EngrTEAMS

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

Mineral Mayhem

Grades 7-8

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

This material is based upon work supported by the National Science Foundation under grant NSF DRL-1238140. Any opinions, findings and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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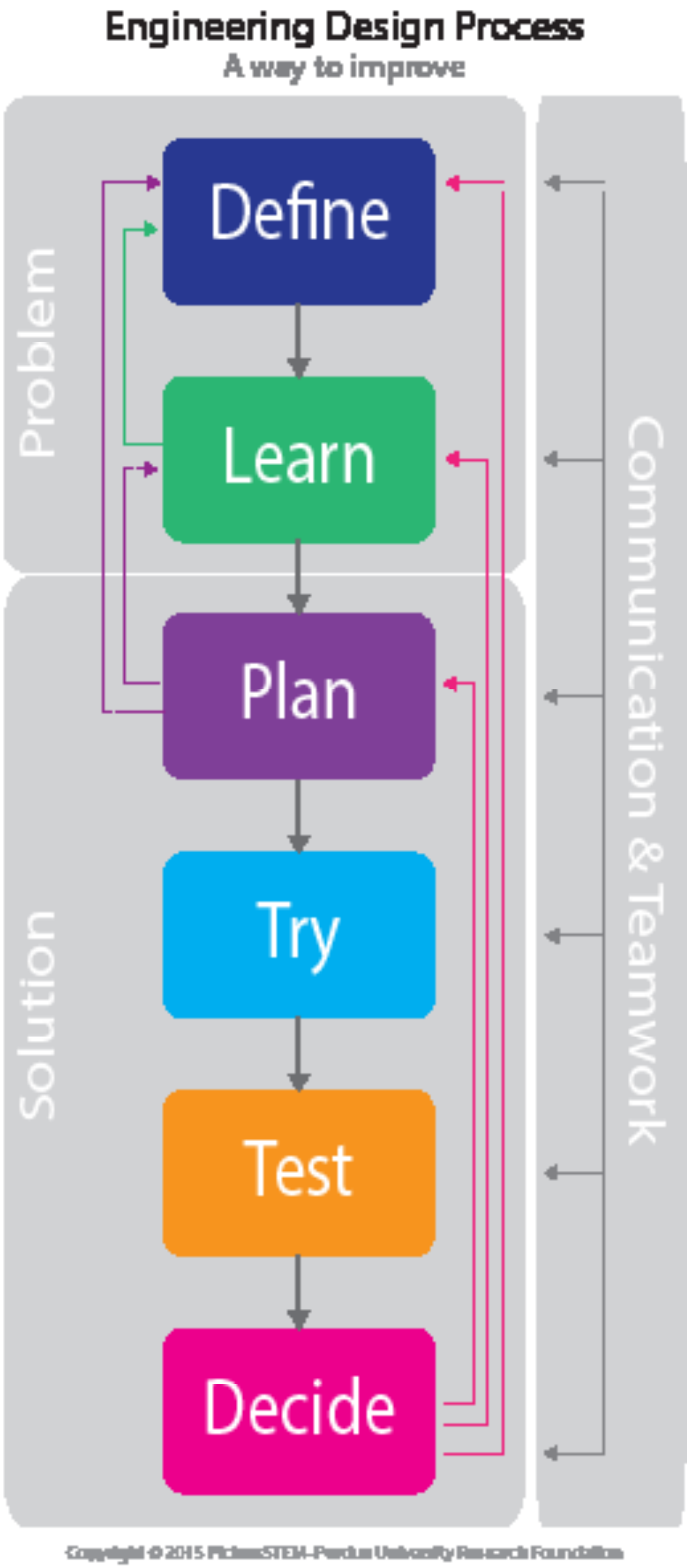
About EngrTEAMS
Purpose
The project is designed to help 200 teachers develop engineering design-based curricular units for each of the major science topic areas within the Minnesota State Academic Science Standards, as well as data analysis and measurement standards for grades 4-8.

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
Problem
Solution
Define
Learn
Plan
Try
Test
Decide
Communication & Teamwork
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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: 7-8

Approximate Time Needed to Complete Unit: Fourteen 50-minute class periods

Unit Summary

Mineral properties and identification tests provide the basis for this engineering-driven STEM unit. Built on the real-world premise of a cargo train derailing from its tracks, students will complete an engineering challenge to design a process to sort minerals that have been spilled into a lake. As they learn about mineral properties and the value of non-renewable mineral resources, students will use this information to support evidence-based reasoning as they make design decisions. In addition, there are components of research and mathematical reasoning in thinking about cost-benefit analysis and in considering the physical property of density, including how to calculate and represent mass, volume and density in different ways. Students will also strengthen their communication skills by creating a presentation to explain their process and justify their decisions, aiming to convince a client that their process is the best option.

Science Connections	Technology & Engineering Connections	Mathematics Connections
Properties of minerals, identification methods for minerals, non-renewable resources	Engineering design process, Environmental & Civil Engineering, Process design, Process modeling, Process-Flow diagrams	Proportional reasoning, Scatterplots, Lines of best fit, Slope of a line, Density, Volume

Unit Standards

Next Generation Science Standards

- 5-PS1-3: Make observations and measurements to identify materials based on their properties.
- MS-ETS1-1: Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.
- MS-ETS1-2: Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.
- MS-ETS1-3: Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.
- MS-ETS1-4: Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.

Common Core State Standards - Mathematics

- CCSS.MATH.CONTENT.8.EE.B.5: Graph proportional relationships, interpreting the unit rate as the slope of the graph. Compare two different proportional relationships represented in different ways.
- CCSS.MATH.CONTENT.HSS.ID.C.7: Interpret the slope (rate of change) and the intercept (constant term) of a linear model in the context of the data.

Overview

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 design. 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/Power Point 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 sometimes set up as handouts in the lessons. 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.
- There is a pre-post content assessment in this unit.
- The final summative piece of this unit requires students to provide a process and a presentation for their client.

Overview

Lesson Summaries

Lesson 1: Off the Rails

Students will be introduced to the engineering problem by reading a client memo, which orients them to the problem of sorting minerals reclaimed from a lake after a train accident. They will be introduced to the engineering design process and will conduct research on the importance of minerals as a non-renewable resource.

Lesson 2: Let's Sort It Out

Students will work in small groups of three to sort a set of minerals according to their similarities and differences and identify possible ways of distinguishing between minerals. They will learn about the mineral identification methods used by geologists.

Lesson 3: Which Mineral is That?

Working in teams, students will work through a series of stations to measure the physical properties of minerals. They will learn about mineral hardness, streak, shape (cleavage/fracture), luster (metallic/glassy/dull), magnetism, and color.

Lesson 4: Discovering Density

In their teams, students will investigate the relationship between mass and volume for a material. They will measure the mass and use water displacement to determine volume of mineral samples. They will create a scatterplot of mass vs. volume, draw a line of best fit, and calculate the slope of the line to discover the density of the minerals. Students will also use the density formula to calculate densities of additional minerals.

Lesson 5: Go with the Flow

Students will revisit the criteria and constraints of their engineering design challenge. They will be introduced to the various machines that will be available for their use, how the machines work, and their associated costs. Students will be given a sample process flow diagram that shows a process that could be used to sort a set of minerals. They will learn how to interpret the diagram, calculate the cost of the process, and determine the value of the minerals that are sorted. This process will not be optimized, so students will have an opportunity to investigate possible improvements.

Lesson 6: Engineering Design Challenge

Teams will be given the names of a new set of minerals to sort and identify. They will work together to create a process flow diagram that shows how the minerals could be sorted. They will justify each choice and evaluate their process design based on the cost of the machines they use and the value of the minerals they sort.

Lesson 7: Process Redesign

Student teams will find out that plastic and wood are also mixed in with the minerals being recovered from the lake. Given the new constraint, they will modify their previous process flow diagram to separate the plastic and wood from the minerals.

Overview

Lesson 8: Convincing the Client

Having optimized their process designs, teams will create presentations about their sorting processes. They will justify their choices and try to convince the client that their process is the best option. Students will also draft a memo to the client summarizing the design and their arguments in favor of it.

Overview

Lesson	Time Needed	**Objectives** The student will be able to:
1: Off the Rails	Two 50-minute class periods	• Identify the engineering design problem. • Research mineral value and importance. • Describe economic, social, and ethical considerations related to minerals.
2: Let's Sort it Out	One 50-minute class period	• Identify similarities and differences of minerals through hands-on investigation. • Identify physical properties of minerals that can be used to sort and classify them.
3: Which Mineral is That?	Two 50-minute class periods	• Conduct tests of mineral properties. • Record mineral data in a table. • Use mineral properties to identify three mystery minerals. • Describe which properties would be most useful in separating specific minerals.
4: Discovering Density	Three 50-minute class periods	• Measure the volume of irregularly shaped minerals using the water displacement method. • Generate and interpret a scatterplot. • Calculate the slope of a line of best fit on a scatterplot. • Calculate density using the formula density - (mass/volume).

Overview

Materials * required materials not included in the kit	Duplication Masters
• **Per classroom:** *1 sheet of poster paper, *Markers, *White out, *Permanent marker, Engineering design process poster • **Per group:** Set of 10-12 minerals (any diverse mix of minerals will suffice, but a possible set could include quartz, feldspar, magnetite, calcite, talc, hornblende, muscovite, bauxite, graphite, and pyrite) • **Per student:** *Pencil, *Engineering notebook, Engineering design process slider	• 1.a. Content Pre-Assessment • 1.b. Client Letter 1 • 1.c. Problem Scoping Prompts • 1.d. Mineral Research • 1.e. Non-Renewable Resources Guide • 1.f. Mineral Uses Guide • 1.g. Environmental Impacts Guide **EDUCATOR RESOURCES** • 1.h. Client Letter 2 Template
• **Per classroom:** *1 sheet of poster paper, *Markers, Engineering design process poster • **Per group:** Set of 10-12 minerals (any diverse mix of minerals will suffice, but a possible set could include quartz, feldspar, magnetite, calcite, talc, hornblende, muscovite, bauxite, graphite, and pyrite) • **Per student:** *Pencil, *Engineering notebook, Engineering design process slider	• 2.a. Client Letter 3 • 2.b. Mineral Sort • 2.c. Mineral Identification Tests
• **Per classroom:** *Rag, *Water, Engineering design process poster • **Per group:** Mineral set for property testing (bauxite, calcite, graphite, hornblende, magnetite, and talc), Mystery minerals: quartz, calcite, muscovite, *Mineral identification testing materials (streak plates, glass plates, steel nails, pennies, magnets, hand lenses) • **Per student:** *Pencil, *Engineering notebook, Engineering design process slider	• 3.a. Client Letter 4 • 3.b. Mineral Identification Data • 3.c. Mineral Station Information Sheets • 3.d. Mineral Identification Chart • 3.f. Mystery Minerals Claims & Evidence • 3.g. Mystery Minerals Exit Slip **EDUCATOR RESOURCES** • 3.e. Mineral Identification Chart (Master)
• **Per classroom:** *1 permanent marker (for labeling bags), 2 sets of inch density cubes, 2 sets of equal mass rods, 1 set of 1000 plastic centimeter cubes, 1 sheet of poster paper, Markers, Engineering design process poster • **Per group:** *Electronic balance, *Overflow can, *Pieces of aluminum gathered from home and school (varied sizes), 5 pieces of graphite, 5 pieces of magnetite, *Metric ruler, Handful of centimeter cubes, Plastic beaker (for holding water), Transparent plastic graduated cylinder - 25 mL, graduated to .5 mL, Transparent plastic graduated cylinder - 100 mL, graduated to 1 mL • **Per student:** Pipette, *Ruler or straightedge, *Graph paper, *Pencil, *Engineering notebook, Engineering design process slider	• 4.a. Density Pre-Assessment • 3.d. Mineral Identification Chart (Lesson 3) • 4.b. Client Letter 5 • 4.c. Materials Observations • 4.d. Mineral Mass and Volume • 4.e. Mass and Volume Data • 4.f. Mineral Density Calculations

Overview

Lesson	Time Needed	**Objectives** The student will be able to:
5: Go with the Flow	One 50-minute class period	• Identify the criteria and constraints of the engineering design challenge. • Evaluate a process flow diagram that shows a mineral sorting process. • Make recommendations to improve a mineral sorting process.
6: Engineering Design Challenge	Two 50-minute class periods	• Create a process flow diagram to sort a given set of minerals. • Use evidence-based reasoning to justify their design choices. • Evaluate their process based on equipment costs and mineral values.
7: Process Redesign	One 50-minute class period	• Redesign their mineral sorting processes based on new constraints. • Evaluate their redesigned processes based on machine costs and mineral values.
8: Convincing the Client	Two 50-minute class periods	• Communicate science and engineering ideas by creating presentations to convince the client that their end product is the best option. • Use evidence-based reasoning to support their engineering decisions.

Overview

Materials * required materials not included in the kit	**Duplication Masters**
• **Per classroom:** Engineering design process poster • **Per group:** *Glue or tape, *Poster or butcher paper • **Per student:** *Pencil, *Engineering notebook, Engineering design process slider	• 5.a. Client Letter 6 • 5.b. Machine Overview • 5.c. Machine Exploration • 5.d. Process Flow Diagram: Sample 1 • 5.e. Machine Cards • 5.f. Process Flow Diagram: Sample 2 • 5.g. Process Recommendations • 3.d. Mineral Identification Chart (Lesson 3)
• **Per classroom:** Engineering design process poster • **Per group:** *Glue or tape, *Poster or butcher paper, 3 samples of each of the 7 minerals to be sorted: (bauxite, feldspar, hornblende, magnetite, pyrite, quartz, talc) • **Per student:** *Pencil, *Engineering notebook, Engineering design process slider	• 6.a. Client Letter 7 • 6.b. Evidence-Based Reasoning • 3.d. Mineral Identification Chart (Lesson 3) • 5.e. Machine Cards (Lesson 5) **EDUCATOR RESOURCES** • 6.c. Evidence-Based Reasoning - Poster with Explanation • 6.d. Teacher Observation Protocol (Plan/Try/Test)
• **Per classroom:** Engineering design process poster • **Per group:** *Glue or tape, *Poster or butcher paper, 3 samples of each of the 7 minerals to be sorted: (bauxite, feldspar, hornblende, magnetite, pyrite, quartz, talc), .*Samples of wood and plastic • **Per student:** *Pencil, *Engineering notebook, Engineering design process slider	• 7.a. Client Letter 8 • 7.c. Redesign Report • 3.d. Mineral Identification Chart (Lesson 3) • 5.e. Machine Cards (Lesson 5) **EDUCATOR RESOURCES** • 7.b. Teacher Observation Protocol (Redesign)
• **Per classroom:** Engineering design process poster • **Per group:** *Presentation materials (different options depending on available materials) • **Per student:** *Pencil, *Engineering notebook, Engineering design process slider	• 8.a. Client Letter 9 • 8.b. Client Communication Requirements • 8.c. Presentation Planning Sheet • 8.d. Client Letter 10 • 8.e. Content Post-Assessment

Overview

	Material	Lessons Where Material is Used
Per classroom	Mineral Samples - any 3-5 samples, just select from minerals already available	1
	2 sets of inch density cubes	4
	2 sets of equal mass rods	4
	1 set of 1000 plastic centimeter cubes	4
	Engineering design process poster	1, 2, 3, 4, 5, 6, 7, 8
	*Rag and water	3
	*4 sheets of poster paper	1, 2, 4
	*Markers	1, 2, 4
	*White out (for labeling mineral samples)	1, 2
	*Fine-tip permanent marker (for labeling mineral samples)	1, 2
	*Permanent marker	4
Per group (assuming 3 students per group)	Minerals (at least 3 pieces each): quartz, feldspar, magnetite, calcite, talc, hornblende, muscovite, bauxite, graphite, pyrite	2, 3
	*Electronic balance	4
	*Pieces of aluminum collected from home and school	4
	5 pieces of graphite, varied sizes ranging from 1-50 g	4
	5 pieces of magnetite, varied sizes ranging from 15-110 g	4
	*Mineral identification testing materials (streak plates, glass plates, steel nails, pennies, magnets, hand lenses)	3
	*Metric ruler	4
	Handful of centimeter cubes	4
	Plastic beaker (for holding water)	4
	Transparent plastic graduated cylinder - 25 mL, graduated to .5 mL	4
	Transparent plastic graduated cylinder - 100 mL, graduated to 1 mL	4
	*1 overflow can (optional)	4
	*Glue or tape	5, 6, 7
	*4 sheets of poster paper	5, 6, 7
	*Samples of wood and plastic	7
	*Markers	8
Per student	Pipette	4
	Engineering design process slider	1, 2, 3, 4, 5, 6, 7, 8
	*Ruler or straightedge	4
	*Graph paper	4
	*Pencil	1, 2, 3, 4, 5, 6, 7, 8
	*Engineering notebook	1, 2, 3, 4, 5, 6, 7, 8

* required materials not included in the kit

LESSON 1

Off the Rails

Lesson Objectives
The students will be able to:
- Identify the engineering problem including criteria and constraints and the needs of the client and end-user.
- Identify different stages in an engineering design process.
- Research mineral value and importance.
- Describe economic, social, and ethical considerations related to mineral use.

Time Required
Two 50-minute class periods

Materials
- **Per classroom:** *1 sheet of poster paper, *Markers, *White out, *Permanent marker, Engineering design process poster
- **Per group:** Set of 10-12 minerals (any diverse mix of minerals will suffice, but a possible set could include quartz, feldspar, magnetite, calcite, talc, hornblende, muscovite, bauxite, graphite, and pyrite)
- **Per student:** *Pencil, *Engineering notebook, Engineering design process slider

Standards Addressed
- Next Generation Science Standards: MS-ETS1-1

Key Terms
engineering design process, mineral, non-renewable resource

Lesson Summary
Students will be introduced to the engineering problem by reading a client memo, which orients them to the problem of sorting minerals. They will be introduced to engineering and the engineering design process and will conduct research on the importance of minerals as a non-renewable resource.

Background
Teacher Background
- **Teamwork:** Students should be grouped strategically and may or may not be assigned jobs within their group. When forming student groups, consider academic, language, and social needs. In place of strategic grouping, a random grouping can be substituted. Students will work in these groups, or “teams” throughout the unit. Effective teamwork is essential in this unit as well as in engineering in general; however, this unit does not provide specific support to develop those skills. If your students do not have experience with teamwork, it is highly recommended that you do some targeted team-building activities prior to beginning this unit.
- **Engineering & Engineering Design:** This lesson includes discussion about engineers and engineering. This may take more or less time depending on how much prior experience students have with engineering. The unit focuses on process engineering, where engineers design and optimize processes in various industries. In this unit, students will be designing a sorting process; they will not build or design any of the sorting machines. They are not responsible for removing the minerals from the lake. Additionally, the unit is also related to environmental engineering where engineers create solutions to mitigate human impact on the environment.
- **Engineering Notebook:** Throughout the unit students will be recording information in an engineering notebook. This can be either a binder or a bound notebook, but in either case students will need the notebook in Lesson 1.

Before the Activity
- Administer the *1.a. Content Pre-Assessment* prior to starting this lesson, either on a different day or at the start of the class period.
- Label all minerals using white out and a fine-tip permanent marker:
  - A: feldspar
  - B: talc
  - C: quartz
  - D: calcite
  - E: bauxite
  - F: magnetite
  - G: hornblende
  - H: muscovite
  - I: graphite
  - J: pyrite
- After completing Activity #2, make a new version of the *1.h Client Letter 2 Template* to include responses to the set of questions students identified in previous lesson. The 1.h. template provides directions.

Off the Rails

Classroom Instruction

1. **Introduce the unit. Say:** *We will be working on an engineering project related to helping sort minerals after a train derails.*
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 well help you assess the students ideas as well as help them recognize their own contributions and 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 prompts in their notebooks prior to teaching them anything else about the unit or about engineering. Tell students 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?

   Have them write their response in their engineering notebook, then discuss their answers with their neighbors. Have students share their responses with the class, and use students' responses to gauge their understanding of engineering and guide the following discussion. Encourage students to record new ideas in a different color in their notebooks.
4. **Introduce the Engineering Design Process.** Show Engineering Design Process graphic. Briefly describe each step. See the front matter for explanations of the steps of the engineering design process.

Introduction

1. **Introduce the client and the problem.** Explain that the students are going to be working in small groups to solve a problem being brought to them by the *Rocky Rails* transportation company. Divide students into groups of three. These groups should be their *teams* throughout the rest of the unit. Distribute copies of *1.b. Client Letter 1* and direct students to read the letter.

   Note: For ELL students or students who struggle with reading, a graphic organizer or other reading support strategy will be useful.
2. **Discuss ongoing communication with the client.** Explain that engineers often need to ask questions to help clarify the problem and what they are being asked to do. Initial communications from the client may

Assessments

Pre-Activity Assessment
- *Content Pre-Assessment*
- Notebook - Individual
  - Prompt 1: What do engineers do?
  - Prompt 2: How do engineers solve problems?
  - Use these prompts to gauge students' understanding of engineering as a profession and engineers as professionals.

Activity Embedded Assessment
- Problem Scoping Prompts for the Engineering Notebook
- *Mineral Research* worksheet

Post-Activity Assessment
- Engineering Notebook Response: *Write a claim with evidence about why the company is recovering the minerals from the lake instead of just getting a new supply.*

DUPLICATION MASTERS
- 1.a. Content Pre-Assessment
- 1.b. Client Letter 1
- 1.c. Problem Scoping Prompts
- 1.d. Mineral Research
- 1.e. Non-Renewable Resources Guide
- 1.f. Mineral Uses Guide
- 1.g. Environmental Impacts Guide

EDUCATOR RESOURCES
- 1.h. Client Letter 2 Template

be missing important information that the client might not have known the engineers would need. Students will need to ask questions of the client to better understand their task. Throughout the unit, students will continue to communicate with the client on a regular basis to receive more information and provide progress updates.

Activity #1

1. **Problem Scoping Part 1: Generating Questions**. The problem statement given in *1.b. Client Letter 1* purposefully does not provide all the information necessary to solve the problem. In this activity, students generate questions about the problem. This processes of generating questions for the client is an important skill on its own, but it also helps to ensure that the students fully understand the problem and their task. Once students have finished reading, have them generate questions to ask of the client.
    - Have students respond to the following prompt in their notebooks: *What questions do you want to ask the client?*
    - Ask students to share their questions. As students share, record these questions so that they are visible for all students to see.
        - "The Client" should provide answers to these questions. Compile a list of questions for the client, which can then be answered with *1.h. Client Letter 2.* Some questions, however, may need to be answered right away by the teacher on behalf of the client.
        - Students should be generating questions that 1) they need answered to solve the problem and 2) will help them understand the problem better. Students will probably have many relevant questions, but if they struggle you can give them an example. See *1.h. Client Letter 2 Template* for sample questions and strategies for answering the questions.
    - Once students have exhausted their questions, instruct them that you will share the questions with the client and get back to them with more information.
2. **Engineering Design Process. Ask:** *Which phase of the engineering design process are we in right now?* (Defining the problem) **Say:** *We are getting ready to begin learning about minerals and why they are important.*

Activity #2

Note: This activity can be done either before or after Problem Scoping Part 2. Here it is placed before Problem Scoping Part 2 to facilitate the time necessary for the teacher to prepare *1.h. Client Letter 2.* If there is a class period break at the end of Problem Scoping Part 1, however, the next period can begin with Problem Scoping Part 2.

3. **What do you notice and wonder.** Show students several minerals and tell them that these are minerals similar to the ones spilled by the Rocky Rails company. **Ask:** *What do you notice about these minerals? What do you wonder about minerals?* Allow students to share answers to both prompts.
4. **Defining minerals.** Explain that a mineral is defined as a naturally occurring, inorganic solid with a definite composition and crystal structure. This means that minerals are not living and that minerals of the same type have the same characteristics, including their structure and what they are made of.

5. **Researching mineral value, uses, & impacts.** Tell students that they are going to work with their teams to research minerals and find out why they are important. There are three different research guides available for use, and each group member will be responsible for gathering information from one guide. Each individual will record their findings on the *1.d. Mineral Research* worksheet or in their engineering notebooks, and the group will come together to share what they have found. These research guides constitute the minimum of what is necessary for the unit. Teachers are encouraged to supplement with resources suitable for their class.
   - Distribute resources to students - *1.e. Non-Renewable Resources Guide, 1.f. Mineral Uses Guide*, and *1.g. Environmental Impacts Guide*.
6. **Mineral research jigsaw.** Provide students with time to view the resources, take notes, and share information with their teammates. Each student will only use one of the research guides. Individuals are responsible for sharing what they learned from their packet with their teammates.

Activity #3

7. **Problem Scoping Part 2: Formulating the Problem**
   Note: Prior to this, the teacher must prepare a new version of the *1.h. Client Letter 2* with answers to the students' questions (see the *1.h. Client Letter 2 Template)*.
   - **Share *1.h. Client Letter 2*:** Have students read the response from the client.
     Note: Consider using visuals to support student understanding of the problem and their role in designing a sorting process. For example, images or videos of material being removed from a body of water would illustrate what will be done by others and not by the students.
   - **Individually:** Based on the original client letter and the response letter, have students fill out their engineering notebooks with the prompts from the *1.c. Problem Scoping Prompts* master (or attach the worksheet in their notebooks).
   - **In Teams:** Once all students have completed the prompts individually, have students discuss their answers with their team. Using a different colored pen or pencil, students should add to or change their answers based on the consensus within the group (or write in the team answers section). Make sure that students indicate which color represents individual and team work.
   - **Class Discussion:** Call students back together for a whole group discussion. **Ask:** *What is the client's problem?* (Minerals have fallen into a lake and must be sorted.) **Ask:** *What is your role in solving the problem?* (Learn how to identify minerals, create a process to sort the minerals, and justify why their process is the best option.) **Ask:** *What questions do you still have about the situation or your role in addressing it?* (Answers will vary – you can either answer these questions immediately or record them and include the answers in a later client letter.)
     - As students share these answer and/or questions, use markers

to record questions on an anchor chart to reference throughout the unit. **Note:** The purpose of an anchor chart is to make thinking visible to all in the classroom. Anchor charts are often made with poster paper and markers but could also be written on a whiteboard/ chalkboard or created electronically. While the anchor chart can take multiple forms, it should be visible to students throughout the unit.

- Tell students that they will continue to get more information that may help answer their questions over the course of the next eight lessons.

8. **Engineering Design Process. Ask:** *Which phase of the engineering design process are we in right now?*
   - Still defining the problem & gaining background information, learning about minerals and why they are important

Closure

1. **Restating the problem. Ask:** *What is the big problem in our engineering challenge?* (Sorting minerals that have been recovered from a lake.)
2. **Exit Slip—Reclaim vs. Replace.** Direct students to respond to the following prompt in their engineering notebook: Write a claim with evidence about why the company is recovering the minerals from the lake instead of just getting a new supply. Their responses to this prompt will indicate their understanding that minerals are valuable and non-renewable resources. If student responses do not indicate this, the topic will need to be re-addressed later.

Off the Rails

LESSON 1

LESSON 1

Name________________________________ Date___________ Period _____

1.a. Content Pre-Assessment

1. You are asked to take a mineral and scratch it across a porcelain plate. Which mineral property are you testing?
   a. Hardness
   b. Streak
   c. Density
   d. Luster

2. The way light reflects off a mineral's surface is its:
   a. Luster
   b. Cleavage
   c. Streak
   d. Color

3. You are given two mineral samples. One is feldspar, which has a rating of 6 on the Mohs hardness scale. You are not sure what the other mineral is, but it cannot be scratched by the feldspar. What can you tell about the hardness of the second mineral?
   a. It has a hardness of less than 6.
   b. It has a hardness of 6.
   c. It has a hardness of greater than 6.
   d. You cannot tell anything about the hardness.

4. You are given samples of three minerals. Mineral A has a mass of 3.5 grams. Mineral B has a mass of 4.8 grams. Mineral C has a mass of 5.7 grams. Which mineral has the greatest density?
   a. Mineral A
   b. Mineral B
   c. Mineral C
   d. It is impossible to tell with this information.

5. You have information about three samples of the same mineral. Based on the information below, what is the density of the mineral? Round to the nearest hundredth.

____

Sample Number	Mass (g)	Volume (cm3)
1	1	0.347
2	14	4.861
3	37	12.847

LESSON 1

Name_________________________________ Date____________ Period _____

1.a. Content Pre-Assessment

6. If you found a yellow piece of metal in a stream, how could you tell if it was real gold?

7. Describe the physical properties that can be used to identify minerals.

1.b. Client Letter 1

Rocky Rails Transport
14 Rail Drive
St. Paul, MN 55111

Dear Process Engineers,

I write to you in the hopes that you can help my company out of a very difficult situation. Our trains are used to transport valuable minerals across the country to where they are needed. One of our trains recently derailed, dumping train cars full of minerals into a lake. We need to collect the minerals from the lake to save some of our profit.

There were many different minerals on board the train. We are able to get them out of the lake, but they will all be mixed together once we retrieve them. Therefore, we need your help sorting the minerals by type. This will require you to learn how to identify minerals, then create a process that we can scale up to sort all of the minerals once they are recovered from the lake. We are looking for the best process, so we would like different teams of engineers to develop alternate proposals. With your team, you will need to explain your process and why it is our best option for sorting the minerals. You will need to justify your reasoning to show why your process is the best.

You will receive daily memos from our other engineering teams as they continue to work on this problem. The memos will provide you with information about your daily tasks. For now, spend some time learning about minerals and why it's so important that we successfully recover them from the lake.

Thank you for your consideration,

Maria Mayer

Maria Mayer
President, Rocky Rails Transport
m.mayer@rrt.com

LESSON 1

Name____________________________________ Date___________ Period _____

1.c. Problem Scoping Prompts

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

1. Who is the client?

My response:

Team response:

2. What is the client's problem that needs a solution?

My response:

Team response:

3. Why is the problem important to solve?

My response:

Team response:

LESSON 1

Name________________________________ Date___________ Period _____

1.c. Problem Scoping Prompts

4. Who are the end-users?

My response:

Team response:

5. What will make a solution effective (criteria)?

My response:

Team response:

6. What will limit how you can solve the problem (constraints)?

My response:

Team response:

7. Think about the problem of minerals spilled into a lake. In terms of sorting the minerals, what do you need to learn in order to create procedure to separate the minerals?

My response:

Team response:

LESSON 1

Name____ Date____________ Period ______

1.d. Mineral Research

Notes	Importance for Mineral Recovery Project

1.e. Non-Renewable Resources Guide

Humans use many natural resources from the Earth. Renewable resources are ones that can be replaced as quickly as we use them. Non-renewable resources have a limited supply or are used faster than they can be created.

Minerals are non-renewable resources, which means people will eventually run out of them. It is difficult to predict how long mineral reserves will last because new mineral deposits continue to be discovered. In addition, people can make changes to how quickly they use minerals to help make sure the minerals are not used up in their lifetimes.

It is important that people conserve and recycle minerals to maintain adequate supplies for future generations. When possible, people should use alternative resources, especially if renewable resources can be used in place of non-renewable minerals. People can also work to reduce their use of minerals and avoid wasting mineral resources. When possible, reusing or recycling minerals can also lengthen the amount of time minerals will continue to be available for human use.

Gold is a mineral with a limited supply. This makes gold expensive for humans to buy, but the high cost of gold has also helped to encourage people to reuse or recycle the gold they have. Like gold, other minerals also have limited supplies. Because minerals are important non-renewable resources, people need to make efforts to conserve and recycle minerals whenever possible.

LESSON 1

1.f. Mineral Uses Guide

There are over 4,000 different types of minerals, and they can be used for a variety of purposes. People use minerals every day – they are in our houses, cars, technology, cleaning materials, and even our food. The list below provides examples of some everyday mineral uses

- Halite is the mineral name for salt, which we likely eat every day.
- Quartz is used to make glass.
- Graphite is found in pencils.
- Magnetite is one component of iron, which is used to make cars.
- Gold is used in electronics because it conducts electricity.
- Gold is also found in jewelry.
- Fluorite is found in toothpaste to strengthen our teeth.
- Muscovite is ground up to add glitter to makeup.
- Bauxite is a source of aluminum, which is used in cars and airplanes, food packaging, building, and other ways.
- Feldspar is used to make pottery and porcelain.
- Talc is used in deodorant.

LESSON 1

1.g. Environmental Impacts Guide

Minerals are removed from the Earth by mining. There are different ways to mine, but the most common technique for mining minerals is called surface mining, which removes large layers of land to dig down to the mineral deposits.

Mining causes many environmental problems, including pollution and effects on plant and animal populations. Chemuscovitels that are used in the mining process can pollute the soil and water, contaminating it and making it dangerous for plants and animals, including humans. Some of the pollutants can cause diseases in humans.

In addition to the harmful water and soil pollution that can kill plants and animals, mining damages the land by removing the surface vegetation, including trees and plants. This destroys habitats that are home to animals. Some species are very sensitive to changes in the environment, and animals that cannot adjust to such changes will leave the area completely.

Mining creates a large amount of waste. In many cases, a mine produces more waste than usable minerals. This waste can be toxic, so it is important that it is handled properly. Mining can be very dangerous for the miners that work to extract the minerals from the Earth. Many miners have health problems with their skin and lungs.

1.h. Client Letter 2 template

Rocky Rails Transport
14 Rail Drive
St. Paul, MN 55111

Dear Process Engineers,

Thank you for your excellent questions. Here are answers to most of your questions.

[INSERT ANSWERS TO QUESTIONS]

If you have more questions for me or my team give them to your teacher who will pass them along to us.

Sincerely,

Maria Mayer

Maria Mayer
President, Rocky Rails Transport
m.mayer@rrt.com

[DO NOT INCLUDE THIS SECTION -- THESE ARE DIRECTIONS FOR THE TEACHER]

TEACHER NOTE: Before distributing this to students, fill in answers to their questions. Students will come up with a variety of questions, but good problem scoping questions help clarify the problem, identify what needs to be done, and identify the acceptable ways it can be done. Here are some sample questions/responses. Note that many of the questions will be answered with later client letters, so a promise to find the information and send it later might suffice for some questions.

Relevant Questions:

- **What kinds of minerals need to be sorted? How many minerals?**
  POSSIBLE ANSWER: "That's a good question. I will get that information from the train's shipping log and send it to your teacher in a couple of days.
- **Where will we put the minerals once they are sorted?**
  POSSIBLE ANSWER: "We have taken care of moving the sorted and unsorted minerals and storing them. You just need to worry about the process that we will use to separate them.
- **What tools can we use to sort the minerals?**
  POSSIBLE ANSWER: "We have several different kinds of machines that you will find useful. I will start working on a list of the tools we have available, and I will send it to your teacher soon.

Less Relevant Questions: These questions are related to the situation but not to solving the problem. The questions deserve answers, but it should be clear that they go beyond their specific task.

- **Why did the train crash? Where did it crash? Who is responsible for the crash?**
  POSSIBLE ANSWER: These are really important questions, and we have another team who is working with authorities to find out what happened. We will also work to make sure it does not happen again. For your part, however, you just need to worry about sorting the minerals we've retrieved.
- **Did the minerals hurt the fish and animals in the lake?**
  POSSIBLE ANSWER: We are still trying to determine the impact, and we are working to remove the minerals as quickly as possible. We also have a team of environmental engineers working specifically on that problem. You do not have to take that into consideration when designing your process.

LESSON 2

Let's Sort It Out

Lesson Objectives

The students will be able to:

- Identify similarities and differences of minerals through hands-on investigation.
- Identify and measure physical properties of minerals that can be used to sort and classify them.

Time Required

One 50-minute class period

Materials

- **Per classroom:** *1 sheet of poster paper, *Markers, Engineering design process poster
- **Per group:** Set of 10-12 minerals (any diverse mix of minerals will suffice, but a possible set could include quartz, feldspar, magnetite, calcite, talc, hornblende, muscovite, bauxite, graphite, and pyrite)
- **Per student:** *Pencil, *Engineering notebook, Engineering design process slider

Standards Addressed

- Next Generation Science Standards: 5-PS1-3

Key Terms

physical property, categorize/ sort

Lesson Summary

Students will work in small groups of three to sort a set of minerals according to their similarities and differences and identify possible ways of distinguishing between minerals. They will learn about the mineral identification methods used by geologists.

Background

Teacher Background

Physical properties provide ways of describing and sorting different types of matter, especially minerals. Minerals are naturally occurring, inorganic solids with definite composition and crystal structure. They are identified by their physical properties. These physical properties include color, streak, hardness, density, luster, shape/crystalline structure, and solubility (and others). These physical properties can be used to classify or group minerals (e.g., metallic and nonmetallic) and ultimately identify specific minerals.

Before the Activity

Create student sets of minerals. Any diverse mix of minerals will suffice, but a possible set could include quartz, feldspar, magnetite, calcite, talc, hornblende, muscovite, bauxite, and graphite.

Classroom Instruction

Introduction

1. **Revisit engineering design challenge. Ask:** *What did we learn about our design challenge yesterday?* Student answers will vary. Make sure students remember that the challenge involves sorting minerals. Remind students that they made claims in their engineering notebooks about why the company was recovering the minerals from the lake instead of getting a new supply of minerals. **Ask:** *Why do you think the company decided to recover and sort the minerals instead of just getting a new set of minerals?* Student answers will vary. Make sure students recall that minerals are nonrenewable resources that are limited in quantity and can be expensive to acquire.
2. **Create anchor chart.** Post a new anchor chart with the terms economic, political, social, and ethical written on it. **Ask:** *Based on what you learned in the last lesson, how does our mineral problem relate to economic, political, social, and ethical issues?* (Examples: cost of recovering non-renewable resources (economic), trains might not be allowed to ship minerals if they spill (political), determining who is responsible for the train derailment (social), considering environmental pollution aspects of the problem (ethical).) As students share impacts, record them in the appropriate categories. Remind students that their task is to sort minerals, so in today's activity they will begin to learn about sorting minerals.
3. **Connecting to the Engineering Design Challenge.** Tell students a new letter has arrived from the client. Show *2.a. Client Letter 3* to students (use document camera/projector or distribute copies). Give students time to read, or read the letter aloud. **Ask:** *What phase of the engineering design process does this ask us to do?* Have them write it in their engineering notebook next to the date. (It asks them to do the Learn phase of the engineering design process).

Let's Sort It Out

Activity

1. **Introduce mineral sorting activity.** Tell students they will be thinking of sorting criteria they could use to categorize minerals based on how the minerals are the same and different. Tell students that each group is going to get a set of minerals that they need to sort. Their sorting criteria should create two distinct groups of minerals. All the minerals they are given must be in exactly one of the groups.

   Note: Sorting by criteria where some of the minerals are not in a group will be less effective during their final design process. If students end up in this situation here, encourage them to think of a different way to sort that does clearly put each mineral in one group or the other.
2. **Share safety information.** Determine and use appropriate safety procedures. Although all minerals in this unit are safe, some minerals are dangerous to breathe in or have on your skin for long periods of time. Make sure not to smell or taste the minerals, and everyone will need to wash their hands after testing the minerals.
3. **Mineral sorting activity.** Direct students to discuss their ideas with their teammates and record the unique qualities of the minerals using the *2.b. Mineral Sort* worksheet (have them attach these to their engineering notebook page). Distribute *2.b. Mineral Sort* worksheets to each student and mineral sets to each small group. Provide students with time to sort and record qualities.

   Note: Do not give students information about the criteria they should use to sort. Groups will develop different ideas, and some may struggle to think of how to sort the materials into only two groups. Generating a variety of ideas and experiencing productive struggles are both authentic aspects of engineering.
4. **Whole group discussion.** Call students back together for whole group discussion. **Ask:** *How did you sort the minerals into groups?* As students share ideas, instruct students to record new ideas on their *2.b. Mineral Sort* worksheets or in their engineering notebooks.
5. **Introduce physical properties.** Introduce the term physical property. Explain that a physical property is a characteristic that can be used to identify and describe a mineral. **Ask:** *Which physical properties worked best to create groups? Why?* **Ask:** *Which physical properties did not work well to create groups? Why?* Tell students that geologists have certain tests they can use to identify properties of minerals. They also need to find ways to communicate the results of their tests. This is done through units of measure. Note that measurement is not just length, weight, or volume. **Ask:** *Which physical properties do you think geologists use to identify and classify minerals? Why?*
6. **Introduce mineral identification tests.** Describe the following mineral identification tests (projecting photos or providing students with copies of *2.c. Mineral Identification Tests* handout): Color, Streak, Shape (cleavage/fracture), Luster (metallic/glassy/dull), Hardness, Magnetism. **Ask:** *How could someone measure these physical properties?* Explain that students will have the opportunity to perform the mineral tests in the next class period.

Assessments

Pre-Activity Assessment

- As a whole class, make a chart to categorize impacts according to economic, political, social, and ethical. Answers students give will indicate their understanding of the previous lesson's activity researching minerals.

Activity Embedded Assessment

- *Mineral Sort* Worksheet

Post-Activity Assessment

- Have a class discussion about which characteristics of the minerals were most and least useful to sort the minerals into two groups.
- In their engineering notebooks, ask students to choose a property they think will be helpful in their design challenge and explain why it will be helpful.

DUPLICATION MASTERS

- 2.a. Client Letter 3
- 2.b. Mineral Sort
- 2.c. Mineral Identification Tests

Closure

1. **Revisit engineering design challenge.** Remind students that they will be using their knowledge of minerals to sort the minerals that are recovered from the lake. In their engineering notebooks ask students to choose a property they think will be helpful in their design challenge and explain why it will be helpful.

Let's Sort It Out

•

2.a. Client Letter 3

Rocky Rails Transport
14 Rail Drive
St. Paul, MN 55111

Dear Process Engineers,

My team of environmental engineers is still working to recover the minerals from the lake. Today, I'd like you and your fellow engineers to examine the mineral samples I sent. See if you can find some ways of sorting or separating the minerals that might be helpful in designing your sorting process.

Sincerely,

Maria Mayer

Maria Mayer
President, Rocky Rails Transport
m.mayer@rrt.com

LESSON 2

Name________________________________ Date____________ Period ______

2.b. Mineral Sort

Mineral Characteristic/ Description of Groups	**Notes:** • How big were the groups? • How easy/difficult was it to sort into these groups?

2.c. Mineral Identification Tests

Color

Color refers to the color of the whole mineral. One type of mineral can come in multiple colors, so this test alone does not provide enough information to determine the type of mineral.

Streak

Streak is the color of a mineral's powder. A mineral may be one color and have a different colored streak.

Shape (cleavage/fracture)

Shape refers to how a mineral breaks. Cleavage is the tendency of a mineral to break along flat planes or surfaces, creating a smooth break. Fracture is the tendency of a mineral to break along curved surfaces without a definite shape.

Luster (metallic, glassy, dull)

Luster describes how well a mineral reflects light.

- Metallic luster: light reflects off the mineral's surface, like light reflecting off a mirror
- Dull luster: light does not reflect off the mineral's surface.
- Glassy luster: light can travel through the mineral, like light shining through glass, but it doesn't reflect.

Hardness

Hardness describes how easy it is to scratch the surface of a mineral. Scientists use the Mohs scale to describe hardness, where a 1 is the softest mineral and a 10 is the hardest.

Magnetism

Some minerals are magnetic. This can be tested using a magnet or compass.

LESSON

3 Which Mineral is That?

Lesson Objectives
The students will be able to:
- Conduct tests of mineral properties.
- Record mineral data in a table.
- Use mineral properties to identify three mystery minerals.
- Describe which properties would be most useful in separating specific minerals.

Time Required
Two 50-minute class periods

Materials
- **Per classroom:** *Rag, *Water, Engineering design process poster
- **Per group:** Mineral set for property testing (bauxite, calcite, graphite, hornblende, magnetite, and talc), Mystery minerals: quartz, calcite, muscovite, *Mineral identification testing materials (streak plates, glass plates, steel nails, pennies, magnets, hand lenses)
- **Per student:** *Pencil, *Engineering notebook, Engineering design process slider

Standards Addressed
- Next Generation Science Standards: 5-PS1-3

Key Terms
streak, luster, cleavage, fracture

Lesson Summary
Working in small groups, students will work through a series of stations to measure the physical properties of minerals. They will learn about mineral hardness, streak, shape (cleavage/fracture), luster (metallic/glassy/dull), magnetism, and color.

Background
Teacher Background
The tests carried out in this lab are important as well as common, but they are not the only ways that scientists and geologists can classify and identify minerals. Additionally, some of these tests admit a fair amount of subjectivity into the measurements, and some minerals have a wide range of variability for some of the tests (color for example). For this reason, this lesson provides a good opportunity to discuss variability in data, uncertainty in measurement, and the confidence we can place on different measured values.

Before the Activity
- Print (laminate, if desired) *3.c. Mineral Station Information Sheets*.
- Set up mineral testing stations. There are six total station types; depending on the number of student groups, you will likely want to set up two of each type of station. For example, if you have ten groups of students, you should set up two of each station type, for a total of 12 stations. Ideally, you will have more stations than groups so that students can move to an open station without having to wait.
- Create mineral sets (each group of three students gets a set of six minerals: bauxite, calcite, graphite, hornblende, magnetite, and talc)

Classroom Instruction
Introduction
1. **Connecting to the previous lesson. Ask:** *Based on what you learned in our last class period, how can we tell minerals apart?* **Ask:** *Which properties might be helpful for the design challenge? Why*? Tell students to reference the Lesson #2 closing reflection in their engineering notebooks. (They can use their physical properties, like shape, luster, color, streak, hardness, and magnetism.)
2. **Connecting to the Engineering Design Challenge.** Tell students a new letter has arrived from the client. Show *3.a. Client Letter 4* to students (use document camera/projector or distribute copies). Give students time to read, or read the letter aloud. **Ask:** *What phase of the engineering design process does this ask us to do?* Have them write it in their engineering notebook next to the date. (It asks them to do the Learn phase of the engineering design process).

Activity
1. **Introduce mineral testing activity.** Tell students that the client sent some minerals and testing materials to start identifying the properties of each mineral. Explain that students will work through six different testing stations with their small groups. Each person will be responsible for testing two minerals at each station, so the group will collect data on six different minerals.

2. **Explain data collection.** Have students record the data in their engineering notebooks. Encourage the students to devise a clear and systematic way to organize and record the data on their own. Alternatively, show students the *3.b. Mineral Identification Data* sheet and explain how to record data for each of their minerals. Emphasize the importance of placing data in the correct row and column of the data sheet. Throughout the lab, you should monitor that students are interpreting and recording the data correctly.
3. **Describe station rotation.** Briefly describe the stations to students. Tell students that each station contains an information sheet to remind them of the procedures for conducting each test. Tell students that they should work efficiently at the stations - each station should take less than five minutes. Determine the starting station for each group and tell students how they should rotate to the next station.

   Note: If there are more stations than groups, students should be able to move to an open station that they have not yet visited. Distribute *3.b. Mineral Identification Data* sheets (if necessary) to each student and mineral sets to each small group. Have the students attach these sheets in their notebooks.
4. **Share safety information.** Determine and use appropriate safety procedures. Although all minerals in this unit are safe, some minerals are dangerous to breathe in or have on your skin for long periods of time. Make sure not to smell or taste the minerals, and everyone will need to wash their hands after testing the minerals.
5. **Station work time.** Give students time to work through each station. Students should carry their minerals from station to station so they are always measuring the same samples.
6. **Whole group discussion.** When groups are done collecting data from each station, call the class together for a whole group discussion. Display the *3.d. Mineral Identification Chart* (or provide copies to students). Explain that the information chart provides some information but has gaps that need to be filled in based on student research. Tell students that they will be working to complete the chart, which will then be made available to all of the students.
   - **Note:** The *3.d. Mineral Identification Chart* will be used in multiple lessons. Ideally, you will project a digital version that can be updated in real time during class.
   - **Ask:** *Based on your tests of minerals today, which information can be added at this point?* It is likely that groups will have different answers in some cases. In these instances, try to reach a group consensus about what should be recorded. In the event that group consensus cannot be reached, record the discrepancies to send back to the client. It is important to emphasize that even though groups disagree, it does not (necessarily) mean the one group is wrong and one group is correct. This is a good time to discuss variation in data and the limitations of measuring instruments or techniques.
7. **Identify mystery minerals.** Once the *3.d. Mineral Identification Chart* is updated, give each group of students a set of three mystery minerals (quartz, muscovite, and calcite) and explain that they should work together to determine which minerals they have. Remind students that the minerals

Assessments
Pre-Activity Assessment
- Class discussion about how minerals can be distinguished.
- Use this information to gauge students' recollection of what they learned in the previous lesson about mineral properties. If necessary, the introduction to today's activity may need to be altered.

Activity Embedded Assessment
- *Mineral Identification Data* sheet

Post-Activity Assessment
- *Mystery Minerals Claims & Evidence* worksheet
- *Mystery Minerals Exit Slips* worksheet

DUPLICATION MASTERS
- 3.a. Client Letter 4
- 3.b. Mineral Identification Data
- 3.c. Mineral Station Information Sheets
- 3.d. Mineral Identification Chart
- 3.f. Mystery Minerals Claims & Evidence
- 3.g. Mystery Minerals Exit Slip

EDUCATOR RESOURCES
- 3.e. Mineral Identification Chart (Master)

may be ones they used earlier in the lesson, or they may be new minerals. Students will need to conduct some identification tests and use the *3.d. Mineral Identification Chart*. Instruct students to record their findings in their engineering notebooks. Tell them that they will need to make a claim about which minerals they have and support their claims with evidence from their identification tests. They should record their claims and evidence on the *3.f. Mystery Minerals Claims & Evidence* sheet.

Note: If this is the first time students are being asked to provide evidence and explanations for their solutions, this worksheet will be challenging. In this case, prior to starting the work, talk through each box and provide an example for a different problem.

- **Question:** What are we trying to figure out?
  Example: What are the three mystery minerals?
- **Claim:** What is the answer to the question?
  Example: I claim that mineral H is muscovite.
- **Data/Evidence:** What observations/data support the claim?
  Example: Mineral H and muscovite both have a glassy luster, a hardness of 2, are not magnetic, have a light streak, and are light in color.
- **Explanation, Reasoning:** Why does the evidence support the claim? What overarching science concept, understanding, or principle makes it valid to use the evidence to support the claim?
  Example: Minerals have specific physical properties that can be used to identify them. The data we collected about mineral H's properties helped us determine that it is muscovite because the properties of mineral H match the properties of muscovite. There are not any other minerals listed that have all of the same properties as mineral H.

8. **Extension for groups that finish quickly.** Groups will likely finish testing their minerals and making evidence-based claims at different times. For groups that finish quickly, provide an additional set of minerals for them to identify. Use any minerals that you have available.

Closure

1. **Connect mineral identification activity to the engineering design challenge.** Distribute the *3.g. Mystery Minerals Exit Slip* and have students answer the questions. Remind students that the client asked for a report to share their progress. Their *3.f. Mystery Minerals Claims & Evidence* worksheets and these exit slips will be shared with the client, so they need to make sure they have a complete set of information, including answers to the last two questions.

   Note: If students struggle to answer the two exit questions, the next lesson should begin with a discussion of how properties can be used for sorting and not just identification. This is not an obvious connection and may need some scaffolding.

Which Mineral is That?

3.a. Client Letter 4

Rocky Rails Transport
14 Rail Drive
St. Paul, MN 55111

Dear Process Engineers,

I received an update about your progress and am pleased that you are starting to identify physical properties that can be used to sort the minerals.

Please use the mineral samples I sent yesterday to conduct the mineral identification tests. Make sure you record your findings about the physical properties of each mineral so that you can use the information to help you once we have recovered all of the minerals that need to be sorted.

I have included a set of mystery minerals that I would like you to identify based on your findings about the physical properties. You will need to justify your reasoning using evidence from the tests. I would also like you to start thinking about which properties would be most useful in sorting a mixture of minerals. My engineers will need to develop machines that can carry out your processes if we don't already have them, so we need to start planning. I'll expect a report from your team within the next two days.

Thanks,

Maria Mayer

Maria Mayer
President, Rocky Rails Transport
m.mayer@rrt.com

Name______________________________ Date____________ Period ______

3.b. Mineral Identification Data

Color

Mineral	Color
B – Talc	
D – Calcite	
E – Bauxite	
F – Magnetite	
G – Hornblende	
I – Graphite	

Luster

Mineral	Luster (glassy, metallic, or dull)
B – Talc	
D – Calcite	
E – Bauxite	
F – Magnetite	
G – Hornblende	
I – Graphite	

---(cut here)---

Hardness

Mineral	Fingernail 2.5	Penny 3.5	Nail 4.5	Glass 5.5	Streak Plate 6.5	Hardness
Example	*No*	*No*	*Yes*	*X*	*X*	*4*
B – Talc						
D – Calcite						
E – Bauxite						
F – Magnetite						
G – Hornblende						
I – Graphite						

LESSON 3

3.b. Mineral Identification Data

Magnetism

Mineral	Magnetic?
B – Talc	
D – Calcite	
E – Bauxite	
F – Magnetite	
G – Hornblende	
I – Graphite	

Shape

Mineral	Shape (fracture or cleavage)
B – Talc	
D – Calcite	
E – Bauxite	
F – Magnetite	
G – Hornblende	
I – Graphite	

---(cut here)---

Streak

Mineral	Streak Color
B – Talc	
D – Calcite	
E – Bauxite	
F – Magnetite	
G – Hornblende	
I – Graphite	

Color

Property Description:
Color refers to the color of the whole mineral. One type of mineral can come in multiple colors, so this test alone does not provide enough information to determine the type of mineral.

Station Instructions:
1. Look carefully at the mineral sample.
2. Work with your teammates to brainstorm color names that describe the mineral. Be extra descriptive, thinking back to a box of 100 crayons, not a box of 10 crayons.
3. When your team agrees on the best color name, record that color in the table.

3.c. Mineral Stations Information Sheet

Hardness

Property Description:
Hardness describes how easy it is to scratch the surface of a mineral. Scientists use the Mohs scale to describe hardness, where a 1 is the softest mineral and a 10 is the hardest.

Station Instructions:

1. Use your fingernail to try to scratch the mineral. If you are able to scratch the mineral with your fingernail, your fingernail is harder than the mineral. This would mean the hardness of the mineral is less than 2.5, so record the hardness as 1-2.
   NOTE: Sometimes it seems like the mineral scratched when really the tool was scratched and left powder on the mineral. Look at the mineral carefully to determine whether it has been scratched.
2. If you are not able to scratch the mineral with your fingernail, use the next hardest object – a penny.
3. Continue from the lowest to highest hardness, stopping once you are able to scratch the mineral.
4. Once the mineral scratches, stop testing and record the hardness based on which object was able to scratch the mineral. If none of the objects can scratch the mineral, record the hardness as 7-10.

Hardness Rating	Object Used to Test Hardness
1	
2	Fingernail – 2.5
3	Penny – 3.5
4	Nail – 4.5
5	Glass – 5.5
6	Streak Plate – 6.5
7-10	Diamond – 10

3.c. Mineral Stations Information Sheet

Luster

Property Description:
Luster describes how well a mineral reflects light.

- Metallic luster: light reflects off the mineral's surface, like light reflecting off a mirror
- Dull luster: light does not reflect off the mineral's surface.
- Glassy luster: Light can travel through the mineral, like light shining through glass, but it doesn't reflect.

Station Instructions:

1. Look carefully at the mineral sample.
2. Examine whether light reflects off the surface of the mineral or can shine through the mineral.
3. Compare your observations to the luster descriptions above.
4. Record the luster of the mineral.

Magnetism

Property Description:
Some minerals are magnetic. This can be tested using a magnet or compass.

Station Instructions:
1. Select one mineral sample and move it away from the others.
2. Put a permanent magnet close to the mineral sample.
3. Observe whether the magnet is attracted to the mineral.
4. If the mineral and magnet attract, record that the mineral is magnetic.

3.c. Mineral Stations Information Sheet

Shape

Property Description:
Shape refers to how a mineral breaks. Cleavage is the tendency of a mineral to break along flat planes or surfaces, creating a smooth break. Fracture is the tendency of a mineral to break along curved surfaces without a definite shape, creating rough or jagged sides.

Station Instructions:
1. The minerals are already broken, so you do NOT need to break them to examine their shape.
2. Examine each side of the mineral.
3. If you find flat, smooth edges, record the mineral's shape as cleavage.
4. If you find curved, rough, or jagged edges, record the mineral's shape as fracture.

3.c. Mineral Stations Information Sheet

Streak

Property Description:
Streak is the color of a mineral's powder. A mineral may be one color and a different colored streak.

Station Instructions:

1. Set the streak plate (tile) on the table.
2. Rub a mineral sample on the tile until it forms a line of powder. You should only rub the mineral 1-4 times, as excessive rubbing will wear the mineral down. Soft minerals will easily make a streak, but some harder minerals are too hard to leave a streak.
3. Record the color of the powder.
4. Wipe the streak plate with a wet rag before testing another mineral.

LESSON 3

3.d. Mineral Identification Chart

Name	Color	Streak	Shape	Luster	Hardness	Magnetic		
Bauxite								
Biotite	brown/black/ dark green (dark)	white (light)	cleavage	glassy	2.5 to 3	no		
Calcite								
Feldspar	orange (light)	white (light)	cleavage	glassy to dull	6	no		
Galena	platnium/ dark silver (dark)	grey (dark)	cleavage	metallic	2.5	no		
Gold	gold (dark)	gold (dark)	fracture	metallic	3	no		
Graphite								
Hornblende								
Magnetite								
Muscovite	off white (light)	white/ glitter (dark)	cleavage	glassy	2	no		
Pyrite	golden/yellow (dark)	greenish black (dark)	fracture	metallic	6 to 6.5	no		
Quartz	clear/white/ rose (light)	no streak	fracture	glassy	7	no		
Talc								

3.e. Mineral Identification Chart (Master)

Name	Color	Streak	Shape	Luster	Hardness	Magnetic	Density (g/cm^3)	Density - max	Points
Bauxite	tan with spots (light)	white/tan (light)	fracture	dull	1 to 3	no	3.3	3.3	4
Biotite	brown/black/ dark green (dark)	white (light)	cleavage	glassy	2.5 to 3	no	2.8	3.5	4
Calcite	white/clear (light)	white (light)	cleavage	glassy	3	no	2.71	2.71	4
Feldspar	orange (light)	white (light)	cleavage	glassy to dull	6	no	2.56	2.56	10
Galena	platinum/ dark silver (dark)	grey (dark)	cleavage	metallic	2.5	no	7.2	7.6	8
Gold	gold (dark)	gold (dark)	fracture	metallic	3	no	17.64	17.64	15
Graphite	grey (dark)	grey (dark)	cleavage	metallic to dull	1 to 2	no	2.27	2.27	4
Hornblende	black (dark)	white (light)	cleavage	metallic to dull	5 to 6	no	3	3.47	5
Magnetite	dark Grey/ black with rust spots (dark)	black (dark)	fracture	metallic	6	yes	5.15	5.15	4
Muscovite	off white (light)	white/ glitter (light)	cleavage	glassy	2	no	2.88	2.88	5
Pyrite	golden/yellow (dark)	greenish black (dark)	fracture	metallic	6 to 6.5	no	5.01	5.01	4
Quartz	clear/white/ rose (light)	no streak	fracture	glassy	7	no	2.62	2.62	7
Talc	white/ Green (light)	white (light)	cleavage	dull to pearly	1	no	2.75	2.75	3
Wood (pine)	light brown (light)	yellow (light)	fracture	dull	1	no	0.5	0.6	
Plastic	varied	none	fracture	varied	1	no	0.95	1.3	

LESSON 3

Name____ Date______________ Period ______

3.f. Mystery Minerals Claims & Evidence

Make a claim with evidence about which minerals were part of the mystery set.

Question: What are the three mystery minerals?	
Claim:	**Data/Evidence:**
Explanation, Reasoning:	

LESSON 3

Name________________________________ Date___________ Period _____

3.g. Mystery Minerals Exit Slip

1. If you had a pile of calcite and quartz mixed together, which properties could you use to separate them? Which properties would not be helpful?

2. If you had a white, glassy mineral, what else would you need to know in order to identify it?

LESSON 4

Discovering Density

Lesson Objectives
The students will be able to:
- measure the volume of irregularly shaped minerals using the water displacement method.
- generate and interpret a scatterplot.
- calculate the slope of a line of best fit on a scatterplot.
- calculate density using the formula: density = mass/ volume

Time Required
Three 50-minute class periods

Materials
- See Unit Overview (p. 11)

Standards Addressed
- Next Generation Science Standards: 5-PS1-3
- Common Core State Standards – Mathematics: 8.EE.B.5, HSS.ID.C.7

Key Terms
density, mass, volume, displacement, proportional relationship, slope, scatter plot, line of best fit

Lesson Summary
In their small groups, students will measure the mass and use water displacement to determine volume of mineral samples. They will create a scatterplot of mass vs. volume, draw a line of best fit, and calculate the slope of the line to discover the density of the minerals. Students will also use the density formula to calculate densities of additional minerals.

Background
Teacher Background
- This lesson is split into three sections labeled A, B, and C.
    - Lesson 4A introduces the concepts of mass and volume, including the practice of water displacement to measure volume.
    - Lesson 4B teaches about using a scatterplot to show the relationship between mass and volume.
    - Lesson 4C identifies the slope of the "line of best fit" through the data points on the scatterplot as a way of quantifying the proportional relationship between mass and volume, which is called density.
- This multi-part lesson is aimed at developing students' understanding of density as a physical property of matter in parallel with the mathematical ideas of proportional relationships and constant rates of change. As students' intuition and understanding of one of these ideas builds they should apply that understanding to the other so that both concepts develop throughout the lesson.
- This lesson contains activities aimed at helping develop important ideas about volume. You can use your knowledge of your students' understanding to determine how much or how little to emphasize each of these:
    - "Size" corresponds with volume, which is a measure of the number of unit cubes required to compactly fill a space.
    - The volume of regular solids can be measured using a formula such as L x W x H.
    - L x W x H is just a shortcut for counting the number of unit cubes in a solid.
    - Solids displace a volume of water equal to their volume when they are submerged.
    - Measuring displacement is a way to measure the volume of both regular and irregular solids.

Lesson 4A

Before the Activity - Lesson 4A
- Gather the materials described in the lesson needed for the *4.a. Density Pre-Assessment*. Make copies for the class or plan to have students write their responses in their engineering notebooks.
- Make sure that the class *3.d. Mineral Identification Chart* is updated with accurate information.
- Organize cubes, rods, and pieces of aluminum for easy distribution.

Classroom Instruction - Lesson 4A
Introduction
1. **Continuing the discussion of mineral properties. Ask:** *What mineral*

properties have we measured so far? (Streak, hardness, color, shape, luster, magnetism) Explain that students are going to be investigating another mineral property today.

2. **Density pre-assessment.** Distribute *4.a. Density Pre-Assessment,* display the following:
   - Question 1: Show students two containers of roughly equal volume filled with different materials, e.g. rock and plastic.
   - Question 2: Show students two different sized containers both filled with the same material, e.g. rock or plastic.
   - Question 3: Show students a large sample of a low density object and a small sample of a high density object. (Example: large piece of Styrofoam and small piece of metal or rock)

   Give students time to answer the questions. Have students answer the questions directly in their engineering notebooks or direct students to insert the *4.a. Density Pre-Assessment* worksheet into their engineering notebooks so you can view it later.
3. **Connecting to the engineering design challenge.** Show the *3.d. Mineral Identification Data* sheet. Remind students that there were some disagreements or discrepancies in the class about some of the mineral identification data. Those issues were shared with the client to get help resolving them, and the values were updated based on advice from mineral experts. Show *4.b. Client Letter 5* to students (use document camera/projector or distribute copies). Give students time to read, or read the letter aloud.
4. **Engineering design process. Ask:** *What phase of the engineering design process will we be doing today?* (Learn) Have them move the engineering design process slider to the appropriate position and write it in their notebooks next to the date.

Activity

1. **Equal volumes & different mass—density cubes.** Explain that students will have three sets of materials. They will look at one set of materials at a time and record observations about those materials on the *4.c. Materials Observations* sheet which they should attach in their engineering notebooks. Tell students they should examine each set for similarities and differences within that set.
   - Distribute 4.c. *Materials Observation* worksheets, then distribute the density cubes.

     Note: Students will have to take turns with the equal mass rods and density cubes. Each set of 10 density cubes can be divided into two groups to increase the number of sets of materials available to students.
   - Give students time to record observations of the set of materials,

     Note: if students request additional measurement tools (electronic balances or metric rulers), you may provide those tools. At this point, specific measurements are not required, but if students desire more accurate measurements, you may decide to allow them to do so.
   - Call students back together for a whole group discussion. Hold up set of density cubes. **Ask:** *What did you observe about these cubes?*

Assessments

Pre-Activity Assessment
- Density Pre-Assessment

Activity Embedded Assessment
- Materials Observations worksheet
- Mineral Mass and Volume worksheet

Post-Activity Assessment
- Mineral Density Calculations or Mass and Volume Data worksheet

DUPLICATION MASTERS
- 4.a. Density Pre-Assessment
- 3.d. Mineral Identification Chart (Lesson 3)
- 4.b. Client Letter 5
- 4.c. Materials Observations
- 4.d. Mineral Mass and Volume
- 4.e. Mass and Volume Data
- 4.f. Mineral Density Calculations

How were they similar? How were they different? Based on student responses, guide them to recognize that items of the same size/volume can have different masses. Direct students to record this claim in the conclusions section of the *4.c. Materials Observation* worksheet.

Note: Students may not make the connection between size and volume. Help them to understand that volume is a way of measuring the size of a 3D object.

- **Ask:** *What evidence do we have for this claim?* Guide students to record their evidence in the conclusions section of the *4.c. Materials Observation* worksheet.

2. **Different volumes & equal mass—equal mass rods.** Repeat the process above for the equal mass rods. After students make and record individual observations, hold up a set of equal mass rods. **Ask:** *What did you observe about these rods? How were they similar? How were they different?* Based on student responses, guide them to recognize that items can have the same mass, even when they are different sizes/volumes. Contrast this with what they saw from the density cubes. Direct students to record this claim in the conclusions section of the *4.c. Materials Observation* worksheet. **Ask:** *What evidence do we have for this claim?* Guide students to record their evidence in the conclusions section of the *4.c. Materials Observation* worksheet.
3. **Same material, different mass & volume—aluminum samples.** Repeat again but this time with the aluminum pieces. Make sure students know that all samples are the same material. After students make and record individual observations, hold up the pieces of aluminum. **Ask:** *What did you observe about these pieces of aluminum? How were they similar? How were they different?* **Ask:** *What do you know about the mass and volume of these items?* Explain that although the items have different masses and volumes/sizes, they do share something in common because they are the same material. **Ask:** *What do you think these items might have in common?* Student answers will vary - at this point, do not guide them to identify density unless they bring it up themselves (which is unlikely). Collect aluminum pieces and explain that students are going to investigate how mass and volume are related, but to do so they will need to make more accurate measurements.
4. **Measuring mass with an electric balance.** Model how to use the electronic balance, emphasizing that the unit of measure is grams. Demonstrate using either an inch cube from the density cubes set (preferred) or a centimeter cube.
5. **Measuring volume using dimensions. Ask:** *How could we measure the volume of this inch cube (a rectangular prism)?* Student answers will vary, but they are likely to suggest the formula of length x width x height. If they don't suggest this measurement, guide students to the idea.

   Note: If possible, this is a great place to coordinate with the students' math teachers on a lesson on volume.
6. **Distribute rulers so students can measure the three dimensions of the cube.** Measure an inch cube to show that each dimension is equal to one inch. Emphasize that the volume is equal to one cubic inch (or in^3), reminding students that volume is expressed in units to the third power. Record the volume of one cube on an anchor chart. Repeat using a

centimeter cube. Again record the volume of one cm cube on an anchor chart. Remeasure the inch cube using centimeters and compare. Explain that *volume* is a measure of the number of unit cubes (for a certain unit) required to fill in a specific space.

7. **Volume for regular shapes**. Show students a larger rectangular prism (like a shoe box). The more precisely rectangular the better. E.g., a pencil case may be nearly rectangular but have rounded edges and a rounded top, and these rounded edges can lead to confusion. **Ask:** *How could we find the volume of this box?* Answers may vary but the following two methods should be discussed. Both are valid methods that should give the same answer.
   - Fill the box with centimeter cubes and count them.
   - Measure the length, width, and height, and multiply.

   Filling the box with centimeter cubes and then demonstrating how the cubes are organized into layers, which are organized into rows and columns can help students to make the connection between the *L x W x H* formula and the concept of volume as the number of unit cubes that it takes to fill a space.
8. **Exploration with graduate cylinders.** Show students a graduated cylinder. **Ask:** *Have you ever seen or used this tool? What do you think it could be used for?* Depending on student responses, guide students to recognize that graduated cylinders can measure liquid volume. Encourage students to think of similar graduated containers they might have around the house: measuring cups, certain water bottles, etc. Tell students they are going to practice using the graduated cylinders and record some information about them. On the *4.c. Materials Observation* worksheet, they will record how much water each cylinder holds and how the volume is marked. This is to ensure that they are aware of the different scales on the different cylinders. Misreading a tick mark is a common error.
   - Distribute two graduated cylinders, a beaker of water, and three pipettes to each team. Each team of three students should get two graduated cylinders of different sizes.
   - Explain to students what the *meniscus* is and how to use it to determine the water level in a graduated cylinder.
   - Students should then add some water to each of the graduated cylinders. Students should use the beaker and pipettes to attempt to get the water level at a major tick mark on the measurement scale (i.e. for a graduated cylinder that has major tick marks 5 mL apart, students might fill it to 5, 10, or 15 mL). Pouring water from the beaker or a faucet will get the level close to a tick mark. Then the pipette can be used to bring the level up a small amount to a major tick mark.
   - After a few minutes of investigation time, direct students to make sure there is an identifiable amount of liquid in each cylinder.
9. **Measuring volume by displacement.** Distribute centimeter cubes to each team and direct students to drop a centimeter cube in the smallest graduated cylinder into which it will fit. Instruct them to watch the water level as they do so. **Ask:** *What do you notice when you drop a centimeter cube in the graduated cylinder?* (The water level rises.) **Ask:** *How much did it change? How can you determine how much it changed?* Direct students to record the change in water level on their Materials Observation

worksheet. Instruct students to repeat this several times, dropping different numbers of cubes in each time.

Note: To remove a cubes from the cylinder, students should carefully dump the entire contents back in the beaker, catching the cube as it comes out. This should avoid too much mess, but you will still want to have paper towels handy near each group.

10. **Call the group back together. Ask:** *What do you notice about the amount the water rose for each cube? How does it compare to the volume of the centimeter cube we measured before?* (They are the same! 1 mL is equal to 1 cm^3. Guide students to recognize that the two units are equivalent.) If students are not already familiar with it, introduce the word displacement. Make the connection between the rise in the water level or change in volume, and the volume of the object. Students need to understand the correlation between the volume of the object as measured using linear measures (and the L x W x H formula) and the volume of the water displaced before they can make sense of the displacement method of measuring irregular solids. Have students write the equation $1mL = 1cm^3$ on the *4.c. Materials Observation* sheet.
11. **Volume for regular and irregular shapes.** Show them an irregular shaped object. **Ask:** *How could we find the volume of an object that wasn't a perfect cube or regular shape?* (Student answers will vary.) Explain that they can use the relationship between volume and displacement they noticed before to measure irregular shapes. Model the water displacement method for measuring the volume of irregular solids. Pour water from a cup into a graduated cylinder, making sure to use enough water that it will cover the sample. Demonstrate again how to read the graduated cylinder by looking at the bottom of the meniscus, or the curve in the water. Record the number of milliliters (mL) as the initial water level. Tilt the graduated cylinder and gently slide the sample into the water. Return the graduated cylinder to its upright position and record the final water level. Explain that the volume of the object can be determined by finding the difference between the initial and final water level. Students may find this difference by subtracting the initial volume from the final or they may determine the change by counting on from the initial volume. Either method is fine. If time allows, instruct students to practice using the water displacement method to measure the volume of the equal mass rods.

Closure

1. **Reiterate how to measure volume of irregular shapes. Ask:** *How can we use what we learned today to measure the volume of our irregularly shaped mineral samples?* Have them write their response in their engineering notebooks. (We can use the water displacement method to measure the volume.) Explain that the water displacement method will allow students to measure the volume of their mineral samples and that they will have the opportunity to do so in Lesson 4b.

Lesson 4B

Before the Activity - Lesson 4B

- This lesson requires students to record data about mineral samples. A worksheet with a data table is provided, however because setting up a data table is an important skill for students to develop and can aid in their understanding of the data, only use the *4.d. Mineral Mass and Volume* worksheet if time does not allow students to create their own data table.
- Create mineral density testing kits - each group will need a set of graphite and a set of magnetite. Place five pieces of a single mineral in each bag and label the bags with the name of the mineral. If possible, pieces should be selected to provide the greatest possible variety of sizes across the class, while still choosing pieces small enough to fit into the available graduated cylinders or overflow cans.

    Note: Overflow cans can be used as an alternative means for measuring water displacement. This strategy may be easier for some students and may also provide more accurate results.

Classroom Instruction - Lesson 4B

Introduction

1. **Review of methods for measuring mass. Ask:** *What tool can we use to measure the mass of a mineral sample?* (Electronic balance)
2. **Review methods for measuring volume.** Direct students to talk in their teams about the answer to the question: *How can we find the volume of an object that isn't a perfect cube or regular shape?* Ask some teams to share their answers with the whole group. Remind students of their claims about mass and volume from the *Materials Observation* worksheet if necessary.
3. **Measuring mineral samples**. Explain that they will be collecting mass and volume data about their minerals to try to find a relationship between the two. This relationship will be used to classify and identify minerals. **Ask:** *How can we measure the volume of a mineral sample?*

    Note: Despite having just discussed this, it is likely that some students will still want to use a ruler to measure length, width, and height. If students suggest using a ruler to measure the sample and use the length x width x height formula, ask them what is the length (or width or height) of a mineral sample, i.e., an irregular solid (the answer is that it varies). If students persist (for example by arguing for using an average length or the maximum length) show them two images like the ones above. Ask if they have the same area. (They clearly do not.) Then point out that both images have the same length (at the widest part) and height (at the tallest part). This should be enough to get them to realize that L x W (and therefore L x W x H) only applies to rectangles (or rectangular prisms) and will not give an accurate answer if the shape is irregular. If not, explain this to them. Modeling this with centimeter cubes may also help.

Guide them to recall the water displacement method from the previous class period as a method that is easy to use with irregularly shaped items like minerals and will give accurate measurements.

4. **Connecting to the engineering design challenge:** Ask students why finding a relationship between mass and volume might be helpful for the design challenge.

Activity:

1. **Share safety information.** Determine and use appropriate safety procedures. Although all minerals in this unit are safe, some minerals are dangerous to breathe in or have on your skin for long periods of time. Make sure not to smell the minerals, and everyone will need to wash their hands after testing the minerals.
2. **Measuring the mass and volume of mineral samples.** Remind students of the procedures for measuring mass and volume, modeling again if necessary. Explain that each group will start with five samples of one type of mineral. They will measure the mass and volume of all five different samples of that mineral, and record their data on the *4.d. Mineral Mass and Volume* worksheet which they should attach in their engineering notebooks. When they have completed the measurements of that mineral, they will put the pieces back in the bag, trade the bag for a bag containing the other mineral, and repeat the measurement and recording process. Measuring the mass will take much less time than measuring volume, if you do not have enough electronic balances for each group, groups can share or rotate through a balance station.
   - Distribute *4.d. Mineral Mass and Volume* worksheet and materials needed for testing (graduated cylinders, pipettes, bag of mineral samples, beaker with water, electronic balances). Give students time to measure the mass and volume of the samples. As they work, circulate around the classroom and check in with groups, making sure they are measuring accurately and recording their data.

     Note: As you observe, make sure that students are recording the displacement as the volume. For some students, it may be helpful to have them record both the initial volume and final volume in the cylinder to aid in determining the displacement. For other students, (specifically students who find the displacement by counting on rather than subtracting) this may add confusion, so it is not advisable to require all students to record initial and final values—only those students for whom this information will be helpful.
   - As groups finish, have them help clean up and organize the materials. If they have additional time, tell them to look at their tables to see what kind of information it provides about the minerals. Ask them to identify any patterns or trends they see in the data. You may also encourage them to redo one or two of the samples to make sure they get the same (or similar) values.
3. **Class discussion of mass & volume data.** When all of the groups are

done making their measurements, call the class together for a whole group discussion, directing students to examine their data tables.

- **Ask:** *What do you notice about the mass and the volume of the minerals? What can the data tell you about the minerals?* Answers will vary here. It is difficult to identify trends from this table of data (too few data points, and not the best representation), so it is unlikely that students will identify the proportional or linear relationship between mass and volume for each sample. This is expected.
- **Ask:** *How accurate is your data?* Hopefully it is fairly accurate, but even if they did their best, there will still be some measurement error. This question is just meant to prime the students to expect a little variation before they examine a scatterplot of the class data.
- **Ask:** *What differences do you see between the two different minerals you measured?* Answers here will also vary.

4. **Representing the data in a different way.** Tell students that although the data tables provide useful information, it can be difficult to interpret that representation. **Ask:** *How could we show this data in another way?* Student answers will vary. Ask follow-up questions to further probe student thinking and get them to explain in more detail how they could represent the data. Students will likely suggest making a graph or plot, but if they don't, guide them to that idea. Explain that a scatterplot can be useful for looking at patterns in data. (Note the points on the following and all subsequent scatter plots should not be connected.) Project a blank scatterplot (with labeled axis) as an example and model how to plot several points. Make sure that volume in cubic centimeters is on the x-axis and mass in grams is on the y-axis. If time allows, distribute graph paper and direct students to graph all of their data.

   Note: Graphing mass vs. volume (instead of volume vs. mass) is essential in this case because the lesson is working toward density (g/cm^3). Purely in terms of investigating this data, however, it would be acceptable to graph volume vs. mass.

Closure:

1. **Making sense of variation in measurements.** Explain that students' measurements will include some error because of the limitations of the tools being used. Some of the data are too high and some are too low, but using more data can help give a better sense of what the data shows. Combining all of the groups' data into a single scatterplot will allow them to get a better sense of what is actually going on with the data. Tell the students that you will create a single scatterplot using all of their data points. Collect a data table from one student in each group for use in creating the class scatterplot.

   Note: This could be done on the fly if using a digital graphing tool by having students enter the data into a spreadsheet or graphing program once they are finished collecting their data.

2. **Building toward density—relating mass & volume.** Remind students that they are working to understand how mass and volume are related for different minerals and that they will continue to investigate this property in the following class period.

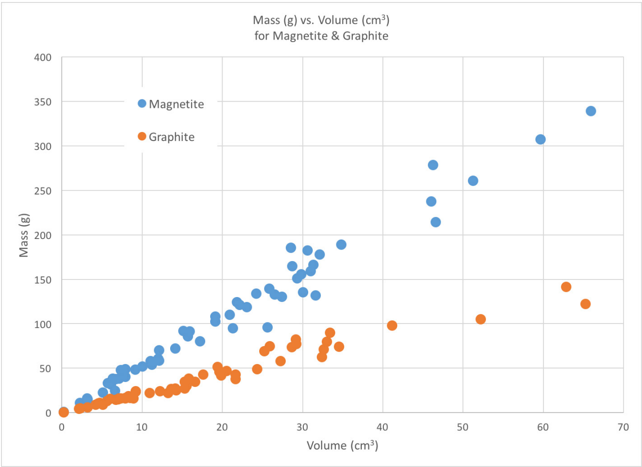
Lesson 4C

Before the Activity - Lesson 4C

- Combine the provided sample data with class data on mass and volume and create a scatterplot using a different color or symbol to represent the two different minerals (see sample below). You may create the plot by hand, but graphing technology would speed the process and allow for greater accuracy. Possible graphing tools include Desmos (desmos.com), plot.ly, Microsoft Excel, Google Sheets, etc. An excel file containing the sample data is included with the digital materials accompanying this unit.

  Note: The scatterplot should include aggregated data from the entire class along with the sample data provided (next page), not just a single groups' data. Having students compare their individual data with other groups' data encourages certain misconceptions. Having students analyze aggregated data avoids these issues and should result in a more accurate determination of the density. Additionally, the data the students collect are not likely to span a wide enough range of masses and volumes to make the linear relationship clearly visible. Including the sample data should add enough variation to make the trend more clear. An example of what you can expect the combined class and sample data scatterplot to look like is pictured below.

  Note: Be forewarned that even very careful measurements will most likely yield determinations of the densities of the minerals significantly different from the standard or accepted values. This is okay and to be expected based on the precision of the instruments being used. The emphasis in this lesson is not on the accuracy of the final measurements, but on the linearity of the relationship between mass and volume and the relationship between slope and density (i.e., steeper slopes indicate a higher density). This also affords a great opportunity to discuss the limitations on the precision of measuring tools and different sources of measurement error.
- Print a copy of the class scatterplot for each student.



Sample Class Scatterplot: When class data and sample data are combined, the scatterplot should look similar to this.

Sample Data that should be added to the class data:			
Magnetite		**Graphite**	
Volume (cm^3)	**Mass (g)**	**Volume (cm^3)**	**Mass (g)**
0.2	0.90	0.2	0.46
2.2	11.40	2.1	4.69
3.0	13.39	2.3	5.30
3.1	16.02	3.2	6.05
5.1	22.95	4.2	9.38
5.7	33.63	6.7	14.89
17.2	80.36	9.2	24.34
21.8	124.61	21.6	42.93
32.1	178.21	25.9	75.07
46.0	237.71	27.2	58.00
46.2	278.67	33.4	90.22
46.6	214.65	41.1	98.09
51.2	261.00	52.1	105.07
59.6	307.58	62.8	141.87
65.9	339.54	65.2	122.38

Classroom Instruction - Lesson 4C

Introduction

1. **Connecting to the engineering design challenge.** Ask for a student volunteer to restate the client's problems. Ask for another student to restate their challenge. Remind them that they are investigating the relationship between mass and volume of minerals to help them to separate and sort the minerals.
2. **Initial examination of the class scatterplot. Ask:** *What data did we collect in the last class period?* (Mass and volume.) Display the class scatterplot and remind students that you used all of their data to create the plot in order to have a better interpretation despite measurement error. Distribute copies of the class graph to students and return *4.d. Mineral Mass and Volume* worksheets or engineering notebook tables to students whose tables were used in compiling the data. Direct students to look at their data table and find their data points on the class scatterplot. This will allow them to practice reading a scatterplot.

Activity:

1. **Class discussion of broad patterns in the data.** After students have had time to find at least two of their data points, call the whole class back together. **Ask:** *What do you notice about the data on our scatterplot?* (There is a pattern in the data, so the points move from the bottom left up and to the right.) **Ask:** *What do the two different symbols (or colors or shapes depending on how you created the graph) represent?* (The two minerals we measured, graphite and magnetite.) **Ask:** *What do you*

notice about the data for each mineral individually? Students should notice that the data are linear, or "are in a line," or "follow a line." If they do not notice this, continue to prompt them until they do.

Note: Minimally, students need access to a large (one full sheet) copy of the full scatterplot to work on. Ideally they would also be given two more scatterplots each showing only one of the minerals. Both of these scatterplots should have the same scale for both x- and y-axes.

2. **Introducing lines of best fit.** Explain that a line of best fit can show a pattern in a set of data. Pick one of the minerals to start, and as a group, have students follow your example to hold a pencil or a ruler (on edge) or even a taught piece of string to the data to form a line through the data for only one of the minerals. Have them put it where they think the line of best fit should go. Be sure to make it clear that the students are only trying to fit one of the symbols, i.e., the data from one of the minerals (not both). This is where the scatterplots with only one mineral are useful. Point out that some points are above the line and some are below.

   Note: Do not be too concerned with formally defining 'best fit.' At this point students can rely on their intuitive understanding of what a 'best fit' to the data is.

   Ask: *Does your line go through any of the points? Do you think it has to?* (The line may or may not go through the data points, but it does not have to go through any to be a line of best fit.) **Ask:** *Does your line of best fit go through the origin, (0,0)?* (Student answers will vary) **Ask:** *Would it make sense for our line of best fit to start at the origin in this case? What would that tell us about the mass and volume at that point?* (It does make sense for the line of best fit to go through the origin because a mineral sample of zero grams would also have zero cubic centimeters of volume.)
3. **Drawing a line of best fit.** Have students make their best fit line again with the rulers, but this time make sure it goes through the point at the origin. Have them trace this line with pen or pencil on the graph. It may help to have students work in pairs with one student holding the guide (pencil, ruler, or string) and the other tracing it. Repeat this entire process for the data for the second mineral.
4. **Interpreting the linear nature of the data. Ask:** *Why do you think our data for each of the minerals creates a straight line? What does that tell us about the minerals?* Student answers will vary. Guide students to realize that larger pieces of the minerals have more mass and volume, and smaller pieces of minerals have less mass and volume. Tell them that because the line is straight and goes through the origin we know the relationship is a "proportional relationship." If they have learned and remember this from mathematics class, encourage them to share what they know about proportional relationships. If not, it is not necessary to pursue the idea beyond identifying a linear relationships through the origin as proportional.
5. **Identifying the slope of the lines. Ask:** *What is different about the two lines?* (One is steeper than the other.) Explain that we measure how steep a line is with slope. Introduce the idea that each line has a slope that shows how a change in one variable relates to a change in the other variable. As x increases, y also increases. Do this by drawing right triangles below (or above) each line to indicate the "rise" and "run" at different points. Have them pick (and mark) a point on one of the lines (and model this). Pick a

point above a major tick mark on the x-axis. For example, in the sample scatterplot given, you might pick the point above 40 cm^3. Have them move their pencil horizontally to the next major tick mark (e.g., 50 cm^3). Now have them move vertically back to the line of best fit and ask them how much they went up. Have them record this value. Pick a different point and repeat, again going from one tick mark to the next on the x-axis. Make sure that students notice that because they move the same amount horizontally, they also moved the same amount vertically.

6. **Calculating slope.** Show them that the ratio of rise/run is the same at all points for a given line. Have them draw two or three slope triangles and have them calculate the ratio for each. Explain that for a given straight line, the slope is constant or unchanging. Slope can be calculated using the idea of "rise over run" which can be written as the formula: $m=(y_2-y_1)/(x_2-x_1)$. Have students calculate the slope for each of their lines. (They've already done this for one line. Have them do it for the other). Do the same for your lines.

   Note: Students may not have learned about slope in their math class yet, but it is still a good idea to introduce the concept to provide a foundation for their future math lessons. If they have not yet learned about it in mathematics class, they will soon.

7. **Comparing slope values and connecting them to graphs.** Once students have calculated the slope for both of their lines, have them compare the two values. Ask them to relate those values to each other and to the graphs.
   - Key points to hit: The value of the slope is larger for magnetite than for graphite. The line for magnetite is steeper than graphite. When the slope value is larger, the line is steeper and visa versa.

8. **Adding units to slope.** When a slope is calculated for the relationship between mass and volume of a particular mineral, it represents the density of one of the minerals because it is showing the proportional relationship between mass and volume. To introduce this idea, redo one of the slope calculations, but this time make sure to include the units for the numerator and denominator (if you didn't before). This time focus on those units and write the final answer with units of g/cm^3 (e.g., magnetite might yield 5.1 g/cm^3).

9. **Reinterpreting the scatterplot.** The following two prompts will help students make sense of the scatter plot, and connect the slopes of the lines to the idea of density.
   - On a fresh copy of the scatter plot (with both lines of best fit drawn), draw a vertical line at some point along the x-axis, e.g., at 40 cm^3 (ideally so that it hits both lines of best fit but does not hit any of the data points). Ask students to predict what they think the mass of a 40 cm^3 sample of graphite would be. Then, ask students to predict what they think the mass of a 40 cm^3 sample of magnetite would be. As students answer mark the places where the vertical line intersects the lines of best fits and show how this indicates the mass at that particular volume. Connect this back to the *4.a. Density Pre-Assessment* where they examined two buckets with the same volume but different masses and to the density cubes where they examined several samples with the same volume and different masses.

- Repeat this, but now draw a horizontal line at a particular mass (e.g., 125 g). Ask students to predict what they think the volume of a 125 g sample of graphite would be. Then, ask students to predict what they think the volume of a 125 g sample of magnetite would be. Connect this back to the *4.a. Density Pre-Assessment* where they examined two buckets with the same mass but different volumes and to the equal mass rods where they examined samples with the same mass but different volumes.

10. **Formally introducing density.** Explain the concept of density to the students. Although you can have big or small pieces of a material, as long it is the same material the bigger pieces will be heavier and the small pieces will be lighter. Not only that, the ratio of the mass to the volume will always be the same. In other words, the relationship between mass and volume is a proportional relationship. Connect this idea to the constant slope of the lines they created. Explain that we call this ratio *density*. Materials with high density will have larger mass per unit volume, while materials with low density will have smaller mass per unit volume. Connect this idea to the steeper and shallower lines on the graph.
11. **Comparing the density of magnetite and graphite. Ask:** *What does their plot tell them about the density of these minerals? Which has the highest density? Lowest density? How can you tell?* Guide students to recognize that magnetite has a greater density than graphite.
12. **Calculating density.** Explain that a mineral's density can also be determined with just the mass and volume of a single sample because of the fact that the density is a proportional relationship between these properties that remains constant regardless of the size of the sample. The proportion can be found using the formula *density = mass / volume* because density is a constant ratio for a given mineral.

    Note: The students' depth of understanding will determine the amount of detail shared in getting to this formula. Since the slope is dealing with physical properties and a sample of 0 g would have a volume of 0 cm^3, the origin (0, 0) could be substituted in the slope formula $m=(y_2-y_1)/(x_2-x_1)$ for the (x_1, y_1) values. Therefore, the slope of a line that passes through the origin is just $m=y_2/x_2$. That means the density can be calculated with the mass and volume of one sample. However, repeated measurements increase the accuracy of findings, so relying on a single sample may not always be the best strategy.

    Demonstrate how to calculate the density of a mineral using the formula *density = mass / volume* and using a given mass and volume.

    - For example, scientists measured the mass and volume of a sample of feldspar. The sample had a mass of 15 g and a volume of 5.9 cm^3. Using the formula, the scientist can take 15 divided by 5.9 to find that the feldspar sample has a density of about 2.54 g/cm^3.
13. **Filling in the *3.d. Mineral ID Chart*.** Display the *3.d. Mineral Identification Chart* that has been completed with student data and have students add a new column header for mineral density ("mineral density g/cm^3"). Explain that the class needs to work to fill in the density column for the listed minerals. There are two options for completing the *3.d. Mineral Identification Chart*, depending on the amount of available time:
    - Fewer than 15 minutes: provide students with the *4.e. Mass and Volume*

Data sheet so they can use the given values to calculate the density of the minerals.
- 15 minutes or more: *4.f. Distribute Mineral Density Calculations* worksheet (have students attach it in their engineering notebooks) and provide students with materials to measure mass and volume in calculating density.

Fill in the density column on the *3.d. Mineral Identification Chart* based on students' findings. If significant discrepancies arise among groups (this is especially likely if they were measuring the mass and volume, rather than using the given mass and volume information), facilitate a group discussion to reach consensus. If groups cannot reach a consensus based on their data, provide them with information from the *4.e. Mass and Volume Data* (just for that particular mineral) and have them re-calculate.

Closure:
1. **Sharing information with the client.** Tell students that their completed *3.d. Mineral Identification Chart* will be shared with the client and that they will receive more information about their next task in the next class period.
2. **Density calculations exit slip prompts.** Direct students to complete the final two questions on the worksheet (either *4.e. Mass and Volume Data* or *4.f. Mineral Density Calculations*) independently before they leave the classroom. Collect these worksheets or review students' engineering notebooks to assess their understanding of the concepts presented in this lesson.

LESSON 4

Name________________________________ Date____________ Period _____

4.a. Density Pre-Assessment

1. Which of these containers is heavier? How do you know?

___

___

___

___

2. Which of these is heavier – A or B? How do you know?

___

___

___

___

3. Can you tell which of these is heavier? If so, how? If not, why not?

___

___

___

___

4.b. Client Letter 5

Rocky Rails Transport
14 Rail Drive
St. Paul, MN 55111

Greetings Process Engineers,

Thank you for the reports you submitted to me. I was happy to see that you were able to identify my mystery minerals as quartz, calcite, and muscovite. My mechanical engineers have also started considering what it would take to make full-scale machines that are capable of sorting the minerals based on your process design specifications. I'll keep you updated on their progress.

I noticed that you didn't refer to the physical properties of mass and volume as related to minerals. Is there any way that these properties could be useful to you? Over the next couple of days, I'd like you to take a closer look at mass and volume to see how they might help in sorting the minerals.

Sincerely,

Maria Mayer

Maria Mayer
President, Rocky Rails Transport
m.mayer@rrt.com

Name________________________________ Date___________ Period _____

4.c. Materials Observations

Material	Observations
Cubes	
Rods	
Aluminum	

1. Graduated Cylinder A:
   a. How much does it hold? ___________
   b. How is it marked? ________________
2. Graduated Cylinder B:
   a. How much does it hold? ___________
   b. How is it marked? ________________

Conclusions

Idea	Data/Evidence

Number of Cubes	Change in Volume

3. What is the relationship between milliliters and cubic centimeters?

____

____

____

Name________________________________ Date____________ Period ______

4.d. Mineral Mass and Volume

Graphite Data

Sample Volume (mL or cm^3)	Sample Mass (grams)

Magnetite Data

Sample Volume (mL or cm^3)	Sample Mass (grams)

LESSON 4

Name________________________________ Date____________ Period _____

4.e. Mass and Volume Data

1. Use the information in the table below to calculate the density of the minerals based on the sample mass and volume.

Mineral	Mass (g)	Volume (cm^3)	Density (g/cm^3)
bauxite	51	15.5	
calcite	34	12.5	
hornblende	63	19.4	
talc	22	8	

2. If you were to measure many samples of each of these minerals, plot Mass vs. Volume for each, and draw a line of best fit for each, which would have the steepest slope? The shallowest slope?

____

____

____

____

3. You have two samples of the same mineral. One sample has a mass of 30 grams and a volume of 5.988 cubic centimeters. The other sample has a mass of 75 grams and a volume of 14.97 cubic centimeters.

   a. What is the density of this mineral?

   ____

   b. What type of mineral are these samples? How do you know?

   ____

   ____

LESSON 4

Name______________________________ Date__________ Period _____

4.f. Mineral Density Calculations

1. Calculate the density of the four minerals listed below:

Mineral	Calculations	Density (g/cm^3)
bauxite		
calcite		
hornblende		
talc		

2. If you were to measure many samples of each of these minerals, plot Mass vs. Volume for each, and draw a line of best fit for each, which would have the steepest slope? The shallowest slope?

____

____

____

____

3. You have two samples of the same mineral. One sample has a mass of 30 grams and a volume of 5.988 cubic centimeters. The other sample has a mass of 75 grams and a volume of 14.97 cubic centimeters.

   a. What is the density of this mineral?

   ____

   b. What type of mineral are these samples? How do you know?

   ____

   ____

LESSON 5

Go with the Flow

Lesson Objectives
The students will be able to:
- identify the criteria and constraints of the engineering design challenge.
- evaluate a process flow diagram that shows a mineral sorting process.
- make recommendations to improve a mineral sorting process.

Time Required
One 50-minute class period

Materials
- **Per classroom:** Engineering design process poster
- **Per group:** *Glue or tape, *Poster or butcher paper
- **Per student:** *Pencil, *Engineering notebook, Engineering design process slider

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

Key Terms
constraint, criteria, process flow diagram, optimization

Lesson Summary
Students will revisit the criteria and constraints of their engineering design challenge. They will be introduced to the various machines that will be available for their use, how the machines work, and their associated costs. Students will be given a sample process flow diagram that shows a process that could be used to sort a set of minerals. They will learn how to interpret the diagram, calculate the cost of the process, and determine the value of the minerals that are sorted. This process will not be optimized, so students will have an opportunity to investigate possible improvements.

Background
Teacher Background
Process flow diagrams help in automating processes and, because they are similar to decision trees, can help in making decisions. Effective process flow diagrams will clearly separate choices or materials into two or more categories. Problems occur when something does not fall into any of the categories. Students will be asked to develop such a diagram for their final design challenge, but before they can design one they need the opportunity to explore and experience some examples. This lesson provides them with at least two different examples. Before students examine process flow diagrams for mineral sorting, they learn about how recycling plants sort materials and how a process flow diagram can be used to represent that sorting process.

Before the Activity
- Copy and cut *5.e. Machine Cards* into sets for each group of students. Students should receive four of each card type.
  Optional: Print each type of machine card on a different color of paper.
- **Optional:** Locate a short video that shows how a recycling plant uses different machines in sequence to sort recyclable materials.
- Create a process flow diagram to model a recycling sorting process. If you did find a video of such a process, the diagram should match the video.

Classroom Instruction
Introduction
1. **Revisit engineering design challenge.** Show *5.a. Client Letter 6* to students (use document camera/projector or distribute copies). Give students time to read, or read the letter aloud. **Ask:** *Based on what you read in the new client letter, what are our goals for today?* (Learn about the machines we can use and make recommendations for improving the sample process.)
2. **Revisit the engineering design process.** Show the *Engineering Design Process*. **Ask:** *Which phase or phases of the Engineering Design Process will we be using?* Have them write it in their notebooks next to the date (Learn - when they learning about the machines and the Process Flow Diagrams, and/or Try - when they test the sample Process Flow Diagram, and/or Design - when they redesign the Process Flow Diagram)
3. **Introduce sorting processes.** You will be showing how materials move through a recycling plant. If you choose to show a video, show students the video (see “Before the Activity” section) of a sorting process at a recycling plant. With or without the video, discuss how materials move through a

recycling plant. Draw students' attention to the fact that there are different machines, each machine has one specific job, and different materials take different paths through the sorting process. Show students the process flow diagram (see "Before the Activity") for a recycling sorting process and explain how the diagram represents what happens with the physical machines and materials.

Activity

1. **Introduce process flow evaluation activity.** Explain that students will review the document sent by the client in order to learn about the machine options available to them. The document describes what each machine is able to do and the relative cost of operation in points. Remind students that machines with lower point values cost less to use with each mineral. Distribute *5.b. Machine Overview* document to students and provide them time to review the document in their groups.
2. **Exploration of each machine.** Distribute one copy of the *5.c. Machine Exploration* worksheet to each student (have them attach this to their notebook). Instruct students to fill out the pros and cons of using each machine to sort the minerals. They should use the writing utensil that represents that they are working in teams.
   Note: This is part of "plan" in the engineering design process. They are evaluating machines as part of their planning for their solution.
3. **Large group discussion.** When students have had time to review the document, call the group back together. **Ask:** *Which machines do you think would be most useful for sorting the minerals? Why?* (Student answers will vary.)
4. **Explain process flow diagrams.** Show the *5.d. Process Flow Diagram Sample 1.* Either project the sample or provide students with copies. It is imperative that students are able to see the details in the diagram. Tell students that process flow diagrams are used by process engineers to show the major equipment that is involved in a process, the steps taken during the process, and the order of those steps. Explain that the engineers who created this process flow diagram had to sort biotite, calcite, galena, gold, graphite, and muscovite.
5. **Student work time.** Tell students to work in their small groups to interpret the diagram. Remind them to think about the machines that are available for use and how the machines relate to the process. Give students time to discuss the diagram, then call them back together.
6. **Large group discussion. Ask:** *Which machine did the engineers use first?* (Streak Sensor) **Ask:** *How much did that test cost them? Why?* (It cost 6 points - one point for each of the six minerals that went into the machine.) **Ask:** *After the streak sensor, what did the engineers do next?* (Minerals that had a light streak were sent to one color detector, and materials that had a dark streak were sent to another color detector.) Emphasize that the process flow diagram directs the minerals down different paths, so the minerals may undergo different tests. **Ask:** *What is the total cost for all of the machines that are part of this process flow diagram?* Have students total this up. (15 points) **Ask:** *Is the process successful at sorting all of the minerals apart? How do you know?* (No,

Assessments
Pre-Activity Assessment
- none

Activity Embedded Assessment
- Class discussion about machines and small group work to optimize process

Post-Activity Assessment
- Process Recommendations worksheet

DUPLICATION MASTERS
- 5.a. Client Letter 6
- 5.b. Machine Overview
- 5.c. Machine Exploration
- 5.d. Process Flow Diagram: Sample 1
- 5.e. Machine Cards
- 5.f. Process Flow Diagram: Sample 2
- 5.g. Process Recommendations
- 3.d. Mineral Identification Chart (Lesson 3)

the process does not sort all of the minerals. This is shown because some of the minerals are still grouped with others at the far right of the diagram.)

7. **Explain mineral point values.** Remind students that minerals are non-renewable resources that have associated value. Because certain minerals are more valuable than others, students will earn points based on which minerals they are able to isolate from the others. Display the point values from the *3.e. Mineral Identification Chart* (Master) and have students fill in the column title for "Point Value" on their *3.d. Mineral Identification Chart* then copy the point values from the Master onto their own chart. [DO NOT display the rows for *Wood (pine)* and *Plastic*.] Explain that the points show how much students can earn if that mineral is successfully separated from the rest. **Ask:** *How many points did this process earn based on the minerals they sorted?* (They sorted biotite and gold for a total of 19 points.) **Ask:** *If the process earned 19 points but cost 15 points, how many points did they have in the end?* (Four points.) Define the word profit for the students and explain that they will calculate the profit for each design by subtracting the total cost of using the machines (cost) from the total value of the sorted minerals (value).
8. **Explain optimization.** Explain that engineers work to optimize their designs, or make them as effective and efficient as possible. In the sample process flow diagram, there are multiple ways that students could increase the total number of points earned (profit). Remind students that the client expressed dissatisfaction with the sample process because she thought it wasted time and money. Ask students to look for ways to improve the process that sorts more minerals, costs less, or both. They may have to make several attempts to reach a process that is more efficient, but they should keep trying. Tell students they need to have their best option for the process completed by the end of the class session.
9. **Students try to improve the process.** Distribute *5.e. Machine Cards*, glue or tape, and large sheets of poster or butcher paper for students to use in arranging their new process flow diagrams. Also distribute samples of the minerals (if available) so that students can sort them as they go along. Give students time to work in their small groups.

   Note: If students are not able to find a better process by the end of the class period, you can share *5.f. Process Flow Diagram Sample 2*.
10. **Large group discussion. Ask:** *How is this process different from the first?* (Student answers will vary, but may include: fewer machines needed, minerals sorted in groups that are more equal in size, doesn't use the shape machine, etc.) **Ask:** *Is this process better or worse than the first process? Why?* (Student answers will vary. The process sorts more of the minerals but costs more.)

    Note: Muscovite and calcite can not be separated with any of the machines provided. You may want to discuss what would be necessary, or what kind of machine would be able to separate those two minerals.

Closure

1. **Make recommendations to the client.** Distribute *5.g. Process Recommendations* worksheet (have them attach these in their engineering notebooks) and tell students their group needs to make at least one recommendation to share with the client. Their recommendation should explain how the process can be improved and provide evidence for how

they reached that conclusion. Collect the *5.g. Process Recommendations* worksheets.

LESSON 5

5.a. Client Letter 6

Rocky Rails Transport
14 Rail Drive
St. Paul, MN 55111

Dear Process Engineers,

I'm very pleased with your efforts as you learned about the density of minerals and how it might be useful in sorting them. My crew has been working hard to recover the minerals from the lake, and we're getting close to the point where we will need your help in finalizing the sorting process.

The mechanical engineers here at Rocky Rails Transport have identified some machines that will be available for us to use in sorting, and I'm attaching the details of those machines. You'll need to consider the machines and their costs and capabilities as you design your sorting process. The machines aren't perfect, but they will automate the process and save a lot of time. Please review the attached information about the machines so you know what will be available to you. Note that the machine costs are not finalized, so for now we've just assigned points to the machines based on their relative costs. Machines with a higher point value cost more to use.

I reached out to another engineering firm that has sorted minerals in the past and obtained one of their process flow diagrams. They were sorting different minerals than the ones we are working with. Also, I was not satisfied with the process this company used because I think it wasted time and money. I would like you to make some recommendations for how the sample process could be improved to show me that you're ready to take on the challenge of efficiently sorting the minerals that spilled into the lake.

Sincerely,

Maria Mayer

Maria Mayer
President, Rocky Rails Transport
m.mayer@rrt.com

LESSON 5

5.b. Machine Overview

Machine	Description	Notes
Magnet (1 point per mineral)	This machine separates materials that are magnetic from those that are non-magnetic.	This machine is very accurate. It rarely misses any magnetic pieces.
Color Detector (1 point per mineral)	This machine sorts materials into two groups: light colored and dark colored.	Because some minerals are not very light but also not very dark, this machine sometimes sorts incorrectly. About 1 out of every 10 pieces is sorted wrong.
Streak Sensor (1 point per mineral)	This machine sorts materials into two groups based on whether the streak is light or dark in color.	For some minerals, the streak will vary in color, and this makes it hard for the machine. About 2 out of every 10 pieces are sorted wrong.
Crusher (2 points per mineral)	This machine tests the hardness of materials according to the Mohs hardness scale.	This machine has trouble separating minerals whose hardness is within 1 above or below another mineral on the Mohs hardness scale.
Shape Detector (1 point per mineral)	This machine separates materials that fracture from materials that cleave.	For about 1 out of every 10 minerals, this machine puts the mineral in the wrong category.
Reflector (3 points per mineral)	This machine shines light on materials to separate them into three groups based on their luster: metallic, dull, or glassy.	Some minerals can have two of the three lusters (e.g. metallic to dull). The machine has trouble sorting these. Minerals with two or more lusters are sorted into groups unpredictably
Density Calculator (3 points per mineral)	This machine allows you to sort materials into 4 groups based on the density of the materials (all in g/cm3): 0 to 1.0, 1.1 to 2.9, 3.0 to 4.9, and 5.0 or more	
Human Power (5 points per mineral)	Human power allows you to hire people to sort out one material by hand.	Besides being expensive, it is also very time consuming to use human power.

LESSON 5

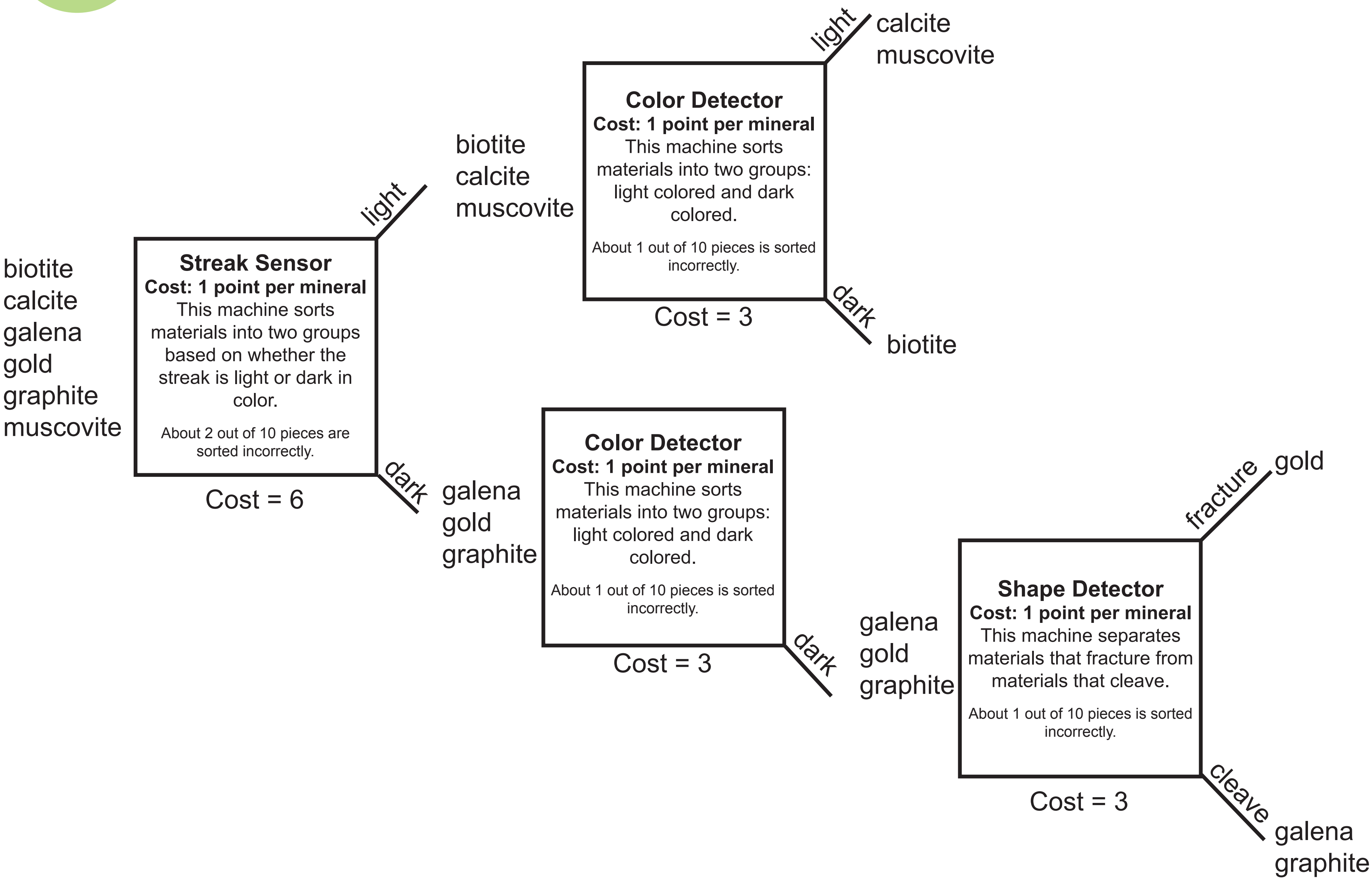
Name________________________________ Date____________ Period ______

5.c. Machine Exploration

Machine Name	Pros	Cons
Magnet		
Color detector		
Streak sensor		
Crusher		
Shape detector		
Reflector		
Density calculator		
Man power		

LESSON 5

5.d. Process Flow Diagram: Sample 1



5.e. Machine Cards

Color Detector **Cost: 1 point per mineral** This machine sorts materials into two groups: light colored and dark colored. About 1 out of 10 pieces is sorted incorrectly.	**Color Detector** **Cost: 1 point per mineral** This machine sorts materials into two groups: light colored and dark colored. About 1 out of 10 pieces is sorted incorrectly.
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5.e. Machine Cards

Magnet **Cost: 1 point per mineral** This machine separates materials that are magnetic from those that are non-magnetic. This machine is very accurate.	**Magnet** **Cost: 1 point per mineral** This machine separates materials that are magnetic from those that are non-magnetic. This machine is very accurate.
Magnet **Cost: 1 point per mineral** This machine separates materials that are magnetic from those that are non-magnetic. This machine is very accurate.	**Magnet** **Cost: 1 point per mineral** This machine separates materials that are magnetic from those that are non-magnetic. This machine is very accurate.
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5.e. Machine Cards

Crusher **Cost: 2 points per mineral** This machine sorts materials according to the Mohs hardness scale. If the hardness of two materials is with 1 of each other on the Mohs hardness scale, this machine CAN NOT separate them.	**Crusher** **Cost: 2 points per mineral** This machine sorts materials according to the Mohs hardness scale. If the hardness of two materials is with 1 of each other on the Mohs hardness scale, this machine CAN NOT separate them.
Crusher **Cost: 2 points per mineral** This machine sorts materials according to the Mohs hardness scale. If the hardness of two materials is with 1 of each other on the Mohs hardness scale, this machine CAN NOT separate them.	**Crusher** **Cost: 2 points per mineral** This machine sorts materials according to the Mohs hardness scale. If the hardness of two materials is with 1 of each other on the Mohs hardness scale, this machine CAN NOT separate them.
Crusher **Cost: 2 points per mineral** This machine sorts materials according to the Mohs hardness scale. If the hardness of two materials is with 1 of each other on the Mohs hardness scale, this machine CAN NOT separate them.	**Crusher** **Cost: 2 points per mineral** This machine sorts materials according to the Mohs hardness scale. If the hardness of two materials is with 1 of each other on the Mohs hardness scale, this machine CAN NOT separate them.

5.e. Machine Cards

Streak Sensor **Cost: 1 point per mineral** This machine sorts materials into two groups based on whether the streak is light or dark in color. About 2 out of 10 pieces is sorted incorrectly.	**Streak Sensor** **Cost: 1 point per mineral** This machine sorts materials into two groups based on whether the streak is light or dark in color. About 2 out of 10 pieces is sorted incorrectly.
Streak Sensor **Cost: 1 point per mineral** This machine sorts materials into two groups based on whether the streak is light or dark in color. About 2 out of 10 pieces is sorted incorrectly.	**Streak Sensor** **Cost: 1 point per mineral** This machine sorts materials into two groups based on whether the streak is light or dark in color. About 2 out of 10 pieces is sorted incorrectly.
Streak Sensor **Cost: 1 point per mineral** This machine sorts materials into two groups based on whether the streak is light or dark in color. About 2 out of 10 pieces is sorted incorrectly.	**Streak Sensor** **Cost: 1 point per mineral** This machine sorts materials into two groups based on whether the streak is light or dark in color. About 2 out of 10 pieces is sorted incorrectly.

5.e. Machine Cards

Reflector **Cost: 2 points per mineral** This machine shines light on materials to separate them into three groups based on their luster: metallic, dull, or glassy. Minerals with multiple lusters are sorted unpredictably into one of their lusters.	**Reflector** **Cost: 2 points per mineral** This machine shines light on materials to separate them into three groups based on their luster: metallic, dull, or glassy. Minerals with multiple lusters are sorted unpredictably into one of their lusters.
Reflector **Cost: 2 points per mineral** This machine shines light on materials to separate them into three groups based on their luster: metallic, dull, or glassy. Minerals with multiple lusters are sorted unpredictably into one of their lusters.	**Reflector** **Cost: 2 points per mineral** This machine shines light on materials to separate them into three groups based on their luster: metallic, dull, or glassy. Minerals with multiple lusters are sorted unpredictably into one of their lusters.
Reflector **Cost: 2 points per mineral** This machine shines light on materials to separate them into three groups based on their luster: metallic, dull, or glassy. Minerals with multiple lusters are sorted unpredictably into one of their lusters.	**Reflector** **Cost: 2 points per mineral** This machine shines light on materials to separate them into three groups based on their luster: metallic, dull, or glassy. Minerals with multiple lusters are sorted unpredictably into one of their lusters.

5.e. Machine Cards

Shape Detector **Cost: 1 point per mineral** This machine separates materials that fracture from materials that cleave. About 1 out of 10 pieces is sorted incorrectly.	**Shape Detector** **Cost: 1 point per mineral** This machine separates materials that fracture from materials that cleave. About 1 out of 10 pieces is sorted incorrectly.
Shape Detector **Cost: 1 point per mineral** This machine separates materials that fracture from materials that cleave. About 1 out of 10 pieces is sorted incorrectly.	**Shape Detector** **Cost: 1 point per mineral** This machine separates materials that fracture from materials that cleave. About 1 out of 10 pieces is sorted incorrectly.
Shape Detector **Cost: 1 point per mineral** This machine separates materials that fracture from materials that cleave. About 1 out of 10 pieces is sorted incorrectly.	**Shape Detector** **Cost: 1 point per mineral** This machine separates materials that fracture from materials that cleave. About 1 out of 10 pieces is sorted incorrectly.

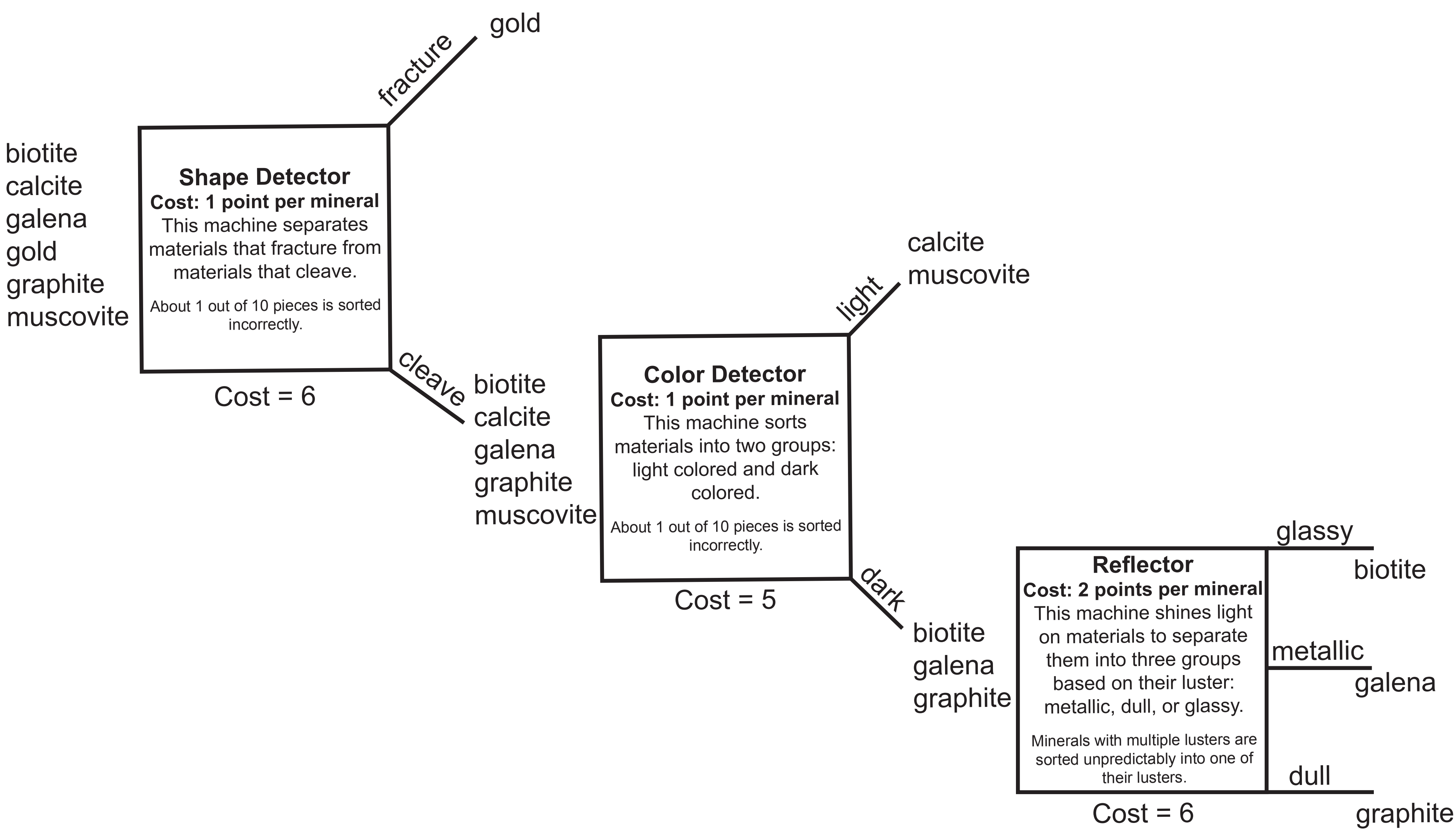
5.e. Machine Cards

Density Calculator **Cost: 3 points per mineral** This machine sorts materials into 4 groups based on the density of the materials (all in g/cm3): 0 to 1.0, 1.1 to 2.9, 3.0 to 4.9, and 5.0 or more	**Density Calculator** **Cost: 3 points per mineral** This machine sorts materials into 4 groups based on the density of the materials (all in g/cm3): 0 to 1.0, 1.1 to 2.9, 3.0 to 4.9, and 5.0 or more
Density Calculator **Cost: 3 points per mineral** This machine sorts materials into 4 groups based on the density of the materials (all in g/cm3): 0 to 1.0, 1.1 to 2.9, 3.0 to 4.9, and 5.0 or more	**Density Calculator** **Cost: 3 points per mineral** This machine sorts materials into 4 groups based on the density of the materials (all in g/cm3): 0 to 1.0, 1.1 to 2.9, 3.0 to 4.9, and 5.0 or more
Density Calculator **Cost: 3 points per mineral** This machine sorts materials into 4 groups based on the density of the materials (all in g/cm3): 0 to 1.0, 1.1 to 2.9, 3.0 to 4.9, and 5.0 or more	**Density Calculator** **Cost: 3 points per mineral** This machine sorts materials into 4 groups based on the density of the materials (all in g/cm3): 0 to 1.0, 1.1 to 2.9, 3.0 to 4.9, and 5.0 or more

5.e. Machine Cards

Human Power **Cost: 5 points per mineral** Human power allows you to hire people to sort out one material by hand.	**Human Power** **Cost: 5 points per mineral** Human power allows you to hire people to sort out one material by hand.
Human Power **Cost: 5 points per mineral** Human power allows you to hire people to sort out one material by hand.	**Human Power** **Cost: 5 points per mineral** Human power allows you to hire people to sort out one material by hand.
Human Power **Cost: 5 points per mineral** Human power allows you to hire people to sort out one material by hand.	**Human Power** **Cost: 5 points per mineral** Human power allows you to hire people to sort out one material by hand.

5.f. Process Flow Diagram: Sample 2



LESSON 5

Name________________________________ Date__________ Period _____

5.g. Process Recommendations

Propose a recommendation supported by evidence about how to improve the process flow diagram.

Problem: Find ways to improve the process flow diagram provided by the client.	
Recommendation:	**Data/Evidence:**
Explanation, Justification, Reasoning:	

LESSON 6

Engineering Design Challenge

Lesson Objectives

The students will be able to:

- Create a process flow diagram to sort a given set of minerals.
- Use evidence-based reasoning to justify their design choices.
- Evaluate their process based on equipment costs and mineral values.

Time Required

One 50-minute class period

Materials

- **Per classroom:** Engineering design process poster
- **Per group:** *Glue or tape, *Poster or butcher paper, 3 samples of each of the 7 minerals to be sorted: (bauxite, feldspar, hornblende, magnetite, pyrite, quartz, talc)
- **Per student:** *Pencil, *Engineering notebook, Engineering design process slider

Standards Addressed

- Next Generation Science Standards: 5-PS1-3, MS-ETS1-3, MS-ETS1-4

Key Terms

process flow diagram, evidence

Lesson Summary

Small groups will be given the names of a new set of minerals to sort and identify. They will work together to create a process flow diagram that shows how the minerals could be sorted. They will justify each choice and evaluate their process design based on the cost of the machines they use and the value of the minerals they sort.

Background

Teacher Background

Students should apply what they have learned from previous lessons in creating their designs. As they choose and sequence their machines it will be helpful for them to actually use the mineral samples and separate them into groups as the machine would. Some machines are described with uncertainty or error rates. As an optional extension you can add a spinner or dice to make this uncertainty real. For example, if the machine makes errors 1 out 10 times, you could have them use a spinner with the numbers 1 to 10 on it. For each sample, spin the spinner. If it comes up 1, the machine sorts it incorrectly. If it comes up anything else, it is sorted correctly.

Before the Activity

- Compile sets of *5.e. Machine Cards* for each group of students.

Classroom Instruction

Introduction

1. **Revisit engineering design challenge.** Remind students that in the previous lesson they were given a mineral sorting process that was not optimized. Ask student groups to share their recommendations for improving the process and the evidence they used as justification, and make sure a variety of ideas are shared. Explain that there is more than one way to have a successful process design.
2. **Show *6.a. Client Letter 7* to students (use document camera/projector or distribute copies).** Give students time to read, or read the letter aloud. **Ask:** *What phase of the engineering design process are we in now?* (Plan.) Have them write it in their engineering notebook next to the date.

Activity

1. **Review process flow diagrams.** Distribute blank paper to students and tell them to write the names of the minerals (bauxite, feldspar, hornblende, magnetite, pyrite, quartz, and talc) on the left side of the paper. Explain that students will be creating a process flow diagram to show the best process they can identify to sort the new set of minerals. Remind students that each machine has a cost and each mineral has a value. Their total score will be the mineral value minus the machine cost.
2. **Review *3.d. Mineral Identification Chart*.** Display *3.d. Mineral Identification Chart* and instruct students to use their knowledge of mineral properties to inform their design choices. (NOTE: Based on student needs, you may provide a copy of the *3.d. Mineral Identification Chart* that only contains information about the minerals students are sorting.)
3. **Introduce the evidence-based reasoning related to process design.** Explain that students will need to provide evidence to justify their sorting

process ideas. They need to convince the client that their process is the best possible option. **Ask:** *What kind of evidence could explain why a machine is a good choice in your process?* (Student answers will vary. Guide students to recognize that they can justify their selection based on cost, what the machine can accomplish, and the reliability of the machine). **Ask:** *What kind of evidence could explain why order of machine choice makes a difference in quality of sorting?* (Student answers will vary. Guide students to recognize that they can justify the order based on number of minerals that need to be tested at each step, the mineral composition of the sorted groups at each step, and the value of the minerals at each step. A machine might be better or worse depending on which minerals need to be sorted when it is used, so teams should think carefully about where to place machines in the process flow diagram.)

4. **Share safety information.** Determine and use appropriate safety procedures. Although all minerals in this unit are safe, some minerals are dangerous to breathe in or have on your skin for long periods of time. Make sure not to smell the minerals, and everyone will need to wash their hands after testing the minerals.
5. **Student creation of process flow diagrams ("plan and try" are the same in this unit).** Distribute *5.e. Machine Cards* and glue or tape for students to use in creating their process flow diagrams. Provide students time to work on their process flow diagrams. Teams need to create at least 2 different process flow diagram ideas to compare. Have students complete one *Evidence-Based Reasoning* template (below) for each idea in their notebooks. See 6.c. Evidence-Based Reasoning - Poster with Explanation for information about how to fill out the template. After they have designed each of their process flow diagrams, have them answer the notebook prompt: *What are the pros and cons of each of your solutions?* (If you prefer, you can print the *6.b. Evidence-Based Reasoning* template and have students attach them to their notebooks.)

<table>
<tr><td colspan="2">Problem including Criteria & Constraints (What do you need to worry about?)</td></tr>
<tr><td colspan="2">Simplifying Assumptions (if any) (What do you not need to worry about?)</td></tr>
<tr><td>Plan (Design Idea)</td><td>Data/Evidence (Facts)</td></tr>
<tr><td colspan="2">Explanation, Justification, Reasoning (Why do you think this will work?)</td></tr>
</table>

Assessments

Pre-Activity Assessment

- Process Recommendations from previous lesson

Activity Embedded Assessment

- Process Flow Diagram
- Machine Exploration worksheet
- Teacher Observation Protocol (Plan/Try/Test)

Post-Activity Assessment

- Engineering notebook prompts

DUPLICATION MASTERS

- 6.a. Client Letter 7
- 6.b. Evidence-Based Reasoning
- 3.d. Mineral Identification Chart (Lesson 3)
- 5.e. Machine Cards (Lesson 5)

EDUCATOR RESOURCES

- 6.c. Evidence-Based Reasoning - Poster with Explanation
- 6.d. Teacher Observation Protocol (Plan/Try/Test)

6. **Assess students with the teacher observation protocol. (Plan/Try)** As they work, circulate throughout the classroom, using the *Teacher Observation Protocol (Plan/Try/Test)*. The teacher observation protocol includes questions you can ask students relating to their solutions and the problem.
7. **Test the process designs.** Have the teams sort their mineral samples with their process flow diagrams. Then have them calculate the cost of the machines and the value of the minerals sorted for each of their process flow diagrams. Identify which minerals will be sorted at each step.
   Optional: Have students trade their process flow diagrams and let another team use their process to sort their mineral samples and provide feedback to the team. Continue to assess student work as they test using the *Teacher Observation Protocol* (Plan/Try/Test).

Closure

1. **Choose a process design.** Have students consider each process flow diagram that they developed. Instruct students to list pros and cons of each process in their engineering notebooks. Then have students decide on their final solution. When students have settled on their best option, have them answer the notebook prompt: *Which solution did your team choose and why?* Tell students you will share their process flow diagrams with the client for further evaluation.
2. **Reflect on the testing of the process designs.** Have the students individually answer the following prompts in their engineering notebooks:
   - *What have you learned about the performance of your solution from your 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.*
   - *What changes will you make to your solution based on the science and/or math you have learned? Explain why you want to make those changes.*
   - *In what ways does your solution meet the criteria and constraints of the problem?*
   - *In what ways does your solution not yet meet the criteria and constraints of the problem?*
   - *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.)*

LESSON 6

Engineering Design Challenge

LESSON 6

6.a. Client Letter 7

Rocky Rails Transport
14 Rail Drive
St. Paul, MN 55111

Dear Process Engineers,

Thank you for your recommendations regarding the sample mineral sorting process I sent to you. Your great ideas make me confident that you will be able to successfully sort the minerals that spilled into the lake. You will need to sort:

- bauxite
- feldspar
- hornblende
- magnetite
- pyrite
- quartz
- talc

I need you to create a draft of a process flow diagram to share with my other engineers. Each team in your class needs to submit a draft. Remember that I'll be selecting the process that most successfully sorts the most minerals at the least cost.

You have lots of work to do - get started!

Sincerely,

Maria Mayer

Maria Mayer
President, Rocky Rails Transport
m.mayer@rrt.com

LESSON 6

Name________________________________ Date___________ Period _____

6.b. Evidence-Based Reasoning

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

6.c. 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 **Criteria:** the requirements, or goals, of the designed solutions **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 • Drawings of the design, different views • Dimensions (sizes) • Label materials in design (show where they are used) • Interesting features	Observations and data that show why you think your design will work Examples: • Data from Conductor Lab and Insulator Lab • Total cost of design
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, idea, and data/evidence.	

6.d. Teacher Observation Protocol (Plan/Try/Test)

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 solutions. In addition, this is opportunity to further assess that students are making design decisions based on understanding the problem.

- **Part 1 and 2:** As you walk around to each team, please put a check by the behaviors you observe. *Note that Part 3 goes with Part 1 (both during the Plan time)*
- **Part 3:** 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 observation notes.

Part 1: Plan 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 something unrelated to problem.

Notes:

Part 2: Try/Test Behaviors

- ☐ 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:

6.d. Teacher Observation Protocol (Plan/Try/Test)

Part 3: Plan Question Prompts

Note: You do not need to ask all of these questions. Please make sure to ask some questions to each team. 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 of supporting learning. There is space to make notes about 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?

4. Why is that machine the best choice? Is there another option that would be more efficient?

5. Why did you put the machines in that order?

LESSON

7 Process Redesign

Lesson Objectives

The students will be able to:

- redesign their mineral sorting processes based on new constraints.
- evaluate their redesigned processes based on machine costs and mineral values.

Time Required

One 50-minute class period

Materials

- **Per classroom:** Engineering design process poster
- **Per group:** *Glue or tape, *Poster or butcher paper, 3 samples of each of the 7 minerals to be sorted: (bauxite, feldspar, hornblende, magnetite, pyrite, quartz, talc), .*Samples of wood and plastic
- **Per student:** *Pencil, *Engineering notebook, Engineering design process slider

Standards Addressed

- Next Generation Science Standards: 5-PS1-3, MS-ETS1-1, MS-ETS1-3

Key Terms

process flow diagram, constraint

Lesson Summary

Student groups will find out that plastic and wood are also mixed in with the minerals being recovered from the lake. Given the new constraint, they will modify their previous process flow diagram to separate the plastic and wood from the minerals.

Background

Teacher Background

- none

Before the Activity

- none

Classroom Instruction

Introduction

1. **Revisit engineering design challenge.** Show *7.a. Client Letter 8* to students (use document camera/projector or distribute copies). Give students time to read, or read the letter aloud. **Ask:** *What is our new problem?* (We need to separate plastic and wood from the minerals.) **Ask:** *What phase of the engineering design process are we in now? How do you know?* Have students write it in their engineering notebook next to the date.
2. **Introduce redesign.** Explain that engineers often redesign as new criteria and constraints arise, and students must also complete a redesign. Clarify that the Process Flow Diagrams they have been making are a type of model we can use to test the process for efficiency without having to use up minerals, electricity for the machines, and human power to operate the machines.

Activity

1. **Review definition of minerals and clarify that wood and plastic are not minerals. Ask:** *What is a mineral?* (A mineral is defined as a naturally occurring, inorganic solid with a definite composition and crystal structure. This means that minerals are not living and that minerals of the same type have the same characteristics, including their structure and what they are made of.) **Ask:** *Is wood a mineral? Why or why not?* (Wood is not a mineral because it was living when it was part of a tree.) **Ask:** *Is plastic a mineral? Why or why not?* (Plastic is not a mineral because it is not naturally occurring.) Tell students that because plastic and wood are not minerals, it is not possible to do all of the same identification tests as were done with the minerals. The client shared the information that is available, and that has been included in the *3.d. Mineral Identification Chart.* Have students add the titles to the last two rows ("wood (pine)" and "plastic". Then display the values from the *3.e. Mineral Identification Chart (Master)* and have students fill in the rest of the information on their *3.d. Mineral Identification Chart*.
2. **Share safety information.** Determine and use appropriate safety procedures. Although all minerals in this unit are safe, some minerals are dangerous to breathe in or have on your skin for long periods of time. Make sure not to smell the minerals, and everyone will need to wash their hands after testing the minerals.

3. **Review process design criteria.** Remind students that they need to redesign their processes to have the highest number of points possible. This means they should separate the wood, plastic, and as many minerals as possible using machines that cost the least. Distribute *Machine Cards*, glue or tape, and paper for student process flow diagrams. As students work, circulate throughout the classroom and **ask questions such as:** *Which machines can separate the plastic and wood from the minerals? Is there another option that would be more efficient?* You should also assess teams with the *7.b. Teacher Observation Protocol (Redesign).*

Closure

1. **Revisit engineering design challenge and redesign report.** Tell students that their redesigned processes will be sent to the client. Remind them that the client asked for a report about their redesign, so they must complete the *7.c. Redesign Report* worksheet.

Assessments

Pre-Activity Assessment

- Class discussion about whether wood and plastic are minerals

Activity Embedded Assessment

- Process Flow Diagram
- *Teacher Observation Protocol* (Redesign)

Post-Activity Assessment

- *Redesign Report*

DUPLICATION MASTERS

- 7.a. Client Letter 8
- 7.c. Redesign Report
- 3.d. Mineral Identification Chart (Lesson 3)
- 5.e. Machine Cards (Lesson 5)

EDUCATOR RESOURCES

- 7.b. Teacher Observation Protocol (Redesign)

7.a. Client Letter 8

Rocky Rails Transport
14 Rail Drive
St. Paul, MN 55111

Dear Process Engineers,

Thank you for sending your process flow diagram plans and your justifications for each machine you included. It was very useful for me to understand the decisions you made, and I appreciate your work on addressing my company's problem.

Unfortunately, it has come to my attention that as the minerals were recovered from the lake, we also collected some wood and plastic. These materials are mixed in with the minerals and need to be separated out for recycling. My materials scientists conducted some tests of the plastic and wood, and I have attached information about their physical properties.

Please redesign your process flow diagrams so that they successfully separate the wood and plastic from the minerals. I will give your team a bonus of 5 points if you are able to separate the wood and plastic from the minerals in addition to separating the minerals. I'll expect a report that details your redesign by tomorrow.

Sincerely,

Maria Mayer

Maria Mayer
President, Rocky Rails Transport
m.mayer@rrt.com

7.b. Teacher Observation Protocol (Redesign)

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: Plan/Try Behaviors

☐ 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:

Part 2: Question Prompts During Retest

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 of supporting learning.

6. What did you find out from testing?

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

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

LESSON 7

Name________________________________ Date___________ Period _____

7.c. Redesign Report

1. What physical properties can you use to separate wood and plastic from the minerals?

____

____

____

____

2. How did your team change your sorting process to make sure the wood and plastic are separated?

____

____

____

____

3. How do you know your process is the best option?

____

____

____

____

LESSON 8

Convincing the Client

Lesson Objectives
The students will be able to:
- Communicate science and engineering ideas by giving presentations.
- Use evidence-based reasoning to support their engineering decisions.

Time Required
Two 50-minute class periods

Materials
- **Per classroom:** Engineering design process poster
- **Per group:** *Presentation materials (different options depending on available materials)
- **Per student:** *Pencil, *Engineering notebook, Engineering design process slider

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

Key Terms
criteria, constraint, process flow diagram

Lesson Summary
Having optimized their process designs, teams will create presentations about their sorting processes. They will justify their choices and try to convince the client that their process is the best option.

Background
Teacher Background
In this lesson, students will be making presentations to convince the client that their process is the best option. You can choose from a variety of presentation options based on the materials and technology that you have available. Presentations can be live, video recorded, or use any other technology resources available. Alternatively, you may choose to have students write a letter to the client that includes the same information that would be included in the presentation. This lesson is structured to allot one class period for preparation and one for presentation and conclusion, but this should be adjusted to meet the needs of your class.

Before the Activity
- Before distributing *8.d. Client Letter 10*, it is recommended that you add feedback specific to your students presentations. If you want to do this, you will need to treat *8.d. Client Letter 10* as a template (as you did in *1.h. Client Letter 2 Template*) and make a new version. You will add feedback specific to your students after the first sentence of the body of the letter.
- After students complete their presentations, you will evaluate their designs based on the *8.b. Client Communication Requirements* document. **CAUTION:** Although some students thrive on competition, it can have a negative impact on the engagement of other students. You will need to decide on the level of competition based on your students.

Classroom Instruction
Introduction
1. **Revisit engineering design challenge.** Show *8.a. Client Letter 9* to students (use document camera/projector or distribute copies). Give students time to read, or read the letter aloud. **Ask:** *What is the client asking us to do?* (Prepare a presentation to convince the client our process is best.)
2. **Introduce presentation.** Explain that communication is an important part of the *Engineering Design Process*. Although students have been communicating with their teammates every day, today is their opportunity to have some formal communication with the client. **Ask:** *What do you think would be important in presenting your group's information to the client?* (Student answers will vary. Guide students to realize that they should present themselves professionally to show the client that they are deserving of being selected to take on the project. Their presentation should be clear and describe why their process is effective, including evidence for their decisions.)
3.

Activity
1. **Share client communication guidelines.** Distribute copies of *8.b. Client Communication Requirements* sheet to students. Briefly describe what is

required. Share the presentation options that are available to students. Explain that teams will need to plan their presentation using the *8.c. Presentation Planning Sheet* to document their plan (this can be attached to their notebooks).

2. **Presentation planning.** While students work in their small groups, circulate around the classroom, encouraging students to address all aspects of the *8.b. Client Communication Requirements* by **asking questions such as:**
   - *What is the problem we are trying to solve?*
   - *Who is the presentation for?*
   - *What other information would be helpful to client?*
   - *What evidence are you providing for your design decisions?*
   - *How did you use the engineering design process?*

   Distribute any resources that are needed for their presentation.
3. **Prepare presentations.** Give students time to finish preparation for delivering their presentation (e.g., creating visuals, filming video, rehearsing scripts, etc.).
4. **Students give presentations.** As students present, encourage their peers to ask questions the client might have about the presentation or process design.

Closure
1. **Revisit engineering design challenge.** Tell students that their presentations will be shared with the client, who will evaluate each process design. Tell them you will share any feedback from the client on the processes and presentations as soon as the information is available.
2. **Conclude engineering design challenge.** When ready, share *8.d. Client Letter 10* with students. Review engineering design process, highlighting how the process was used throughout the unit.
3. **Administer *8.e. Content Post-Assessment*.**

Conclusion of the Unit:
1. **Reflect on the engineering design process.** Have the students reflect in their engineering notebooks about the entire unit both individually and then in their teams. Remind students to use different colors for individual and team responses. Make sure that students indicate which color represents individual and team work. Use the following prompts:
   - *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.*
   - *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.*
   - *How do engineers solve problems?*
   - *What science understanding did you need to have in order to solve this problem?*

Assessments
Pre-Activity Assessment
- Class discussion about what is important in a presentation

Activity Embedded Assessment
- *Presentation Planning Sheet*

Post-Activity Assessment
- Final Presentation assessed using Presentation Requirements
- Content Post-Assessment

DUPLICATION MASTERS
- 8.a. Client Letter 9
- 8.b. Client Communication Requirements
- 8.c. Presentation Planning Sheet
- 8.d. Client Letter 10
- 8.e. Content Post-Assessment

8.a. Client Letter 9

Rocky Rails Transport
14 Rail Drive
St. Paul, MN 55111

Dear Process Engineers,

Thank you for your fantastic work designing a mineral sorting process that can also separate wood and plastic. You presented me with such great options that I would like to hear more about the thinking behind your designs.

I would like you to prepare a presentation describing your process design, how you worked with your team to develop it, and how you know it is an effective mineral sorting process. This is your opportunity to convince me that your team's process is the best. I have attached a list of requirements, so please make sure to use my guidelines in preparing your presentation. I look forward to hearing from you!

Sincerely,

Maria Mayer

Maria Mayer
President, Rocky Rails Transport
m.mayer@rrt.com

LESSON 8

Team________________________________ Date___________ Period _____

8.b. Client Communication Requirements

- ☐ Students introduce themselves.
- ☐ Students summarize the client's problem including criteria and constraints.
- ☐ Students explain why it is important to recover the minerals from the lake.
- ☐ Students describe their solution to the problem.
    - Cost of machines
    - Value of minerals recovered
- ☐ Students show their process flow diagram.
- ☐ Students show data and evidence gathered and used in their design.
- ☐ Students justify their process design decisions using data/evidence.
- ☐ Students explain how the engineering design process, including redesign, was used to develop their process design.
- ☐ All team members have a role in the presentation.
- ☐ Students demonstrate in-depth knowledge of the topic.
- ☐ Students thank the client for her time.

LESSON 8

Team________________________________ Date___________ Period _____

8.c. Presentation Planning Sheet

Topic	Main Points	Person Responsible	Visual

8.d. Client Letter 10

Rocky Rails Transport
14 Rail Drive
St. Paul, MN 55111

Dear Process Engineers,

I received your presentations and reviewed them this morning. The processes you designed will be extremely helpful in recovering the minerals from the lake.

Thank you for your dedication and hard work in solving my company's problem. I hope to have the opportunity to work with you again in the future.

Sincerely,

Maria Mayer

Maria Mayer
President, Rocky Rails Transport
m.mayer@rrt.com

LESSON 8

Name________________________________ Date___________ Period _____

8.e. Content Post-Assessment

1. You are asked to take a mineral and scratch it across a porcelain plate. Which mineral property are you testing?
   a. Hardness
   b. Streak
   c. Density
   d. Luster

2. The way light reflects off a mineral's surface is its:
   a. Luster
   b. Cleavage
   c. Streak
   d. Color

3. You are given two mineral samples. One is feldspar, which has a rating of 6 on the Mohs hardness scale. You are not sure what the other mineral is, but it cannot be scratched by the feldspar. What can you tell about the hardness of the second mineral?
   a. It has a hardness of less than 6.
   b. It has a hardness of 6.
   c. It has a hardness of greater than 6.
   d. You cannot tell anything about the hardness.

4. You are given samples of three minerals. Mineral A has a mass of 3.5 grams. Mineral B has a mass of 4.8 grams. Mineral C has a mass of 5.7 grams. Which mineral has the greatest density?
   a. Mineral A
   b. Mineral B
   c. Mineral C
   d. It is impossible to tell with this information.

5. You have information about three samples of the same mineral. Based on the information below, what is the density of the mineral? Round to the nearest hundredth.

____

Sample Number	Mass (g)	Volume (cm3)
1	1	0.347
2	14	4.861
3	37	12.847

Name______________________________ Date__________ Period _____

8.e. Content Post-Assessment

6. If you found a yellow piece of metal in a stream, how could you tell if it was real gold?

7. Describe the physical properties that can be used to identify minerals.

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 minerals spilled into a lake. In terms of sorting the minerals, what do you need to learn in order to create procedure to separate the minerals?

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.

Notebook Prompts and Titles

Section 2:

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

How solution meets criteria and constraints:

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

How solution does not yet meet criteria and constraints:

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

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.

