EngrTEAMS

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

# Chill Out: Vaccines and Heat Transfer

## Grades 4-5

University of Minnesota
STEM Education Center
NSF
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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 Minnesota State Academic Science Standards, as well as data analysis and measurement standards for grades 4-8.

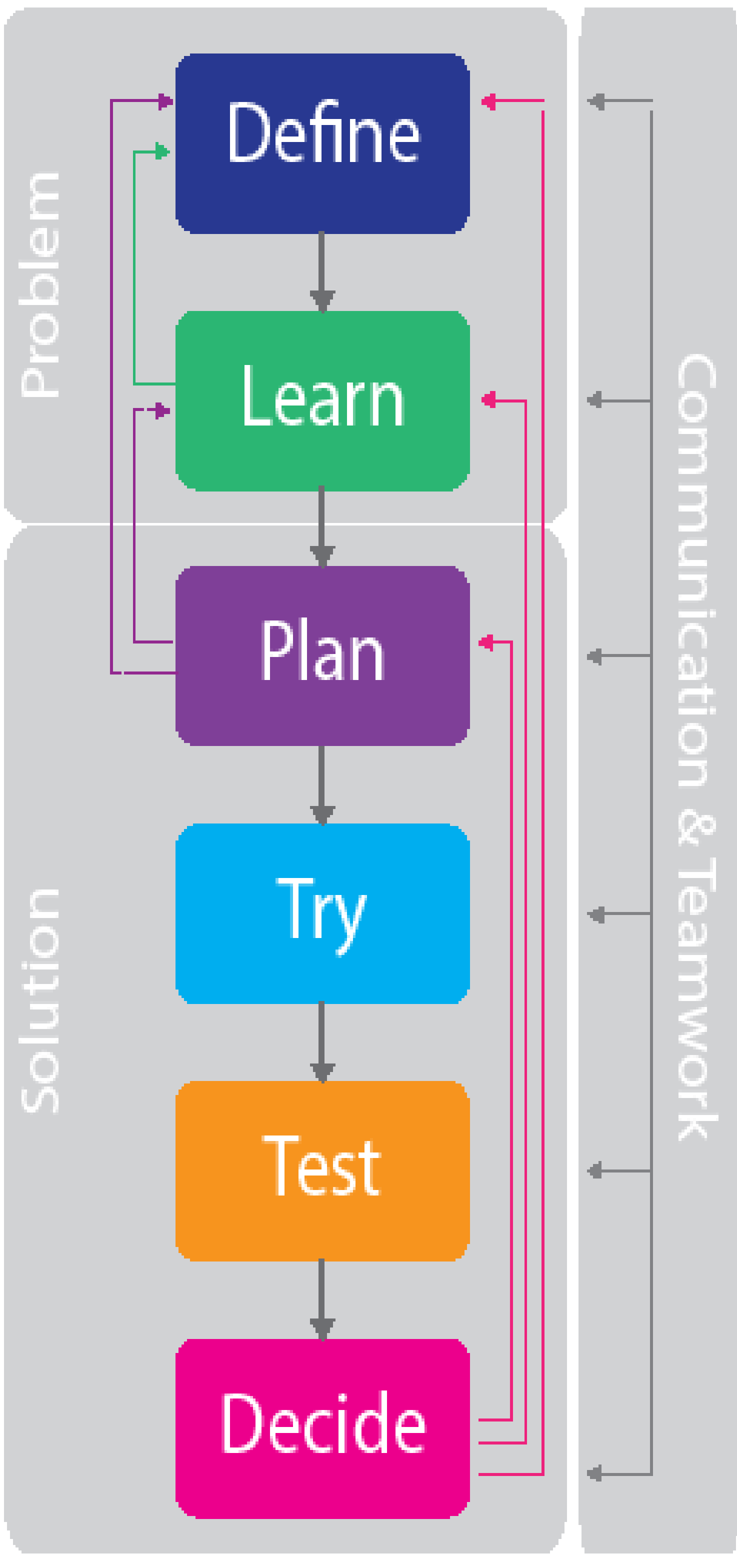
With a focus on vertical alignment and transition from upper elementary to middle-level, this project will impact at least 15,000 students over the life of the grant.

To learn more about the project and find additional curricular units go to www.engrteams.org.

# Overview

**Engineering Design Process**

A way to improve



## DEFINE THE PROBLEM

- Who is the client? What does the client need? Why does she or he need it? Who are the end-users?
- Why is the problem important to solve? What are the criteria (requirements) of the solution? What are the constraints (limits)?
- Problem Scoping: WHO needs WHAT because WHY

## LEARN ABOUT THE PROBLEM

- What kind of background knowledge is needed to solve the problem? What science/mathematics 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 improvement?

## PLAN A SOLUTION

- Continue to specify the criteria and constraints
- Idea generation
- Develop multiple possible solution paths
- Consider trade-offs and relative constraints
- Choose a solution to try
- Develop plans (blueprints, schematics, cost sheets, storyboards, notebook pages)

## TRY A SOLUTION

- Put the plan into action
- Consider risk and how to optimize work
- Use criteria, constraints, and trade-offs from 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 know if the solution is meeting the stated criteria, constraints, and needs
- Collect and analyze data

## DECIDE WHETHER SOLUTION IS GOOD ENOUGH

- Are users able to use the design to help with the problem?
- Does your design meet the criteria and stay within the constraints?
- How could your design be improved based on your test results and feedback from client/user?
- Iterative nature of design: Consider always which step should be next!

## COMMUNICATION & TEAMWORK

- Good oral and written communication and teamwork are needed throughout the entire design process.
- The client should be able to create/follow the solution without ever speaking to you. Include claims and use evidence to support what you believe is true about your solution so that the client knows why they should use it.

# Overview

**Grade Levels:** 4-5

**Approximate Time Needed to Complete Unit:** Ten 45-minute class periods

## Unit Summary

The True Chill Company is working on helping countries that have unreliable access to power keep vaccines cool in warm climates. The students will design a device for the True Chill Company that will keep vaccines cool without being plugged into a power source. Students learn about vaccines and their role in disease prevention. Before designing solutions, students learn about the science of heat energy and heat transfer, conductors, and insulators. Students then plan (design), try (build), test, and decide about (evaluate) a solution to the problem twice, once as an initial design and once in redesign. Finally, student teams write letters to their client describing their vaccine cooler solutions and justifying them with evidence.

| Science Connections | Technology & Engineering Connections | Mathematics Connections |
|---|---|---|
| vaccines, heat energy and heat transfer, conductors, insulators | 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 | interpret line graphs, use data tables, measure temperature, perform operations with decimals in real world problems |

## Unit Standards

**Next Generation Science Standards**

- 4-PS3-2 Make observations to provide evidence that energy can be transferred from place to place by sound, light, heat, and electric currents.
- *MS-PS3-3 Apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer.
- *While this standard is a middle school standard in NGSS, it addresses two of the key points of this unit: that heat energy transfers from regions of hot to cold, and that heat transfer concepts can be used to design a device that minimizes heat transfer. While this unit does not fully cover the disciplinary core ideas of this standard, it covers enough that it is included in this unit.
- 3-5-ETS1-1 Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.
- 3-5-ETS1-2 Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.
- 3-5-ETS1-3 Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.

# Overview

**Common Core State Standards - Mathematics**

- 4.NBT.A.2 Read and write multi-digit whole numbers using base-ten numerals, number names, and expanded form. Compare two multi-digit numbers based on meanings of the digits in each place, using >, =, and < symbols to record the results of comparisons.
- 4.NF.C.7 Compare two decimals to hundredths by reasoning about their size. Recognize that comparison are valid only when the two decimals refer to the same whole. Record the results of comparisons with the symbols >, =, or < and justify the conclusions, e.g., by using a visual model.
- 4.MD.A.2 Use the four operations to solve word problems involving distances, intervals of time, liquid volumes, masses of objects, and money, including problems involving simple fractions or decimals, and problems that require expressing measurements given in a larger unit in terms of a smaller unit. Represent measurement quantities using diagrams such as number line diagrams that feature a measurement scale.

## Unit Assessment Summary

- Throughout this unit, each student will maintain an Engineering Notebook to document their engineering design processes. In this, students will make observations, collect data, and plan for their vaccine cooler. Part of the Engineering Notebook will include answering specific questions related to that day's activities. You may choose to post the questions in your overhead/PowerPoint slides, or give the students printed versions to tape into their Notebooks. Students will also use their Notebooks as a reference – a place to maintain the information they are learning through design. Additionally, students will 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 and their design process. Read the Notebooks and provide feedback to students. You are encouraged to assign points for responses in the engineering notebooks.
- 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 write a letter or create a presentation for the client recommending a vaccine cooler design and justifying its success as a solution to the engineering problem.

# Overview

## Lesson Summaries

### Lesson 1: Vaccines and Context of the Problem

Students learn that vaccines are weak or dead germs that help teach the body how to find and fight a disease and that vaccines should be given before a person gets sick with a disease. They then interpret a line graph of the reported cases of pertussis globally from 1980 to the present, identifying the major trend in the data and connecting that trend to the spread of vaccines throughout the world. Finally, students are introduced to the context of the engineering design problem, which is that they will need to design a way to keep vaccines cool in places with limited electrical power.

### Lesson 2: Define the Engineering Problem

Students learn about the organized system of problem-solving steps called the engineering design process. They then learn the specifics of their engineering problem, which is to design a cooler that will keep vaccines from spoiling even when power sources are unreliable, by reading a letter from the client and asking the client additional questions. Based on this information, students define the engineering problem, which includes identifying the problem and why it's important, client, end users, criteria, constraints, and what else they need to learn before they begin designing solutions.

### Lesson 3: Heat and Conductors

Students will first review the engineering problem, which is to design a device that will keep vaccines cool without electric power, and identify that they are in the Learn (about the problem) step of the engineering design process. Students will learn that heat is a form of energy that always flows from warmer to colder. They will observe and explore how different materials affect the movement of heat with a specific focus on conductors.

### Lesson 4: Heat and Insulators

Lab teams will use digital thermometers to measure the temperature of water inside differently-wrapped 4 oz. glass jars. They will analyze these measurements to determine the change in temperature from the beginning of the activity to the end, which will indicate the effectiveness of the variety of materials used to insulate the jars. They learn that heat moves slower through some materials than others, and that these materials are called insulators.

### Lesson 5: Plan a Solution

Students will review what information they have learned about the engineering problem and use it to begin solution generation. They will use a list of materials and their cost, as well as what they have learned about vaccines, heat, conductors, and insulators, to design a model vaccine cooler that will cost $5.00 or less. Students will first generate multiple possible design solutions individually; then, in their teams, they will use the ideas generated individually to determine one design solution that will be implemented and tested. Students will use evidence-based reasoning to justify their proposed design solution.

# Overview

### Lesson 6: Try a Solution

Students will implement their planned design and create a prototype vaccine cooler. Before students can obtain materials, they will submit two items to the teacher for approval: an *Evidence-Based Reasoning* worksheet explaining the team's chosen design and a *Materials Cost Sheet* with materials chosen and cost amounts calculated. Once checked, the teacher will distribute materials and offer guidance to teams if they seem to have forgotten materials such as vials or scissors.

### Lesson 7: Test and Decide About a Solution

Students will test their vaccine cooler prototypes' performance by placing their coolers, each with two mini ice packs and a vial of ice water inside, under heat lamps for 10 minutes. They will measure the final temperature and calculate the temperature change. All student teams will share their design's cost, temperature change, and additional characteristics with the whole class. Students will analyze these data, determine why some designs worked better than others, and begin to think about redesigning.

### Lesson 8: Redesign

Based on the discussion and analysis of the initial design test results, students will work to improve their cooler. Students will redesign, rebuild, retest and reevaluate the performance of a model vaccine cooler. Students will compare and contrast their results with the results of their initial design and decide on which design to suggest to the client as the solution to the engineering problem.

### Lesson 9: Communicate to the Client

In this lesson, students will write a letter or create a poster to the client, Peyton Sadler of The True Chill Company, about their design. The letter or poster will need to explain the design with text and drawings and justify the design with evidence and explanations.

# Overview

| Lesson | Time Needed | **Objectives**<br>The students will be able to: |
|---|---|---|
| 1: Vaccines and Context of the Problem | One 45-minute class period | • Define vaccine.<br>• Identify that people receive vaccines before they get sick.<br>• Give an example of at least one disease that can be prevented by a vaccine.<br>• Analyze a line graph to identify trends in the data. |
| 2: Define the Engineering Problem | One 45-minute class period | • Describe important aspects of the engineering design process.<br>• Define an engineering problem from the perspective of stakeholders.<br>• Generate a description of the problem based on information.<br>• Engage in problem scoping (i.e., define the problem and needs, and then identify the knowledge, criteria, and constraints required for a desirable solution). |
| 3: Heat and Conductors | One 45-minute class period | • Explain that heat is a type of energy that moves from warm to cold.<br>• Identify conductors as materials that transfer heat more easily and quickly.<br>• Plan and conduct lab experiments.<br>• Analyze and explain the results of lab experiments. |
| 4: Heat and Insulators | One 45-minute class period | • Explain that heat is a kind of energy that always moves from warmer to colder.<br>• Measure the temperature of a liquid using a thermometer.<br>• Subtract decimals to calculate temperature changes.<br>• Analyze the results of an experiment.<br>• Identify insulators as materials that stop or slow the flow of heat. |

# Overview

| **Materials**<br>* required materials not included in the kit | **Duplication Masters** |
|---|---|
| • **Per classroom:** 1 old empty milk carton (not washed out), 1 blank pre-assembled Key Terms Cube, 3-4 pictures of rural, hot locations (e.g., Laos, Mexico, Somalia, parts of the US) with limited electrical power, digital technologies to display video<br>• **Per student:** 2 different colors or types of writing utensils, 1 engineering notebook | • **Per group:** (1) 1.a. Global Cases of Pertussis Graph<br>• **Per student:** (1) 1.b. Global Cases of Pertussis Graph Activity, (1) 1.c. Key Terms Cube, (1) 1.d. Vaccines Exit Slip<br><br>**EDUCATOR RESOURCES**<br>• 1.b. Global Cases of Pertussis Graph Activity<br>• 1.d. Vaccines Exit Slip |
| • **Per classroom:** 1 Engineering Design Process poster, 1 blank pre-assembled Key Terms Cube, 1 poster size sticky note paper labeled "Questions for Client", markers<br>• **Per student:** 2 different colors or types of writing utensils, 1 engineering notebook, 1 Engineering Design Process slider | • **Per student:** (1) 2.a.True Chill Client Letter, (1) 2.b.Define the Problem, (1) 1.c. Key Terms Cube (from Lesson 1)<br><br>**EDUCATOR RESOURCES**<br>• 2.b. Define the Problem |
| • **Per classroom:** 1 Engineering Design Process poster, 1 blank pre-assembled Key Terms Cube, 1 poster size sticky note paper, markers, 1 18" long piece of 18 gauge copper wire, 4 4oz. glass jars, 2 metal lids for glass jars, 1 butane lighter, 5 milk chocolate chips, 1 wood pencil, 3 ice cubes (same size), 1 small opaque plastic plate, 1 small piece of wood, 1 small metal loaf pan, (optional) digital technologies to display video<br>• **Per group:** 1 pocket heat warner, 1 aluminum foil 12"x12" (folded), 1 construction paper 9"x12" (folded), 1 wax paper 12"x12" (folded), 2 pieces foam board 5.5"x8.5" (stacked), 2 pieces felt 6"x6" (stacked), 1 bubble wrap 12"x12" (folded), 12 cotton squares (2 6-piece sheets, stacked), (optional) 1 stopwatch<br>• **Per student:** 2 different colors or types of writing utensils, 1 engineering notebook, 1 Engineering Design Process slider | • **Per student:** (1) 3.a. Heat and Conductors, (1) 1.c. Key Terms Cube (from Lesson 1)<br><br>**EDUCATOR RESOURCES**<br>• 3.a Heat and Conductors |
| • **Per classroom:** 1 Engineering Design Process poster, 1 blank pre-assembled Key Terms Cube, 1 poster size sticky note paper, markers, 1 stopwatch or clock, 2 pitchers of ice water, 1 large kitchen spoon, 8 glass jars (4 oz.) with metal lids, each wrapped in two layers of (nothing, construction paper, felt, bubble wrap, plastic craft foam, aluminum foil, cotton squares, wax paper), (optional) 1 analog thermometer, (optional) 2-3 mini ice packs, (optional) 2-3 empty vials<br>• **Per group:** 1 digital thermometer<br>• **Per student:** 2 different colors or types of writing utensils, 1 engineering notebook, 1 Engineering Design Process slider | • **Per student:** (1) 4.a. Insulator Lab, (1) 1.c. Key Terms Cube (from Lesson 1)<br><br>**EDUCATOR RESOURCES**<br>• 4.a. Insulator Lab |

# Overview

| Lesson | Time Needed | Objectives<br>The students will be able to: |
| --- | --- | --- |
| 5: Plan a Solution | One 45-minute class period | • Use evidence from problem scoping to generate multiple initial ideas for a design solution.<br>• Systematically evaluate various solutions based on the problem to narrow to one design solution.<br>• Justify why their proposed design solution is appropriate based on the application of core science (i.e., heat transfer, conductors, insulators)/mathematics concepts and information obtained in problem scoping.<br>• Add and multiply decimals to calculate the cost of the design, keeping the cost under $5.00. |
| 6: Try a Solution | One 45-minute class period | • Implement a design and create a prototype vaccine cooler.<br>• Add and multiply decimals to calculate the cost of the design, keeping the cost under $5.00. |
| 7: Test and Decide About a Solution | One 45-minute class period | • Test their vaccine cooler prototypes.<br>• Measure the temperature of a liquid, their “vaccine,” using a thermometer.<br>• Subtract decimals to calculate the change in temperature of their vaccine.<br>• Compare temperature and cost values with decimals to compare their design’s performance with the performance of their peers’ designs.<br>• Analyze the characteristics of the best performing vaccine coolers. |

# Overview

| **Materials**<br>* required materials not included in the kit | **Duplication Masters** |
|---|---|
| • **Per classroom:** 1 Engineering Design Process poster, 1 blank pre-assembled Key Terms Cube, 1 poster size sticky note paper with Evidence-Based Reasoning template on it, markers, 2 pitchers, ice water, 1 large kitchen spoon, 4 heat lamps with clamps, 4 40W light bulbs<br>• **Per group:** 2-3 aluminum foil 12”x12”, 2-3 construction paper 9”x12”, 2-3 wax paper 12”x12”, 2-3 foam board 5.5”x8.5”, 2-3 felt 6”x6”, 2-3 bubble wrap 12”x12”, 12-18 cotton squares 2”x2”, craft sticks, scotch tape, masking tape, rubber bands, 1 vial, 2 mini ice packs (frozen)<br>• **Per student:** 2 different colors or types of writing utensils, 1 engineering notebook, 1 Engineering Design Process slider | • **Per student:** (1) 5.a. Design Ideas - Individual Plan, (1) 5.b. Evidence-Based Reasoning, (1) 5.c. Materials Cost Sheet, (1) 1.c. Key Terms Cube (from Lesson 1)<br><br>**EDUCATOR RESOURCES**<br>• 5.b. Evidence-Based Reasoning - Poster with Explanation<br>• 5.b. Evidence-Based Reasoning - Chill Out Example |
| • **Per classroom:** 1 Engineering Design Process poster, (optional) 1 pre-assembled Key Terms Cube, (optional) 1 poster size sticky note paper with Evidence-Based Reasoning template on it, 2 pitchers, ice water, 1 large kitchen spoon, 4 heat lamps with clamps, 4 40W light bulbs<br>• **Per group:** 2-3 aluminum foil 12”x12”, 2-3 construction paper 9”x12”, 2-3 wax paper 12”x12”, 2-3 foam board 5.5”x8.5”, 2-3 felt 6”x6”, 2-3 bubble wrap 12”x12”, 12-18 cotton squares 2”x2”, craft sticks, scotch tape, masking tape, rubber bands, 1 vial, 2 mini ice packs (frozen), 1-2 scissors, 1-2 rulers<br>• **Per student:** 2 different colors or types of writing utensils, 1 engineering notebook, 1 Engineering Design Process slider | • **Per student:** (1) 5.b. Evidence-Based Reasoning (from Lesson 5), (1) 5.c. Materials Cost Sheet (from Lesson 5), (optional) (1) 1.c. Key Terms Cube (from Lesson 1)<br><br>**EDUCATOR RESOURCES**<br>• 6.a. Teacher Observation Protocol: Try Lesson |
| • **Per classroom:** 1 Engineering Design Process poster, (optional) 1 pre-assembled Key Terms Cube, 1 poster size sticky note paper, markers, 2 pitchers, ice water, 1 large kitchen spoon, 4 heat lamps with clamps, 4 40W light bulbs<br>• **Per group:** 1 vial, 2 mini ice packs (frozen), 1 digital thermometer, (optional) 1-2 scissors, (optional) scotch tape<br>• **Per student:** 2 different colors or types of writing utensils, 1 engineering notebook, 1 Engineering Design Process slider | • **Per student:** (1) 7.a. Test and Decide, (1) 5.b. Evidence-Based Reasoning (from Lesson 5), (1) 5.c. Materials Cost Sheet (from Lesson 5), (optional) (1) 1.c. Key Terms Cube (from Lesson 1)<br><br>**EDUCATOR RESOURCES**<br>• 7.b. Teacher Observation Protocol: Test Lesson |

# Overview

| Lesson | Time Needed | Objectives<br>The students will be able to: |
|---|---|---|
| 8: Redesign | Two 45-minute classes period | • Use evidence from problem scoping and initial design test analysis to plan an improved design.<br>• Perform operations with decimals to calculate cost and temperature change.<br>• Implement a design and create a prototype vaccine cooler.<br>• Measure the temperature of a liquid, their “vaccine,” using a thermometer.<br>• Test the performance of the improved solution.<br>• Compare temperature and cost values with decimals to compare their second design’s performance with the performance of their initial design.<br>• Evaluate the alignment between their proposed solution and the problem. |
| 9: Communicate to the Client | One 45-minute class period | • Evaluate the alignment between their proposed solution and the problem.<br>• Communicate their design solution through the use of evidence-based reasoning.<br>• Justify why their design solution is appropriate based on application of core science (i.e., heat transfer, conductors, insulators)/mathematics concepts, information obtained in problem scoping, and interpretation of acquired or gathered evidence. |

# Overview

| **Materials**<br>* required materials not included in the kit | **Duplication Masters** |
|---|---|
| • **Per classroom:** 1 Engineering Design Process poster, 1 poster size sticky note paper with Evidence-Based Reasoning template on it, markers, 2 pitchers, ice water, 1 large kitchen spoon, 4 heat lamps with clamps, 4 40W light bulbs<br>• **Per group:** 2-3 aluminum foil 12"x12", 2-3 construction paper 9"x12", 2-3 wax paper 12"x12", 2-3 foam board 5.5"x8.5", 2-3 felt 6"x6", 2-3 bubble wrap 12"x12", 12-18 cotton squares 2"x2", craft sticks, scotch tape, masking tape, rubber bands, 1 vial, 2 mini ice packs (frozen), 1-2 scissors, 1-2 rulers<br>• **Per student:** 2 different colors or types of writing utensils, 1 engineering notebook, 1 Engineering Design Process slider | • **Per team:** (1) 8.a. Evidence-Based Reasoning, (1) 8.b. Materials Cost Sheet<br>• **Per student:** (1) 8.c. Redesign, (1) 7.a. Test and Decide (from Lesson 7), (1) 5.b. Evidence-Based Reasoning (from Lesson 5), (1) 5.c. Materials Cost Sheet (from Lesson 5), (1) assembled 1.c. Key Terms Cube (from Lesson 1)<br><br>**EDUCATOR RESOURCES**<br>• 8.a. Evidence-Based Reasoning - Poster with Explanation<br>• 8.d. Teacher Observation Protocol: Redesign Lesson |
| • **Per classroom:** 1 Engineering Design Process poster, 1 poster size sticky note paper with Evidence-Based Reasoning template on it, (optional) 1 poster size sticky note paper, (optional) markers<br>• **Per student:** 2 different colors or types of writing utensils, 1 engineering notebook, 1 Engineering Design Process slider | • **Per student:** (1) 2.a. True Chill Client Letter (from Lesson 2), (optional) (1) blank 8.a. Evidence-Based Reasoning, (optional) 1 assembled 1.c. Key Terms Cube (from Lesson 1), any other previous resources students want to use |

# Overview

| | Material | Lessons Where Material is Used |
|---|---|---|
| Per classroom | 1 Unwashed milk carton* | 1 |
| | 2-3 pictures of rural, hot locations* | 1 |
| | 1 blank pre-assembled Key Terms Cube* | 1,2,3,4,5,6,7 |
| | 1 Engineering Design Process poster* | 2,3,4,5,6,7,8,9 |
| | Poster size sticky note paper* | 2,3,4,5,6,7,8,9 |
| | Digital technologies to display video* | 1,3 |
| | Markers | 2,3,4,5,7,8,9 |
| | 1 eighteen inch long piece of 18 gauge copper wire | 3 |
| | 12 four oz. glass jars with metal lids (baby food or jelly jars)* | 3,4 |
| | 1 butane lighter* | 3 |
| | 5 milk chocolate chips * | 3 |
| | 1 wood pencil* | 3 |
| | 3 ice cubes approximately the same size* | 3 |
| | 1 small opaque plastic plate | 3 |
| | 1 small piece of wood* | 3 |
| | 1 small metal loaf pan | 3 |
| | 1 stopwatch or clock* | 4,7,8 |
| | (optional) 1 analog thermometer | 4 |
| | (optional) 2-3 mini ice packs | 4 |
| | (optional) 2-3 empty vials | 4 |
| | 4 – heat lamps with clamps | 5,6,7,8 |
| | 4 – 40W light bulbs | 5,6,7,8 |
| | 1 large kitchen spoon* | 4,5,6,7,8 |
| | 2 gallon pitchers with slats in | 4,5,6,7,8 |
| | Ice water | 4,5,6,7,8 |
| Per group (assuming 3 students per group) | 1 copy of 1.a. Global Cases of Pertussis graph* | 1 |
| | 1 pocket heat warmer | 3 |
| | (optional) 1 stopwatch | 3 |
| | aluminum foil 12 x 12 in. squares | 3,4,5,6,8 |
| | construction paper 9 x 12 in. rectangles | 3,4,5,6,8 |
| | wax paper 12 x 12 in. squares | 3,4,5,6,8 |
| | foam board 5.5 x 8.5 in. rectangles | 3,4,5,6,8 |
| | felt 6 x 6 in. squares | 3,4,5,6,8 |
| | bubble wrap 12 x 12 in. squares | 3,4,5,6,8 |
| | 1 digital thermometer | 4,7,8 |
| | 1 vial | 4,5,6,7,8 |
| | 2 mini ice packs (frozen) | 4,5,6,7,8 |
| | craft sticks | 4,5,8 |
| | masking tape | 4,5,8 |
| | cellophane tape | 4,5,7,8 |
| | rubber bands | 4,5,8 |
| | 1-2 scissors | 5,7,8 |
| | 1-2 rulers | 5,8 |
| | 1 copy of 8.a. Evidence-Based Reasoning worksheet* | 8 |
| | 1 copy of 8.b. Materials Cost Sheet* | 8 |

# Overview

| | Material | Lessons Where Material is Used |
|---|---|---|
| Per student | 2 different colors or types of writing utensils | 1,2,3,4,5,6,7,8,9 |
| | 1 engineering notebook | 1,2,3,4,5,6,7,8,9 |
| | 1 copy of 1.b. Global Cases of Pertussis Graph Activity worksheet* | 1 |
| | 1 copy of 1.d. Vaccines Exit Slip worksheet* | 1 |
| | 1 copy of 1.c. Key Terms Cube worksheet* | 1,2,3,4,5,6,7,8,9 |
| | 1 Engineering Design Process slider* | 2,3,4,5,6,7,8,9 |
| | 1 copy of 2.a. True Chill Client Letter* | 2,9 |
| | 1 copy of 2.b. Define the Problem worksheet* | 2 |
| | 1 copy of 3.a. Heat and Conductors worksheet* | 3 |
| | 1 copy of 4.a. Insulator Lab worksheet* | 4 |
| | 1 copy of 5.a. Design Ideas - Individual Plan* | 5 |
| | 2 copies of 5.c. Material Cost Sheet* | 5,6,7,8 |
| | 2 copies of 5.b. Evidence-Based Reasoning worksheet* | 5,6,7,8,9 |
| | 1 copy of 7.a. Test and Decide worksheet* | 7,8 |
| | 1 copy of 8.c. Redesign worksheet* | 8 |

* required materials not included in the kit

# LESSON 1 Vaccines and Context of the Problem

### Lesson Objectives
Students will be able to:
- Define vaccine.
- Identify that people receive vaccines before they get sick.
- Give an example of at least one disease that can be prevented by a vaccine.
- Analyze a line graph to identify trends in the data.

### Time Required
One 50-minute class period

### Materials
- **Per classroom:** 1 old empty milk carton (not washed out), 1 blank pre-assembled Key Terms Cube, 3-4 pictures of rural, hot locations (e.g., Laos, Mexico, Somalia, parts of the US) with limited electrical power, digital technologies to display video
- **Per student:** 2 different colors or types of writing utensils, 1 engineering notebook

### Standards Addressed
- Common Core State Standards-Mathematics: 4-NBT.A.2

### Key Terms
- Primary: vaccines, pertussis/whooping cough, trend
- Secondary: disease, vaccination, increase, decrease

## Lesson Summary
Students learn that vaccines are weak or dead germs that help teach the body how to find and fight a disease and that vaccines should be given before a person gets sick with a disease. They then interpret a line graph of the reported cases of pertussis globally from 1980 to the present, identifying the major trend in the data and connecting that trend to the spread of vaccines throughout the world. Finally, students are introduced to the context of the engineering design problem, which is that they will need to design a way to keep vaccines cool in places with limited electrical power.

## Background
### Teacher Background
Whooping cough, also known as pertussis, is a very contagious disease caused by bacteria. As described on the CDC website, “The disease starts like the common cold, with runny nose or congestion, sneezing, and maybe mild cough or fever. But after 1–2 weeks, severe coughing can begin. Unlike the common cold, pertussis can become a series of coughing fits that continues for weeks. Pertussis can cause violent and rapid coughing, over and over, until the air is gone from the lungs and you are forced to inhale with a loud “whooping” sound. In infants, the cough can be minimal or not even there. They may instead have life-threatening pauses in breathing (apnea).”

Because there is not much that can be done once someone contracts the disease, and because whooping cough can be fatal for infants and very young children, vaccination is highly recommended. When more than 90% of the population is vaccinated, we have “herd immunity” – this means the disease can’t spread because there aren’t enough susceptible people in the community. Although vaccinated children can develop pertussis, they are less infectious, have milder symptoms, are sick for a shorter time, and are at reduced risk for severe complications.

The vaccine in the shots usually consists of weakened or dead pertussis cells. When these cells arrive in the body, they trigger the immune system to recognize and prepare for any future whooping cough infections. The pertussis vaccine is usually teamed with vaccines against diphtheria and tetanus in series of shots called the Tdap. While it used to be thought that the traditional childhood series of vaccinations gave lifetime immunity, recent research has revealed that this immunity wanes as teens approach adulthood, so the Tdap booster is now recommended for teens and adults.

Like many other vaccines, the pertussis vaccine needs to be kept cool, but not frozen, in order to maintain its efficacy. This can be a problem in places with warm climates where there is no power or where the power is unreliable. (This problem is the basis of the engineering problem for this unit.) However, maintaining specific temperatures for vaccines is also a problem in the U.S. In 2012, an investigation by the Department of Health and Human Services’ Office of the Inspector General found that many clinics providing immunizations meant for low-income children did not store the vaccines at cool enough temperatures, potentially making them ineffective and putting children at risk. The exact effect these storage problems have on the spread of diseases like pertussis are not yet known, but the issue might be of interest to students involved in the design and construction of model vaccine coolers.

This unit focuses on the science of vaccines, not issues related to whether or not families choose to vaccinate their children. We acknowledge that some families choose not to vaccinate their children, for religious, political or personal reasons. Some have been discouraged by misinformation and misconceptions widely circulated on the Internet. Some of these misconceptions are addressed on the CDC website at http://www.cdc.gov/vaccines/vac-gen/6mishome.htm. While unvaccinated children are not currently a large factor in the rise of whooping cough, it is true that children who haven't received pertussis vaccines are at least 8 times more likely to get whooping cough than children who have received all of the recommended doses. Also, among diseases preventable by vaccination, whooping cough is the most common in the United States.

Additional information about vaccines and pertussis can be found at the following websites:

- Centers for Disease Control (www.cdc.gov)
- World Health Organization (www.who.int/en/)

**Before the Activity**

Find several pictures of rural, hot locations (e.g., Laos, Mexico, Somalia, parts of the U.S.) where the photos indicate that there is limited or non-existent electrical power. These will need to be displayed to the students to provide context for the engineering problem, so either print them off to pass around to students or use digital technologies to display them to the entire class.

Print off and assemble a blank *1.c. Key Terms Cube.* This cube will be used as an example for students. Therefore, it might be helpful to print off a larger copy of the template so that students can see the cube more easily.

Open, or cue up, the video about vaccines (see Introduction step 3). Because video links are not always consistently functional, there are several options to choose from.

Most recommended: How Vaccines Work by Immunize for Colorado

- Link: http://www.immunizeforgood.com/vaccines/how-vaccines-work
- https://www.youtube.com/watch?v=SduMbjW2V9A

Another recommendation: How Vaccines Work courtesy of Health Canada

- Link: https://www.youtube.com/watch?v=pMSSu7QLAlw

Adequate recommendation, but a bit technical: Immunity and Vaccines Explained by PBS NOVA

- Link: https://www.youtube.com/watch?v=IXMc15dA-vw

(Optional) Create an updated version of the *1.a. Global Cases of Pertussis* graph. The data included in this curriculum are from 1980 to 2014. More recent data may be found in the World Health Organization data repository. These data may be found via:

- A direct link: http://apps.who.int/gho/data/view.main.1520_43?lang=en
- On the World Health Organization website (www.who.int/en/), click on

**Assessments**

**Pre-Activity Assessment**

During the lesson introduction while students are discussing what they know about vaccines, note students' prior knowledge and misconceptions.

**Activity Embedded Assessment**

Check students' progressive understanding through their verbal and written responses during activities and discussions.

**Post-Activity Assessment**

At the end of the lesson, check what students write and/or draw in the "vaccine" square of their own cube templates. Note which students work independently and which still seem to need support from their team members. Also, collect and sort the *Vaccines quiz*, looking for students who still need practice with the concept.

**DUPLICATION MASTERS**

- 1.a. Global Cases of Pertussis Graph
- 1.b. Global Cases of Pertussis Graph Activity
- 1.c. Key Terms Cube
- 1.d. Vaccines Exit Slip

**EDUCATOR RESOURCES**

- 1.b. Global Cases of Pertussis Graph Activity
- 1.d. Vaccines Exit Slip

the Data tab. Click on Data Repository tab, and then click on Browse the GHO data repository. Go to the Infectious diseases heading and click on Other infectious diseases. Click on Pertussis; this will lead you to a page that reports cases of pertussis by country. To access the global data, click on Reported cases by WHO region.

**Classroom Instruction**

**Introduction to the Unit**

1. **Introduce the unit. Say:** *We will be working on an engineering project related to helping others keep vaccines cool in very hot weather in places where electricity is not easily available.*
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 first 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 both you assess and the students recognize 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. **Students individually complete notebook prompts about engineering.** Have students individually answer the following 2 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.
   - What do engineers do?
   - How do engineers solve problems?

**Introduction**

1. **Make a personal connection to students' lives. Ask:** *Has anyone in here ever had the flu? How did it feel?* (Take student answers.) *What are some things we can do to keep from getting the flu this year?* (Take student answers.) If a student mentions the flu vaccine, **ask:** *How many of you have ever received a flu vaccination or know someone who has?*
2. **Elicit students' prior knowledge about the term vaccine.** Set the word cube so that the term "vaccine" is face up. **Say/Ask:** *Today we are going to talk about vaccines. What do you already know about this word? What are vaccines? What do they do?*
   - Small group: Within small groups, invite each student to talk for 10-20 seconds about anything they already know about the term and then switch to the next student, repeating until all students in the classroom have had a chance to speak within the small groups. Listen to the

discussions, noting prior knowledge and misconceptions.
- Large group: Invite a representative from each group to share ideas with the whole class.

3. **Watch a short video about vaccines.** The video should define vaccines as “weak or dead germs that help teach the body how to find and fight a disease” (or something similar), and the video should be able to be understood by students. Video links on the Internet are not always functional, so several options are provided.
   Most recommended: How Vaccines Work by Immunize for Colorado
   - Link: http://www.immunizeforgood.com/vaccines/how-vaccines-work
   - https://www.youtube.com/watch?v=SduMbjW2V9A

   Another recommendation: How Vaccines Work courtesy of Health Canada
   - Link: https://www.youtube.com/watch?v=pMSSu7QLAlw

   Adequate recommendation, but a bit technical: Immunity and Vaccines Explained by PBS NOVA
   - Link: https://www.youtube.com/watch?v=IXMc15dA-vw
4. **Discuss the video. Ask:** *So what else do we now know about vaccines?* Guide discussion to remind students that vaccines are often made from real viruses, or at least parts of them, and that they help teach the body how to find and fight specific diseases.
5. **(Optional) Clarify the difference between vaccine and vaccination. Say/Ask:** *You may also have heard of the word vaccination. Vaccinations are the injection, or shot, that puts vaccines inside people’s bodies. Vaccines are the stuff inside the syringe. We will mostly be talking about vaccines, but you may also hear the word vaccination sometimes.*
6. **Predict/Discuss when people should be vaccinated. Ask:** *When should someone get a vaccination – before, during, or after being sick? Why?* Guide discussion so students understand that people need to receive vaccines before they get sick so the body has time to learn how to find and fight the disease.

**Activity**

**Activity Part 1: Reading a Line Graph**

1. **Elicit students’ prior knowledge about types of diseases that vaccines can prevent. Ask:** *What are some other diseases, besides flu, that vaccines protect against?* Answers could include: measles, mumps, rubella, diphtheria, tetanus, polio, pertussis/whooping cough, etc.
2. **Introduce the concept of pertussis. Say/Ask:** *One disease that vaccines can help prevent is called “pertussis,” or “whooping cough.” Just from the sound of the name, what do you probably already know about the disease “whooping cough?”* (Take student answers.) Tell students that whooping cough starts like the common cold, but then severe coughing fits begin and occur for weeks. These coughing fits are violent and include rapid coughing, over and over, until air is gone from the lungs and the infected person is forced to inhale with a loud “whooping” sound. In babies and young children, whooping cough can lead to pneumonia, brain damage, and sometimes death.
3. **Introduce the graph activity.** Pass out copies of the *1.a. Global Cases of Pertussis* graph (1 per small group). To answer questions for this activity, students may either write on the *1.b. Global Cases of Pertussis Graph*

*Activity* worksheet (1 per student) or write questions and answers from the worksheet into their engineering notebooks. **Say:** *Now we are going to look at a graph that shows us data about reported cases of pertussis from around the world. These data are from the World Health Organization.*

4. **Clarify the title and axes labels of the graph.** Point out that the y-axis and title refer to "cases of pertussis." **Ask:** *What do you think a "case" means?* (Take student answers.) Say that a "case" means someone who got sick from the disease pertussis, but it does not mean that they died from it. If needed, also clarify that "global" means that these cases were reported from around the whole world.
5. **Read values on the graph.** In small groups, have students read the graph and write down the approximate number of reported cases of pertussis in the years 1980, 1990, 2000, and 2010.

   **Note:** It may be helpful to have students round their answers to the nearest line. For example, the number of cases in 2010 is clearly less than 200,000, but it may be easier for the students to use 200,000 instead of attempting to determine that it is actually 160,000.

   **Note:** If needed, demonstrate how to read one or two points or treat this as a teacher-guided whole class activity.
6. **Determine trends in the data. Say:** *A "trend" is a pattern in data. Data can be increasing, decreasing, or staying the same.* (If needed, review what "increasing" and "decreasing" mean.) **Ask:** *What trend(s) do you see in the data on this graph? What is this graph telling us?* Have teams turn and talk briefly with each other. When all teams have had time to discuss, pull the groups back together to share aloud. As groups report their claims about the trend(s) in the graph, ask them for evidence to support the claims. Have students record the trend and evidence.

   **Note:** There are two ways this graph could be interpreted in terms of trends. Students could say that the overall trend is a decrease in the number of reported cases, or they could say that there was a decrease until 1995-2000 and then the number of cases stayed about the same. For the purposes of this activity, either of these trends is correct.

   **Note:** If needed, clarify that in a trend, not every point has to be increasing, decreasing, or staying exactly the same. For example, the number of cases of pertussis increased from 1981 to 1982, but the overall trend from 1980 to 1990 is a decrease in the number of cases. Similarly, the number of cases reported from 1995 to the present are not exactly the same, but they stay about the same (i.e., close to 200,000).
7. **Relate the trend back to vaccines. Ask:** *Why do you think this trend happened?* (Take student answers.) Guide discussion so students connect this graph to the idea that as more people around the world receive vaccines for pertussis, there are fewer numbers of people that get the disease pertussis. Have students record their answers.

**Activity Part 2: Context for the Engineering Design Problem**

8. **Make a connection to students' past experience. Ask:** *What do you think could happen if vaccines were frozen or got too warm?* Hold up the old milk carton that is empty but was not washed out. Ask for volunteers to smell as the teacher "wafts" the odor to them with a hand. As volunteers smell, **ask:** *What do you notice?* To the whole class, **ask:** *Why did that*

*happen?* (Take student answers.) **Say:** *Like milk, vaccines also need to be kept cool so that they don't spoil. But they also cannot be frozen because that could destroy the vaccine.*

9. **Discuss how things are kept cold in different parts of the world. Ask:** *What do we do to keep things cold?* (Take student answers.) *How might that be different in other parts of the world?* Show pictures of rural, hot locations (e.g., Laos, Mexico, Somalia) with limited electrical power. **Say:** *In some warm places, there is no power or the power is not reliable. This means that the power goes on and off at any time, sometimes for hours, days, or weeks. How might doctors and nurses keep things cold in these places?* (Take student answers.)
10. **Connect back to vaccines.** Remind students that vaccines need to be kept cool but not frozen, even in warm places where there isn't any power or where the power is not reliable. **Say:** *In this unit, we will use engineering to design solutions to this problem. In the next lesson, we will learn more about engineering, the engineering design process, and our engineering design problem.*

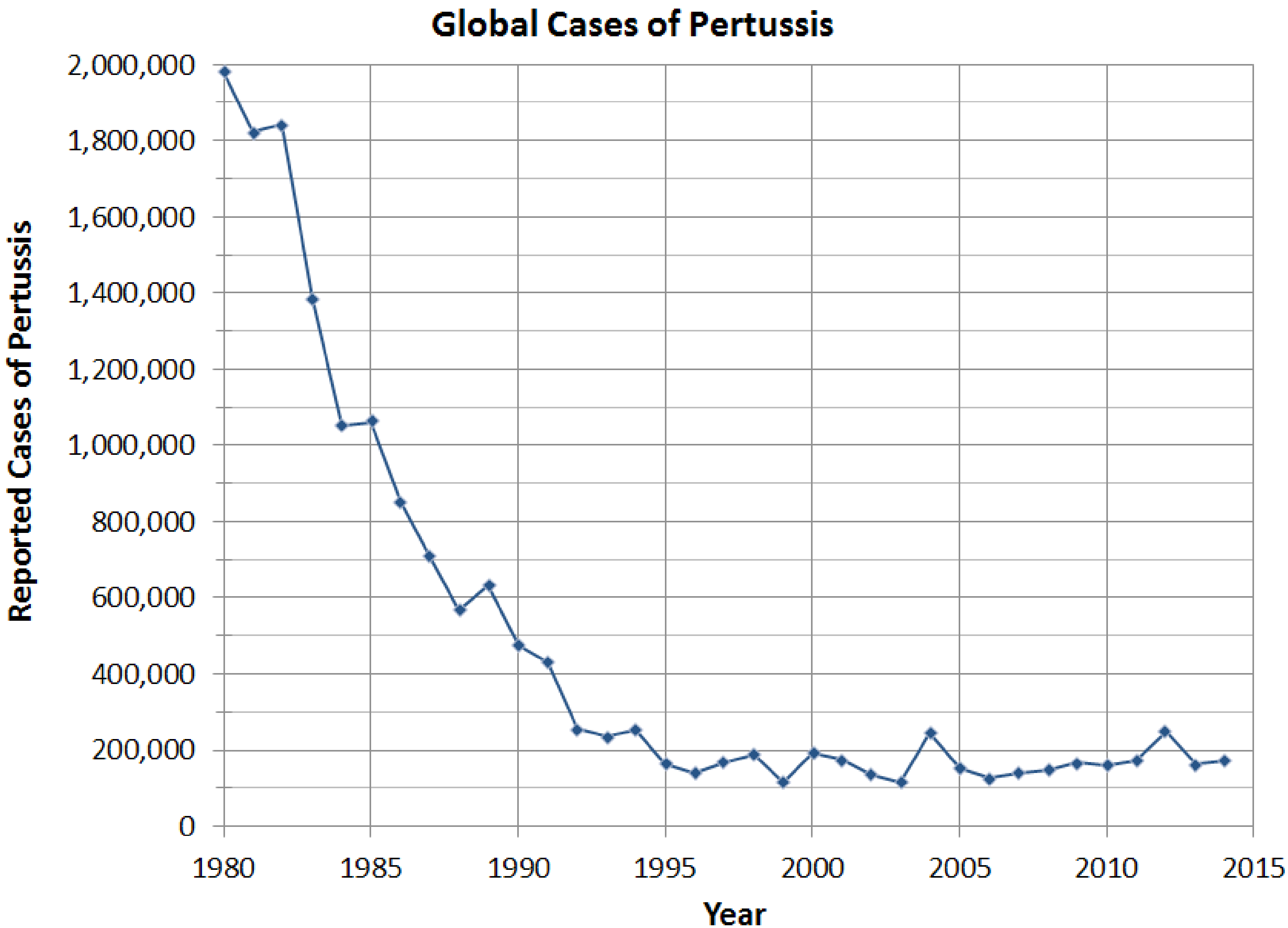
**Closure**

1. **Fill out the "vaccines" square of the vocabulary cube.** Pass each person a *1.c. Key Terms Cube* worksheet. Have students find the box marked "vaccines." **Ask:** *What are the important points we learned about vaccines today?* Tell students to write words or phrases, and to sketch pictures or diagrams to show what they now know about vaccines.

    **Note:** As students fill out the vaccines square of the cube, circulate and check what they are writing and/or drawing. Note which students work independently and which still seem to need support from their team members.
2. **Fill out the *1.d. Vaccines Exit Slip*.** Pass out one copy of the *1.d. Vaccines Exit Slip* to each student. Read through the questions aloud as students choose and mark their responses. Collect the exit slips.

Name________________________________ Date____________ Period _____

# 1.a. Global Cases of Pertussis Graph



LESSON 1

Name________________________________ Date___________ Period _____

# 1.b. *Global Cases of Pertussis* Graph Activity

1. For each year, write how many cases of pertussis were reported.

| Year | Cases of Pertussis |
|---|---|
| 1980 | |
| 1990 | |
| 2000 | |
| 2010 | |

A **trend** is a pattern in data. Data can be *increasing*, *decreasing*, or *staying the same*.

2. What is the trend in the number of cases from 1980 until today? Write a sentence.

3. What evidence supports that claim? Use numbers from the data to write a sentence.

4. Why do you think this trend happened? Think about what you have learned about vaccines.

LESSON 1

Name________________________________ Date___________ Period _____

# 1.b. *Global Cases of Pertussis* Graph Activity

1. For each year, write how many cases of pertussis were reported.

| Year | Cases of Pertussis |
| --- | --- |
| 1980 | 2,000,000 |
| 1990 | 470,000-500,000 acceptable |
| 2000 | 200,000 |
| 2010 | 150,000-200,000 acceptable |

A **trend** is a pattern in data. Data can be *increasing*, *decreasing*, or *staying the same*.

2. What is the trend in the number of cases from 1980 until today? Write a sentence.
   Two acceptable answers:
   The number of cases of pertussis decreased from 1980 until today.
   The number of cases of pertussis decreased from 1980 until 1995, and then stayed about the same from 1995 until today.
3. What evidence supports that claim? Use numbers from the data to write a sentence.
   Exact answers vary, but make sure students use numbers from the graph here. For example, an answer could be, "We know the trend is decreasing because there were 2,000,000 cases in 1990 but only 200,000 in 2010."

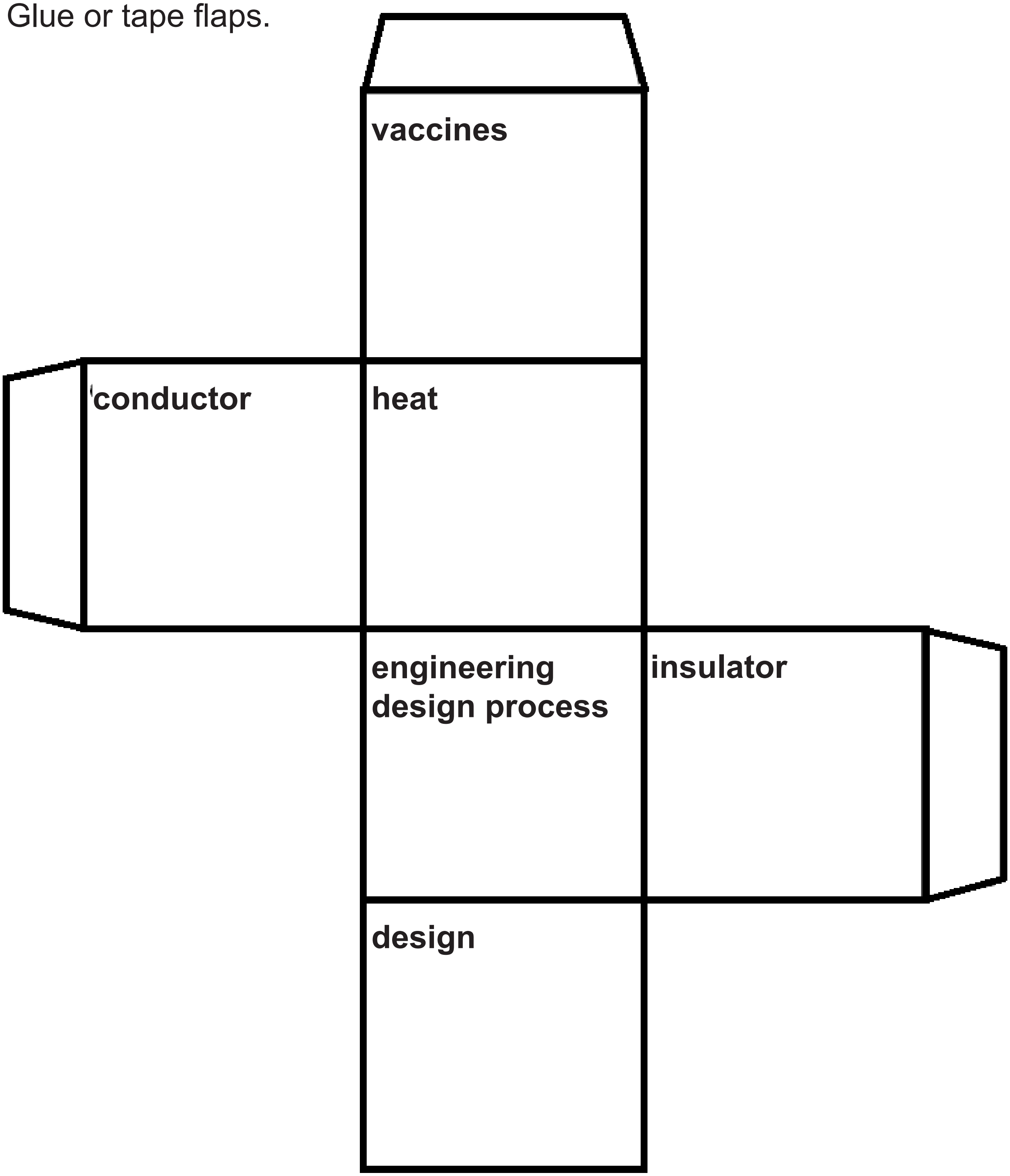
4. Why do you think this trend happened? Think about what you have learned about *vaccines*.
   As more people around the world receive vaccines for pertussis, there are fewer numbers of people who get the disease.

LESSON 1

Name______________________________ Date__________ Period _____

# 1.c. Key Terms Cube

1. Use words and pictures to show what you know about each term.
2. When all six squares are done, cut on the outside lines.
3. Fold on each inside line to make a cube.
4. Glue or tape flaps.



LESSON 1

Name________________________________ Date___________ Period _____

## 1.d. Vaccines Exit Slip

1. How do vaccines keep us healthy?
   a. Vaccines are medicine we get when we are sick.
   b. Vaccines teach our bodies how to find and fight germs.
   c. Vaccines clean germs from our blood.

2. When should people get vaccinated?
   a. Before they get sick.
   b. When they are sick.
   c. After they have been sick.

3. What is one disease that can be prevented by getting a vaccine?

LESSON 1

Name________________________________ Date___________ Period _____

## 1.d. Vaccines Exit Slip

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   a. Vaccines are medicine we get when we are sick.
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2. When should people get vaccinated?
   a. Before they get sick.
   b. When they are sick.
   c. After they have been sick.

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LESSON 1

Name________________________________ Date___________ Period _____

# 1.d. Vaccines Exit Slip

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   a. Vaccines are medicine we get when we are sick.
   b. Vaccines teach our bodies how to find and fight germs.
   c. Vaccines clean germs from our blood.

2. When should people get vaccinated?
   a. Before they get sick.
   b. When they are sick.
   c. After they have been sick.

3. What is one disease that can be prevented by getting a vaccine?
   Answers vary, but could include: pertussis/whooping cough, flu, tetanus, measles, etc.

LESSON 2

# Define the Engineering Problem

## Lesson Objectives

Students will be able to:

- Describe important aspects of the engineering design process.
- Define an engineering problem from the perspective of stakeholders.
- Generate a description of the problem based on information.
- Engage in problem scoping (i.e., define the problem and needs, and then identify the knowledge, criteria, and constraints required for a desirable solution).

## Time Required

One 50-minute class period

## Materials

- **Per classroom:** 1 Engineering Design Process poster, 1 blank pre-assembled Key Terms Cube, 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: 3-5-ETS1-1, 3-5-ETS1-2

## Key Terms

- Primary: engineering design process
- Secondary: engineers, client, end user, criteria, constraints

## Lesson Summary

Students learn about the organized system of problem-solving steps called the engineering design process. They then learn the specifics of their engineering problem, which is to design a cooler that will keep vaccines from spoiling even when power sources are unreliable, by reading a letter from the client and asking the client additional questions. Based on this information, students define the engineering problem, which includes identifying the problem and why it's important, client, end users, criteria, constraints, and what else they need to learn before they begin designing solutions.

## Background

### Teacher Background

The engineering design process 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. In the version provided in this unit, there are six main steps broken down into two major categories: the Problem and the Solution. While there is a general trend of moving from one step to the next, moving backwards and repeating parts of the process is often necessary. Communication and Teamwork are important throughout any entire engineering design process. For more information about the engineering design process presented in this unit, see the front matter section about it.

The Bill and Melinda Gates foundation is dedicated to protecting the world's children against preventable diseases. They award millions of dollars in grants to different companies that work on various aspects of this challenge. (For example, in 2012, the Bill and Melinda Gates foundation awarded $1.7 million in grants to 17 different companies working on challenges related to creating, storing, transporting, and using vaccines.) More information about the Gates foundation and its support of vaccines can be found at:

- http://www.gatesfoundation.org/
- http://www.technet-21.org/en/
- http://vaccinenewsdaily.com/

In 2013, the British firm True Energy, Ltd., received one of these $100,000 grants to develop a cooler that would store vaccines at a steady temperature for more than 10 days without electric power. Since then, this company has changed its name to The Sure Chill Company, and its chairman is Peter Saunders. For the purposes of this unit, the names of both the company and chairman have been fictionalized, changed to The True Chill Company and Peyton Sadler, respectively. More information about the Sure Chill Company can be found at:

- http://www.coolinnovations.co.uk/ (Company website)
- http://www.bbc.com/news/uk-wales-north-west-wales-21784159 (Article about the company, then called True Energy, receiving the Gates foundation grant)

## Before the Activity

If not already made, assemble the Engineering Design Process Sliders. First, make enough copies of the Engineering Design Process document so that each student will have one. Then, cut the copies into individual Engineering Design Process segments. Next, laminate the segments. Finally, attach a paper clip to the side of each Engineering Design Process segment.

## Classroom Instruction

### Introduction

1. **Review vaccines. Ask:** *What have we learned about vaccines?* (Take student answers.) In the discussion, students should review what vaccines are, that vaccines need to be given before someone gets sick, and some example of diseases that can be prevented by vaccines.
   **Note:** If there were common misconceptions about vaccines revealed in the previous lesson's discussions and students' *Vaccine Exit Slips*, address them during this review discussion.
2. **Review the engineering problem. Say/Ask:** *We have also talked about storing vaccines and a possible problem with storing them. What is this problem?* (Take student answers.) Students should review that vaccines need to be kept cool but not frozen, otherwise they can spoil. Also, in some parts of the world, vaccines need to be kept cool even when there is no power or the power is not reliable.
3. **Introduce engineering. Say/Ask:** *In order to create solutions to this 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.*
4. **Introduce the engineering design process.** Display the *Engineering Design Process* poster and pass out *Engineering Design Process* sliders to each student. Also, set the word cube so that the term "engineering design process" is face up. **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.*
5. **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).
   - 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).
   - Communication and teamwork are important to the entire engineering design process (gray box on the right side).

   **Note:** While this is not evident on the slider, it important to inform students

### Assessments

**Pre-Activity Assessment**
Check students' verbal responses during the whole class discussion for the understandings about vaccines, the problem, and the engineering design process. Clarify misunderstandings as needed.

**Activity Embedded Assessment**
Check students' progressive understanding through their verbal and written responses during the Define the Problem activity and discussions. This is particularly important when students are answering the *2.b. Define the Problem* worksheet or notebook 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**
At the end of the lesson, check what students write and/or draw in the "Engineering Design Process" square of their own cube templates. Note which students work independently and which still seem to need support from their team members.

### DUPLICATION MASTERS

- 2.a. True Chill Client Letter
- 2.b. Define the Problem

### EDUCATOR RESOURCES

- 2.b. Define the Problem

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.

6. **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**

1. **Introduce the problem.** Pass out the *2.a.True Chill Client Letter* to students. Read the letter using whatever method of reading is preferred (e.g., reading in small groups, teacher reading aloud to the whole class, volunteers in the class reading aloud to the whole group).
2. **Introduce the concepts of clients and end users. Say/Ask:** *A "client" is a person or group 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 client is Peyton Sadler of The True Chill Company; he or she is asking the student engineers to solve the engineering problem. (Peyton was purposefully chosen as a gender neutral name, so you can determine whether the client is male or female.) The end users are the doctors and nurses who store the vaccines and the people who transport the vaccines; they will actually use the vaccine cooler.
3. **Develop questions for the client. Say:** *We will not be able to speak with the end users directly, but we now have an opportunity to ask the client questions about the problem so we can understand it better.* Have them individually answer the prompt: *"What questions do you want to ask the client?"* 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 response.
4. **Share questions.** As a whole group, 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.

   **Note:** 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 are addressed at this time. If the class has not thought of these two 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. You should not spend more than $5.00. The less money you spend, the better.*
   - Do the coolers need to look nice? *No. Appearance doesn't matter to us.*

- What size should the coolers be? *The coolers need to be large enough to hold one vial of vaccine. Your teacher has an example vial so you can see how big it is. However, your cooler should not be too big either. We need it to be small enough that we can transport many of them at once. The smaller it is, the more vaccines we can transport and store.*
- What shape does the cooler need to be? *It is up to you.*
- How do we get the vaccine in an out of the cooler? *The cooler needs to have a way to put the vaccine vial in the cooler and also take it out. The easier this process is, the better.*
- Does it matter how easy the cooler is to make? *The easier the cooler is to create, the better, but this is not a huge factor in our decision.*

5. **Provide answers to the questions.** This may be done in several ways. This includes, but is not limited to: 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; inviting a guest speaker to pretend to be the client and answer students' questions. Record the client's answers to the questions on the chart paper labeled "Questions for Client", preferably in a different color than the questions.
6. **Define the problem, including identifying the client and end users.** Pass out the *2.b. 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 *2.b. 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 groups, decide what their team answer is, and write down that possibly revised answer on the *2.b. Define the Problem* worksheet or directly in their engineering notebooks.
   **(Optional)** If student teams seem to be struggling with a question, address it as a whole class.
7. **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 *2.b. Define the Problem* worksheet. When students finish answering the questions on their own, instruct them to share their responses in small groups, decide what their team answer is, and write down that possibly revised answer on the *2.b. Define the Problem* worksheet or directly in their 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.
8. **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 design that keeps*

*vaccines cool?* Ask students to individually answer the final question on the *2.b. 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 groups, decide what their team answer is, and write down that possibly revised answer on the *2.b. 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 keep vaccines cool.

**Closure**

1. **Fill out the "engineering design process" square of the vocabulary cube.** Ask students to take out their *1.c. Key Terms Cube* worksheet. Have students find the box marked "engineering design process." **Ask:** *What are the important points we learned about the engineering design process today?* Tell students to write words or phrases, and to sketch pictures or diagrams to show what they now know about the engineering design process.

    **Note:** As students fill out the engineering design process square of the cube, circulate and check what they are writing and/or drawing. Note which students work independently and which still seem to need support from their team members.

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# Define the Engineering Problem

Name________________________________ Date___________ Period _____

# 2.a. True Chill Client Letter

The True Chill Company
United Kingdom

Dear Student Engineers,

My name is Peyton, and I am the Chairman of The True Chill Company. Our company would like to hire you for one of our projects.

Vaccines are important to people all around the world. They prepare people's bodies to resist certain diseases. This is very important for children, since these diseases are most dangerous to young people. If vaccines get too warm, they do not work well anymore. Vaccines need to be kept cool, but not frozen, while they are being transported and stored. This can be difficult in some parts of the world, since some places have warm climates but no power or unreliable power. In these places, doctors and nurses can't rely on normal refrigerators to keep vaccines cool. They need another way to keep vaccines cool but not frozen.

Our company wants to help solve this problem. Our goal is to design a cooler that will store vaccines at a cool temperature without being plugged in to a power source. This cooler will let doctors and nurses store vaccines safely. Also, it will let the people who transport vaccines move them safely.

We need you engineers to help us design a solution to this problem. Your cooler prototype will need to be able to keep a vaccine between 32°F and 42°F for at least 10 minutes while under a heat lamp. Also, when you communicate your final design to us, you will need to justify your design with evidence.

Sincerely,

*Peyton Sadler*

Peyton Sadler
Chairman, The True Chill Company

Name_________________________________ Date___________ Period _____

LESSON 2

# 2.b. Define the Problem

- First, **on your own**, answer each of the following questions beside the "My Response" space.
- Then, in your teams, **share** your response, listen to your teammates' responses, and discuss.
- Last, in the space "Team Response", **write your revised answer** to the question, based on discussion with your team.

**1. Who is the <u>client</u>?**

My response:

Team response:

**2. What is the client's <u>problem</u> that needs a solution?**

My response:

Team response:

**3. Why is the <u>problem important</u> to solve?**

My response:

Team response:

Name_________________________________ Date___________ Period _____

# 2.b. Define the Problem

**4. Who are the <u>end-users</u>?**

My response:

Team response:

**5. What will make the solution effective (<u>criteria</u>)?**

My response:

Team response:

**6. What will limit how you can solve the problem (<u>constraints</u>)?**

My response:

Team response:

**7. Think about the problem of keeping vaccines cool when there is no power or unreliable power. What do you <u>need to learn</u> in order to create a design that successfully keeps vaccines cool?**

My response:

Team response:

LESSON 2

Name________________________________ Date____________ Period _____

# 2.b. Define the Problem

1. **Who is the client?**
   The client is Peyton Sadler of The True Chill Company.

2. **What is the client's problem that needs a solution?**
   The True Chill Company needs us to design a cooler prototype that will keep vaccines cool without being plugged in to a power source. They also need us to justify our designs with evidence.

3. **Why is the problem important to solve?**
   This problem is important to solve because vaccines do not work well when they get warm, so they need to be kept cool. It is also important that the cooler work without electricity, since some places have no power or unreliable power.

4. **Who are the end-users?**
   The end users are the doctors and nurses who store the vaccines, and the people who transport the vaccines.

5. **What will make the solution effective (criteria)?**
   (Main) The vaccine needs to stay between 32°F and 42°F for at least 10 minutes while under a heat lamp. It needs to cost less than $5.
   (Possible additional) The coolers need to be big enough to hold one vial of vaccine but small enough to transport many of the coolers at once. The cooler must have a way to get the vaccine vial in and out.

6. **What will limit how you can solve the problem (constraints)?**
   We can only use materials on the list. Our prototype needs to cost less than $5, and cheaper is better.

7. **Think about the problem of keeping vaccines cool when there is no power or unreliable power. What do you need to learn in order to create a design that successfully keeps vaccines cool?**
   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 keep things cool, how heat moves, make a cooler, etc.

LESSON 3

# Heat and Conductors

**Lesson Objectives**
Students will be able to:
- Explain that heat is a type of energy that moves from warm to cold.
- Identify conductors as materials that transfer heat more easily and quickly.
- Plan and conduct lab experiments.
- Analyze and explain the results of lab experiments.

**Time Required**
One 50-minute class period

**Materials**
- See Overview

**Standards Addressed**
- Common Core State Standards: 4-PS3-2, *MS-PS3-3

**Key Terms**
heat, heat transfer, conductor

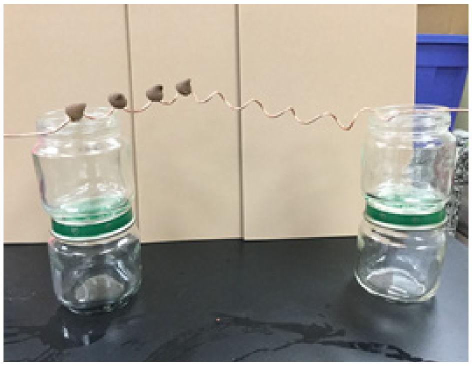
## Lesson Summary

Students will first review the engineering problem, which is to design a device that will keep vaccines cool without electric power, and identify that they are in the Learn (about the problem) step of the engineering design process. Students will learn that heat is a form of energy that always flows from warmer to colder. They will observe and explore how different materials affect the movement of heat with a specific focus on conductors.

## Background

### Teacher Background

Energy is not an object or material; it is something that moves, or flows, through objects and materials. Light and sound energy move through many materials, but we usually think about them in terms of how they move through the air. Electricity moves through wires in a cord. Heat is another form of energy, also called thermal energy. Heat always moves from warmer areas or objects to those that are cooler. A common misconception is that cold is a kind of 'negative energy' that also moves. However, cold is just the absence of heat in the same way that a shadow, or darkness, is the absence of light. When energy moves through a material, whether it's light energy through a window or heat energy through a frying pan, the material it moves through is usually unaltered. Just like electrical energy, heat energy flows better through some materials than others. Those materials that allow heat energy to flow through quickly and easily are called conductors. Metals, cotton fabric, wax, and water are good conductors of heat.



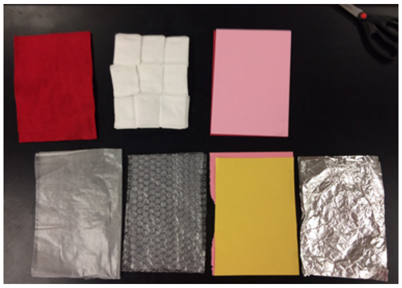
### Before the Activity

Prepare the Copper Wire/Chocolate Chip Heat Transfer Demonstration (if doing the actual demonstration; a video is also provided if that is preferred over an in class demonstration)
Note: A picture is provided to show the final set-up.
1. Wrap the middle section of the 18" of 18 gauge copper wire around a wooden pencil approximately 10 times. Each wrap should be about 1 cm apart, and there should be excess wire on either side of the pencil. Remove the wire from the pencil.
2. Place the lids on two of the 4 oz. glass jars. Create two stacks of two glass jars. Each stack should have one lidded jar on the bottom and one open jar (no lid) on top.
3. Gently push 4-5 milk chocolate chips so they stick to the wire and are slightly forward leaning.
4. Place the wire with the chocolate chips on top of the jar stacks. The coils of the wire and also chocolate chips should be in between the two jar stacks, with the straight ends of the wire resting on top of the jar stacks.
5. The butane lighter is also needed for this demonstration, so have that ready.

Acquire three ice cubes of approximately the same size. It is most useful if the cubes are still frozen in their original sizes as close to the beginning of class as possible. If they are removed from a freezer or cooler too early, they will melt before they need to be used in the Conductor Demonstration.

Set out the rest of the materials for the Conductor Demonstration. This includes one small plastic plate, one small metal loaf pan, and one piece of wood. This can be an actual block of wood, or a makeshift wood surface can be made by stacking wooden rulers or craft sticks two deep and at least three wide, taping their ends together.

Prepare materials for the Conductor Lab. Each lab group will need one inactivated hand warmer; the students will activate it at the beginning of the lab. Each lab group will also need the following (which are also shown in the accompanying picture):
- Aluminum foil, one 12 x 12 in. square, fold in half
- Construction paper, one 9 x 12 in. rectangle, fold in half crosswise
- Wax paper, one 12 x 12 in. square, fold in half
- Foam, two 5.5 x 8.5 in. rectangles, stacked
- Felt, two 6 x 6 in. squares, stacked
- Bubble wrap, one 12 x 12 in. square, fold in half
- Cotton squares, 12 squares taped together into two sheets of six, stack the sheets



Use one sheet of poster size sticky note paper to make a data table on which student teams will record the results of the Conductor Lab. The data table should include the types of materials used in the activity and space for each team to rank them.

## Classroom Instruction
### Introduction
1. **Tie to the engineering problem. Ask:** *What is our engineering design problem?* (Take students answers.)
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 "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. Students should say something about heat moving, keeping things cool, etc.
4. **Feel heat transfer.** Have students put one hand on a metal surface and the other hand on a wood 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 at the same time.) **Ask:**

**Assessments**
**Pre-Activity Assessment**
Students should have their engineering notebooks and/or worksheets from the last two days. What engineering problem are we tasked with solving? Check that students can state the defined problem.

**Activity Embedded Assessment**
Check students' progressive understanding through their verbal and written responses during activities and discussions, especially their explanations during the three major activities: why the chocolate chips fell off the wire in the order that they did (Copper Wire/ Chocolate Chip Heat Transfer demonstration), which ice cube melted the most and why (Conductor Demonstration), and how students know which materials are the best conductors and explaining their rankings (Conductor Lab). These written explanations will be either on the *3.a. Heat and Conductors* worksheet or in their engineering notebooks.

**Post-Activity Assessment**
At the end of the lesson, check what students write and/or draw in the "heat" and "conductor" squares of their own cube templates. Note which students work independently and which still seem to need support from their team members.

**DUPLICATION MASTERS**
- 3.a. Heat and Conductors

**EDUCATOR RESOURCES**
- 3.a Heat and Conductors

*Which surface is colder?* (Take student answers; they will probably say that the metal is colder.) Point out that everything in the classroom is at room temperature, so actually the metal and the wood are the same temperature. **Ask:** *Why do you think the metal feels colder, even if it isn't?* (Take student answers.) Explain that for both surfaces, heat energy moves from a person's warm hand (about 98.6°F) to the cooler surface (both surfaces are at room temperature, usually about 70°F). However, the heat flows 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 flow well or quickly from a hand to wood, so the flow is blocked, and the hand doesn't feel as cold.

5. **Describe heat as a form of energy.** Display and/or ask the following, allowing students to answer and discuss.
   - *What is light? What can light move through? What is darkness?*
   - *What is sound? What can sound move through? What is silence?*
   - *What is heat? What can heat move through? What is cold?*

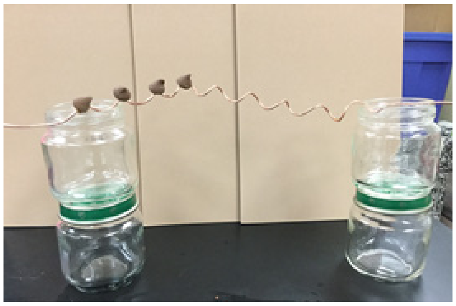
   Guide discussion to help students understand that heat is one of many kinds of energy, similar to light or sound. Also, just like how darkness is the absence of light and silence is the absence of sound, cold is the absence of heat.

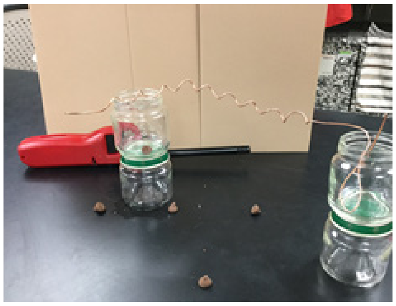
**Activity**

**Copper Wire/Chocolate Chip Heat Transfer Demonstration**

**Note:** A one minute video clip of this demonstration is also available if video is preferred to an in-class demonstration. This video clip can be found at: https://youtu.be/f0Ow4TCHq2I

1. **Introduce the demonstration.** Pass out the *3.a. Heat and Conductors* worksheet if your students are recording answers in worksheets and then gluing them into their engineering notebooks; otherwise, have students record questions and answers directly into their engineering notebooks. Direct students' attention to the demonstration set-up. Tell students that you will be holding a flame to one end of the copper wire; then, ask them to predict what they think will happen.
2. **Perform the demonstration.** Instructions and pictures of the demonstration are as follows:
   - Turn the butane flame level to high, hold the safety and light the flame. Put the butane lighter to the side closest to the chocolate chips.
   - Hold the lighter flame so the copper wire in engulfed in the flame.
   - Continue to hold the flame to the copper wire until all of the chocolate chips have melted and fallen off the wire. It should take about 30 seconds for the heat to travel down the wire, melting off each chocolate chip one by one along the way.





3. **Discuss what happened in the demonstration. Ask:** *Why did the chocolate chips fall off the wire in the order that they did?* Guide discussion toward the idea that heat energy moves from warm to cold, in this case, from the hot flame along the cooler, room temperature wire. As the heat flowed through the wire, it melted the chocolate chips, so the chocolate chips closest to the flame melted first and the ones farthest away melted last. Have students record this information.
4. **Connect heat transfer back to the engineering problem.** Remind students of their task, which is to design a container that keeps vaccines cool so they don't spoil. **Say:** *We have already seen how heat moves differently through metal and wood. We will need to learn more about how heat energy moves through different materials in order to know how we should design our vaccine containers.*

**Conductor Demonstration – Part 1**

5. **(Optional) Write the Conductor Demonstration in student engineering notebooks.** If students are using engineering notebooks, have them write the title (*Conductor Demonstration*) and purpose (*Observe heat energy*) of the demonstration in their notebooks.
6. **Introduce the Conductor Demonstration.** Hold up each of the containers: a small, opaque plastic plate; a small, metal loaf pan; and a piece of wood (see **Before the Activity** for information about how to create a piece of wood out of rulers or craft sticks if a block of wood is not readily available). **Say/Ask:** *I will place one ice cube on each of these three surfaces. Do you think the speed of melting of the ice cubes will be different for the plastic plate, piece of wood, and metal loaf pan?* Have students predict which ice cube will melt the fastest and slowest and also explain why. Have students discuss their predictions and record them.
7. **Perform the demonstration.** Place one ice cube on each of the three surfaces (see photos). Tell students that they need to wait for the ice cubes to melt, which is at least 15 minutes, before they can make observations and finish the conductor demonstration. In the meantime, they will do the conductor lab.

   **Note:** If students are using engineering notebooks instead of the Heat and Conductor worksheet, instruct them to leave space for more writing for the Conductor Demonstration before they start writing questions and answers for the Conductor Lab.

**Conductor Lab**

8. **(Optional) Write the Conductor Lab in student engineering notebooks.** If students are using engineering notebooks, have them write the title (*Conductor Lab*) and purpose (*Rank materials in order from best conductor to worst conductor. Support your ranking with observations from the lab*) of the lab in their notebooks.
9. **Introduce the concept of a conductor. Say/Ask:** *Another way that we discuss heat flow, or heat transfer, is to talk about how well materials "conduct" heat energy. We call materials different names, depending on whether they conduct, or transfer, heat energy well or not. One of these names is "conductor." If a material is a heat "conductor", what do you think that means?* (Take student answers.) *Think back to when you felt the metal and the wood; which one of these materials was the better heat conductor?* (Take student answers.)
10. **Introduce the Conductor Lab.** Hold up each of the seven materials: aluminum foil, construction paper, wax paper, foam, felt, bubble wrap, and cotton square sheets (see **Before the Activity** for more information about how to prepare these materials for the lab). **Say:** *Today, you will use each of these seven materials and a hand warmer to determine which of the materials are better heat conductors and which are worse.*
11. **Plan the Conductor Lab.** Before student teams conduct the lab, have them think about and record their plan for how to do the lab. They need to answer these questions:
    - *How will your group know when the heat has transferred from the hand warmer through the material?*
    - *How will you measure that?*
    - *How will you know what material is the best conductor?*

    **Note:** This activity can be done with a stopwatch or timer. Students measure the time it takes to feel the warmth of the hand warmer through each of the materials, and the materials with the shorter times are the better conductors. However, a qualitative estimation of the time it takes to feel the warmth through the material is usually adequate for this lab.
12. **Conduct the Conductor Lab.** Instruct student teams to activate their hand warmer (see directions on the hand warmer packet) and place in on a flat surface. They can then place each of the seven materials on top of the hand warmer and determine when they can first feel the heat through the material by their hands.

    **Note:** It is recommended to place the hand warmer on a more insulating surface, such as wood or plastic. If the activated hand warmer is placed on a conductive surface, such as metal, the heat will transfer out of it more quickly and thus the results from the beginning of the lab and end of the lab may be inconsistent.
13. **Analyze results of the Conductor Lab.** Have each group use their observations and data to rank the seven materials in order from best conductor to worst conductor. Instruct them to record this ranking and an explanation of why they ranked the materials in this order.

    **Note:** If using qualitative estimates of time, ties between materials will likely happen.
14. **Share results of the Conductor Lab.** Have the student groups write

their materials conductor rankings on a piece of poster size sticky note paper so the whole class can see all of the teams' rankings. Discuss the similarities and differences among the different rankings. If some materials are close together, they may be ordered slightly different by different groups. As a class, agree on a whole-class ranking of the materials from best to worst conductor. Record this information on the poster paper.

**Note:** This can be done in different ways. Students may choose to leave materials tied in the rankings, or they may find a class average of each material and use that to rank them.

**Note:** Additional time is given for this in the next lesson if needed.

**Conductor Demonstration – Part 2**

15. **Make observations for the Conductor Demonstration.** After the Conductor Lab is completed, have students look at the three ice cubes from the Conductor Demonstration and record which ice cube melted the most.
16. **Explain the results of the Conductor Demonstration.** Have the class discuss and record why they observed the results that they did. Encourage them to use the term "heat transfer" and, if they want, the term "conductor."

**Closure**

1. **Fill out the "heat" and "conductor" squares of the vocabulary cube.** Ask students to take out their *1.c. Key Terms Cube* worksheet. Have students find the boxes marked "heat" and "conductor". **Ask:** *What are the important points we learned about heat and conductors today?* Tell students to write words or phrases, and to sketch pictures or diagrams to show what they now know about heat and conductors.

    **Note:** As students fill out the heat and conductor squares of the cube, circulate and check what they are writing and/or drawing. Note which students work independently and which still seem to need support from their team members.

LESSON 3

Name________________________________ Date____________ Period _____

# 3.a. Heat and Conductors

**Copper Wire and Chocolate Chip Demonstration**

Why did the chips fall off the wire in the order that they did?

**Conductor Demonstration**

**Purpose:** Observe heat energy

1. Do you think the speed of melting of the ice cubes will be different for the plastic plate, piece of wood, and metal loaf pan?  Explain why you think so.

2. Which ice cube melted the most?

3. Explain why this happened and include the term heat transfer.

4. What is heat? How does it move, or transfer?

LESSON 3

Name________________________________ Date__________ Period _____

# 3.a. Heat and Conductors

**Conductor Lab**

**Purpose:** Rank materials in order from best conductor to worst conductor. Support your ranking with observations from the lab.

1. How will your group know when the heat has transferred from the hand warmer through the material?

2. How will you measure that?

3. How will you know what material is the best conductor?

4. Rank the materials in order from best conductor to worst conductor. Use a scale from 1 to 7. Make 7 the worst conductor. Why did you rank the conductors in this order?

5. What is a conductor?

# 3.a. Heat and Conductors

**Copper Wire and Chocolate Chip Demonstration**
Why did the chips fall off the wire in the order that they did?
The heat flowed/transferred/moved through the wire from warmer (the flame) to colder (the room temperature copper wire). As it moved, it melted the chocolate chips off of the wire, so the chocolate chip closest to the flame melted off first.

**Conductor Demonstration**
**Purpose:** Observe heat energy

1. Do you think the speed of melting of the ice cubes will be different for the plastic plate, piece of wood, and metal loaf pan? Explain why you think so.
Answers may vary.

2. Which ice cube melted the most?
The ice cube in the metal loaf pan melted the most.

3. Explain why this happened and include the term heat transfer.
The heat transferred from the warmer loaf pan to the colder ice cube the easiest of the three materials, so it melted the fastest and most. Heat did not transfer as well from the plastic or wood to the ice, so those ice cubes did not melt as much.
(Optional) Metal was a better conductor of heat than plastic or wood.

4. What is heat? How does it move, or transfer?
Heat is a type of energy that transfers from warmer areas to colder areas.

# 3.a. Heat and Conductors

**Conductor Lab**
**Purpose:** Rank materials in order from best conductor to worst conductor. Support your ranking with observations from the lab.

1. How will your group know when the heat has transferred from the hand warmer through the material?
Answers may vary, but will be along the lines of “when we can feel the warmth through the material”.

2. How will you measure that?
Answers may vary, but will be along the lines of “we will time how long it takes before we can feel the heat”.

3. How will you know what material is the best conductor?
Answers may vary, but will be along the lines of “the best conductor will be the materials with the shortest time”.

4. Rank the materials in order from best conductor to worst conductor. Use a scale from 1 to 7. Make 7 the worst conductor. Why did you rank the conductors in this order?
Answers may vary, but the rankings are usually:
Starting at 1: aluminum foil, wax paper, construction paper, felt, cotton, foam, bubble wrap

5. What is a conductor?
A conductor is a material that allows heat to transfer through it quickly and easily.

# LESSON 4 Heat and Insulators

## Lesson Objectives
Students will be able to:
- Explain that heat is a kind of energy that always moves from warmer to colder.
- Measure the temperature of a liquid using a thermometer.
- Subtract decimals to calculate temperature changes.
- Analyze the results of an experiment.
- Identify insulators as materials that stop or slow the flow of heat.

## Time Required
One 50-minute class period

## Materials
- See Overview

## Standards Addressed
- Next Generation Science Standards: 4-PS3-2, *MS-PS3-3
- Common Core State Standards - Mathematics: 4.NF.C.7, 4.MD.A.2

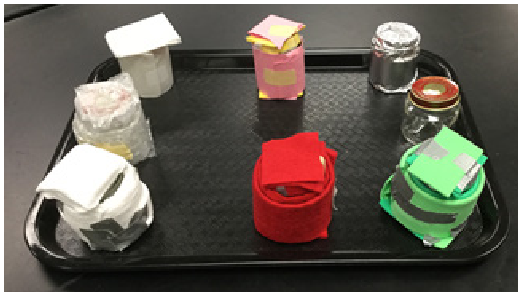
## Key Terms
- Primary: insulator, heat transfer, conductor
- Secondary: temperature, thermometer

## Lesson Summary
Lab teams will use digital thermometers to measure the temperature of water inside differently-wrapped 4 oz. glass jars. They will analyze these measurements to determine the change in temperature from the beginning of the activity to the end, which will indicate the effectiveness of the variety of materials used to insulate the jars. They learn that heat moves slower through some materials than others, and that these materials are called insulators.

## Background
### Teacher Background
Students sometimes confuse the terms temperature and thermometer. A thermometer is a tool used to measure temperature.  At this point, some students may need support differentiating between these terms and assistance in using them correctly.

Heat energy flows from warmer areas or objects to those that are cooler, unless something stops or slows the flow of energy. Materials that stop or slow the flow of heat energy are called insulators.

### Before the Activity
Prepare the 4 oz. glass jars for the Insulator Lab. Gather eight 4 oz. glass jars and metal lids. Keep one jar and lid unwrapped (to use as a control), and wrap the other seven jars in: construction paper, felt, bubble wrap, plastic craft foam, aluminum foil, cotton squares, and wax paper.



**Note:** All of the glass jars need to be double-wrapped with each material (see picture). Also, wrap in such a way as to cover as much of the glass jar as possible. The lids also need to have material on them, while still being removable.

Acquire two pitchers of ice water for the Insulator Lab. Make sure to stir the ice water in the pitcher using the large kitchen spoon before dispensing it into the baby food jars. This helps to make sure that the water poured is at or below 33°F.

Use one sheet of poster size sticky note paper to make a data table on which student teams will record the results of the Insulator Lab. The data table should include Type of material, Initial temp of water (°F), Final temp of water (°F), Change in temp of water (°F), and Rank: best insulator to worst (see *4.a. Insulator Lab* worksheet in duplication masters for an example).

## Classroom Instruction
### Introduction
### Insulator Lab Part 1
**Note:** This lab needs to be started as soon as possible into class. The water in the jars needs to sit at room temperature for a minimum of 20 minutes in order to see results, and longer times (e.g., 30 minutes) yield even better results.

# Heat and Insulators

1. **Record the initial temperature of the ice water.** Pass out the *4.a. Insulator Lab* worksheets. Stir the pitchers of ice water, then measure the ice water temperature. Record this initial temperature on the board. Tell students that this represents the initial temperature (at time = 0 minutes) of all eight glass jars, since the same ice water will be poured into each of the jars.
2. **Distribute the cold water to the glass jars.**
   - Separate the class into 8 groups. Each group will be responsible for recording the temperature data for one jar, so assign each group to a jar.
   - Have one student from each group bring their jar to the teacher.
   - Pour only water, not ice, into each jar until they are full.
   - Have the students put the lids back on the jars before walking away from the pouring station.
   - Have students place the jars around the room so that they are exposed to the room temperature air, no direct sunlight, and are safe from tipping over.
   - Let the jars sit for at least 20 minutes; 30 min will result in even better data.

   **Note:** At this point, students can stay in their lab groups near their assigned jar or move back to their seats, depending on how the room is arranged.

**Review Previous Lessons**

3. **Review the concept of conductors.** Ask students to explain what they have learned about conductors.
4. **(Optional) Analyze the whole class's results of the Conductor Lab.** Discuss the similarities and differences among the different groups' rankings of best conductor (1) to worst conductor (7). As a class, agree on a whole-class ranking of the materials from best to worst conductor. Record this information on the poster paper.

   **Note:** This can be done in different ways. Students may choose to leave materials tied in the rankings, or they may find a class average of each material and use that to rank them.
5. **Connect the Conductor Lab with the Insulator Lab.** Hold up the materials from the Conductor Lab. Point out that those materials are the same ones that are covering the jars filled with cold water. **Say/Ask:** *We're testing the same materials for the Insulator Lab today as we did for the Conductor Lab in the previous lesson. What is different about the two labs?* (Take student answers.) Guide the discussion so students point out two major differences. First, they measured time (either quantitatively or qualitatively) in the Conductor Lab, but in the Insulator Lab, they are directly measuring temperature of the water inside the jars. Second, in the Conductors Lab, they were measuring how well heat transferred from the hot hand warmer through the materials. In this lab, they will measure how well the heat transfers from the room temperature air through the materials into the cool water in the glass jar.
6. **Tie to the engineering problem. Ask:** *Why do we need to know how well heat transfers through materials?* (Take student answers.) Guide the discussion so it includes the following points:

**Assessments**

**Pre-Activity Assessment**
Check students' understanding of heat, heat transfer, conductors, and the details of the engineering design problem during the discussions in the introduction.

**Activity Embedded Assessment**
Check students' progressive understanding through their verbal and written responses during activities and discussions. In particular, pay attention to their explanations during the Insulator Lab, which will either be written on the *4.a. Insulator Lab* worksheet or directly into their engineering notebooks.

**Post-Activity Assessment**
At the end of the lesson, check what students write and/or draw in the "insulator" square of their own cube templates. Note which students work independently and which still seem to need support from their team members.

**DUPLICATION MASTERS**

- 4.a. Insulator Lab

**EDUCATOR RESOURCES**

- 4.a. Insulator Lab

- The client is Peyton Sadler of The True Chill Company; the end users are the people who will store and transport vaccines.
- The engineering problem is to design a device that will keep vaccines cool without being plugged into a power source.
- It is important for vaccines to stay cool because otherwise they spoil. (Remind students of the spoiled milk carton activity from Lesson 1.)

Point out that so far students have learned about materials that let heat energy flow through easily and quickly (conductors). However, for the design challenge, they need to know about materials that do the opposite of that, materials that will not let heat energy through and warm up the vaccines.

7. **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. **Ask:** *Based on what we have talked about so far, what other science do we need to learn about?*

**Activity**

**Insulator Lab – Part 2**

1. **Introduce the concept of insulators. Say/Ask:** *Conductors are materials that allow heat energy to transfer through them quickly and easily. Today we will learn about materials that stop or slow the flow of heat energy. Does anyone know what we call these materials, which are the opposite of conductors?* (Take student answers.) If the students don't volunteer it, introduce the term "insulators".
2. **Predict the results of the Insulator lab.** Pass out the *4.a. Insulator Lab* worksheet if students are recording answers in worksheets instead of directly into their engineering notebooks. **Ask/Say:** *Which jar do you think will work the best to keep the water cold?* Write down your prediction and explain why you think that. Have students turn and talk in a team before recording their answers on either the worksheet or directly into their engineering notebooks.

   **Note:** If students are stuck, connect this prediction with their results from the Conductor Lab from the previous lesson. Remind students that conductors and insulators are opposites, so the best insulating materials are the ones that don't let heat flow through easily.
3. **Introduce thermometers.** Hold up one digital thermometer (optional: and also one analog thermometer). Ask students to identify the tool and explain its use.

   **Note:** Look for confusion between the words temperature and thermometer. If needed, explain that "thermometer" is the tool used to measure "temperature". Talk with students who are confused by this concept. Ask them to explain what they know, and assist them in differentiating between the terms.
4. **Practice using the thermometers.** Each group should have one digital thermometer. Allow students to figure out how to turn the thermometers on and off, as well as switch between measuring Celsius and Fahrenheit. Make sure the thermometers are set to measure Fahrenheit for this lab. Have students practice using the thermometers by measuring the temperature of the air and the temperature when someone grasps it in their hand.

5. **Connect the thermometers with the glass jar activity. Ask:** *How can we know which glass jar contains the coolest water? How does this relate to heat transfer?* (Take students answers.) Ask more questions (if needed) and guide the discussion that the following points are addressed:
    - High numbers measured by the thermometer mean a hot temperature; low numbers mean cooler temperatures.
    - Therefore, the jar with the lower final temperature has the coolest water. Another way to see this is to calculate the change in temperature. The jar with the smallest change in temperature has the coldest water (i.e., the temperature did not change by much).
    - This relates to heat transfer because the jar with the coolest water had the least amount of heat energy transfer from the room temperature air through that material.

    **Note:** If needed, distinguish between temperature and heat. Temperature is a measure of how hot or cold some material is, while heat is a kind of energy that flows from hot to cold.
6. **(Optional) Create a data table for the Insulator Lab.** If students are using engineering notebooks, have them create a data table for the Insulator Lab. An example of what this table could look like can be found in the *4.a. Insulator Lab* worksheet.
7. **Begin to fill out the data table.** Have students fill in the Initial Temperature of the Water (°F) column in their *4.a. Insulator Lab* Data Table. This number should be the initial temperature that the teacher measured before pouring the cold water into the jars.
8. **(Optional) Become familiar with the vaccine coolers' contents.** Pass around 2-3 mini ice packs that will be used inside the students' vaccine coolers, as well 2-3 empty vials, so the students can feel and see what they look like. **Say:** *In many coolers, including vaccine coolers, there are a few pre-formed ice packs along with the actual cooler contents. For this engineering problem, each of your cooler designs will need to hold one vial of vaccine and two mini ice packs. The ice packs and your designed cooler will need to be able to prevent the heat from the air and the sun from warming the vaccine.*

    **Note:** This activity is a useful way to use up time if the jars have not been sitting out at least 20 minutes. If enough time has passed, this activity can be skipped.
9. **Measure final temperatures for the Insulator Lab.** After 20-30 minutes have passed, have student teams measure the temperature of their assigned jar. Before the actual measurement, instruct the students on the process:
    - Have one student from each team ready at their teams' assigned jar with the thermometer on and set to Fahrenheit.
    - When the teacher says, "Go," one team member should hold the base of the jar still, another team member should lift the lid, and the team member with the thermometer should place the thermometer into the water.
    - The team member with the thermometer should stir the water without touching the sides or bottom of the jar; this team member should read the lowest temperature the digital thermometer reports.

    **Note:** When the teacher says, "Go," the teacher should note how much

time has passed since the water was first poured into the jars.
**(Optional)** Have students return the jars and thermometers to the appropriate spots in the classroom.

10. **Record and share data.** Instruct each group to share their jar's final temperature with the whole class. Have students record these final temperatures in the appropriate boxes in the *4.a. Insulator Lab* Data Table. As the teacher, record these values on a piece of poster size sticky note paper so the whole class can see. Also, share the total time that passed during the activity so the students can record it.
11. **Calculate the change in temperature.** Have student groups calculate and record the change in temperature for each jar. Student groups should check with each other to make sure they correctly did the calculations.
**(Optional)** Students may use calculators if necessary but are encouraged not to since this is good practice for subtracting decimals.
12. **Discuss the results.** Pose the following discussion/conclusion questions to student groups. Have students discuss them in their teams and record their answers individually, on the *4.a. Insulator Lab* worksheet or in their engineering notebooks. If there seems to be confusion about any of the questions, address them as a whole class.
    - What does a large change in temperature mean?
    - What does a small change in temperature mean?
    - In the last column in the data table, rank the insulators from best to worst. Make 1 = best and 8 = worst.
    - Which materials in this lab were good insulators? What evidence supports that claim? (How can you tell?)
    - Which materials were not good insulators? What evidence supports that claim? (How can you tell?)
    - How do the Conductor Lab's rankings compare to the Insulator Lab's rankings?
    - How do the conductors and insulators compare?
    - Were there any results that surprised you?
    - Is there anything that might have affected these results?

    **Note:** These questions are all on the *4.a. Insulator Lab* worksheet. Their answers, along with sample data, are available on the teacher guide version of the worksheet.

**Closure**

1. **Fill out the "insulator" square of the vocabulary cube.** Ask students to take out their *1.c. Key Terms Cube* worksheet. Have students find the box marked "insulator". **Ask:** *What are the important points we learned about insulators today?* Tell students to write words or phrases, and to sketch pictures or diagrams to show what they now know about insulators.

    **Note:** As students fill out the insulator square of the cube, circulate and check what they are writing and/or drawing. Note which students work independently and which still seem to need support from their team members.

# Heat and Insulators

LESSON 4

Name________________________________ Date___________ Period _____

# 4.a. Insulator Lab

**Predict:** Which glass jar do you think will work the best to keep the water cold? Explain why you think that.

Insulator Lab Data Table                    Total Time: _____________min

| Type of material | Initial temp of water (°F) | Final temp of water (°F) | Change in temp of water (°F) | Rank: best insulator to worst |
|---|---|---|---|---|
| None/control | | | | |
| Aluminum foil | | | | |
| Foam board | | | | |
| Felt | | | | |
| Wax paper | | | | |
| Bubble wrap | | | | |
| Cotton | | | | |
| Construction paper | | | | |

Name______________________________ Date__________ Period _____

# 4.a. Insulator Lab

**Discuss and Conclude:**

1. What does a large change in temperature mean?

2. What does a small change in temperature mean?

*In the last column in the data table, rank the insulators from best to worst. Make 1=best and 7=worst.*

3. Which materials in this lab were good insulators?

4. What evidence supports that claim?  (How can you tell?)

5. Which materials were not good insulators?

6. What evidence supports that claim (How can you tell?)

Name________________________________ Date___________ Period _____

# 4.a. Insulator Lab

7. How do the Conductor Lab's rankings compare to the Insulator Lab's rankings?

8. How do the conductors and insulators compare?

9. Were there any results that surprised you?

10. Is there anything that might have affected these results?

# 4.a. Insulator Lab

**Predict:** Which glass jar do you think will work the best to keep the water cold? Explain why you think that.
Answers may vary. An example would be, "I think that the felt will keep the water cold the best because it wasn't a good conductor in the hand warmer lab and didn't let the heat flow through it."

**Sample Data:**

Insulator Lab Data Table

Total Time: 25 min

| Type of material | Initial temp of water (°F) | Final temp of water (°F) | Change in temp of water (°F) | Rank: best insulator to worst |
|---|---|---|---|---|
| None/control | 32.1 | 53.3 | 21.2 | 8 |
| Aluminum foil | 32.1 | 51.3 | 19.2 | 7 |
| Foam board | 32.1 | 46.4 | 14.3 | 3 |
| Felt | 32.1 | 45.7 | 13.6 | 2 |
| Wax paper | 32.1 | 49.2 | 17.1 | 6 |
| Bubble wrap | 32.1 | 48.3 | 16.2 | 4 |
| Cotton | 32.1 | 42.3 | 10.2 | 1 |
| Construction paper | 32.1 | 49.1 | 17.0 | 5 |

# 4.a. Insulator Lab

**Discuss and Conclude:**

1. What does a large change in temperature mean?

A large change in temperature means that the heat transferred through that material well and warmed up the water, so it is a bad insulator.

2. What does a small change in temperature mean?

A small change in temperature means that the heat did not transfer through that material well so the water stayed pretty cool, so it is a good insulator.

In the last column in the data table, rank the insulators from best to worst. Make 1=best and 7=worst.

3. Which materials in this lab were good insulators?

Answers may vary, but usually: felt, foam, cotton

4. What evidence supports that claim? (How can you tell?)

Students can refer to a low final temperature (e.g., “Felt was a good insulator because it had a low final temperature of 44.5°F”) or a small change in temperature (e.g., “Felt was a good insulator because it’s temperature changed the smallest amount, 11.5°F”).

5. Which materials were not good insulators?

Answers may vary, but usually: control (no material), wax paper, aluminum foil, construction paper

6. What evidence supports that claim (How can you tell?)

Students can refer to high final temperatures or large change in temperatures (see above similar question for examples).

# 4.a. Insulator Lab

7. How do the Conductor Lab's rankings compare to the Insulator Lab's rankings?
The rankings are the opposite. The materials that were ranked high in the Conductor Lab were ranked low in the Insulator lab.

8. How do the conductors and insulators compare?
The materials that are the best conductors are the worst insulators, and the materials that are the best insulators are the worst conductors.

9. Were there any results that surprised you?
Answers may vary.

10. Is there anything that might have affected these results?
Answers may vary, but could include statements like: leaving the lid off of the jar too long before measuring the temperature, not stirring while taking the temperature, etc.

LESSON 5

# Plan a Solution

**Lesson Objectives**
The students will be able to:
- Use evidence from problem scoping to generate multiple initial ideas for a design solution.
- 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 (i.e., heat transfer, conductors, insulators)/ mathematics concepts and information obtained in problem scoping.
- Add and multiply decimals to calculate the cost of the design, keeping the cost under $5.00.

**Time Required**
One 50-minute class period

**Materials**
- See Overview

**Standards Addressed**
- Next Generation Science Standards: 4-PS3-2, *MS-PS3-3, 3-5-ETS1-2
- Common Core State Standards – Mathematics: 4.MD.A.2
-

**Key Terms**
design

## Lesson Summary

Students will review what information they have learned about the engineering problem and use it to begin solution generation. They will use a list of materials and their cost, as well as what they have learned about vaccines, heat, conductors, and insulators, to design a model vaccine cooler that will cost $5.00 or less. Students will first generate multiple possible design solutions individually; then, in their teams, they will use the ideas generated individually to determine one design solution that will be implemented and tested. Students will use evidence-based reasoning to justify their proposed design solution.

## Background

### Teacher Background

For the past four 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 is developing written plans; trying (i.e., implementing or building) the planned solution and testing and evaluating that implemented prototype solution will occur in the next two 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

On one poster size sheet of sticky note paper, draw an Evidence-Based Reasoning template (like worksheet 5.b.). 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 *5.b. Evidence-Based Reasoning* worksheets. Rather, they are to use it as a guide to help them fill out their own versions of the template.
**(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 suggestions that are not already present.

Prepare the materials needed for testing the design solution. While students will not actually be trying/building during this lesson, they will need to be able to see and feel the materials they will be working with in order to adequately plan a design solution.
- Mini ice packs: Students need to see the mini ice packs and feel what it is like to work with them. Make sure the pre-formed mini ice packs are frozen the night before. Freeze enough so that there are two available per team. On the day of class, put ¼ water and ¼ ice in two pitchers. When the mini ice packs are removed from the freezer for class, put them in the ice water so they stay frozen. If the mini ice packs stick to each other, use a large kitchen spoon to stir the ice water and loosen them.
- Empty vials: Have one empty vial available per team so students can get a grasp of the size of the vial.  This will let the students identify the size of

what goes inside the cooler.
- Testing stations: Put one 40 Watt bulb in each of the four heat lamps. (Since two coolers fit under one lamp, four heat lamps are needed to test eight prototype vaccine coolers.) Clamp each heat lamp approximately 1.5 feet off a surface where the coolers will be placed; they can be clamped to a cabinet, counter top, or ring stand. The heat lamps need to be far enough apart that each of their emitted heats doesn't interfere with the others. Turn on each of the heat lamps and place a piece of masking tape directly under the most direct light of the lamp. One cooler will be placed on each side of the tape during testing. Turn the heat lamps off for the rest of this lesson.
  **Warning:** Heat lamps become hot quickly. Do not touch!

Materials: Set out the materials that students can purchase for their design. They will not actually start constructing in this lesson, but it is helpful for them to see what materials are available and in what sizes.
- For some of the materials (i.e., aluminum foil, wax paper, foam, felt, bubble wrap), make sure that they are cut to the appropriate size if necessary. It is recommended to have 2-3 of each of these materials, along with the construction paper, 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 preferred by many teams.)
- Teams may end up using many cotton squares and craft sticks, so have a package of each ready.
- Tape may be pre-cut into 6 inch strips or cut as students need it. It is up to the teacher and the space constraints of the classroom.

## Classroom Instruction

### Introduction

1. **Tie to the engineering 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?* (Design a container that keeps vaccines cool so they don't spoil.)
2. **Identify where they 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 heat energy, heat transfer, and conductors and insulators, 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. **Introduce the term "design". Say:** *We have used the term "design" a lot in this unit. So far, we have used it as something we do; we are*

## 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 generating design ideas using the *5.a. Design Ideas Worksheet* and *5.b. 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**
At the end of the lesson, check what students write and/or draw in the "Design" square of their own cube templates. Note which students work independently and which still seem to need support from their team members

## DUPLICATION MASTERS

- 5.a. Design Ideas - Individual Plan
- 5.b. Evidence-Based Reasoning
- 5.c. Materials Cost Sheet

## EDUCATOR RESOURCES

- 5.b. Evidence-Based Reasoning - Poster with Explanation
- 5.b. Evidence-Based Reasoning - Chill Out Example

*going to design a solution. However, "design" can also refer to an object in engineering. In this case, a design is a written plan and/or drawing that shows how the engineering problem is solved. The solution to the problem is usually a design. Today you will be planning your designs, which means that you will create a written plan with drawings for how to build a vaccine cooler.*

4. **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**

1. **Introduce evidence-based reasoning.** Post an evidence-based reasoning template drawn on a sheet of poster size sticky note paper. Pass out an *5.b. Evidence-Based Reasoning* worksheet to each student or have them draw the EBR template in their notebooks. **Say:** *To help you with your planning, 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 information specific to their engineering design problem.
2. **Review the problem.** Direct students' attention to the "Problem including Criteria and Constraints" section of the *5.b. Evidence-Based Reasoning* worksheet and posters. On the poster, write down a general definition of "problem" (e.g., the problem the client asked you to solve). Instruct students to write a summary of their engineering problem in this section, leaving room for criteria and constraints.
3. **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 *Evidence-Based Reasoning* poster. Refer students back to their lists of criteria and constraints from their *2.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 including Criteria and Constraints" section of the *5.b. Evidence-Based Reasoning* worksheet.

   **Note:** Use this time to show students the vial, mini ice packs, and heat lamps that are now set up in the classroom. Remind students that their coolers need to surround a vial of vaccine and two mini ice packs. Also, explain that to test how well their prototypes keep the vaccines cool, they will place their coolers (with a vial of cool vaccine and two mini ice packs inside) under a heat lamp for 10 minutes.
4. **Introduce the cost sheet.** Point out that one of the constraints of the problem is that the prototype should cost less than $5.00, but students

don't yet know how much each material costs. Pass out a *5.c. Materials Cost Sheet* to each student. **Say:** *You will need to use this Materials Cost Sheet to calculate the cost of your designs. If your design costs more than $5.00, then it does not meet the requirements, or constraints, that the client asked for.*

5. **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?*

   **Note:** 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
6. **Explain what information goes in each of the remaining sections.** Have students guess at what kind of information they think should go in the "Plan," "Data/Evidence," and "Explanation, Justification, Reasoning" sections of the *5.b. Evidence-Based Reasoning* worksheet. Write down relevant student suggestions in the appropriate section of the *Evidence-Based Reasoning* poster. This could include:
   - **Plan:** 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
   - **Data/Evidence:** Observations and data that show why you think your design will work. Examples: data from the Conductor Lab and the Insulator Lab; total cost of the design
   - **Explanation, Justification, Reasoning:** 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.
7. **Individual plan.** Pass out one *5.a. Design Ideas - Individual Plan* worksheet to each student or have students draw a table similar to the one on the worksheet in their engineering notebooks. **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 idea that you will write in the rest of the 5.b. Evidence-Based Reasoning template. To be the most creative and ensure 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 *5.a. Design Ideas - Individual Plan* worksheet (or similar version drawn in their engineering notebooks). Point out that for these initial designs, they don't need to separate their data/evidence from their explanation,

justification, and reasoning; that information should be written in the "Why do you think will will work" section.

**Note:** Remind students that even though they are not yet filling out the bottom three sections of the *5.b. Evidence-Based Reasoning* template, they should still think about the information they wrote in the "Problem including Criteria and Constraints" and "Simplifying Assumptions" sections when they generate their individual design ideas.

**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.

8. **Group plan.** As students in the same team finish, encourage them to talk with other team members about their cooler design ideas and what materials they should use. Have the students evaluate each of the possible solutions in their notebooks by answering the prompt: *What are the pros and cons of each of the solutions?* Have teams develop one team design, using what they think are the best parts of their multiple design ideas. As a team, have them fill out the rest of their *5.b. Evidence-Based Reasoning* worksheet or template in their notebook with their team's design. During these discussions, circulate, 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 good insulators. As a summary, have the individual students answer the following prompt in their notebooks: *Which solution did your team choose and why?*

**Closure**

1. **Fill out the "design" square of the vocabulary cube.** Ask students to take out their *1.c. Key Terms Cube* worksheet. Have students find the box marked "design". **Ask:** *What are the important points we learned about designs today?* Tell students to write words or phrases, and to sketch pictures or diagrams to show what they now know about designs.
   **Note:** As students fill out the design square of the cube, circulate and check what they are writing and/or drawing. Note which students work independently and which still seem to need support from their team members.

LESSON 5

Name________________________________ Date____________ Period ______

# 5.a. Design Ideas - Individual Plan

| Design Idea | Why do you think this will work? |
| --- | --- |
| #1 | |
| #2 | |
| #3 | |

LESSON 5

Name________________________________ Date__________ Period _____

# 5.b. Evidence-Based Reasoning

| **Problem with Criteria & Constraints** (What do you need to worry about?) | |
|---|---|
| **Problem:** ______________________________ | |
| **Criteria:** ______________________________ | |
| **Constraints:** ______________________________ | |
| **Simplifying Assumptions** (What do you not need to worry about?) | |
| | |
| **Plan** (Design Idea) | **Data/Evidence** (Facts) |
| | |
| **Explanation, Justification, Reasoning** (Why do you think this will work?) | |
| | |

# 5.b. Evidence-Based Reasoning

## Poster with Explanation

<table>
<tr><td colspan="2">Problem with Criteria & Constraints (What do you need to worry about?)</td></tr>
<tr><td colspan="2">Problem: the engineering problem the client asked you to solve<br><br>Criteria: the requirements, or goals, of the designed solutions<br>Constraints: things that limit design possibilities</td></tr>
<tr><td colspan="2">Simplifying Assumptions (What do you not need to worry about?)</td></tr>
<tr><td colspan="2">Ways to make a complex problem simpler</td></tr>
<tr><td>Plan (Design Idea)</td><td>Data/Evidence (Facts)</td></tr>
<tr><td>• Description of the design<br>• Drawings of the design, different views<br>• Dimensions (sizes)<br>• Label materials in design (show where they are used)<br>• Interesting features<br><br>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.</td><td>Observations and data that show why you think your design will work<br><br>Examples:<br>• Data from Conductor Lab and Insulator Lab<br>• Total cost of design</td></tr>
<tr><td colspan="2">Explanation, Justification, Reasoning (Why do you think this will work?)</td></tr>
<tr><td colspan="2">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.</td></tr>
</table>

# 5.b. Evidence-Based Reasoning

## Chill Out Example

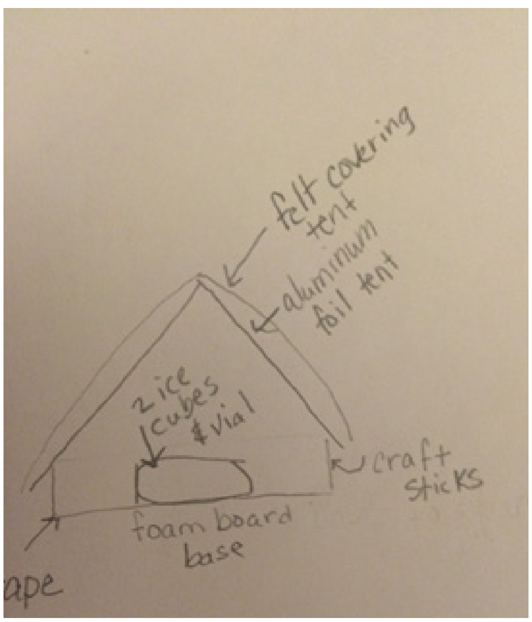
**Problem with Criteria & Constraints** (What do you need to worry about?)

**Problem:** To build a container that will keep a vaccine cool without power.
**Criteria:** The temperature of the vaccine must stay between 32-42°F for 10 minutes under the heat lamp. It needs to hold one vial and two ice packs and needs to have a way to put the vial of vaccine in and get it out.
**Constraints:** The cooler should cost $5.00 or less.

**Simplifying Assumptions** (What do you not need to worry about?)

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

**Plan** (Design Idea)




**Data/Evidence** (Facts)

The poorest ranked conductors were the felt, foam board, and cotton; they had the longest time to feel the heat warmer to our hand.

In the insulator lab, the felt had the smallest change in temperature at 11.5°F. Foam board and cotton tied at about 13°F temperature change.

The amount of materials needed for this design would cost $4.90.

**Explanation, Justification, Reasoning** (Why you think this will work?)

We will be using felt, foam board, and cotton since our data show them to be the worst conductors/best insulators. Insulators prevent heat transfer from warm to cold, so they should keep the vaccine cool. Our design also meets the constraint of costing $5.00 or less, since our materials would only cost $4.90.

LESSON 5

Name________________________________ Date____________ Period ______

# 5.c. Materials Cost Sheet

| | |
|---|---|
| aluminum foil, one 12 x 12 in. square | $0.50 |
| construction paper, one 9 x 12 in. piece | $0.25 |
| wax paper, one 12 x 12 in. square | $0.50 |
| foam board, one 5.5 x 8.5 in. rectangle | $1.00 |
| felt, one 6 x 6 in. square | $1.00 |
| bubble wrap, one 12 x 12 in. square | $1.00 |
| cotton square, 2 x 2 in. (6 pieces) | $1.00/ 6 squares |
| craft stick, each | $0.10/ each |
| tape, one 6 in. piece | $0.25/ 6 inch piece |
| rubber band, one | $0.25/ each |
| vial, each | free |
| 2 mini ice packs | free |

| Material | Price for One Item x | Quantity Needed = | Total Cost for Item |
|---|---|---|---|
| | | | |
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| | | | |
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| | | | |
| | | | |
| | | | |

**Total Materials Cost** = ________________

LESSON

# 6 Try a Solution

## Lesson Objectives
The students will be able to:
- Implement a design and create a prototype vaccine cooler.
- Add and multiply decimals to calculate the cost of the design, keeping the cost under $5.00.

## Time Required
One 50-minute class period

## Materials
- See Overview

## Standards Addressed
- Next Generation Science Standards: 4-PS3-2, *MS-PS3-3, 3-5-ETS1-2
- Common Core State Standards: 4.MD.A.2

## Key Terms
none

## Lesson Summary
Students will implement their planned design and create a prototype vaccine cooler. Before students can obtain materials, they will submit two items to the teacher for approval: an *5.b. Evidence-Based Reasoning* worksheet explaining the team's chosen design and a *5.c. Materials Cost Sheet* with materials chosen and cost amounts calculated. Once checked, the teacher will distribute materials and offer guidance to teams if they seem to have forgotten materials such as vials or scissors.

## Background
### Teacher Background
Students will be using scissors to construct their prototype vaccine coolers. Reinforce with the class safety rules already in place for using scissors.

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 it to gather all of the materials in a tub and move from team to team distributing materials. 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 and rubber bands. 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 cooler without any planning.

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

### Before the Activity
The mini ice packs and empty vials will be needed for this lesson as students implement/create their vaccine cooler prototypes. These materials will need to be collected at the end of class for use during the next day. The directions for preparing these are in lesson 5 and also here:
- Mini ice packs: Make sure the pre-formed mini ice packs are frozen the night before. Freeze enough so that there are two available per team. On the day of class, put ¼ water and ¼ ice in two pitchers. When the mini ice packs are removed from the freezer for class, put them in the ice water so they stay frozen. If the mini ice packs stick to each other, use a large kitchen spoon to stir the ice water and loosen them.
- Empty vials: Have one empty vial available per team so students can get a grasp of the size of the vial.  This will let the students identify the size of what goes inside the cooler.

The four testing stations are not needed for this lesson, since students will not yet test their prototypes. However, it may be useful to have them set up. Instructions for preparing the heat lamp testing stations are in lesson 5 and also here:
- Testing stations: Put one 40 Watt bulb in each of the four heat lamps. (Since

two coolers fit under one lamp, four heat lamps are needed to test eight prototype vaccine coolers.) Clamp each heat lamp approximately 1.5 feet off a surface where the coolers will be placed; they can be clamped to a cabinet, counter top, or ring stand. The heat lamps need to be far enough apart that each of their emitted heats doesn't interfere with the others. Turn on each of the heat lamps and place a piece of masking tape directly under the most direct light of the lamp. One cooler will be placed on each side of the tape during testing. Turn the heat lamps off for the rest of this lesson.
**Warning:** Heat lamps become hot quickly. Do not touch!

The most essential part of this lesson is to prepare and organize the materials that students will need in order to create their prototype vaccine coolers.

- For some of the materials (i.e., aluminum foil, wax paper, foam, felt, bubble wrap), make sure that they are cut to the appropriate size if necessary. It is recommended to have 2-3 of each of these materials, along with the construction paper, 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.)
- Teams may end up using many cotton squares and craft sticks, so have a package of each ready.
- Tape may be pre-cut into 6 inch strips or cut as students need it. It is up to the teacher and the space constraints of the classroom.

## Classroom Instruction

### Introduction

1. **Tie to the engineering challenge. Say:** *In the previous lesson, your team decided on a plan for a prototype vaccine cooler, as requested by our client, Peyton Sadler of The True Chill Company.*
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 yesterday?* (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

1. **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.

## Assessments

**Pre-Activity Assessment**
Check students' ability to 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 model coolers. Go to each team assess their progress with the *6.a. Teacher Observation Protocol*. Note which groups are using materials that are proven insulators. Look for groups 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 sharing at least one feature of their cooler they believe will make it successful, ask them why they think that. The purpose is to get students to use their lab data as evidence.

## DUPLICATION MASTERS

- none

## EDUCATOR RESOURCES

- 6.a. Teacher Observation Protocol: Try Lesson

- Before a team can get materials, they need to present their completed *5.b. Evidence-Based Reasoning* worksheet describing their design solution AND one completed *5.c. Materials Cost Sheet* 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.)
- Once a team has purchased materials, they will not be allowed to go to the store again, except to purchase more tape and rubber bands. The teams should be creating what they have decided upon in their plans, so they should have all of the materials they might need.

2. **Try/build/create.** Instruct students to start working. If needed, they can finish discussing their plan and filling out the *5.b. Evidence-Based Reasoning* sheet and *5.c. Materials Cost Sheet* for that 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 with the *6.a. Teacher Observation Protocol: Try Lesson*. 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 model be the most successful and be prepared to explain why to the class.
3. **(Optional) Create *1.c. Key Terms Cube*.** After teams have completed building their designs but before students put their scissors away, have them cut out their completed *1.c. Key Terms Cube*. Distribute tape to students so that they can tape it into a cube. Have students write their names on their cubes and store them with their team's prototype.
4. **Clean up.** Leave enough time for students to put their cooler materials neatly away and pick up the room. Be sure to collect the empty vials (for safe storage) and the mini ice packs (need be re-frozen again).

**Closure**

1. **Share designs.** Invite teams that have finished their coolers to present them to the class and explain the design features they think will make their model successful.

# 6.a. Teacher Observation Protocol: Try Lesson

**Directions:**

This is an observation assessment. The main purpose of this assessment is to observe evidence that student teams are working together to make their solution. In addition, this is opportunity to further assess that students are making design-decisions based on understanding the problem.

- **Part 1:** As you walk around to each team, please put a check by the behaviors you observe.
- **Part 2:** Interact with each team to assess their progress on the project. You may choose to ask some of the following questions or your own questions. You may also choose to add (or not) your own additional teaming-related assessment, as you deem appropriate. There is space for you to take notes of your observations.

**Part 1: Behaviors**

☐ All team members are on-task to make/try their solution.

☐ One or more team members are not on-task.

Notes:

☐ Team has made appropriate progress on their solution.

☐ Team is struggling to make their solution.

Notes:

☐ Team is making/made a solution directly related to problem.

☐ Team is making/made a something unrelated to problem.

Notes:

 

# 6.a. Teacher Observation Protocol: Try Lesson

**Part 2: 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. Please note student responses below.*

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 7 Test and Decide About a Solution

**Lesson Objectives**
The students will be able to:
- Test their vaccine cooler prototypes.
- Measure the temperature of a liquid, their "vaccine," using a thermometer.
- Subtract decimals to calculate the change in temperature of their vaccine.
- Compare temperature and cost values with decimals to compare their design's performance with the performance of their peers' designs.
- Analyze the characteristics of the best performing vaccine coolers.

**Time Required**
One 50-minute class period

**Materials**
- See Overview

**Standards Addressed**
- Next Generation Science Standards: 4-PS3-2, *MS-PS3-3, 3-5-ETS1-1, 3-5-ETS1-2, 3-5-ETS1-3
- Common Core State Standards - Mathematics: 4.MD.A.2

**Key Terms**
None

## Lesson Summary
Students will test their vaccine cooler prototypes' performance by placing their coolers, each with two mini ice packs and a vial of ice water inside, under heat lamps for 10 minutes. They will measure the final temperature and calculate the temperature change. All student teams will share their design's cost, temperature change, and additional characteristics with the whole class. Students will analyze these data, determine why some designs worked better than others, and begin to think about redesigning.

## Background
### Teacher Background
It is important to have the heat lamps on for 3-5 minutes before testing to make sure the temperature under the lamps is consistent during testing.

Keep a note of any groups that take longer than the majority of the other groups to get the vial and ice cubes into their cooler. Decreasing the setup time would be valuable information when students are in their redesign stage.

(This note is for the end of the lesson, when students start to think about redesigning.) For redesign, students have two options as far as materials and cost. The first is to continue to work on their initial design, changing it or adding to it. If they choose this option, any additional materials they purchase will be added to the cost of their initial design. In other words, the total materials of the redesign, including the initial design plus changes, should still cost less than $5.00. The second option is to scrap the initial design's materials and start over. If students choose to do this, they use all new materials, but all of these new materials should remain under $5.00.

### Before the Activity
The mini ice packs and vials will be needed for this lesson when students test their vaccine cooler prototypes. These materials will need to be collected at the end of class for use during the next day. The directions for preparing these are:
- Mini ice packs: Make sure the pre-formed mini ice packs are frozen the night before. Freeze enough so that there are two available per team. On the day of class, put ¼ water and ¼ ice in two pitchers. When the mini ice packs are removed from the freezer for class, put them in the ice water so they stay frozen. If the mini ice packs stick to each other, use a large kitchen spoon to stir the ice water and loosen them.
- Vials: Have one vial available per team. Before class begins, fill each vial with ice-cold water. Place these vials in the ice water in the two pitchers along with the mini ice packs. This will ensure that the water inside the vials stays close to freezing temperature.

The four testing stations are needed for this lesson. Instructions for preparing the heat lamp testing stations are in lessons 5 and 6 and also here:
- Testing stations: Put one 40 Watt bulb in each of the four heat lamps. (Since two coolers fit under one lamp, four heat lamps are needed to test eight prototype vaccine coolers.) Clamp each heat lamp approximately 1.5 feet off a surface where the coolers will be placed; they can be clamped to a cabinet, counter top, or ring stand. The heat lamps need to be far enough

apart that each of their emitted heats doesn't interfere with the others. Turn on each of the heat lamps and place a piece of masking tape directly under the most direct light of the lamp. One cooler will be placed on each side of the tape during testing. Make sure that the heat lamps are on for 3-5 minutes before testing begins to keep the temperature under the lamps consistent. Turn the lamps off when testing finishes.
**Warning:** Heat lamps become hot quickly. Do not touch!

Use one sheet of poster size sticky note paper to make a data table on which student teams will record their results. The data table should include Team Name, Cost, Starting Temperature, Final Temperature, Temperature Change, and Additional Features (see *7.a. Test and Decide* worksheet in duplication masters for an example).

## Classroom Instruction

### Introduction

1. **Tie to the engineering challenge. Say/Ask:** *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 and Decide)** Draw students' attention to the *Engineering Design Process* poster and their *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 and Decide)
   **Note:** While students will mostly likely have a good idea of what it means to test their solutions, clarify that "Decide" means "decide whether their solutions are good enough". In other words, students will determine whether their solutions adequately meet the criteria of the problem.
3. **Discuss the importance of testing. Ask:** *Why do you think it is important for engineers to test their models and prototypes?* (Take student answers.) Guide discussion so students' realize that engineers test and evaluate models/prototypes to see if they work the way the engineers predict.

### Activity

1. **Retrieve coolers.** Have student teams get their built vaccine cooler prototypes and any other materials they intend to use to close it.
2. **Walk students through the testing procedures.** Pass out the *7.a. Test and Decide* worksheet if students are using worksheets. Otherwise, they will write their testing data and evaluation questions and answers directly into their engineering notebooks. Before actually performing the heat transfer test of the vaccine cooler prototypes, go over the directions with the students. Emphasize to students that testing is sensitive to time. Everyone needs to have their vaccine coolers under the heat lamps for the same amount of time, so the teams have to wait until everyone else is ready to put their vaccine coolers under the lamp. The longer a team takes to pack their vaccine coolers, the more likely it is that the vial of vaccine will start to warm up. The directions given to students are:
   **Begin the test:**
   1. Get a vial with "vaccine" in it and two mini ice packs.
   2. Put the vial and two mini ice packs in your vaccine cooler.

**Assessments**

**Pre-Activity Assessment**
Check students' ability to 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 *7.b. Teacher Observation Protocol: Test Lesson*. Check how well students remember to use the digital thermometers when the teams practice measuring temperature while the coolers are under the heat lamps. Also, check student teams' math when subtracting decimals of the temperature measurements. Most importantly, check students' understanding during the discussion analyzing the results of the tests; this should indicate students' understanding of heat transfer, conductors, and insulators. Students will complete engineering notebook prompts (or use the *7.a. Test and Decide* worksheet) to assess their test results.

**Post-Activity Assessment**
Check in with students teams as they evaluate the success of their coolers and begin to think about redesign.

**DUPLICATION MASTERS**
- 7.a. Test and Decide

**EDUCATOR RESOURCES**
- 7.b. Teacher Observation Protocol: Test Lesson

3. Wait until all of the teams have their vaccine coolers ready.
4. Put your vaccine cooler under a lamp. It should be next to the tape.

**End the test:**

1. Remove your cooler from under the lamp.
2. Open the cooler.
3. Take the "vaccine" out and QUICKLY take the temperature.
   The temperature is the LOWEST number that displays on the digital thermometer.

**Note:** Assign teams to heat lamps (two teams per heat lamp). Students will then know exactly where to place their vaccine cooler when it's packed up and ready to be tested.

4. **Measure the initial temperature. Say:** *I have your vials of cool "vaccine" sitting in ice water. They have been in the ice water long enough that the temperature of the "vaccine" inside the vials should be the same as the temperature of the water in the pitcher. Rather than measure the temperature of all of the vials, I will measure the temperature of the water in the pitcher, and we will assume that the pitcher water and all vial "vaccines" are the same temperature.* Stir the ice water in the pitchers using a large kitchen spoon to make sure the temperature is the same throughout each pitcher. Measure the temperature of the water; it should be approximately 33°F. Write this temperature in each box under the "Starting Temperature" column of the poster data table.
5. **Distribute vials of vaccine and mini ice packs.** Have one person from each team come to the ice water pitchers. Give each person one vial of vaccine and two mini ice packs.
6. **Pack the vaccine coolers.** Have each team pack a vial and two mini ice packs into their vaccine cooler. When all vaccine coolers are packed, have teams place them under the heat lamps. There should be two vaccine coolers per lamp, one on either side of the piece of tape.
   **Note:** Start timing the 10 minutes for testing when teams place their vaccine coolers under the heat lamps.
   **Note:** Keep a note of any groups that take noticeably shorter or longer to get the vial and ice packs into their cooler. If a team has a short packing time, they may be able to cite this as a desirable "Additional Feature". On the other hand, decreasing the setup time would be valuable for redesign.
7. **Practice taking temperature.** During the ten minutes of testing, have students practice using their digital thermometers by taking temperature measurements of the air and also body temperature (by holding the thermometer). If students are struggling, review the buttons that turn the thermometers on and off, as well as how to change the degrees from Celsius to Fahrenheit.
8. **(Optional) Create a data table in engineering notebooks.** If students are using engineering notebooks, give them time to create the class data table in their notebooks.
9. **Measure the temperatures of the "vaccines."** After 10 minutes have passed, instruct student teams to remove their vaccine coolers from under the heat lamps and bring them to their team work areas. Teams should then open the coolers, remove the vial of vaccine, and measure the temperature of the liquid inside the vial. When they are finished, they should re-cap the

vial so the "vaccine" doesn't spill.

10. **Return the vials and mini ice packs.** Have one member from each student team return the vials and mini ice packs to the pitchers.
11. **Record and calculate data.** Have students record data about their vaccine coolers, including the cost of their designs, the starting temperature, the final temperature, and the temperature increase (which they will need to calculate). Students should also record additional features of their prototypes that they think will be appealing to the client. For example, if their vaccine cooler was small but still large enough to be able to hold the vial and two ice packs, the end users could pack more vaccine coolers in. If the container was an easily packable shape (e.g., cube), the cooler might be easier to transport. If the cooler was quick and easy to pack and unpack, that would be useful to the end users.
12. **Share and discuss 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. As class data get written on the data table poster, have students copy them into their own records. When all of the data is recorded, **ask:** *Which coolers had the least amount of temperature change? Why do you think these coolers had less temperature change?* Have teams with the smallest temperature changes show their prototypes to the whole class. Guide student discussion and prompt students to use what they know about heat energy, heat transfer, and insulators. Have students record their answers to these questions in the *7.a. Test and Decide* worksheets or directly into their engineering notebooks.
13. **Assess student progress.** As students are testing, walk around and assess student progress with the *7.b. Teacher Observation Protocol: Test Lesson.*
14. **Discuss other aspects of the vaccine coolers.** Have teams with unique "additional characteristics" share those characteristics with the class and why they think the client and/or end user will find them useful. Also, discuss cost and the relationship between the costs of the coolers and how well they performed.

**Closure**

1. **Team reflection. Say:** *We have finished testing your initial designs for the vaccine cooler prototypes. Now, each team needs to decide how successful their vaccine cooler prototype was and what features they can change for the redesign.* Have students discuss and record answers to the following questions (in the *7.a. Test and Decide* worksheet or directly into their engineering notebooks):
    1. What have you learned about the performance of your solution from your test results? (What worked well and did not work well? How do you know?)
    2. What improvements will you make to your solution based on the results of your tests? Explain why you want to make those changes.
    3. What improvements will you make to your solution based on the science and/or math you have learned? Explain why you want to make those changes.
    4. Is your team going to start over with completely new materials and $5.00 to spend, OR are you going to buy more materials and fix/

change your existing design and add onto your previous cost? Explain why your team chose that option.

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

**Note:** Clarify the two materials and cost options for question 4 (see **Teacher Background**).

7. **Revisit the problem. Ask:** *How has what we learned developing solutions changed how we think about the engineering problem? Do we need to clarify, change, or add information on to the problem?* (Take students answers.) Have students record their answers to the question, "What revisions to your understanding of the problem (criteria, constraints, client needs, and/or things you need to learn) do you need to make based on what you have learned through the testing of your solution?" in their engineering notebooks or in the *7.a. Test and Decide* worksheet (question #7).

    **Note:** While the heat transfer test and cost limit are unlikely to change, students may find that some of the additional features should be added to the problem as additional criteria. For example, ease of getting the vaccine in and out of the cooler may not have been an initial criterion, but students may want to add it to the problem.

8. **(Optional) Create *1.c. Key Terms Cube*.** If there is still time remaining, have students cut out their completed *1.c. Key Terms Cube*. Distribute tape to students so that they can tape it into a cube. Have students write their names on their cubes and store them with their team's initial prototype.

# Test and Decide About a Solution

LESSON 7

Name______________________________ Date__________ Period _____

# 7.a. Test and Decide

How well does your model vaccine cooler work? Let's test it.

**Begin the test:**

1. Get a vial with "vaccine" in it and two mini ice packs.
2. Put the vial and two mini ice packs in your vaccine cooler.
3. Wait until all of the teams have their vaccine coolers ready.
4. Put your vaccine cooler under a lamp. It should be next to the tape.

**End the test:**

1. Remove your cooler from under the lamp.
2. Open the cooler.
3. Take the "vaccine" out and QUICKLY take the temperature.
   The temperature is the LOWEST number that displays on the digital thermometer.

**Results:**

Cost $_______

Starting Temp_______ Final Temp_______ Temp Increase_______

Additional features of your design:

LESSON 7

Name______________________________ Date____________ Period ______

# 7.a. Test and Decide

## Class Data from Vaccine Cooler Testing

| Team Name | Cost $ | Starting Temp (°F) | Final Temp (°F) | Temp increase (°F) | Additional Characteristics |
|---|---|---|---|---|---|
| | | | | | |
| | | | | | |
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| | | | | | |
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| | | | | | |

**Whole Class Discussion Questions:**

1. Which cooler had the least amount of temperature change?

2. Describe why these coolers had less temperature change.

Name__________________________________ Date____________ Period _____

# 7.a. Test and Decide

**Team Reflection Questions:**

1. What have you learned about the performance of your solution from your test results? (What worked well and did not work well? And how do you know?)

2. What improvements will you make to your solution based on the results of your tests? Explain why you want to make those changes.

3. What improvements will you make to your solution based on the science and/or math you have learned? Explain why you want to make those changes.

4. Is your team going to start over with completely new materials and $5.00 to spend, OR are you going to buy more materials and fix/change your existing design and add onto your previous cost? **Explain** why your team chose that option.

Name________________________________ Date__________ Period _____

# 7.a. Test and Decide

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

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

7. What revisions to your understanding of the problem (criteria, constraints, client needs, and/or things you need to learn) do you need to make based on what you have learned through the testing of your solution?

# 7.b. Teacher Observation Protocol: Test Lesson

**Directions:**
This is an observation assessment. The main purpose of this assessment is to observe evidence that student teams are working together to make their solution. In addition, this is opportunity to further assess that students are making design-decisions based on understanding the problem.

- **Part 1:** As you walk around to each team, please put a check by the behaviors you observe.
- **Part 2:** Interact with each team to assess their progress on the project. You may choose to ask some of the following questions or your own questions. You may also choose to add (or not) your own additional teaming-related assessment, as you deem appropriate.  There is space for you to take notes of your observations.

**Part 1: Behaviors**
**Testing**

☐ All team members are on-task to test solution.

☐ One or more team members are not on-task.

Notes:

☐ Team has made appropriate progress on testing and analysis.

☐ Team is struggling to test or analyze their solution.

Notes:

☐ Team has identified how to improve solution.

☐ Team is struggling to consider improved performance.

Notes:

# 7.b. Teacher Observation Protocol: Test Lesson

**Part 2: 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. Please note student responses below.*

4. What did you find out from testing?

5. How did you interpret the findings from your tests? What do you think the results mean?

6. How did you decide what could improve your solution's performance?

# LESSON 8 Redesign

## Lesson Objectives

The students will be able to:

- Use evidence from problem scoping and initial design test analysis to plan an improved design.
- Perform operations with decimals to calculate cost and temperature change.
- Implement a design and create a prototype vaccine cooler.
- Measure the temperature of a liquid, their "vaccine," using a thermometer.
- Test the performance of the improved solution.
- Compare temperature and cost values with decimals to compare their second design's performance with the performance of their initial design.
- Evaluate the alignment between their proposed solution and the problem.

## Time Required

One to two 50-minute class periods

## Materials

- see Overview

## Standards Addressed

- Next Generation Science Standards: 4-PS3-2, *MS-PS3-3, 3-5-ETS1-1, 3-5-ETS1-2, 3-5-ETS1-3
- Common Core State Standards: 4.MD.A.2

## Key Terms

none

## Lesson Summary

Based on the discussion and analysis of the initial design test results, students will work to improve their cooler. Students will redesign, rebuild, retest and reevaluate the performance of a model vaccine cooler. Students will compare and contrast their results with the results of their initial design and decide on which design to suggest to the client as the solution to the engineering problem.

## Background

### Teacher Background

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.

After analyzing and evaluating their first prototype, students will begin to identify potential problems in the design, construction, 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. For students who immediately want to build, remind them of the importance of thinking through a design and creating written plans first. 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 (i.e., keep the vaccine below 42°F, keep cost below $5.00) to focus on meeting those criteria in their redesign. For teams that did meet the two main criteria, encourage them to improve their design (i.e., allows even less heat transfer, costs even less). Additionally, teams can think about other features that came up during defining the problem or testing the solution, such as the need for a relatively small cooler or a cooler that is easy to put in and remove the vaccine vial.

For redesign, students have two options as far as materials and cost. The first is to continue to work on their initial design, changing it or adding to it. If they choose this option, any additional materials they purchase will be added to the cost of their initial design. In other words, the total materials of the redesign, including the initial design plus changes, should still cost less than $5.00. The second option is to scrap the initial design's materials and start over. If students choose to do this, they use all new materials, but all of these new materials should remain under $5.00.

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 through one redesign in one to two class periods. If a group finishes the redesign cycle (plan, try, test, decide) much earlier than other groups, you may choose to let them redesign a third prototype. Another option would be to encourage that student group 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 finish and review their *1.c. Key Terms Cube*, start thinking about the letter to the client, or do any other activity that is deemed necessary for the unit.

It is important to have the heat lamps on for 3-5 minutes before testing to make sure the temperature under the lamps is consistent during testing.

**Before the Activity**
The mini ice packs and vials will be needed for this lesson when students test their second vaccine cooler prototypes. These materials will need to be collected at the end of class for use during the next day. The directions for preparing these are:

- Mini ice packs: Make sure the pre-formed mini ice packs are frozen the night before. Freeze enough so that there are two available per team. On the day of class, put ¼ water and ¼ ice in two pitchers. When the mini ice packs are removed from the freezer for class, put them in the ice water so they stay frozen. If the mini ice packs stick to each other, use a large kitchen spoon to stir the ice water and loosen them.
- Vials: Have one vial available per team. Before class begins, fill each vial with ice-cold water. Place these vials in the ice water in the two pitchers along with the mini ice packs. This will ensure that the water inside the vials stays close to freezing temperature.

The four testing stations are needed for this lesson. Instructions for preparing the heat lamp testing stations are in lessons 5 and 6 and also here:

- Testing stations: Put one 40 Watt bulb in each of the four heat lamps. (Since two coolers fit under one lamp, four heat lamps are needed to test eight prototype vaccine coolers.) Clamp each heat lamp approximately 1.5 feet off a surface where the coolers will be placed; they can be clamped to a cabinet, counter top, or ring stand. The heat lamps need to be far enough apart that each of their emitted heats doesn't interfere with the others. Turn on each of the heat lamps and place a piece of masking tape directly under the most direct light of the lamp. One cooler will be placed on each side of the tape during testing. Make sure that the heat lamps are on for 3-5 minutes before testing begins to keep the temperature under the lamps consistent. Turn the lamps off when testing finishes.
  **Warning:** Heat lamps become hot quickly. Do not touch!

**Assessments**
**Pre-Activity Assessment**
Check students' ability to 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 activities and discussions. Examine new prototypes and ask teams to explain how…

- *Does/did their new design address the shortcomings of design 1?*
- *Will/did the construction of design 2 make the cooler work better?*
- *Will/did the materials chosen improve the performance of the cooler?*
- *Will/did you lower the cost?*

While students are testing their redesigned vaccine coolers, walk around to teach team and assess their progress using the *8.d. Teacher Observation Protocol: Redesign Lesson.*

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

**DUPLICATION MASTERS**

- 8.a. Evidence-Based Reasoning
- 8.b. Materials Cost Sheet
- 8.c. Redesign

**EDUCATOR RESOURCES**

- 8.a. Evidence-Based Reasoning - Poster with Explanation
- 8.d. Teacher Observation Protocol: Redesign Lesson

LESSON 8

# Redesign

Prepare and organize the materials that students will need in order to create their second prototype vaccine coolers.

- For some of the materials (i.e., aluminum foil, wax paper, foam, felt, bubble wrap), make sure that they are cut to the appropriate size if necessary. It is recommended to have 2-3 of each of these materials, along with the construction paper, 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.)
- Teams may end up using many cotton squares and craft sticks, so have a package of each ready.
- Tape may be pre-cut into 6 inch strips or cut as students need it. It is up to the teacher and the space constraints of the classroom.

## 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 have made 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?* (Test, Decide, and re-Defining the problem.) Point out that in addition to testing their prototypes and deciding upon the prototype vaccine coolers' success, they also discussed the problem again and redefined it in terms of what they learned from designing a solution. **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

1. **Review the initial solution's evaluation.** Allow students a few minutes to finish up and/or review what they have written in the Team Reflection Questions from the *7.a. Test and Decide* notes (written on the worksheet or directly in their engineering notebooks). Check what students have written to make sure they correctly reviewed the performance and cost of their original designs and applied what they learned to their suggestions for a new design. Remind students about their option to either keep their initial design and change it, adding new materials on to their previous cost, or scrap their initial design and start over from $0.00. Either way, the second design materials' total cost should still remain under $5.00.

2. **Re-introduce EBR.** Pass out one *8.a. Evidence-Based Reasoning* sheet (or post for them to see) and one *8.b. Materials Cost Sheet* to each team. Review what goes in each box by referencing the *Evidence-Based Reasoning* explanations sticky note poster created in Lesson 5. In the box marked Evidence, add "**Data from prototype testing**". **Say:** *Now that we have tested out initial vaccine cooler designs, we have evidence from those tests in addition to the evidence we had before from the heat transfer, conductors, and insulators labs and demonstrations. When you are supporting your new design, you can use both kinds of evidence to support your design.*
3. **Plan the redesign.** Allow student teams time to fill out the *8.a. Evidence-Based Reasoning* sheet and *8.b. Materials Cost Sheet* 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 their new design will make the cooler work better, what materials they chose to improve the performance of the cooler, and how they lowered the cost. When a team has adequately filled out the *8.a. Evidence-Based Reasoning* sheet and *8.b. Materials Cost Sheet* 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 *8.b. Materials Cost Sheet* that reflects the prices of the original materials plus any additional materials they purchase for the redesign.)

   **Note:** For more information about plan, see Lesson 5.
4. **Try/Build the redesign.** Distribute supplies to teams at request. As before, once teams have filled out their *8.b. Materials Cost Sheet*, 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 tape and rubber bands.) Circulate among the teams as they build their second vaccine cooler prototypes. Continue to ask them questions about the design, why they made the changes they did, and why they think it will improve.

   **Note:** For more information about try/build, see Lesson 6.
5. **Test the redesign.** Pass out the *8.c. Redesign* worksheets, one per student. (This sheet has instructions for testing on it.) The data collected during testing and evaluation questions and answers may also be written directly into students' engineering notebooks. When teams are ready, pass out the vaccines and ice packs and put the second vaccine cooler prototypes under the heat lamps for 10 minutes. When testing is done, have them record the cost, initial temperature, final temperature, temperature increase, and addition features in their *8.c. Redesign* notes. **(Optional)** While students are waiting, have them review key terms on their completed *1.c. Key Terms Cube*. Help them add/correct any unfinished/incorrect cube responses.

   **Note:** For more information about try/build, see Lesson 7.
6. **Decide about the redesign. Say:** *Instead of comparing your second prototypes to other teams' prototypes, now you will compare your second vaccine cooler prototype to your first vaccine cooler prototype.* Have

students compare the results of the two prototype designs and consider the following questions (on the *8.c. Redesign* worksheet or in their engineering notebooks):

1. What worked well with your second vaccine cooler? How do you know?
2. What did not work well with your second vaccine cooler? How do you know?
3. Which of your vaccine cooler prototypes would the client think is better? Explain using evidence. (**Hint:** Think about whether the solution meets the criteria of the problem.)

**Note:** While students are evaluating their designs, circulate the room. Answer questions and encourage students to support their answers with data and explanations.

**Note:** 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.

7. **Assess student progress.** As students are testing and evaluating their redesigned vaccine coolers, walk around and assess student progress with the *8.d. Teacher Observation Protocol: Redesign Lesson*.

**Closure**

1. **Share recommendation to client.** Have each student team briefly share with the class which of their vaccine cooler 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 explanations 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.

LESSON 8

Name____________________ Date__________ Period _____

# 8.a. Evidence-Based Reasoning

| **Problem with Criteria & Constraints** (What do you need to worry about?) | |
|---|---|
| **Problem:** ______________________________ | |
| **Criteria:** ______________________________ | |
| **Constraints:** ______________________________ | |
| **Simplifying Assumptions** (What do you not need to worry about?) | |
| | |
| **Plan** (Design Idea) | **Data/Evidence** (Facts) |
| | |
| **Explanation, Justification, Reasoning** (Why do you think this will work?) | |
| | |

# 8.a. Evidence-Based Reasoning

## Poster with Explanation

| Problem with Criteria & Constraints (What do you need to worry about?) | |
|---|---|
| **Problem:** the engineering problem the client asked you to solve<br><br>**Criteria:** the requirements, or goals, of the designed solutions<br><br>**Constraints:** things that limit design possibilities | |
| **Simplifying Assumptions** (What do you not need to worry about?) | |
| Ways to make a complex problem simpler | |
| **Plan** (Design Idea) | **Data/Evidence** (Facts) |
| • Description of the design<br>• Drawings of the design, different views<br>• Dimensions (sizes)<br>• Label materials in design (show where they are used)<br>• Interesting features<br><br>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. | Observations and data that show why you think your design will work<br><br>Examples:<br>• Data from Conductor Lab and Insulator Lab<br>• Total cost of design<br>• Data from prototype testing |
| **Explanation, Justification, Reasoning** (Why do you think this will work?) | |
| Complete sentences that state why you think your design will be successful. These sentences should refer to the problem, criteria, constraints, solution, and data/evidence. | |

LESSON 8

Name________________________________ Date___________ Period _____

# 8.b. Materials Cost Sheet

| | |
|---|---|
| aluminum foil, one 12 x 12 in. square | $0.50 |
| construction paper, one 9 x 12 in. piece | $0.25 |
| wax paper, one 12 x 12 in. square | $0.50 |
| foam board, one 5.5 x 8.5 in. rectangle | $1.00 |
| felt, one 6 x 6 in. square | $1.00 |
| bubble wrap, one 12 x 12 in. square | $1.00 |
| cotton square, 2 x 2 in. (6 pieces) | $1.00/ 6 squares |
| craft stick, each | $0.10/ each |
| tape, one 6 in. piece | $0.25/ 6 inch piece |
| rubber band, one | $0.25/ each |
| vial, each | free |
| 2 mini ice packs | free |

| Material | Price for One Item x | Quantity Needed = | Total Cost for Item |
|---|---|---|---|
| | | | |
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| | | | |

**Total Materials Cost =** ________________

LESSON 8

Name________________________________ Date__________ Period _____

# 8.c. Redesign

How well does your model vaccine cooler work? Let's test it.

**Begin the test:**

1. Get a vial with "vaccine" in it and two mini ice packs.
2. Put the vial and two mini ice packs in your vaccine cooler.
3. Wait until all of the teams have their vaccine coolers ready.
4. Put your vaccine cooler under a lamp. It should be next to the tape.

**End the test:**

1. Remove your cooler from under the lamp.
2. Open the cooler.
3. Take the "vaccine" out and QUICKLY take the temperature.
   The temperature is the LOWEST number that displays on the digital thermometer.

**Results of 2nd vaccine cooler:**

Cost $_______

Starting Temp_______ Final Temp_______ Temp Increase_______

Additional features of your design:

LESSON 8

Name______________________________ Date__________ Period _____

# 8.c. Redesign

**Team Reflection Questions:**

1. What worked well with your second vaccine cooler? How do you know?

2. What did not work well with your second vaccine cooler? How do you know?

3. Which of your vaccine cooler prototypes would the client think is better? Explain using evidence.
   **Hint:** Think about whether you're the solution meets the criteria of the problem.

LESSON 8

Name______________________________________ Date____________ Period _____

# 8.d. Teacher Observation Protocol: Redesign Lesson

**Directions:**
This is an observation assessment. The main purpose of this assessment is to observe whether teams are testing their improved solution and analyzing results. In addition, this is opportunity to further assess that students are making design-decisions based on understanding the problem.

- **Part 1:** As you walk around to each team, please put a check by the behaviors you observe.
- **Part 2:** Interact with each team to assess their progress on the project. You may choose to ask some of the following questions or ask your own questions. You may also choose to add (or not) your own additional teaming-related assessment, as you deem appropriate. There is space for you to take notes of your observations.

**Part 1: Behaviors Testing Improved Solution**

☐ All team members are on-task to retest solution.

☐ One or more team members are not on-task.

Notes:

☐ Team has attempted to improve performance of solution.

☐ Unclear what improvements team made.

Notes:

# LESSON 9 Communicate to the Client

## Lesson Objectives
The 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 (i.e., heat transfer, conductors, insulators)/ 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 on it, (optional) 1 poster size sticky note paper, (optional) 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: 4-PS3-2, *MS-PS3-3, 3-5-ETS1-1, 3-5-ETS1-2, 3-5-ETS1-3
- Common Core State Standards: 4.MD.A.2

## Key Terms
none

## Lesson Summary
In this lesson, students will write a letter to or create a poster for the client, Peyton Sadler of The True Chill Company, about their design. The letter or poster will need to explain the design with text and drawings and justify the design 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; students could also copy the template into their engineering notebooks. Additionally, have the *Evidence-Based Reasoning* explanations poster 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, the creation of this communication may be done by students 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
(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?* (Take student answers.)
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?* (Take student answers.) 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 been working in teams and communicating within your teams and with other teams. Now you need to communicate to the client, Peyton Sadler of The True Chill Company, so that they know about your design and why it meets their needs.*

# Communicate to the Client

**Activity**

1. **Review the client letter.** Have students review the *2.a.True Chill Client Letter* that they received in lesson 2. Emphasize the last paragraph of the letter. **Say/Ask:** *In the letter we received from Peyton Sadler of The True Chill Company, they stated that they want us to communicate our designs to them. What else did they say that we need include in that communication?* (Justify the designs with evidence)
2. **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.
3. **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**

1. **Reflect on the engineering design process.** Have the students reflect in their engineering notebooks about the entire unit both individually and in their team. Use the following prompts:
   A. Look back in your Engineering Notebook to see how you defined the problem throughout solving the problem. **How has your <u>understanding of the problem changed</u> during the design process?** Think in terms of client needs, criteria, constraints, and the science and mathematics needed to solve the problem.
      a. My response:
      b. Team response:
   B. Look back in your Engineering Notebook to see how you developed your solution throughout solving the problem. **How has your <u>understanding of how to design a solution changed</u> during the design process?** Think in terms of what you did and how you made decisions to solve the problem.
      a. My response:
      b. Team response:
   C. **How do <u>engineers solve problems</u>?**
      a. My response:

**Assessments**

**Pre-Activity Assessment**
Check students' ability to 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**
- none

**EDUCATOR RESOURCES**
- none

b. Team response:

2. **(Optional)** If students finish early, have them review key terms on their completed *1.c. Key Terms Cube*. Help them add/correct any unfinished/incorrect cube responses.
3. **(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 groups, with students reading/viewing the letters/posters of others.

# Communicate to the Client

# 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 questions do you want to ask to the client?

### Section 3:

**Client:**
Who is the client?

**Problem:**
What is the client's problem that needs a solution?

**Why it is important:**
Why is the problem important to solve?

**End-users:**
Who are the end-users?

**Criteria:**
What will make the solution effective (criteria)?

 

# Notebook Prompts and Titles

**Constraints:**
What will limit how you can solve the problem (constraints)?

**What we need to learn:**
Think about the problem of keeping vaccines cool when there is no power or unreliable power. What do you need to learn in order to create a design that successfully keeps vaccines cool?

## 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 solutions?

**Why we chose our solution:**
Which solution did your team choose and why?

## Test Solution Idea(s) Lessons

### Section 1:

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

**Learned from test results:**
What have you learned about the performance of your solution from your test results?

**Changes from test results:**
What changes will you make to your solution based on the results of your tests? Explain why you want to make those changes.

**Changes from science/math learned:**
What improvements will you make to your solution based on the science and/or math you have learned? Explain why you want to make those changes.

### Section 2:

# Notebook Prompts and Titles

*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?

**Changed problem description:**
Go back and look at how you described the problem right after talking with the client. How would you change your description of the problem now that you have planned, tried, and tested a solution? (Think about criteria, constraints, client need, and/or things you need to learn.)

## Decide/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:**
Look back in your Engineering Notebook to see how you defined the problem throughout solving the problem. *How has your understanding of the problem changed during the design process?* Think in terms of client needs, criteria, constraints, and the science and mathematics needed to solve the problem.

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

 