Cost List* to each student. **Say:** *You will need to use this cost list to calculate the cost of your team design. You do not need to fill it out when you are brainstorming new design ideas now, but use it as a reference to estimate how cheap or expensive your ideas are.* NOTE: For this initial idea generation activity, students do not actually need to fill out *7.c. Materials Cost List* for each idea they have, but they should use it as a reference.

12. **Individual plan.** Either pass out three copies of *7.d. Individual Design Ideas* to each student, or have them copy a similar template into their engineering notebooks three times. **Say:** *First, we are going to create some plans on our own. I want to give each of you a chance to come up with your own ideas before you meet as a team and decide on one design that you will describe and justify in more detail. To be the most creative and make sure*

that you don't get stuck on one idea, I want each of you to come up with at least three designs. Instruct students to draw and explain their three ideas on the *7.d. Individual Design Ideas* worksheet (or similar version drawn in their engineering notebooks). Point out that for these initial designs, the "Justification" could include evidence from the previous science lessons, cost, and other justifications. NOTE: If students find the spaces available for sketching their design ideas constricting, encourage them to draw in other pages of their engineering notebooks. If they choose to do this, make sure they are still sketching and explaining why they think each design idea will work. One way to encourage students to be thorough in drawing/writing about their design ideas (e.g., include materials of each component, specific measurements) is to tell them to pretend that another person would be constructing their prototype. This may encourage them to use more detail. It may be helpful to have teammates sit apart from each other for this activity. This will encourage the students to think individually and avoid teammates copying each others' designs. **(Optional)** If it would be helpful, pass out one agar fish for students to observe while they are generating initial design ideas. When they are finished, collect the agar fish.

Closure

13. **Review the engineering problem. Say/Ask:** *Our client asked us to solve an engineering problem. What is that problem? How did we work on it today?* Take student answers. Tell students that they will continue to work on designing a cooker container prototype for several lessons to come.

LESSON 7

Name_____ Date_____ Period _____

7.a. Thermal Properties of Design Materials

Directions: Based on what you have learned in previous lessons, make predictions about the thermal properties of the design materials.

1. Which materials will best transfer heat via conduction (i.e., are conductors)? Why do you think so?

2. Which materials will best block heat transfer via conduction (i.e., are insulators)? Why do you think so?

3. Which materials will best absorb radiation energy? Why do you think so?

4. Which materials will best reflect radiation energy? Why do you think so?

5. Which materials will best transmit radiation energy? Why do you think so?

7.b. Thermal Properties of Design Materials Answers

Directions: Based on what you have learned in previous lessons, make predictions about the thermal properties of the design materials.

1. **Which materials will best transfer heat via conduction (i.e., are conductors)? Why do you think so?**
   Answers will vary, but could include:
   Aluminum foil, copper wire, steel washers, and jumbo paper clips will best transfer heat via conduction because: they are metal, and metals are good conductors; they melted the ice the fastest in the conduction lab, which means they are good conductors.

2. **Which materials will best block heat transfer via conduction (i.e., are insulators)? Why do you think so?**
   Answers will vary, but could include:
   Construction paper, felt, and craft sticks will best insulate against heat transfer heat via conduction because: they are good insulators; they contain air pockets, which makes them good insulators; wood did not melt ice quickly, which means it is a good insulator.

3. **Which materials will best absorb radiation energy? Why do you think so?**
   Answers will vary, but could include:
   Black felt and black construction paper will best absorb radiation energy because they are dark-colored materials, and dark-colored materials absorb light the most.

4. **Which materials will best reflect radiation energy? Why do you think so?**
   Answers will vary, but could include:
   All of the metals, the white construction paper, and the craft sticks will best reflect radiation energy because they are shiny or light-colored materials, and shiny and light-colored materials reflect light the most.

5. **Which materials will best transmit radiation energy? Why do you think so?**
   Answers will vary, but could include:
   The transparency sheet will transmit radiation energy because it is transparent (or see-through).

LESSON 7

Name_____ Date_____ Period _____

7.c. Materials Cost List

	Price for One Item	Quantity Needed	Total Cost for Item
1 piece of aluminum foil, 6”x6”	$1.50		
1 piece of copper wire, 12” long	$2.00		
1 steel washer	$0.75		
1 jumbo paper clip	$0.50		
1 pipe cleaner, 12” long	$1.00		
1 piece of white construction paper, 4.5”x6”	$1.00		
1 piece of black construction paper, 4.5”x6”	$1.00		
1 piece of black felt, 5”x6”	$2.00		
1 piece of white felt, 5”x6”	$2.00		
1 craft stick	$0.25		
6” piece of masking tape	$0.25		
1 piece of transparency sheet, 4.25”x5.5”	$1.50		
		Total Materials Cost:	

LESSON 7

Name_____ Date_____ Period _____

7.d. Individual Design Ideas

Design Plan (include features, dimensions, materials used)	Justification
Bottom view of the cooker container	
Top view of the cooker container	
Side view of the cooker container	

LESSON 8 Planning: Idea Selection and Evidence-Based Reasoning

Lesson Objectives

Students will be able to:

- systematically evaluate various solutions based on the problem to narrow to one design solution.
- justify why their proposed design solution is appropriate based on the application of core science/mathematics concepts, and information obtained in problem scoping.

Time Required

One 50-minute class period

Materials

Per classroom:

- 1 *Engineering Design Process* poster
- materials available for design:
  - aluminum foil, ~6”x6”
  - pieces of 16 gauge copper wire, 12”
  - steel washers (suggested size: 7/8” OD x 3/8” ID)
  - jumbo paper clips
  - pipe cleaners
  - pieces of white construction paper, ~4.5”x6”
  - pieces of black construction paper, ~4.5”x6”
  - pieces of black felt, ~6”x5”
  - pieces of white felt, ~6”x5”
  - pieces of ~4.25”x5.5” transparency sheet
  - craft sticks
- 1 poster-sized sheet of sticky note paper
- markers

Per team:

- 1 ruler
- (optional) 1 agar fish

Per student:

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

Key Terms

evidence-based reasoning, criteria, constraints, prototype

Lesson Summary

Students share their individual ideas with other members of the team. Using one of these ideas or components of several design ideas, the team decides upon an idea for their first design. Students also use evidence-based reasoning to write justifications for every part of the design, including the cost amounts calculated for their first prototype.

Background

Teacher Background

Evidence-based Reasoning: Evidence-based reasoning (EBR) refers to the engineering practice of providing rationale for design ideas and decisions. It is somewhat similar to scientific argumentation in the sense that it involves using evidence and explanations to support a statement, but it is ultimately different. In EBR, the statement being supported is an engineering design idea or decision, whereas in scientific argumentation it is a claim or conclusion about a natural phenomenon. EBR is used in the context of generating solutions for engineering problems; scientific argumentation is used to answer scientific questions about nature. Science and mathematical principles are important justifications for scientific argumentation and EBR. However, EBR often also includes justifications related to the context, criteria, and constraints of the engineering problem (e.g., cost, user needs, technical feasibility). In this lesson, students will use EBR to think deeply about their proposed design ideas and to justify them with information about the engineering problem and their science and mathematics knowledge.

During the next lesson (try/build), students will not be allowed to purchase additional materials once they go to the store, with the exception of tape. The purpose of this is to encourage students to think deeply about and use their design plans rather than just tinker with materials and create a cooker container prototype without any planning. It may be helpful to tell them that in this lesson so that they think more thoroughly about their cooker container prototype design and what materials they think they will need.

Before the Activity

On one poster-size sheet of sticky note paper, draw an Evidence-Based Reasoning template (like worksheet *8.a.*). This poster will contain explanations of the terms on the worksheet and what kind of information goes in each section. An example of this poster is included in the Duplication Masters section of this lesson. Students are not to copy this version into their *8.a. Evidence-Based Reasoning* worksheets. Rather, they are to use it as a guide to help them fill out their own versions of the template. This poster could also be created on a white board or digitally projected. However, students will likely refer to the EBR Poster with Explanations beyond this lesson, so it would be useful to have it visible for the remainder of the unit.

(Optional) This poster can be created in advance of the lesson instead of filling it out as the lesson goes along. However, leave space on the poster for additional information if students make additional suggestions.

Planning: Idea Selection and Evidence-Based Reasoning

LESSON 8

If using the duplication masters, print and make copies of the following worksheets in the labeled amounts:

- *8.a. Evidence-Based Reasoning* (1 per student)
- *8.d. Planning Reflection Questions* (1 per student)

Also, it may be helpful to make extra copies of *7.c. Materials Cost List* (see lesson 7) in case students already wrote on it during the previous lesson. Set out the materials that students can purchase for their design. While they will not start trying/constructing during this lesson, it is helpful for them to see a reminder of what materials are available in order to adequately plan a design solution. The materials pre-cut for lesson 7 may be used here.

(Optional) It may be helpful to have one agar fish available per team so students can look at, measure, and feel the fish.

Classroom Instruction

Introduction

1. **Tie to the engineering problem. Say/Ask:** *Later today, we are going to review all of the details of the engineering problem. For now, can anyone tell me a short version of what our engineering problem is?*

2. **Identify where they are in the engineering design process. (Plan)** 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.

3. **Review the importance of planning.** Have students explain why engineers make plans before trying/building and testing prototypes. They should note that creating/building designs to test and evaluate (whether they are objects or processes) can be expensive, use a lot of materials, and take a lot of time, so engineers work hard and spend a lot of time on their written plans first.

Activity

4. **Reflect on individual design ideas.** Pass out *8.d. Planning Reflection Questions* and have students fill in the answer to the first question on the sheet or in their notebooks. Have students look through the ideas they generated during the previous lesson and evaluate each of their own idea's pros and cons.

5. **Introduce evidence-based reasoning.** Post an evidence-based reasoning template drawn on a sheet of poster size sticky note paper. Pass out a *8.a. Evidence-Based Reasoning* worksheet to each student or have them draw a similar version of the EBR template in their notebooks. **Say:** *To help you continue planning your design, we are going to be using evidence-based reasoning. This means that you will need to support your design ideas with evidence and explanations. We will discuss each of the parts together.* Clarify with students that the Evidence-Based Reasoning poster will have general explanations and reminders of what kind of information should go in each section. This is different from what the students will write in the templates. They will fill out the boxes with

Standards Addressed

Next Generation Science Standards: MS-PS1-4, MS-PS3-3, MS-PS3-4, MS-PS3-5, MS-PS4-2, MS-ETS1-1, MS-ETS1-2, MS-ETS1-3

Assessments

Pre-Activity Assessment
Check students' ability to explain the engineering problem, including the criteria and constraints, as well as identify where they are in the engineering design process. Students should be able to move the paper clip on their sliders to the appropriate step.

Activity Embedded Assessment
Check students' progressive understanding through their verbal and written responses when deciding upon a design idea and filling out *8.a. Evidence-Based Reasoning* template (either on the worksheets or in their engineering notebooks). This is especially important because students will need to use information from each of the four previous lessons in this activity.

Post-Activity Assessment
Check the student teams' design ideas and justifications to see if they make sense within the context of the problem.

DUPLICATION MASTERS

- 8.a. Evidence-Based Reasoning
- 8.d. Planning Reflection Questions

EDUCATOR RESOURCES

- 8.b. Evidence-Based Reasoning Rubric
- 8.c. Evidence-Based Reasoning Instructions
- 8.e. Planning Reflection Questions Rubric

information specific to their engineering design problem.

6. **Review the problem.** Direct students' attention to the "Problem with Criteria and Constraints" section of the *8.a. Evidence-Based Reasoning* worksheet and posters. On the poster, write down a general definition of "problem" (i.e., the problem the client asked you to solve). Instruct students to discuss in their teams and write a summary of their engineering problem in this section, leaving room for criteria and constraints.

7. **Review the criteria and constraints of the problem. Ask:** *Can anyone remind me what the words "criteria" and "constraints" mean?* Criteria are the requirements, or goals, of the designed solutions. Constraints are things that limit design possibilities. Write these definitions on the EBR poster. Refer students back to their lists of criteria and constraints from their *1.b. Define the Problem* notes. **Ask:** *What are some of the criteria and constraints of our engineering problem?* Discuss the criteria and constraints of the problem, and have students write them in the "Problem with Criteria and Constraints" section of the *8.a. Evidence-Based Reasoning* worksheet or in their engineering notebooks. NOTE: Use this time to remind students that their cooker container prototypes need to surround one agar fish, but all teams' prototypes need to fit into the solar oven.

8. **Remind students about the cost sheet.** Point out that one of the criteria of the problem is that the prototype should cost as little as possible. Remind students to use *7.c. Materials Cost List* as a reference when they are discussing possible design ideas in their team. Tell them that they need to fill out the cost list once they have decided on one design. NOTE: Tell students that when they are actually trying/building, they will not be able to purchase materials throughout the building process. Instead, once they turn in their completed *7.c. Materials Cost List* along with their design plans and justifications, they will not be able to purchase additional materials, with the exception of tape. Therefore, they need to think carefully about their designs and what materials they think they will need before they finish their material list and design plan.

9. **Introduce the concept of simplifying assumptions. Say:** *Engineers usually don't deal with every single aspect of a problem at once, otherwise it becomes too difficult to solve. Instead, they make a complex problem simpler, sometimes by ignoring some of the details of the problem and sometimes by pretending certain things are true about the problem when they actually aren't.* Write "ways to make a complex problem simpler" in the "Simplifying Assumptions (if any)" section of the Evidence-Based Reasoning poster. **Ask:** *What are some parts of our engineering problem that we can make simpler?* This may be a difficult concept for students, so provide an example or two if students struggle.
   - Simplifying assumptions (things to ignore): aesthetics/appearance, durability (how well it withstands wear and damage).
   - Simplifying assumptions (assume certain things are true when they aren't): materials used in classroom are household materials similar to those the company has.

Planning: Idea Selection and Evidence-Based Reasoning

10. **Explain what information goes in each of the remaining sections.** Have students guess at what kind of information they think should go in the "Design Idea," "Data/Evidence," and "Justification" sections of the *8.a. Evidence-Based Reasoning* worksheet. Write down relevant student suggestions in the appropriate section of the Evidence-Based Reasoning poster. This could include:
    - **Design Idea:** Description of the design idea; drawings of the design idea, possibly with different views (e.g., top view, side view); dimensions/sizes; label materials in the design idea to show where they are used; interesting features of the design idea; labels of what each part does.
    - **Data/Evidence:** Observations and data that show why you think your design will work. Examples: data conduction and radiation lab; total cost of the design.
    - **Justification:** Complete sentences that state why you think your design will be successful. These sentences should refer to the problem, criteria, constraints, idea, and data/evidence.

11. **Select a design solution.** Have students work in their teams. **Say:** *As you share and talk about all of your teammates' design ideas, think about the pros and cons of each of the solution ideas. As you think about developing one design solution, remember that you can choose one design idea or use the best parts from multiple design ideas.* Have students get into teams and discuss their cooker container design ideas and what materials they could use.

12. **Complete evidence-based reasoning.** When student teams have figured out what their design solution is, have them fill out *7.c. Materials Cost List*, as well as the rest of their *8.a. Evidence-Based Reasoning* worksheet or template in their notebook with their team's design. Circulate during these discussions, listening and touching base with the teams. Ask why they would choose certain materials or ways of putting them together. Refer them to the other data they have already collected about the thermal properties of materials. NOTE: Each student does not need to complete the evidence-based reasoning template; only one completed template is required per team. However, if you would like, each student can fill out 8.a. to include in their notebooks. Remind students to think about the information they wrote in the "Problem including Criteria and Constraints" and "Simplifying Assumptions" sections when they justify their chosen design solution. If students find the space available for sketching their design solution constricting, encourage them to draw in other pages of their engineering notebooks.

Closure

13. **Reflect upon design solution.** Looking back at *8.d. Planning Reflection Questions,* have students fill in the answer to the second question on the sheet or in their notebooks. **Say:** *Now that your team has decided upon one design, explain why you chose that design.* Circulate and check students' rationale, making sure it makes sense in the context of the engineering problem.

LESSON 8

Name_____ Date_____ Period _____

8.a. Evidence-Based Reasoning (1/2)

Problem with Criteria & Constraints
- Explain the client's problem that needs a solution and why it is important to solve.
- List criteria and constraints 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, labels of materials used, and labels of what each part does.	**Data/Evidence** • List science/mathematics learned and/or results of tests that support your design idea.

LESSON 8

Name_____ Date_____ Period _____

8.a. Evidence-Based Reasoning (2/2)

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.

LESSON 8

Student Name_____ Date_____ Period _____

8.b. 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 no	**Identified problem**
		yes no	**Explained why the problem is important**
Criteria	Explain criteria based on given information.	yes no	**Identified at least 1 criterion**
Constraints	Explain constraints based on information.	yes no	**Identified at least 1 constraint**
Simplifying Assumptions	Explain assumptions they have made in order to make solving the problem more manageable.	yes no	**Identified at least 1 simplifying assumption**
Design Idea	Communicate design idea through drawing, including labels for materials and function of parts.	yes no	**Included drawing to represent design idea**
		yes no	**Included labels of materials**
		yes no	**Included labels of what each part does**
Data/Evidence (List math/science learned and/or results of tests that support your design idea)	Apply evidence gathered from testing to choose solution. Apply math/science concepts to choose solution.	yes no	**Listed at least 1 piece of valid evidence**
		yes 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 no	**Included explanation of how their data/ evidence supports their design idea**
		yes no	**Explained why this will work**
		yes no	**Explained how design idea will meet criteria/constraints**
Notes:			

8.c. Evidence-Based Reasoning Instructions

Poster with Explanations

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

Problem: the engineering problem the client asked you to solve

Criteria: the requirements, or goals, of the designed solutions

Constraints: things that limit design possibilities

Simplifying Assumptions (if any)
- List things that might be important but you have decided not to worry about.

Ways to make a complex problem simpler

Design Idea #____	Data/Evidence
• Plan including drawing, labels of materials used, and labels of what each part does.	• List science/mathematics learned and/or results of tests that support your design idea.
• Description of the design • Drawings of the design, different views • Dimensions (sizes) • Label materials in design (show where they are used) • Interesting features	Observations and data that show why you think your design will work Examples: • Data from reflection/refraction measurement lab • Simulation data • Observations from absorption/ transmission activity

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.

Complete sentences that state why you think your design will be successful. These sentences should refer to the problem, criteria, constraints, idea, and data/evidence.

8.c. Evidence-Based Reasoning Instructions

Ecuadorian Fishermen Example

Problem with Criteria & Constraints

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

Problem: **The fishermen want to properly cook and sell fish at the fish market. If the fishermen are able to earn more money at the fish market, it will improve the quality of life for their families and villages.**

Criteria: **The model fish needs to be cooked in the cooker container, which means that it needs to reach as high of a temperature as possible when it is placed in the solar oven. Also, a cheaper cooker container prototype is better. It also needs to be re-usable.**

Constraints: **We can only use materials on the list. The cooker container prototypes must be large enough to hold one model agar fish but still relatively small so multiple can fit into a solar oven.**

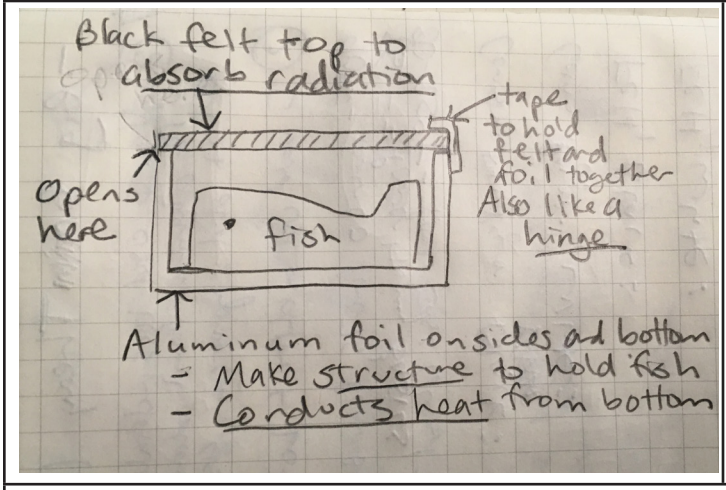
Simplifying Assumptions

- List things that might be important but you have decided not to worry about.

We don't need to worry about the cooker container's appearance.

Design Idea

- Plan including drawing, labels of materials used, and labels of what each part does.



Data/Evidence

- List science/mathematics learned and/or results of tests that support your design idea.

In the Conduction lab, aluminum and the other metals melted the ice cube faster than the wood and polymers, so they conducted heat well.

In the Radiation lab, the black felt had the greatest change in temperature, so it absorbed a lot of thermal energy via radiation heat transfer.

The amount of materials needed for this design would cost $3.75.

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.

We will be using aluminum foil for the base and sides of the prototype. It is not the best conductor compared to other metals, but it still will conduct some heat from the floor of the solar oven. Also, it is easy to make a structure out of it, and it was only $1.50. We chose black felt as the top since it changed the temperature of the air inside the cup during the Radiation lab the most, so it will absorb the most radiation from the lamps in the solar oven. The black felt was expensive at $2.00, but we think it will be worth it since it will help transfer energy to the fish inside the cooker container. We also taped the felt to the aluminum foil on one side so it opens up like a door hinge. Our total cost is kind-of cheap ($3.75), our container is large enough to fit a fish but still really small, and we think a lot of heat transfer will happen through conduction and radiation.

LESSON 8

Name_____ Date_____ Period _____

8.d. Planning Reflection Questions

Answer the following question about your own design ideas:

1. What are the pros and cons of each of your own solution ideas?

Idea 1:

Idea 2:

Idea 3:

After your team decides on a solution to try, answer the following question:

2. Which solution did your team choose and why? Provide evidence for your reason.

LESSON 8

Student Name_____ Date_____ Period _____

8.e. Planning Reflection Questions Rubric

Problem	Question	Learning Objectives	Rubric	
8.d.1	What are the pros and cons of each of your own solution ideas?	Select potential solution through systematic evaluation of various solutions based on the problem.	yes no	**Provided at least 1 pro for each solution generated (as an individual)**
			yes no	**Provided at least 1 con for each solution generated (as an individual)**
8.d.2	Which solution did your team choose and why? Provide evidence for your reason.	Select potential solution through systematic evaluation of various solutions based on the problem.	yes no	**Stated which solution was chosen**
			yes no	**Provided an explanation for why the team chose that solution that was based on evidence**

Notes:

LESSON 9 Trying/Building the First Prototype

Lesson Objectives
Students will be able to:
- implement a design and create a prototype cooker container.

Time Required
One 50-minute class period

Materials
Per classroom:
- 1 *Engineering Design Process* poster
- **(Optional)** solar oven built in lesson 6

Per team:
- materials available for design:
  - 2-3 aluminum foil, ~6”x6”
  - 2-3 pieces of 16 gauge copper wire, 12”
  - 6-8 steel washers (suggested size: 7/8” OD x 3/8” ID)
  - 10 jumbo paper clips
  - 4-5 pipe cleaners
  - 2-3 pieces of white construction paper, ~4.5”x6”
  - 2-3 pieces of black construction paper, ~4.5”x6”
  - 2-3 pieces of black felt, ~6”x5”
  - 2-3 pieces of white felt, ~6”x5”
  - 2-3 pieces of transparency sheet, ~4.25”x5.5”
  - 8-10 craft sticks
- 1 pair of scissors
- 1 ruler
- 1 agar fish

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

Standards Addressed
Next Generation Science Standards: MS-PS1-4, MS-PS3-3, MS-PS3-4, MS-PS3-5, MS-PS4-2, MS-ETS1-4

Lesson Summary
Students implement their planned design and build a cooker container.

Background
Teacher Background
Students will be using scissors to construct their cooker container prototype. Reinforce with the class safety rules already in place for using scissors. Also, the copper wire, pipe cleaners, and paper clips available for purchase have sharp pointy ends; they should take care with these materials if they choose to purchase them.

The main role of the teacher during this lesson will be checking in on student teams and distributing materials. As such, having the materials organized before class is necessary. During the class, there are two suggested options for distributing materials. The first is to set up a Materials Distribution Center that can be a stable position from which the teacher can easily observe and monitor all students while passing out materials. The second is to gather all of the materials in a tub and move from team to team distributing them. Choose whichever option, or create a third, that best meets the needs of the class.

This lesson is written as to not allow students to purchase additional materials once they go to the store, with the exception of tape. The purpose of this is to encourage students to think deeply about and use their design plans rather than just tinker with materials and create a cooker container prototype without any planning. The materials students purchase should reflect the design in their EBR graphic. Avoid letting students purchase overly excess materials. If students do not use certain materials purchased, they may remove them from the Materials Cost list. The cost should reflect the materials used in the prototype.

Have a place ready for students to safely store their prototype cooker containers when class is over.

Before the Activity
Print and make copies of *9.a. Teacher Observation Protocol: Try Lesson* (enough so that each team has a line in the table). This document will not be given to the students, but it will be needed for observations of students during the lesson.

The most essential part of this lesson is to prepare and organize the materials that students will need in order to create their prototype cooker containers.
- Some of the materials may need to be cut into appropriate sizes (i.e., ~6”x6” aluminum foil, 12” copper wire, ~4.5”x6” for both colors of construction paper, ~5”x6” for both colors of felt, ~4.25”x5.5” for transparency sheet). It is recommended to have 2-3 of each of these materials pre-cut and available for each team to purchase. (Teams will likely not use all of the pre-cut materials, but it is useful to have enough ready in case a material type is especially preferred.)
- Have packages of the other materials (i.e., steel washers, jumbo paper clips, pipe cleaners, craft sticks) ready.

Trying/Building the First Prototype

- Masking tape may be pre-cut into 6-inch strips, or cut as teams need it. It is up to the teacher and the space constraints of the classroom.

The agar fish will be needed for this lesson as students implement/build their cooker container prototypes. The fish will need to be collected at the end of class for use during the next day. The fish created for Lesson 6 could be used here. However, if the fish have broken apart since then, create new ones via the directions in *6.a. Making Agar Fish*.

The solar oven testing station is not needed for this lesson, since students will not yet test their prototype cooker containers. However, it may be useful to have it up. If it has been disassembled since Lesson 6 and needs to be reassembled, the instructions for preparing the solar oven are in the Lesson 6 educator resource *6.b. Making the Solar Oven*. The solar oven does not need to be turned on for this lesson, but if it does, keep in mind that the heat lamps become hot quickly.

Classroom Instruction

Introduction

1. **Tie to the engineering challenge. Say:** *In the previous lesson, your team decided on a plan for a prototype cooker container, as requested by our client, The Pescadores Foundation.*

2. **Identify where they are in the engineering design process. (Try/Build)** Draw students' attention to the *Engineering Design Process* poster and their *Engineering Design Process* sliders. **Ask:** *What did we do before?* (Plan). **Ask:** *What do you think we are going to do today?* (Try). NOTE: Clarify with students that Try means to try out their plan by creating it, not to actually try and see how well it performs. This latter step is the Test step, which will happen in the next lesson.

3. **Discuss the importance of creating models/prototypes. Ask:** *Why do you think it is important for engineers to create models and prototypes? Wouldn't it be easier to send our designs to the client now? Why or why not?* Take student answers. Guide discussion so students' realize that it is helpful for engineers to construct model versions of their plans, even if they are not exactly the same as the final version, so that these models/prototypes can be tested and evaluated to see if they work the way the engineers predict.

Activity

4. **Explain the procedures for obtaining materials.** Share the following points with students before they break up into teams to finish planning (if they have not yet) and start implementing.
   - Before a team can get materials, they need to present their completed *8.a. Evidence-Based Reasoning* worksheet describing their design solution AND one completed *7.b. Materials Cost List* for that design solution to the teacher for approval. These may also be written directly in students' engineering notebooks and shown to the teacher for approval.

Key Terms
prototype

Assessments

Pre-Activity Assessment
Check students' ability to explain the engineering problem and identify where they are in the engineering design process. Students should be able to move the paper clip on their sliders to the appropriate step.

Activity Embedded Assessment
Check students' progressive understanding through their discussions, materials choices, and design features as they build their cooker container prototypes. Assess each team's progress with the *9.a. Teacher Observation Protocol: Try Lesson.* For example, note which teams are using materials that are proven to be conductors for the bottom and absorb radiation energy well for the top. Look for teams that seem to be adapting their design as they build. Ask them to explain their decisions.

Post-Activity Assessment
During the closure activity when students are presenting their cooker containers, ask them to justify the use of one material. The purpose is to get students to use their lab data as evidence.

DUPLICATION MASTERS
- NONE

EDUCATOR RESOURCES
- 9.a. Teacher Observation Protocol: Try

Trying/Building the First Prototype

- Once a team has purchased materials, they will not be allowed to go to the store again, except to purchase more tape. The teams should be creating what they have decided upon in their plans, so they should have all of the materials they might need.

5. **Try/build/create.** Instruct students to start working. If needed, they can finish discussing their plan and filling out the *8.a. Evidence-Based Reasoning* and *7.b. Materials Cost List* for their team design either on the worksheets or directly into their engineering notebooks. Otherwise, they may bring their two worksheets up for teacher approval and receive supplies. As teams are working, walk around to each team and assess their progress using *9.a. Teacher Observation Protocol: Try* sheet. The observation protocol also has optional questions you may ask to further draw out students' reasoning. NOTE: Circulate between teams as much as possible (when not distributing supplies). Ask students to verbally justify their materials choices and design features. Answer questions as they arise. **(Optional)** If a team finishes building well in advance of the other teams, have them make a list of design features that they think will help their prototype be the most successful and be prepared to explain why to the class.

6. **Clean up.** Leave enough time for students to put their cooker container materials neatly away and pick up the room. Be sure to collect the agar fish for use in the next lesson.

Closure

7. **Present the prototype.** Invite teams that have finished their cooker containers to present them to the class and explain the design features they think will make their cooker container prototype successful.

Trying/Building the First Prototype

LESSON 9

9.a. Teacher Observation Protocol: Try

Team #	All team members are on-task to make/try their solution.	One or more team members are not on-task.	Team has made appropriate progress on their solution.	Team is struggling to make their solution.	Team is making/made a solution directly related to problem.	Team is making/made something unrelated to problem.	Notes

Optional Question Prompts:

NOTE: These questions can be used to further draw out and scaffold students' evidence-based reasoning. While the main purpose of these questions is to assess students' reasoning, it is also appropriate to interact with students/question for the purpose to support learning.

1. Can you tell me about your solution? What are you designing?
2. What were some of the other solution ideas you generated? How well did they address the problem?
3. How did you decide to move forward with this idea? What evidence do you have that your design will solve the problem for the client?

LESSON 10 Testing and Deciding about First Prototype

Lesson Objectives
Students will be able to:
- test the cooker container prototypes.
- compare their design's performance with the performance of their peer's designs to determine the characteristics of the best performing cooker container prototypes.
- analyze the performance of their first prototype.

Time Required
One-two 50-minute class periods

Materials
Per classroom:
- 1 *Engineering Design Process* poster
- solar oven built in lesson 6
- 1 poster size sticky note paper
- markers
- **(Optional)** sticky notes

Per team:
- 1 digital thermometer
- 1 agar fish

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

Standards Addressed
Next Generation Science Standards: MS-PS1-4, MS-PS3-3, MS-PS3-4, MS-PS3-5, MS-PS4-2, MS-ETS1-1, MS-ETS1-2, MS-ETS1-3

Key Terms
data collection, criteria, constraints

Lesson Summary
Students test their cooker container prototypes' performance by placing them in the classroom oven for 10 minutes. They measure the initial and final temperature and calculate the temperature change. Student teams share their design's cost, temperature change, and additional characteristics with the whole class to determine what features made some designs successful. Students decide how well their design met each of the criteria and as a prompt for them to begin thinking about redesign.

Background
Teacher Background
If this lesson takes more then one day, it is recommended to break before students begin to fill out *10.c. Think About Results*.This provides time for the teacher to analyze all of the teams' data from testing and attempt to figure out how heat transfer processes influenced the measured teamperature change.

In this lesson student will be working with the solar oven, which includes very hot lamps, to test their designs. While the teacher should be the only one near the heat lamps, it would still be useful to reinforce with the class safety rules already in place.

The "Additional Characteristics" column of the data table in *10.b. Test Results* is optional. The class may have decided upon an additional criterion during problem scoping (e.g., size of the prototype, how easy it is to make the prototype) that could be added here. Or, students may want to share features of their design that aren't necessary meeting assigned criteria but that they think make their design more advantageous to the client and/or end user.

If any of the agar fish need disposing at the end of the lesson, they may be placed directly in the trace because they are just plain agar.

Before the Activity
If using the duplication masters, print and make copies of the following worksheets in the labeled amounts:
- *10.b. Test Results* (1 per student)
- *10.c. Think about Results* (1 per student)
- *10.a. Teacher Observation Protocol: Test Lesson* (1 per 4 teams)

If students are writing question prompts directly into their engineering notebooks, it is still recommended to make copies in the specified amounts for *10.a.*, since the teacher will need this document for observations of the students during the lesson.

Set up the solar oven testing station. If it has been disassembled since Lesson 6 and needs to be reassembled, the instructions for preparing the solar oven are in the Lesson 6 educator resource *6.b. Making the Solar Oven*. Keep in mind that the heat lamps become hot quickly; the teacher and students need to be especially careful in removing the cooker container prototypes from the solar oven after the lamps have been on for ten minutes. Also, note that the heating pad in the solar oven will need to be turned on 10-15 minutes before testing begins to allow it to reach a steady temperature.

Testing and Deciding about First Prototype

LESSON 10

The agar fish will be needed for this testing lesson. If they have survived thus far after being handled by the students for several lessons, the fish created for Lesson 6 could be used here. However, if the fish have broken apart since then, create new ones via the directions in *6.a. Making Agar Fish*.

On one sheet of poster size sticky note paper, make a data table on which student teams will record their results. The data table should include Team Name, Cost, Initial Temperature, Final Temperature, and Temperature Change (see *10.b. Test Results* worksheet in duplication masters for an example). This could also be done on a whiteboard with dry erase markers or on a digital document displayed via projector.

Classroom Instruction

Introduction

1. **Tie to the engineering challenge. Say:** *Throughout this unit, we have been designing solutions that aim to solve an engineering problem. What is that problem?*

2. **Identify where they are in the engineering design process. (Test)** Draw students' attention to the *Engineering Design Process* sliders. **Ask:** *What did we do in the previous class?* (Try) **Ask:** *What do you think we are going to do today?* (Test, then later Decide) NOTE: Clarify that "Decide" means "decide whether or not their solutions are good enough." That is, students will determine whether or not their solutions adequately meet the criteria of the problem.

3. **Discuss the importance of testing and deciding. Ask:** *Why do you think it is important for engineers to test their models and prototypes and then decide whether or not they are successful?* Take student answers. Guide discussion so students' realize that engineers test models and prototypes to see if they work the way the engineers predict. They decide whether their prototypes are successful in order to decide whether they are ready to communicate their solution to the client or whether they need to go back and try again, or redesign. It is important for engineers to learn from failures of their designs in order to make a better design.

Activity

4. **Assess student progress.** This will occur throughout the whole lesson, but it is mentioned here at the beginning since it does not clearly fall before or after a specific step. As students are testing, walk around and assess student progress with the *10.a. Teacher Observation Protocol: Test Lesson.*

5. **Retrieve prototypes.** Have student teams retrieve their built cooker container prototypes.

6. **Pass out supplies.** Give one agar fish and one digital thermometer to each team. Also, pass out the *10.b. Test Results* worksheet if students are using worksheets. (Otherwise, have them write their testing data, including final cost, all temperature measurements and calculations, and additional

Assessments

Pre-Activity Assessment
Check students' ability to explain the engineering problem and identify where they are in the engineering design process. Students should be able to move the paper clip on their sliders to the appropriate step

Activity Embedded Assessment
Walk around to each team and assess their progress, using the *10.a. Teacher Observation Protocol: Test Lesson*.
Check students' progressive understanding through their verbal and written responses when analyzing the whole class test results; this should indicate students' understanding of heat transfer.

Post-Activity Assessment
Check students' understanding when they are discussing and filling out the *10.c. Think about Results* questions; this should indicate their understanding of the important science and mathematics concepts, as well as the criteria and constraints, of the problem.

DUPLICATION MASTERS

- 10.b. Test Results
- 10.c. Think About Results

EDUCATOR RESOURCES

- 10.a. Teacher Observation Protocol: Test
- 10.d. Think About Results Rubric

characteristics, into their engineering notebooks.)

7. **Measure the initial temperature.** Have the students measure the initial temperature of the fish using the digital thermometer. Assist students with using the thermometer if necessary. NOTE: Instruct the students to be careful when pushing the probe into the agar fish. It needs to be solidly inside the fish, but if they push it too far or wiggle it around too much, the agar fish may break apart.
   NOTE: Have either a volunteer student team or the teacher measure the temperature of an additional agar fish which will be used as a control during the test.

8. **Prepare the cooker container.** Tell students to put the agar fish into their cooker container. When they are finished, they can bring their cooker container prototype to the solar oven and place it inside. Also, the control agar fish should be placed inside the solar oven at this time.

9. **Start the test.** Start timing the ten minutes for testing.

10. **Fill out individual team's data.** During the ten minutes in which the cooker container prototypes are in the solar oven, have the students fill out information about their initial prototype (i.e., Cost, Initial Temperature, Additional Characteristics) either on *10.b. Test Results* or directly in their engineering notebooks. NOTE: Additional features could include how the cooker container was designed to be structurally sound, reusable, or a very small container that is just big enough to hold an agar fish.

11. **(Optional) Begin filling out the data table poster.** If there is still time, have a volunteer from each student team come up to the poster size data table and fill in their Team Name, Cost, Initial Temperature (°C), and Additional Features. This may be done with markers directly onto the table, or students could fill out sticky notes with each piece of information and place it on the data table. Information for the control agar fish should also be included in the data table.

12. **End the test.** After 10 minutes have passed, carefully remove the lamps from the solar oven and allow students to retrieve their cooker container prototypes.

13. **Measure the final temperature.** Have students remove the agar fish from their cooker container prototype and measure the temperature of the fish, preferably using the same hole as they used to measure the initial temperature. The control fish's temperature should also be measured.
   NOTE: This measurement is time sensitive, since the agar fish will begin to cool off once they are removed from the solar oven. The faster the students can remove their cooker container from the solar oven, remove the fish from the cooker container, and measure the temperature, the better their temperature reading will be.

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14. **Record and calculate data.** Have students fill out the remainder of "My team's results" on *10.b. Test Results* or directly in their engineering notebooks. They should record their Final Temperature and then calculate and record the Temperature Increase.

15. **Share data.** When teams finish recording their own data, have a volunteer from each team come up to the class data table poster and record their data. (A volunteer student team or the teacher should also record the control fish's data.) As class data get written on the data table poster, have students copy them into their own records on either the *10.b. Test Results* worksheet or directly into their engineering notebooks.

16. **Share prototypes.** Have the students share their cooker container prototypes with their classmates. They should describe the prototype and point out their prototype's data in the Whole Class Results data table (from *10.b. Test Results* worksheet). Also, they should describe one thing that worked well in their design and the reasons for why they think it happened. NOTE: This can be done in a couple of ways. One team member could be assigned to stay with the prototype to describe it to classmates and answer questions, while the other team members walk around looking at others' prototypes. Or, a volunteer from each team (or the whole team) could present the prototype and description to the whole class, with each team presenting in turn. An alternative could also be used. It may help to emphasize that the purpose of these comparisons is to help all teams think about how they can learn from each other and improve their own cooker container prototype design. It is not a competition, but rather a learning experience.

17. **Discuss data**. Pass out *10.c. Think About Results* or have students write the answers to the prompts in their engineering notebooks next to the number of that prompt. Tell students to look at data in the "Whole Class Results", either on the poster, on the *10.b. Test Results* worksheet, or in their engineering notebooks. Then, either in their teams or as a whole class, have them discuss and record answers to the first two prompts:
    - Which cooker container prototypes had the largest temperature increase?
    - Describe why these cooker containers had a larger temperature change.

18. **Think about results individually.** Give students time to reflect on their testing results and the next four questions of *10.c.* individually. They should write their answers to questions 3-6 in the "My response" section.

19. **Think about results as a team.** Have students meet in their teams and discuss their answers. When the team has decided upon a response, have them record this in the "Team response" section using a different writing utensil.

Closure

20. **Introduce decide about a solution. Say:** *We have finished testing and comparing your initial designs for the cooker container prototype. Now,*

each team needs to decide how successful their prototype is. How well does it meet the criteria and constraints of the problem?

21. **(Optional) Refine criteria and constraints.** After the class has discussed all of the results of the prototypes, they may want to add or refine criteria and constraints. For example, the criterion of "as cheap as possible" may be refined to define cheap as no more than a specific dollar amount.

22. **Individually decide about a solution.** Have students first individually think about and record answers to questions 7-8 in the "My response" space in *10.c. Think About Results* or directly into their engineering notebooks.

23. **Team decide about a solution.** Have students share their answers to these questions with their team. They should then discuss and record their answers using a different writing utensil under the "Team response" space.

24. **Clean up.** Have students put away their cooker container prototypes. If a team's agar fish is still intact, they may keep their fish for testing of the redesigned prototype. If it is falling apart, have the student team dispose of it. Because the agar is plain, it can be put directly into a trash can.

Testing and Deciding about First Prototype

10.a. Teacher Observation Protocol: Test

Team #	All team members are on-task to test solution.	One or more team members are not on-task.	Team has made appropriate progress on testing and analysis.	Team is struggling to test or analyze their solution.	Team has identified how to improve solution.	Team is struggling to consider improved performance.	Notes

Optional Question Prompts:

NOTE: These questions can be used to further draw out and scaffold students' evidence-based reasoning. While the main purpose of these questions is to assess students' reasoning, it is also appropriate to interact with students/question for the purpose to support learning.

1. What did you find out from testing?
2. How did you interpret the findings from your tests? What do you think the results mean?
3. How did you decide what could improve your solution's performance?

LESSON 10

Name_____ Date_____ Period _____

10.b. Test Results

My team's results:

Cost ($)	Initial Temp. (°C)	Final Temp. (°C)	Temp. Increase (°C)	Additional Characteristics of Our Design

Whole class results:

Team Name	Cost ($)	Initial Temp. (°C)	Final Temp. (°C)	Temp. Increase (°C)	Additional Characteristics

LESSON 10

Name_____ Date_____ Period _____

10.c. Think about Results

Thinking about the Whole Class's Results:

1. Which cooker container prototypes had the largest temperature increase?

2. Describe why these cooker containers had a larger temperature change.

Reflect on the Results of Your Team's Prototype

3. What are the results of your test(s)? (Summarize the results).

4. What have you learned about the performance of your solution from the test results? Explain both the things that worked and did not work.
   My response:

   Team response:

5. What changes will you make to improve your solution based on the results of the test?
   My response:

   Team response:

Name_____ Date_____ Period _____

10.c. Think about Results

6. Why will you make those changes? Think about the results of the test and the science and mathematics you have learned.
   My response:

   Team response:

Reflecting on Your Team's Prototype:

7. In what ways does your solution meet the criteria and constraints of the problem?

My response:

Team response:

8. In what ways does your solution not yet meet the criteria and constraints of the problem?

My response:

Team response:

LESSON 10

Student Name_____ Date_____ Period _____

10.d. Think About Results Rubric

Problem	Question	Learning Objectives	Rubric	
10.c.3	What were the results of your test(s)?	Analyze test results.	yes no	**Listed specific results of tests**
10.c.4-6	4. What have you learned about the performance of your solution from the test results? Explain both the things that worked and did not work. 5. What changes will you make to your solution based on the results of the test? 6. Why will you make those changes? Think about the results of the test and the mathematics and science you have learned.	Analyze test results. Apply evidence gathered through test analysis to improve the performance of chosen solution. Apply evidence gathered from testing to choose solution. Apply mathematics/science concepts to inform redesign.	yes no	**Explained advantages of solution found in tests**
			yes no	**Explained drawbacks of solution found in tests**
			yes no	**Listed planned improvements**
			yes no	**Explained rationale for improvements based on test results**
			yes no	**Explained rationale for improvements based on correct understanding of mathematics/ science**
10.c.7	In what ways does your solution meet criteria and constraints of the problem?	Evaluate the alignment between their proposed solution and the problem.	yes no	**Compared their solution to specified criteria and constraints**
10.c.8	In what ways does your solution not yet meet the criteria and constraints of the problem?	Evaluate the alignment between their proposed solution and the problem.	yes no	**Contrasted their solution to specified criteria and constraints**

Notes:

LESSON 11 Redesigning a Second Prototype

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.
- implement a design and create a prototype cooker container.
- test the performance of the improved solution.
- compare their second design's performance with the performance of their first design.
- evaluate the alignment between their proposed solution and the problem.

Time Required

Two-three 50-minute class periods

Materials

Per classroom:

- 1 *Engineering Design Process* poster
- solar oven built in lesson 6

Per team:

- materials available for design: 2-3 pieces of aluminum foil ~6"x6", 2-3 pieces of 16 gauge copper wire (12"), 6-8 steel washers (suggested size: 7/8" OD x 3/8" ID), 10 jumbo paper clips, 4-5 pipe cleaners, 2-3 pieces of white construction paper ~4.5"x6", 2-3 pieces of black construction paper ~4.5"x6", 2-3 pieces of black felt ~6"x5", 2-3 pieces of white felt ~6"x5", 2-3 pieces of transparency ~4.25"x5.5", 8-10 craft sticks, masking tape
- 1 pair of scissors
- 1 ruler
- 1 digital thermometer
- 1 agar fish

Per student:

- 2 different writing utensils
- 1 engineering notebook
- 1 *EDP* slider

Lesson Summary

Based on the discussion and analysis of the initial design test results, students work to improve their cooker container. Student teams redesign and rebuild prototype cooker containers. They then retest and reevaluate their second design. Students compare and contrast their results with the results of their initial design. By evaluating both designs, student teams decide which design to suggest to the client as the better solution to the engineering problem.

Background

Teacher Background

Learning from failure: One of the most important aspects of engineering is learning from failure. Engineers often purposefully test models and prototypes until failure in order to better understand the limits of their designs. The engineers then use what they learned from this failure to redesign. Thus, in the engineering design process, it is important to continue beyond the first design cycle.

Redesign: After analyzing and evaluating their first prototype, students will begin to identify potential problems in the design, construction, organization, or cost of the original. At this point, some students will want to leap into a new design, others will insist on the success of their first prototype, while others may want to give up. The teacher can be a key factor in encouraging and guiding students through this transitional time. Because some students may be overly eager and want to skip the plan step of redesign, remind them of the importance of thinking through a design and creating written plans. For teams who are satisfied with their initial design's performance, encourage them to create a design that improves performance. For all teams, especially those who may want to give up, remind them that failing and then redesign is a key part of engineering and what professional engineers do. This is the stage in which students' understanding and skills are deepened and strengthened as they struggle with challenges and decisions. Learning from failure is not just an important skill for engineering, but it is also an important life skill. For redesign, encourage student teams that did not meet the main criteria to focus on meeting those criteria in their redesign. For teams that did meet the main criteria, encourage them to improve their design. Additionally, teams can think about other features that came up during defining the problem or testing the solution.

For redesign, students have two options. The first is to continue to work on their initial design, changing it or adding to it. The second option is to scrap the initial design and start over. The students can choose which option they prefer, or the teacher can assign options. For either option:

- Students can use this opportunity to return unused materials from the initial design if they are not planning on using them for the redesign.
- Students can use scraps of previous materials and/or purchase new ones.

Either way, the materials cost list should include only those materials that sudents actually used for the second cooker container prototype.
Ideally, students would be able to redesign through several cycles. If time permits, students can continue this design/test/redesign process. However, because of the time constraint of the classroom, students will most likely get

Redesigning a Second Prototype

through one redesign in two to three class periods. If a team finishes the redesign cycle (plan, try, test, decide) much earlier than other teams, you may choose to let them redesign a third prototype. Another option would be to encourage that student team to start working on their letter to the client explaining and justifying their design.

In terms of management of this lesson, there are two choices: allow each team to proceed at its own pace or keep all teams on approximately the same step at the same time. There will be less downtime for teams if they are allowed to move ahead when ready, but as a whole classroom it will be more chaotic because teams are doing different things. If all teams stay on the same step, the whole classroom will be more organized, but there is a possibility that some teams may be done early. If this happens, have teams start thinking about the letter to the client, or do any other activity that is deemed necessary for the unit. All other Teacher Background information from lessons 7-10 applies during redesign. (For example, it may be helpful to set up a Materials Distribution Center for when students want to purchase materials.) It is recommended to go back and look through those comments as well.

Before the Activity

If using the duplication masters, print and make copies of the following worksheets in the labeled amounts:

- *11.a. Redesign Plan* (1 per student)
- *11.b. Redesign Materials Cost List* (1 per student)
- *11.c. Redesign Test and Decide* (1 per student)
- *11.e. Teacher Observation Protocol: Redesign* (1 per 4 teams)

If students are writing question prompts directly into their engineering notebooks, it is still recommended to make copies in the specified amounts for *11.b* and *11.e.*

Prepare and organize the materials that students will need in order to create their prototype cooker containers.

- Some of the materials may need to be cut into appropriate sizes (i.e., ~6”x6” aluminum foil, 12” copper wire, ~4.5”x6” for both colors of construction paper, ~5”x6” for both colors of felt, ~4.25”x5.5” for transparency sheet). It is recommended to have 2-3 of each of these materials pre-cut and available for each team to purchase. (Teams will likely not use all of the pre-cut materials, but it is useful to have enough ready in case a material type is especially preferred.)
- Have packages of the other materials (i.e., steel washers, jumbo paper clips, pipe cleaners, craft sticks) ready.
- Masking tape may be pre-cut into 6-inch strips, or cut as teams need it. It is up to the teacher and the space constraints of the classroom.

Set up the solar oven testing station. If it needs to be reassembled, the instructions for preparing the solar oven are in the Lesson 6 educator resource *6.b. Making the Solar Oven*. The heating pad will need to be turned on 10-15 minutes before the test begins in order for it to stabilize. Keep in mind that the heat lamps become hot quickly; the teacher and students need

Standards Addressed

Next Generation Science Standards: MS-PS1-4, MS-PS3-3, MS-PS3-4, MS-PS3-5, MS-PS4-2, MS-ETS1-1, MS-ETS1-2, MS-ETS1-3, MS-ETS1-4

Key Terms

redesign, prototype, evidence-based reasoning, criteria, constraints

Assessments

Pre-Activity Assessment
Check students’ ability to explain the engineering problem and identify where they are in the engineering design process using the EDP slider.

Activity Embedded Assessment
Check students’ understanding through their verbal and written responses during activities and discussions. Examine new prototypes and ask teams to explain... *Does their new design address the shortcomings of design 1? Will the construction of design 2 make the cooker container work better? Will the materials chosen improve performance of the cooler?*

Post-Activity Assessment
Check in with student teams as they evaluate the success of their two designs and decide which one to recommend to the client.

DUPLICATION MASTERS

- 11.a. Redesign Plan
- 11.b. Redesign Materials Cost List
- 11.c. Redesign Test and Decide

EDUCATOR RESOURCES

- 11.d. Redesign Test and Decide Rubric
- 11.e. Teacher Observation Protocol: Redesign

to be especially careful in removing the cooker container prototypes from the solar oven after the lamps have been on for ten minutes.

The agar fish will be needed for this testing lesson. If they have survived thus far after being handled by the students for several lessons, the fish created for Lesson 6 and used for testing in Lesson 10 could be used here. However, if the fish have broken apart since then, create new ones via directions in *6.a. Making Agar Fish.*

Classroom Instruction

Introduction

1. **Tie to the engineering challenge.** 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.** Draw students' attention to the *Engineering Design Process* poster and their *Engineering Design Process* sliders. **Ask:** *What did you all do in the previous class?* (Decide.) **Say:** *Now, we will be doing redesign, so we will need to go through solution generation (plan, try, test, and decide) again to create a second, better prototype.*

3. **Discuss the importance of redesign. Ask:** *Why do you think it is important for engineers to learn from their failures and try again?* (Take student answers.) Guide discussion so students' realize that learning from failure is incredibly important to engineering because it allows them to test the limits of their design solutions and then make improvements. If the design solution doesn't meet the client's criteria, then they need to improve it, and even if the design does meet the criteria, they may still want to make it even better for their client.

Activity

4. **Assess student progress.** This will occur throughout the whole lesson, but it is mentioned here at the beginning since it does not clearly fall before or after a specific step. As students are redesigning, walk around and assess student progress with the *11.e. Teacher Observation Protocol: Redesign*.

5. **Introduce the second design process.** Pass out one *11.a. Redesign Plan* sheet (or post for them to see) and one *11.b. Redesign Materials Cost List* to each student. Point out that students can now not only justify their second prototype design with data from the science and mathematics lessons, but also data from their initial design testing. **Say:** *Now that we have tested out initial cooker container designs, we have evidence from those tests in addition to the evidence we had before*.

6. **Introduce the materials cost constraint.** Inform students that they have an option to either keep their initial design and change it or scrap their initial design and start over. Either way, the second cooker container design materials' total cost should still try to be as low as possible.

7. **Plan the redesign.** Allow student teams time to discuss and fill out the *11.a. Redesign Plan* sheet and *11.b. Redesign Materials Cost List* with their new plan; this information can also be recorded in their engineering notebooks. While student teams are planning, circulate and check on their new designs. Ask teams to explain how their new design addresses the problems of design one, how the construction may improve the performance, what materials they chose to improve the performance of the cooker container, and how they lowered the cost. When a team has adequately filled out the *11.a. Redesign Plan* sheet and *11.b. Redesign Materials Cost List* for their new design, they may move on to try/build. (Even if teams are using their previous prototype and adding/changing it, they should make a new *11.b. Redesign Materials Cost List* that reflects the prices of the original materials plus any additional materials they purchase for the redesign.) NOTE: For more information about planning and evidence-based reasoning, see Lessons 7 and 8.

8. **Try/Build the redesign.** Distribute supplies to teams at request. As before, once teams have filled out their *11.b. Redesign Materials Cost List,* those are the materials they get. They need to make sure their plan is well thought out so they have all the materials they need since they can't go back and get more as they need them (with the exception of masking tape.) Circulate among the teams as they build their second cooker container prototypes. Continue to ask them questions about the design, why they made the changes they did, and why they think it will improve in performance. NOTE: For more information about trying/building, see Lesson 9.

9. **Test the redesign.** Pass out the *11.c. Redesign Test and Decide* worksheet, or the data collected during and after testing can be written directly into students' engineering notebooks. When teams are ready, each will measure the initial temperature of the agar fish, place it in their second cooker container prototype, place the prototype in the solar oven, remove the prototype after ten minutes, and measure the final temperature of the agar fish. (The initial and final temperature of a control agar fish should also be measured.) They then record the Cost, Initial temperature, Final temperature, Temperature change, and Additional characteristics in *11.c. Redesign Test and Decide* or directly into their engineering notebooks. NOTE: For more information about testing, see Lesson 10.

Closure

10. **Decide about the redesign. Say:** *Instead of comparing your second prototype to other teams' prototypes, now you will compare your second cooker container prototype to your first cooker container prototype.* Have students compare the results of the two prototype designs and consider the questions 1-3 on the *11.c. Redesign Test and Decide* worksheet or in their engineering notebooks.
NOTE: While students are evaluating their designs, circulate the room. Answer questions and encourage students to support their answers with data and explanations. In more complex engineering projects, it is

common to choose parts of designs that performed best and combine them into an optimal design. For this level of complexity, it will probably be easier and better for students to just pick one of their designs as the better design rather than trying to combine parts of their designs.

11. **(Optional) Share recommendation to client.** Have each student team briefly share with the class which of their resource extraction tool prototypes they think the client will like better and why. Encourage them to include aspects of *Evidence-Based Reasoning:* what their solution is, data/evidence to support it, and justifications connecting the data/evidence to their proposed solution. If time allows, let students ask each other questions about their designs and why they made their choices about which one was better.

Redesigning a Second Prototype

LESSON 11

LESSON 11

Name_____ Date_____ Period _____

11.a. Redesign Plan

Redesign Idea (includes features, dimensions, materials used)	Justification
Bottom view of the cooker container	
Top view of the cooker container	
Side view of the cooker container	

LESSON 11

Name_____ Date_____ Period _____

11.b. Redesign Materials Cost List

	Price for One Item	Quantity Needed	Total Cost for Item
1 piece of aluminum foil, 6”x6”	$1.50		
1 piece of copper wire, 12” long	$2.00		
1 steel washer	$0.75		
1 jumbo paper clip	$0.50		
1 pipe cleaner, 12” long	$1.00		
1 piece of white construction paper, 4.5”x6”	$1.00		
1 piece of black construction paper, 4.5”x6”	$1.00		
1 piece of black felt, 5”x6”	$2.00		
1 piece of white felt, 5”x6”	$2.00		
1 craft stick	$0.25		
6” piece of masking tape	$0.25		
1 piece of transparency sheet, 4.25”x5.5”	$1.50		
		Total Materials Cost:	

LESSON 11

Name_____ Date_____ Period _____

11.c. Redesign Test and Decide

Team results from testing: Cost $_____

Initial temp. _____°C Final temp. _____°C Temperature Increase _____°C

Additional Characteristics of our second design:

Decide about a redesign:

1. What are the results of your tests?
My response:

Team response:

2. Did your redesign improve your solution? Why or why not?
My response:

Team response:

3. If you could do another redesign, how would you try to improve your solution?
My response:

Team response:

LESSON 11

Student Name_____ Date_____ Period _____

11.d. Redesign Test and Decide Rubric

Problem	Question	Learning Objectives	Rubric	
11.c.1	What were the results of your test(s)?	Test improved solution and reflect on test results.	yes no	**Listed specific results of tests**
11.c.2	Did your redesign improve your solution? Why or why not?	Test improved solution and reflect on test results.	yes no	**Answered question and provided reasons for improvement or no improvement.**
11.c.3	If you could do another redesign, how would you try to improve your solution?	Test improved solution and reflect on test results.	yes no	**Listed planned improvements**
Notes:				

11.e. Teacher Observation Protocol: Redesign

Team #	All team members are on-task to retest their solution.	One or more team members are not on-task.	Team has attempted to improve the performance of their solution.	Unclear what has been done to improve their solution.	Notes

Optional Question Prompts:

NOTE: These questions can be used to further draw out and scaffold students' evidence-based reasoning. While the main purpose of these questions is to assess students' reasoning, it is also appropriate to interact with students/question for the purpose to support learning.

1. Can you tell me about how you are working to improve your solution?
2. What were some of the other solution improvement ideas you generated?
3. How did you decide to move forward with this idea? What evidence do you have that your improved design will solve the problem for the client?

LESSON 12 Communicating with the Client

Lesson Objectives
Students will be able to:
- evaluate the alignment between their proposed solution and the problem.
- communicate their design solution through the use of 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
One 50-minute class period

Materials
Per classroom:
- 1 *Engineering Design Process* poster
- 1 poster size sticky note paper with Evidence-Based Reasoning template

Per team:
- If students are creating a poster, each team will need:
  - 1 poster size sheet of paper
  - markers

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

Standards Addressed
Next Generation Science Standards: MS-PS1-4, MS-PS3-3, MS-PS3-4, MS-PS3-5, MS-PS4-2, MS-ETS1-1, MS-ETS1-2, MS-ETS1-3, MS-ETS1-4

Key Terms
client, evidence-based reasoning, criteria, constraints

Lesson Summary
Students write a letter or create a poster for the client, The Pescadores Foundation, about their design. The letter or poster explains the chosen design solution with text and drawings and justifies it with evidence and explanations.

Background
Teacher Background
While students should be using evidence-based reasoning while writing their letters to or posters for the client, they do not necessarily have to fill out an Evidence-Based Reasoning sheet. It may be helpful to have copies of this sheet available if students want to use the template to write their ideas in before they write the letter or create the poster; students could also copy the template into their engineering notebooks. Additionally, have the Evidence-Based Reasoning explanations poster from lesson 8 posted to remind students what kinds of information they need to include (i.e., solution, evidence, explanation) in their letter to or poster for the client.

The communications to the client may take the form of letters or posters, depending on what works best for your classroom. Additionally, students may do the creation of this communication individually or in design teams.

Rubrics for evaluating and grading this communication are not included in this unit. You can create your own if you wish.

Before the Activity
If using the duplication masters, print and make copies of the following worksheets in the labeled amounts:
- *12.a. Reflect About Engineering Design* (1 per student)
- (optional) *8.a. Evidence-Based Reasoning* (extra copies)

(Optional) If there is a specific format/template for writing letters or creating posters that students need to learn and use, create this template on one sheet of poster size sticky note paper before the lesson starts. Students could then refer to this when considering the format of the letter or poster.

Classroom Instruction
Introduction
1. **Tie to the engineering challenge. 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 in order to improve their solutions. Remind students of the Communication and Teamwork piece that has arrows pointing to every step of the engineering design process. **Say:** *Throughout the entire engineering design process, we have*

Communicating with the Client

been working in teams and communicating within your teams and with other teams. Now you need to communicate to the client, The Pescadores Foundation, so that they know about your design and why it meets their needs.

Activity

3. **Review the client letter.** Have students review *1.b. Client Letter* that they received in lesson 1. Emphasize the last paragraph of the letter. **Say/Ask:** *In the letter we received from The Pescadores Foundation, 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* explanation poster to review what it means to justify a design with evidence. Instruct students to use these pieces (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 or poster.** Allow students plenty of time to write their letters or create their posters. 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 of the information from the problem scoping, science lessons and labs, and engineering design results.

Closure

6. **(Optional) Share letters/posters to client.** If time allows, 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 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.

7. **Reflect on the engineering design process.** Pass out *12.a. Reflect About Engineering Design* or have students answer these 2 questions in their engineering notebooks, both individually and in their team.

Assessments

Pre-Activity Assessment
Check students' ability to explain the engineering problem and identify where they are in the engineering design process. Students should be able to move the paper clip on their sliders to the appropriate step.

Activity Embedded Assessment
Check students' progressive understanding through written responses letter writing or poster creation activity. If students are struggling with the science concepts or with using evidence-based reasoning to justify their design solutions with evidence, assist them. The focus of the letters/posters in this unit is that students justify their solutions with evidence and explanations. However, you may choose to assess other aspects of the letter/poster (e.g., proper letter writing format, spelling, grammar).

Post-Activity Assessment
Check students' written reflections of the entire unit: how their thinking about the problem and how to design a solution has changed during the design process, as well as how they think engineers solve problems.

DUPLICATION MASTERS

- 12.a. Reflect About Engineering Design
- (optional) 8.a. Evidence-Based Reasoning

EDUCATOR RESOURCES

- 12.b. Reflect About Engineering Design Rubric

LESSON 12

Name_____ Date_____ Period _____

12.a. Reflect About Engineering Design

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 <u>understanding of the problem</u> 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 <u>understanding of how to design a solution</u> 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:

LESSON 12

Student Name_____ Date_____ Period _____

12.b. Reflect About Engineering Design Rubric

Problem	Question	Learning Objectives	Rubric	
12.a.1	How has your <u>understanding of the problem</u> 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 no	**Explained how their understanding of the problem has changed**
			yes no	**Included at least 1 of client needs, criteria/ constraints, and science/mathematics in their explanation**
12.a.2	How has your <u>understanding of how to design a solution</u> 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 no	**Explained how their understanding of the how to design a solution has changed**
			yes no	**Included at least 1 example from their experience or how they made decisions in their explanation**
Notes:				

Notebook Prompts and Titles

Teacher Directions:

If you prefer to have students write the answers to prompts right in their notebooks (rather than on the handouts and then adhere them to the notebooks), you should have the students put the bold title for each prompt and then answer the question that follows. The format for each will be as follows:

Prompt title:
Question to answer

Have students answer each set of questions as they appear in the curriculum. If any questions are included in the curriculum, but not included here, you may determine the title for the prompt.

Problem Scoping Lessons - Define and Learn

Section 1:

Engineers:
What do engineers do?

Solve Problems:
How do engineers solve problems?

Section 2:

Questions for client:
What are at least 3 questions that you want to ask the client that will help you understand the problem better? Make sure to ask about all important aspects of the problem.

Section 3:

Client:
Who is the client?

Problem:

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.

End-users:
Who are the end-users?

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

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

What we need to learn:
Think about the problem of cooking fish in a solar oven. In terms of being able to properly cook a fish using a cooker container in a solar oven, what are at least 2 things you need to learn in order to design a successful cooker container prototype?

Notebook Prompts and Titles

Generate Ideas/Plan Lessons

Section 1:

EBR Graphics can just be drawn in notebooks.

Section 2:

Have students answer the following after EBR graphics are complete.

Pros and Cons:
What are the pros and cons of each of your own solution ideas?

Why we chose our solution:
Which solution did your team choose and why? Provide evidence for your reason.

Test Solution Idea(s) Lessons

Section 1:

Ask students to complete after they have run their tests.

Test results:
What were the results of your test(s)?

Learned from test results:
What have you learned about the performance of your solution from your test results? Explain both the things that worked and did not work.

Changes from test results:
What changes will you make to your solution based on the results of your tests?

Reason for changes:
Why will you make those changes? Think about the results of your test and the science and mathematics you have learned.

Section 2:

Section 2 questions should come after the students have run their tests and have had an opportunity to answer Section 1 questions.

How solution meets criteria and constraints:
In what ways does your solution meet the criteria and constraints of the problem?

How solution does not yet meet criteria and constraints:
In what ways does your solution not yet meet the criteria and constraints of the problem?

Notebook Prompts and Titles

Redesign Lessons

Ask students to complete after they have run their redesign tests.

Test results:
What were the results of your test(s)?

Improvement?:
Did your redesign improve your solution? Why or why not?

Next ideas for improvement:
If you could do another redesign, how would you try to improve your solution?

Final Solution Lessons

Section 1:

Students use evidence-based reasoning in reporting their final solution to the client. This can happen through use of the EBR graphic as part of their memo or presentation, or you can have the students include the aspects of the EBR graphic (without the graphic itself) in the memo or the presentation.

Section 2:

These questions should be completed after presenting the solution to the client and the entire design challenge is complete.

Understanding of the problem:
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.

Understanding of designing a solution:
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.

