EngrTEAMS

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

Flood Rescue Mission

Grades 4-6

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

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Acknowledgments

Authors
Teacher Fellow Lead Authors: David Rafferty, Elizabeth Scheidel
Project Authors: Emily Dare, Felicia Leammukda

Leadership
Principal Investigator: Tamara Moore
Co-Principal Investigators: Paul Imbertson, Marshall Davis, Selcen Guzey, Gillian Roehrig

Management
Project Director: Cynthia Stevenson
Project Coordinator: Nashad Muse
Past Project Coordinator: Kelly Auxier
Event Assistant: Barbara Wojcik

Technical Assistance
ECSU/GRO: Julie Frame
ECSU/GRO: Jean Jordan
ECSU/GRO: Jane Holmberg

School District Partners
South Washington County: Emily Larsen
Saint Paul: Molly Leifeld, Marshall Davis
North St. Paul: Peter Mau
Minneapolis: Elizabeth Stretch, Charlene Ellingson

Evaluation
Lead Evaluator: Timothy Sheldon
Evaluator: Delia Kundin, Jane Fields

Curriculum Editors
Elizabeth Gajdzik, Tamara Moore

About EngrTEAMS

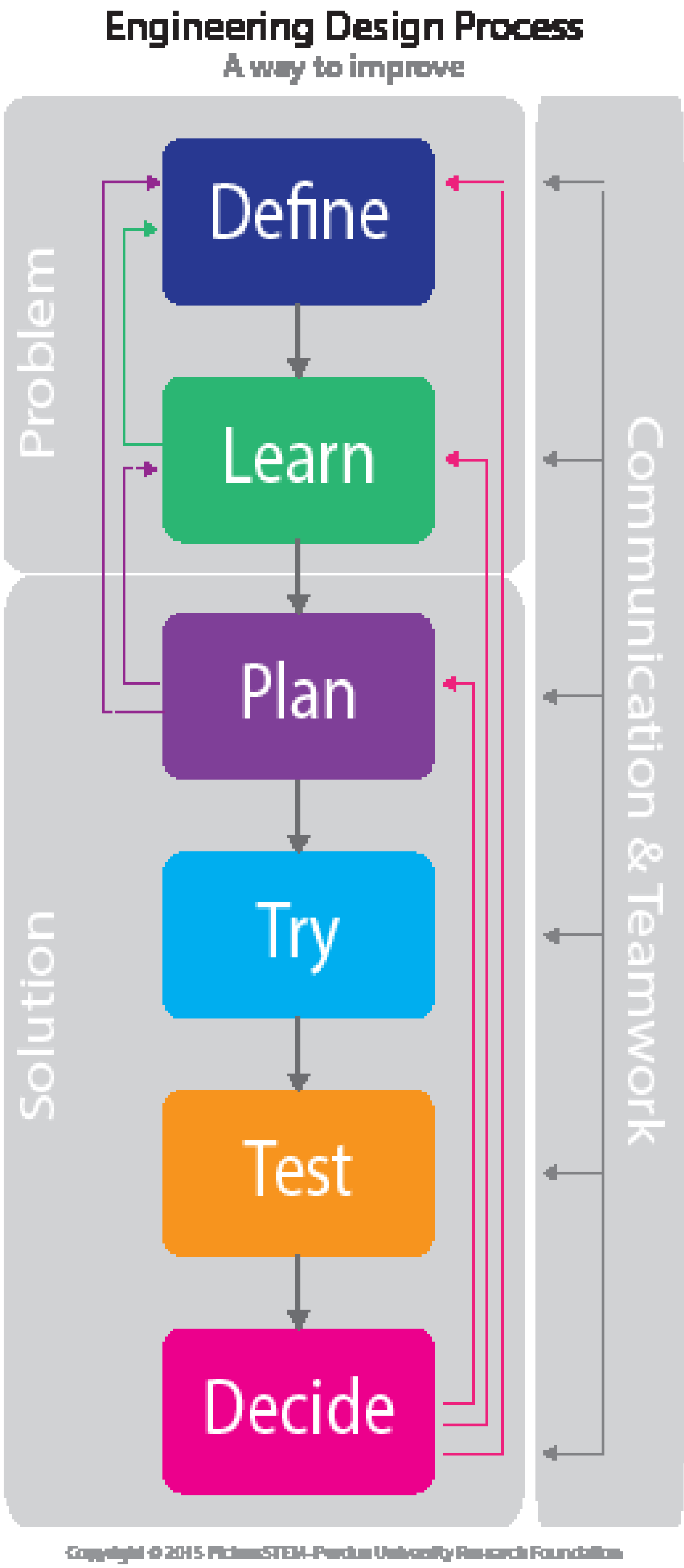
Purpose

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: 4-6

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

Unit Summary

In this unit, students will learn science, mathematics, and engineering concepts to learn about buoyancy through an Engineering Design Challenge. This challenge asks students to create prototypes of watercraft for the National Guard to use in flood emergencies. In this, students need to have an understanding of volume, mass, forces, and maximum capacity in order to address the challenge. Students work both in small teams and as a class to provide letters to the National Guard about what designs work the best.

Science Connections	Technology & Engineering Connections	Mathematics Connections
force, volume, buoyancy, maximum capacity, density	engineering design process	volume

Unit Standards

Next Generation Science Standards

- 5-PS2-1. Support an argument that the gravitational force exerted by Earth on objects is directed down.
- MS-PS2-1. Apply Newton's Third Law to design a solution to a problem involving the motion of two colliding objects.
- MS-PS2-2. Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.
- 3-5-ETS1-1. Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.
- 3-5-ETS1-2. Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.
- 3-5-ETS1-3. Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.
- 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

- 5.MD.3: Recognize volume as an attribute of solid figures and understand concepts of volume measurement.
- 5.MD.4: Measure volumes by counting unit cubes, using cubic cm, cubic in, cubic ft, and improvised units
- 5.MD.5.a: Find the volume of a right rectangular prism with whole-number side lengths by packing it with unit cubes, and show that the volume is the same as would be found by multiplying the edge lengths, equivalently by multiplying the height by the area of the base. Represent threefold whole-number products as volumes, e.g., to represent the associative property of multiplication.
- 5.MD.5.b: Apply the formulas V = l × w × h and V = b × h for rectangular prisms to find volumes of right rectangular prisms with whole number edge lengths in the context of solving real world and mathematical problems.
- 6.G.2: Find the volume of a right rectangular prism with fractional edge lengths by packing it with unit cubes of the appropriate unit fraction edge lengths, and show that the volume is the same as would be found by multiplying the edge lengths of the prism. Apply the formulas V = l w h and V = b h to find volumes of right rectangular prisms with fractional edge lengths in the context of solving real-world and mathematical problems.
- 6.G.4: Represent three-dimensional figures using nets made up of rectangles and triangles, and use the nets to find the surface area of these figures. Apply these techniques in the context of solving real-world and mathematical problems.
- 6.RP.1: Understand the concept of a ratio and use ratio language to describe a ratio relationship between two quantities.
- 6.RP.3: Use ratio and rate reasoning to solve real-world and mathematical problems, e.g., by reasoning about tables of equivalent ratios, tape diagrams, double number line diagrams, or equations.
  - A. Make tables of equivalent ratios relating quantities with whole number measurements, find missing values in the tables, and plot the pairs of values on the coordinate plane. Use tables to compare ratios.
  - D. Use ratio reasoning to convert measurement units; manipulate and transform units appropriately when multiplying or dividing quantities.
- 6.EE.6: Use variables to represent numbers and write expressions when solving a real-world or mathematical problem; understand that a variable can represent an unknown number, or, depending on the purpose at hand, any number in a specified set.
- 6.EE.9: Use variables to represent two quantities in a real-world problem that change in relationship to one another; write an equation to express one quantity, thought of as the dependent variable, in terms of the other quantity, thought of as the independent variable. Analyze the relationship between the dependent and independent variables using graphs and tables, and relate these to the equation
- 6.SP.4: Display numerical data in plots on a number line, including dot plots, histograms, and box plots.

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/PowerPoint slides, or give the students printed versions to tape into their Notebooks. Students will also use their Notebooks as a reference – a place to maintain the information they are learning through design. Additionally, students will reflect on their work throughout the design process. This is important for modeling what real-life engineers do. Collect the Engineering Notebooks at the end of each class. You will use the Notebooks to assess student learning and their design process. Read the Notebooks and provide feedback to students. We encourage you to assign points for responses in the Notebooks.

The final summative piece of this unit requires students to write a letter back to the client that reports back on their findings of which watercraft worked the best; a template is provided to share with students. It is important to make sure that students know to write in complete sentences.

Potential Digital Resources
Much of the documentation of the engineering design process could be replaced with or supplemented with digital tools. If students are familiar with digital notebooks, this could be a great way for students to take photos and/or capture video of their testing, which they could then annotate. Instead of written reflections, students could do an audio reflection.

Overview

Overview

Lesson Summaries

Lesson 1: Introduction to Flood Rescue Mission

In this lesson students are introduced to the Flood Rescue Mission Engineering Design Challenge by reading a memo from the National Guard. Students complete a KWL to identify the key mathematics and science concepts that they have mastered and which concepts they need to learn more about to successfully complete the Flood Rescue Mission Engineering Design Challenge. Students also identify criteria and constraints as part of this introduction to the design challenge.

Lesson 2: Introduction to Volume

Students will use manipulatives to understand that volume is the amount of space something occupies. They will also understand that volume is represented with the units cm3. They will calculate volume in multiple ways, such as filling a container with centimeter cubes (measuring 1cmx1cmx1cm) and using the formula for volume of rectangular prisms (length x width x height). Students will also learn how to measure the volume of irregular objects using a graduated cylinder after understanding that mL is another unit of volume.

Lesson 3: Connecting Volume and Mass

In this lesson, students will build off of their knowledge about volume from Lesson 2. Students will understand that for water not only does 1 cm^3 = 1 mL, but 1 cm3 = 1 mL = 1 g. This lesson provides students with an introduction of what they will need to know for their engineering design challenge in order to make sense of maximum capacity.

Lesson 4: Forces and Buoyancy

Students will first learn about forces before experiencing the buoyant force on objects that are immersed in water. This content is pertinent for their work on the engineering design challenge in which students need to understand that there is a force that pushes up on objects that appear to be “resting” on water. They will intuit that the greater the volume of the object below the water-line, the greater the upward force on the object. Students will use spring scales to estimate the magnitude of the buoyant force and rotate through a variety of lab stations to learn more about buoyancy. Students will also be able to determine that the buoyant force is equal to the weight of the water displaced (Archimedes’ principle); this can either be accomplished by a demonstration, small group activity, or a video. Students will display their data using graphs and/or pictorial representations, which will be used to make predictions of the upward force on different objects.

Lesson 5: Engineering Design Challenge (Plan, Try, Test, Decide, and Redesign)

In this lesson, students will follow an engineering design process to apply concepts of mass, volume, maximum capacity, and buoyant forces to design/plan, build/try, test, and evaluate/decide a watercraft prototype. Students work in teams where they have an assigned role/task that is necessary in order for their team to succeed. If possible, these teams should not compete within one class, but should compete across different hours (i.e., if you teach three sections of 6th grade science, have each of these classes compete with one another. If you know other teachers from other classrooms who are also teaching this unit, you may wish to compete with them as well, perhaps virtually via Google hangout or choosing a day for select classes from nearby schools to get together and compete). Students end their work with writing a brief report back to the client to explain what they did, which should include the specifications of their watercraft. In this, students use evidence-based reasoning to convince their client that they or their class created the best prototype possible.

Overview

Lesson	Time Needed	**Objectives** The student will be able to:
Lesson 1: Introduction to Flood Rescue Mission	One 50-minute class period	• Students will be able to state the problem they are solving for the challenge. • Students will be able to identify the key math and science concepts needed to complete the challenge. These concepts include: Mass, Maximum Capacity, Volume, Gravity, Buoyant Force. • Students will complete a KWL of concepts that have been mastered and concepts which need more understanding. • Students will identify criteria and constraints in their engineering design challenge.
Lesson 2: Introduction to Volume	Two 50-minute class periods	• Students will understand how to calculate the volume of rectangular prisms by measuring length, width, and height. • Students will understand how to measure the volume of liquids using graduated cylinders.
Lesson 3: Connecting Volume and Mass	One 50-minute class period	• Students will understand that 1 cm^3 of water = 1 mL of water = 1 g of water. • Students will understand that objects submerged in water displace a volume of water equal to the object's weight in grams.
Lesson 4: Forces and Buoyancy	Three 50-minute class periods	• Students will be able to understand the relationship between the volume of an immersed object and the upward force (buoyant force) exerted by the water on that object. • Students will use graphs to understand this relationship. • Students will be able to understand different types of forces including balanced, unbalanced, and buoyant forces.

Overview

Materials * required materials not included in the kit	Duplication Masters
• Highlighters • Engineering Notebook • 2 different colored pens	• 1.a. Client Memo • 1.b. Watercraft - Maximum Occupancy • 1.c. Identify Background Information • 1.d. Scientific Method vs. Engineering Design Process **EDUCATOR RESOURCES** • 1.e. Script of Message from the Client • 1.f. Notebook Cover • 1.g. Notebook Table of Contents
• Cm rulers • Graduated cylinders • Funnels • Centimeter cubes • Cups to organize cubes • Engineering Notebook • 2 different colored pens or pencils	• 2.a. Volume of Rectangular Prisms • 2.b. All about Volume
• Centimeter cubes from Lesson 2 • Double pan balance • Aquarium or other large, transparent tank • Graduated cylinder • Clear prisms (1 Liter) • Digital scales • Food coloring • Engineering Notebook • 2 different colored pens or pencils	• none
• Tubs of water (one per four-person group, eight total for thirty-two students. • Sets of empty plastic water bottles of various sizes, (examples of commonly available bottles: 237 mL, 500 mL, 1,000 mL, and 2,000 mL) • Various objects for stations: e.g.,. can of pop, a brick, water bottle full of sand, water bottle full of iron fillings, screwdriver (can be any objects of various weights) • Engineering Notebook • 2 different colored pens • [Optional] YouTube video http://bit.ly/2arLfRt • [Optional] Script for making your own video • Buoyancy-Volume System (see below for details) • Plastic container (one per four-person group, eight total for thirty-two students) • Prism (one per four-person group, eight total for thirty-two students) • Spring scales (1 per 4-person group, 8 total for 32 students in class)	• 4.a. Force Notes • 4.b. Buoyancy Notes • 4.c. Buoyancy Lab Rotation • 4.d. Volume vs Buoyancy Lab • 4.f. Calculating Maximum Occupancy **EDUCATOR RESOURCES** • 4.e. Video Script

Overview

Lesson	Time Needed	Objectives The student will be able to:
Lesson 5: Engineering Design Challenge (Plan, Try, Test, Decide)	Five to ten 50-minute class periods (written for eight class periods)	• Students will be able to use an engineering design process to design, build, and test a watercraft prototype to be used in flood conditions • Students will be able to work in teams to come up with a watercraft design • Students will develop communication skills by working with small groups • Students will calculate the maximum capacity of their watercraft prototypes using their knowledge of volume and buoyancy • Students will learn how to reflect using an engineering notebook. • Students will use evidence-based reasoning to communicate with their client.

Overview

Materials * required materials not included in the kit	Duplication Masters
• Clear Film Canisters 2 per group; 32 students in a class with eight groups of four, this would be at most 16 per class. • Heavy duty aluminum foil - One-500 ft. roll for multiple classes • Popsicle sticks - 1 box of 1000 sticks per classroom • Glue for glue gun - assume 2 sticks per group; For a class of 32 students and 8 groups of 4, this would be 16 glue sticks per class • Waterproof tape - 2 rolls per classroom • Fat bubble tea straws - 3 packs (172 straws per pack) per classroom • Regular straws - 1,000 straws per classroom • 237 ml bottle - 1 per group (a recycled plastic soda bottle works well!) • 500 ml bottle - 1 per group (a recycled plastic soda bottle works well!) • 2 L bottle - per group(a recycled plastic soda bottle works well!) • Plastic tub - 1 per group, 8 per classroom • Glue gun - 2 glue guns per classroom • mini figurines - 10 figurines per group, 4 sets of 20 per classroom • Buckets - 1 bucket per group (8 per classroom) • Neewer® 8 Pieces 1000 Gram Stainless Steel Calibration Weight Set (500g 200g 2x100g 50g 20g 20g 10g) with Case and Tweezers for Digital Jewelery Scale Science Lab Weights Educational & Hobby Weighing Scales Mini Pocket Balance Scale - 1 set per group; 8 sets per classroom • Double pan balance, digital scale or triple- beam balance - 1 per group- 8 per classroom • Graduated cylinders, plastic set of various volumes - 1 set per group, 8 sets per classroom • Clear plastic cube 10 cm3 prism - 1 per group, 8 per classroom • Frisbee- one per classroom • Funnel- 1 per group, 8 per classroom • Plastic centimeter rulers - 1 ruler per pair of 2 students, or 16 per classroom • Plastic bottle or beaker for water - 1 per group • 27 quart clear plastic bin - 1 per group; 8 per classroom • 2 kg push-pull spring scale - 1 per group; 8 per classroom • 100-gram weights - ten weights per group; 80 per classroom; ***each 100 g weight can be substituted with 40 pennies taped together • Calipers, 1 per group, 8 per classroom	• 5.a. Engineering Notebook Daily Goals • 5.b. Helpful Background Information • 5.c. Materials Testing • 5.d. Design Brainstorming • 5.e. Prototype Report • 5.f. Class Data • 5.g. Evidence-Based Reasoning Graphic • 5.h. Memo to the National Guard • 5.j. Company Credit Card • 5.k. Material Cost Sheet **EDUCATOR RESOURCES** • 5.i. Client Memo Rubrics 1 & 2 • 5.l. Teacher Observation Protocol: Try Lesson • 5.m. Teacher Observation: Test Lesson • 5.n. Teacher Observation: Retest Lesson

Overview

	Material	Lessons Where Material is Used
Per classroom		
Per group (assuming 3 students per group)		
Per student		

* required materials not included in the kit

LESSON 1 Introduction to Flood Rescue Mission

Lesson Objectives

The students will be able to:

- State the problem they are solving for the challenge.
- Identify the key math and science concepts needed to complete the challenge. These concepts include: Mass, Maximum Capacity, Volume, Gravity, Buoyant Force.
- Complete a KWL* of concepts that have been mastered and concepts which need more understanding. [*KWL is a chart in which students answer the questions:1) What do I KNOW? 2) What do I WANT to know? and 3) What have I LEARNED?]
- Identify criteria and constraints in their Engineering Design Challenge.

Time Required

One 50-minute class period

Materials

- Notebook Cover [optional]
- Engineering Notebook/each student
- TOCFlood Rescue [optional]
- SMvEDP
- IntrotoEDC
- Highlighters or markers
- 2 differently colored pens/ student

Standards Addressed

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

Key Terms

mass, maximum capacity, volume, gravity, buoyant force, criteria, constraints, engineering design process

Lesson Summary

In this lesson, students are introduced to the Flood Rescue Mission Engineering Design Challenge by reading a memo from the National Guard. Students complete a KWL to identify the key mathematics and science concepts that they have mastered and which concepts they need to learn more about to successfully complete the Flood Rescue Mission Engineering Design Challenge. Students also identify criteria and constraints as part of this introduction to the design challenge.

Background

Teacher Background

This lesson is all about starting with a motivating and engaging context for students. The context (floods) is something that students can understand, and more importantly, is something that does not require them to be experts at science. By providing students with this context, students are able to connect with the Engineering Design Challenge as well as the science and mathematics content related to this challenge. The templates included in this curriculum are specific to Minnesota, but can be easily changed to fit your local area and community.

For students new to engineering - it might be worth your while to address that engineering is another way to really be involved in science and mathematics. Address that even if you don't feel good about science and mathematics, you might do a really great job with this challenge, especially since everyone will be working together to be successful. Engineering is a great way to challenge all students in the classroom, especially those who do not perform well in traditional learning settings. Make sure to encourage your students to think outside of the box and allow them be creative.

Before the Activity

- Have copies of the duplication masters prepared for students. You may choose to either share it using a PowerPoint or print out individual copies. You may want to decide upon groups ahead of time. Throughout this unit, students should work in groups of 3-4 students.
- You may want to have students complete a Notebook Cover (you may use *1.f. Notebook Cover*) and start a Table of Contents page (you may use *1.g. Notebook Table of Contents*). You may choose to have students tape/glue copies of the Engineering Design Challenge (1.a and 1.b.) into their notebooks.
- For optional introduction: Have copies of *1.c. Scientific Method vs Engineering Design Process*.

Classroom Instruction

Unit Introduction

1. Give a brief introduction to the purpose of the unit. **Say:** *In this unit, we are going to be working as engineers to help the National Guard with rescuing people during floods.*
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. You can use one color pen for*

your response and another color for your team's response.

3. *Each day, turn in your engineering notebooks before you leave class.*
4. Ask students to complete to individually complete the questions in their engineering notebooks: *"What do engineers do?"* and *"How do engineers solve problems?"*

Optional Introduction

Note: This optional introduction should be used when students are not familiar with engineering, but may also be used when students just need a refresher.

1. Have students use the *1.d Scientific Method vs Engineering Design Process* document to look at the differences/similarities of scientific and engineering processes.
2. Allow students to work with a table partner to highlight the similarities and underline where there are differences between these processes.
3. **Ask:** *What do you notice about scientific and engineering processes?* Allow students to share their findings with the class.

Introduction

Note: This context of floods is universal. Even if students have not experienced a flood, showing them evidence of the destruction that can occur with floods can help them understand the importance of associations such as the National Guard or the Red Cross.

1. Start the lesson by showing students pictures of floods.
    - As a warm-up, have students come up with a captivating caption that describes what they see.
    - Allow students to do a turn-and-talk with a table partner to share their caption.
    - Have students share some of their captions with the whole class.
    - Engage students in a whole-class discussion about what they know about floods. Ask questions such as:
    - What do you know about floods?
    - Have you ever experienced a flood?
    - What kinds of groups/people/associations help people who are trapped in floods?

Activity 1: Identify Engineering Challenge

2. Read the *National Guard Project Flood Rescue* letter (1.a. Client Memo) to students out loud, allowing them to follow along with their own copy.
    - **Note:** Show pictures of the National Guard or Red Cross to help illustrate this.
3. Based on the client memo, have students prepare questions for the client. **Ask:** *What questions do you want to ask to the client?* Have students record the questions in their notebooks. Do this both individually and then as teams. Then share out questions as a whole class. Answer the questions from the perspective of the client using *1.b. Watercraft - Maximum Occupancy* as a guide.
4. **Say:** *We're going to use our Engineering Notebooks to help us define the problem we need to solve.* Ask students to get out their Engineering Notebooks. There are 6 questions to help students define the problem. **Say:** *First, on your own, write down who you think the client is.* You may then ask students to work together in teams to answer the questions and/or go through

Assessments

Pre-Activity Assessment

Have students respond to these prompts in their engineering notebooks: *"What do engineers do?" ; "How do engineers solve problems?"*

Ask students to identify the similarities/differences between scientific method and the engineering design process.

Activity Embedded Assessment

Notebook prompts:
Questions for the client.
7 problem scoping questions.

Students self-assess and teacher observes what they know about the science and math concepts needed.

Post-Activity Assessment

None

DUPLICATION MASTERS

- 1.a. Client Memo
- 1.b. Watercraft - Maximum Occupancy
- 1.c. Identify Background Information
- 1.d. Scientific Method vs. Engineering Design Process

EDUCATOR RESOURCES

- 1.e. Script of Message from the Client
- 1.f. Notebook Cover
- 1.g. Notebook Table of Contents

the questions as a class. Students can use a different color pens for their response and their team response.

5. Then **say:** *The National Guard needs our help, but it looks like there are some things we need to learn. On your own, answer the next 3 questions in your Engineering Notebook. What is the problem that National Guard is asking us to help with?* [Help design and test watercraft prototypes to use in a flood.] *Why is this problem important to solve? Who are the end-users?*
6. Have students identify the problem/challenge the National Guard is asking them to do: *Design a watercraft to save lives during a flood and calculate the maximum capacity the watercraft can hold.* Students should write this information in their *Engineering Notebook*. Stress that the challenge is not just designing a watercraft, but that they also have to be able to calculate the maximum capacity. Write, use a document camera, or use a projected slide to show students the problem/challenge on the board.
7. Introduce the words “criteria” and “constraints”. Ask students what they think these terms mean before sharing a definition with them. Have students answer the following questions in their Engineering Notebooks:
   - *What will make a solution effective (criteria)?*
   - *What will limit how you can solve the problem (constraints)?*
8. Have students identify what they might need to include at the end - quantitative data, sketches, etc. **Ask:** *Can anyone remind me of the next step in the Engineering Design Process?* [Learn] Elaborate that this means students need to do some work to identify the science and mathematics concepts they will need to learn in order to address the design challenge.

Activity 2: Identify Math/Science Concepts Needed for Background Research

9. Show the client letter on the board again and/or direct students to look at the letter. Also hand out copies of *1.b. Watercraft - Maximum Occupancy* to each student. **Say:** *We need to identify what science and mathematics concepts we might need to learn more about in order to complete this Engineering Design Challenge.* As students identify what concepts they will need to learn, walk around the classroom to assure all students are participating.
   - **Note:** If students struggle with this, go through the first sentence or two as a class to help identify some of these concepts.
10. Have students read the letter again highlighting or underlining any mathematics and science concepts on their own. Have students work with a partner to share what they have highlighted and then come up with a list of mathematics and science concepts needed the complete the challenge. Have students answer the following question on their own, in their Engineering Notebooks
    - *Think about the problem of floods and watercraft. In terms of designing watercraft to aid in rescue, what do you need to learn in order to successful create the largest passenger capacity watercraft?*

    Then, in teams, students make a complete list with no more than 8 concepts. Allow students about 5 minutes to complete this task. Share out group lists with the class and have the class discuss/agree on the most important concepts needed by asking,
    - *What other information would we need to learn in order to design and build a watercraft?*
    - *What math and science concepts might we want to learn more about to build a successful watercraft?* [Maximum Capacity, Volume, Mass, Forces,

Gravity, Buoyant Force]

11. Using *1.c. Identify Background Information* sheet, have students self-assess their current understanding of the identified math and science concepts. Additionally, students will individually write what they currently know about each concept. Alternatively, you can use butcher paper for students to write down everything they know about the following concepts: ***maximum capacity, volume, mass, forces, gravity, buoyant force***. As you continue through the background research phase of the challenge, refer back to the butcher paper and have students add information they learn
    - **Note:** You may choose to collect this page as a way to diagnose what students currently know about the various concepts.

Closure:

1. Use the sample script of the *1.e. Script of Message from the Client* to create a video of the client, a lieutenant from the National Guard, speaking to the students. Show the video at the end of class to get them excited about the challenge.
2. After students have watched the video, remind them that in addition to designing the watercraft they will need to be able to calculate the maximum capacity of their watercraft. Reiterate that is why the background research stage ("Learn") is so important.
3. Inform students that though they will work in small teams of 4 for activities associated with this design challenge, and they will work together as a class to complete the background research and address the Engineering Design Challenge. Explain that each class will be competing as one big team against the other class sections, so it is important that everyone works together. Tell students that once they finish their background research, they will work in teams of 3-4 to design the watercraft.
4. To close, **say:** *In order for our class to be successful, everyone needs to learn these concepts that we have just identified together. Each person in the class must contribute his/her part. Each person will be an engineer that is part of a team. We will also work together as a BIG team--the whole class will work together and compete with other science classes in this school.*

LESSON 1

Name______________________________ Date__________ Period _____

1.a. Client Memo

MINNESOTA NATIONAL GUARD
ESTABLISHED 1856

DUTY HONOR SERVICE RESPECT INTEGRITY EXCELLENCE

To: 6th Grade Physical Science Students
From: LTC Diamond, Minnesota Army National Guard
Subject: Project – Flood Rescue Mission

Dear Students,

The Minnesota National Guard mission is to support civil authorities during flood response efforts by providing forces and resources within Minnesota in order to protect life, property and provide security.
During the summer of 2014 about 40 of Minnesota's 87 counties sustained flood damage caused by torrential rains in June, and the first five counties to assess the destruction reported $32 Million in losses so far to roads, bridges and other public facilities and present a serious threat to families, pets and livestock in those areas.

As *'Citizen Soldiers'* it is important for the National Guard to be prepared to assist our communities in a variety of circumstances. Due to the recent flooding, the National Guard has been busy evaluating current Continuity Plans (CONPLANS) for how we respond to floods. We are asking relevant questions so we can properly plan, prepare and execute our forces for the next event all while meeting future challenges that we have not even anticipated. Questions we need to ask ourselves are: *How can we efficiently, effectively, and safely rescue people stranded in the middle of a flood?*

Ultimately, we know that we cannot do it alone and that is why we need a corps of young bright engineers with the ability to problem solve,who are committed to helping others in times of great need. With the help of your science teachers we have designed a series of challenges that will help us determine if you have what it takes. If you work together as a team and use the skills you have learned in your science and math classes we are confident you can succeed.

Sincerely,

LTC Diamond

LTC Diamond
Minnesota Army National Guard
Enclosures: MN ARNG Website

LESSON 1

Name________________________________ Date___________ Period _____

1.b. Watercraft - Maximum Occupancy

One of the most important criteria for flood rescue is to determine the maximum occupancy (mass held) for each watercraft. Your first mission is to build a prototype watercraft that could be used for flood rescue and accurately calculate the maximum occupancy.

In order to calculate maximum occupancy of your watercraft you will need to master the following mathematics and science principles: forces, balanced and unbalanced forces, buoyancy, Archimedes' Principle, water displacement, mass, and volume.

Before you test your prototype you must submit a report that includes the following information:

1. Accurate drawing of your prototype watercraft – includes labels, descriptions, and measurements
2. Quantitative data of your watercraft design that includes:
    - Mass total watercraft
    - Volume of individual segments of watercraft
    - Total Volume of watercraft
3. Calculation of maximum occupancy (how much mass the watercraft can safely hold)
4. Force drawing of watercraft in water with maximum capacity

Mission time line:

1. Identify what you know and don't know
2. Background knowledge – master all mathematics and science concepts needed
3. Materials testing – design experiments to test materials used for prototype
4. Build prototype
5. Complete prototype report and accurately calculate maximum occupancy
6. Mission evaluation – test your prototype and calculations

LESSON 1

Name______________________ Date__________ Period _____

1.c. Identify Background Information

Rate yourself on your current level of understanding for each mathematics and science concept needed for the mission. No matter what level of understanding your currently have, write down what you know about the concept, even if it is just that you know the word!

Mathematics & Science Concepts List the concepts below.	**Novice** I am starting to learn this but I don't understand it yet	**Apprentice** I am starting to get this but I need more practice.	**Practitioner** I mostly understand this. I could apply it to the mission and explain how/why it is used.	**What do you currently know about this concept?**

LESSON 1

Name______________________________________ Date____________ Period _____

1.d. Scientific Method vs Engineering Design Process

Adopted from: http://sciencebuddies.org

Scientists study how nature works. Engineers create new things such as products, environments, and experiences. Because engineers and scientists have different objectives, they follow different processes in their work. Scientists perform experiments using the scientific methods, whereas engineers follow the creativity-based engineering design process. Both processes can be broken down into a series of steps as seen below.

Keep in mind that although the steps are listed in sequential order, both scientists and engineers return to previous steps multiple times throughout an experiment or project. It is often necessary to revisit stages or steps.

Why are there two processes?

Both scientists and engineers contribute to the world of human knowledge, but in different ways. Scientists use the scientific method to make testable explanations and predictions about the world. A scientists ask a question and develops and experiment or set of experiments, to answer that question. Engineers use the engineering design process to create solutions to problems. An engineer identifies a specific need: Who need(s) what because why? And then he or she creates a solution that meets the need.

Which method should you follow for a project?

In real life, the distinction between science and engineering is not always clear. Scientists often do some engineering work, and engineers frequently apply scientific principles - including the scientific method. Many projects fall in the gray area between science and engineering, and that's OK. Many projects, even if related to engineering, can and should use the scientific method.

LESSON 1

Name______________________________ Date____________ Period _____

1.d. Scientific Method vs Engineering Design Process

Scientific Method

Problem/Question
The question we ask based on observations

↓

Background Research
Describe relevant scientific principles and knowledge

↓

Hypothesize & Identify Variables
What do you think will happen? Make sure only one factor is changed for a fair test.

↓

Experiment
Develop procedures and test your hypothesis

↓

Data/Observations
Record quantitative and qualitative data in a data table

↓

Analyze Data
Use graphs and mathematical formulas to draw conclusions

↓

Conclusion & Communicate Results
Write a summary of the results of the experiment that can be shared with others

Engineering Design Process

Define the Problem
Define a problem that addresses a need

↓

Learn about the Problem
Determine what kind of background knowledge is needed to solve the problem

↓

Plan a Solution
Brainstorm solutions and develop plans (e.g., blue prints, storyboards)

↓

Try a Solution
Put the plan into action and build a prototype

↓

Try a Solution
Put the plan into action and build a prototype

↓

Decide if the Solution is Good Enough
How could your solution be improved?

1.e. Script of Message from the Client

(Warning sound)

(Displayed:) NG_Science UPDATE

(Next frame, displayed:) [Name of National Guard Lieutenant] LTC _________

“[Name of school] middle school students. Thank you for being here. My name is Lieutenant Colonel [First and Last name of Lieutenant]. I work at joint headquarters in the domestic operations. Basically, anything that affects our [city/county/state/country (whatever appropriate. You may be specific and name the state, for example)] comes through my team. And last year, my team was extremely busy. With the torrential rainfall that we had in [June of 2014 or appropriate month and year], my group was out saving lives, public infrastructure, bridges, and livestock. But, I felt as if we didn’t to an efficient and effective job of doing that.”

“That’s why I am asking you [Name of school] middle school students to help us out. I am going to give you two challenges. And your teacher, [name of teacher], is going to be able to explain the challenges a little bit more in detail. But the first challenge that I need you to do, students, is to help design a watercraft to rescue people. So, that’s going to be your first challenge. Now, I know you are going to have limited supplies by [name of teacher], and, you are going to get further instructions, but, the challenge #1 is going to help design a watercraft to save lives.”

“The second challenge, is when you design your watercraft, when will it be used? And, how will you know that it will be effective and useful in saving lives? Now, as I look at where we were last summer, we were extremely busy. And I know that we were missing something. And I hope that all the bright young engineers in your class at [Name of school] and that are out there, that you can help us out. “

“So, I am hoping to hear back from you in a few weeks. Good Luck! Have a great day!”

Display: NG_Science UPDATE

LESSON 1

Name______________________________ Date____________ Period ______

1.f. Notebook Cover

Engineering Challenge: Flood Rescue Mission

Name ______________________________

Hr ______

Team Members

____

____

____

Team Name

____

LESSON 1

Name________________________________ Date__________ Period _____

1.g. Notebook Table of Contents

Engineering Challenge: Flood Rescue Mission

Table of Contents

Page #	Title	Total Points	Teacher - Check

Total Score: _________ / _________ Points

LESSON 2

Introduction to Volume

Lesson Objectives

The students will be able to:

- Calculate the volume of rectangular prisms by measuring length, width, and height.
- Measure the volume of liquids using graduated cylinders.

Time Required

Two 50-minute class periods

Materials

- Centimeter (cm) rulers
- Worksheet: Volume of Rect Prism Activity
- Rectangular prisms
- Graduated Cylinders
- Funnels
- Centimeter cubes
- Cups to organize cubes

Standards Addressed

- Common Core State Standards - Mathematics: 5.MD.3, 5.MD.4, 5.MD5.a, 5.MD.5.b, 6.G.2

Key Terms

volume, capacity, cubic centimeters, milliliter, gram, displacement

Lesson Summary

Students will use manipulatives to understand that volume is the amount of space something occupies. They will also understand that volume is represented with the units cm^3. They will calculate volume in multiple ways, such as filling a container with centimeter cubes (measuring 1 cm x 1cm x 1cm) and using the formula for volume of rectangular prisms (length x width x height). Students will also learn how to measure the volume of irregular objects using a graduated cylinder after understanding that mL is another unit of volume.

Background

Teacher Background

The purpose of this lesson is to remind students of how to measure volume using the formula they should have learned previously (Volume = Length x Width x Height). Students will use both rulers and centimeter cubes to interact with this mathematical concept to find the volumes of rectangular prisms. Find clear open prisms that students can use to put the centimeter cubes in a way for them to "see volume." Students will also learn that cm^3 = mL by filling the already measured prisms with the correct volume of liquid. After making this connection, students will understand how to measure the volume of irregular objects by measuring the displacement of water in a graduated cylinder.

Tip: Using centimeter cubes that are also 1 gram each will be helpful for Lesson 3, but they not required. You can find them for purchase online from eNascco or in the kit.

Before the Activity

- Day 1 - Prepare enough copies of the worksheet *2.a. Volume of Rectangular Prisms* for each student. Make sure to have enough centimeter cubes and prisms for students to work in groups of 3 or 4 (these can be the final engineering design groups or other groups). For ease of classroom management, you may want to put the cubes into cups for distribution.
- Day 2 - Make sure to have enough small irregular objects for each group to practice measuring volume by displacement several times (4 or 5). Examples of irregular objects can be: small toy figures, round objects, screws, nails, paper clips.

Classroom Instruction

Introduction

1. **Say:** *Yesterday we learned that we have been asked to help the National Guard create prototypes of watercraft that could save people in a flood. We were able to identify that we need to learn about maximum capacity and in order to know how to calculate that, we need to learn about volume. Today we will be exploring the connection between the metric units of length and volume. We will be using the units of centimeters for length. We will explore two different ways to measure volume.*
    - **Note:** If desired, you may combine this lesson with Lesson 3 to also explore the connection to mass of water.

Activity

Activity 1 (Day 1)

1. In this first activity students will practice their knowledge of measuring volume using the formula Volume = Length x Width x Height (V = L x W x H). **Ask:** *What is volume? What do you know about measuring volume? What do you recall from either your science or math class last year?* Allow students to share what they know about volume. If students do not remember the formula for measuring volume, guide them through identifying what they need to know in order to measure volume and then show them the formula.
2. Hand out copies of the *2.a. Volume of Rectangular Prism* activity worksheet to students. Pass out a handful of centimeter cubes to student groups so that a group of four students will have enough to complete the worksheet.
    - **Note:** You may want to have cubes stored in cups for convenience.
3. Before starting on the worksheet, have students use a ruler to measure the volume of the cubes to conclude that the total volume of each cube is in fact 1 cm^3.
4. As a class, work on the first problem on the worksheet together. Have students calculate the volume of the drawn box and share with the class. Ask students how many centimeter cubes are needed to "build" the drawing. Students should use the third column to stack the cubes accordingly.
    - **Note:** Depending on students' backgrounds it may be best to start with multiple examples that are just one layer high, for example, 4 x 2 x 1. Have students count the number of blocks (cm^3) and then add another layer, for example, 4 x 2 x 2. They will immediately see that it will have twice as many blocks (cm^3). Then, add a third layer, and it will have three times as many. Now, have them use the formula L x W x H to see how it arrives at the same number. Once this groundwork has been established, the worksheet and activity will go more smoothly.
5. Allow students to work in their groups to complete the rest of the worksheet. As students are working, walk around to check their understanding. Pay special attention the middle column of the worksheet to make sure that students are calculating volume correctly.
6. Once all groups have completed the worksheet, ask students to put all of the cubes back into the cups and have one person from each group return the cup to the front of the classroom or other designated location.
7. Ask students to document their observations in their Engineering Notebook.

Activity 2 (Day 1)

Note: In this second activity, students will calculate the inside volume of the plastic prism/box using a cm ruler and the formula Volume = length x width x height. They will carefully fill the box with the appropriate volume of water using a graduated cylinder (and a funnel if needed) to realize that 1 cm^3 = 1 mL.

8. Once all groups have returned their cups of cubes, allow each group to take a small plastic rectangular prism with an open side and a ruler back to their tables.
9. **Ask:** *Can you think of a situation where we cannot measure the length, width, and height of some objects?* Guide students to consider liquids, which have a definite volume, but no definite shape. Students may also discuss irregular objects; this is addressed in Activity 3 of Lesson 2 found below. Discuss with students that there is another way to measure volume using liquid.

Assessments

Pre-Activity Assessment
Day 1 (Activities 1 and 2)
In the opening of this lesson, pre-assess what students know about volume from their science or mathematics class the previous year.

Day 2 (Activity 3)
In the opening of this day of the lesson, check student understanding of the previous day by asking, "What is the relationship between cubic centimeters and milliliters?"

Activity Embedded Assessment
Day 1 (Activities 1 and 2)
As students work in groups, walk around to check on their progress. Ask them to identify what they notice as they work with the cubes. Have students write their observations in their Engineering Notebook.
Worksheet

Day 2 (Activity 3)
Worksheet

Post-Activity Assessment
Day 2 (Activity 3): Whole class discussion can be used as a way to check how students did in measuring the volume of irregular shaped objects.

Ask students to update their Engineering Notebooks based on the class discussion.

Post-it activity

DUPLICATION MASTERS

- 2.a. Volume of Rectangular Prisms
- 2.b. All about Volume

EDUCATOR RESOURCES

- none

Introduction to Volume

10. Ask: *How do we measure the volume of liquids? What tool do we use [graduated cylinder]? What units do we use [milliliters, mL]? What might that tell us about the relationship between mL and cm³?*
11. Pass out All About Volume Worksheet
12. Have students use the ruler to measure the dimensions of the prism, making sure that they understand to measure the inside parameters (it helps if the prism is at least somewhat transparent). Students should record their length, width, height, and calculated volumes into their engineering notebook or onto *2.b. All about Volume* (which should later be attached to their notebook). As students work, walk around the room to check what numbers students are coming up with and address any discrepancies. When students have approximately the correct answer, allow them to proceed to the next step. If students are not close, ask students to describe how they arrived at their answer, helping them to identify where errors may have occurred.
    - **Note:** Make sure you know ahead of time the correct volume for the prism.
13. Once students have calculated the volume of the prism to within a few cm^3, allow them to fill their prisms with water. Carefully, pour the water from the prism into the graduated cylinder, using a funnel to help alleviate some spillage. Have students note the volume of water they start with(initial volume) and end with (final volume) and subtract to find the liquid volume (final volume minus initial volume = total liquid volume). You may want to have students working over a sink or over plastic containers to catch any spilled water. Students should be able to see that the volume they calculated should be very close to the volume of the water, thus they will recognize that $1cm^3 = 1mL$.
14. Once all groups have finished this mini-lab, have them clean up their stations.
    - **Note:** Students will be amazed to discover this relationship.

15. Ask: *What did you learn from this lab?* [Volume can be measured in cm^3 or mL; $1cm^3 = 1mL$; you can measure the volume of a prism by measuring the volume of water it can hold] *How might this lab help us with the engineering design challenge?* [Learning volume will help us to understand maximum capacity, which is needed to solve the challenge.]
    - **Note:** If you want to bring up the “wow” factor, have students try to determine how much water a frisbee can hold. You might want to do this as a demonstration.

16. Remind students to document what they did today and their observations in their Engineering Notebook.

Activity 3 (Day 2)
Note: In this last activity students will learn another way to measure volume that is especially helpful when dealing with irregular objects.

17. Say: *Yesterday we learned how to measure the volume of rectangular prisms. What did you learn about the relationship between mL and cm³?* [Allow students to respond] *We first learned how to use a formula to calculate the volume of the prism and then we used graduated cylinders to learn that $1cm^3$ = 1 mL. For objects that are not a regular shape (i.e. prisms, spheres), how can we find their volume? In today’s lab, we’ll discover another way to measure volume that may be useful for our engineering design challenge.*

18. Have students work in groups of three or four (either the same from the previous day or different). Provide them with a cup of cubes and a graduated cylinder. Ask students to remind you of the volume of each cube.

19. Have students fill the graduated cylinder with some amount of water and record the volume. You may take this time to remind them of how to read water levels when using a graduated cylinder. As a check, ask them to record this volume in both cm^3 and mL.
20. Have students put one centimeter cube in the graduated cylinder at a time and record the new volume in a table they create (or you have provided to them). Again, ask them to record this volume in both cm^3 and mL. Have them do this for 10 cubes.
    - **Note:** Students should be able to see that for each cube they put into the graduated cylinder, the level of water increases by 1 mL.
21. Once all groups are done with this mini-lab, have them set the tools aside.
22. Ask students to share what they found in their groups and to document in their Engineering Notebooks. Guiding questions can be similar to:
    a. *What happened to the water level each time you added a cube?*
    b. *How much did the water level rise after you put in ten cubes?*
    c. *What do you remember about the volume of each cube?*
    d. *Can you identify another way to measure volume from this activity?*
23. Address that this way to measure the volume of an object is called measuring volume by displacement and it is useful when dealing with irregular shaped objects. Explain that displacement is the volume of water pushed out of the way by an object that is partially or fully submerged in the water.
24. Have the students repeat the mini-lab lab, but with irregular-shaped objects of unknown volume. Make sure that you have each object measured by at least two different groups to identify any errors that come up. Have each group practice measuring volume with four or five different objects.
25. Remind students to write down their observations and take notes in their Engineering Notebooks.
26. Once all groups have completed this lab, have each group share what volume they measured for their objects, checking for consistency across different groups.
    - **Note:** You may want to create a table on the board for students to add the volumes that they found. This way, students will have a visual to aid in this discussion.

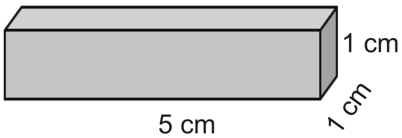
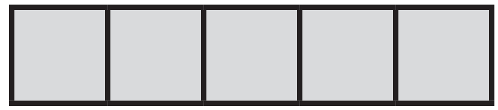
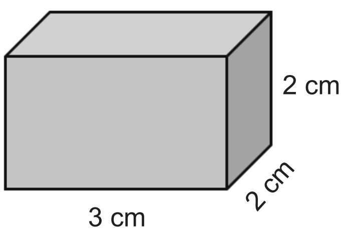
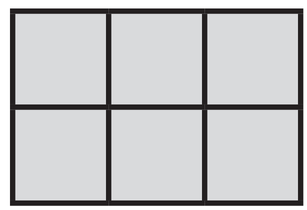
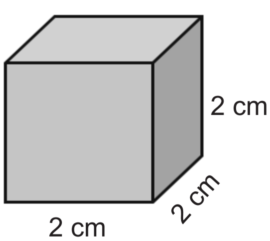
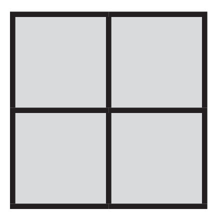
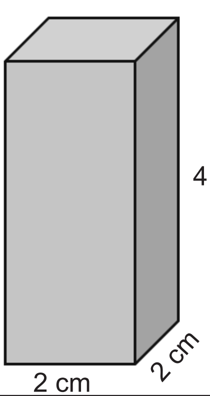
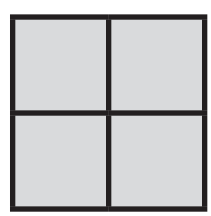
Closure

1. Check their understanding of this lesson's activities by **asking**, *"Name two ways to measure volume."*
2. As an exit-slip, have students draw displacement and a caption on a sticky note to hand in as they leave the room.

LESSON 2

Name______________________________ Date____________ Period ______

2.a. Volume of Rectangular Prisms

Rectangular Prism	Calculate It!	Built It!
Example 	Calculate the volume using the formula: length x width x height L x W x H 5 cm x 1 cm x 1 cm = 5 cm^3	Now place the cubes on the paper so they fit on the squares below. Make this one 1 layer high!  The number of cubes matches the volume that you calculated!
	Calculate the volume. L x W x H _____ cm x _____ cm x _____ cm = _____ cm^3	Use this base to build a prism two layers high.  How many cubes did you use? _____
	Calculate the volume. L x W x H _____ cm x _____ cm x _____ cm = _____ cm^3	Use this base to build a prism two layers high.  How many cubes did you use? _____
	Calculate the volume. L x W x H _____ cm x _____ cm x _____ cm = _____ cm^3	Use this base to build a prism four layers high.  How many cubes did you use? _____

LESSON 2

Name________________________________ Date___________ Period _____

2.b. All About Volume

Measuring the Volume of Prisms

1. Find the volume of the prism using V = length x width x height.

   Length = _________ cm   Height = __________ cm

   Width = __________ cm   Volume = _________cm^3

2. Follow the following steps to find the liquid volume of the prism.
   1. Fill your prism with water.
   2. Carefully pour the water from the prism into the graduated cylinder using the funnel.
   3. Measure the liquid volume using the graduate cylinder.
   4. Record the liquid volume in mL.

   Liquid volume = ______________ mL

3. What does Step 1 and Step 3 tell you about the ways you can measure volume?

Measuring the Volume of Irregular Objects

Procedure

1. Add water to the graduated cylinder and record the volume (mL) as your “Starting Volume”.
2. Carefully drop an object into the graduated cylinder.
3. Record the new volume (mL) in the “Ending Volume” column.
4. Subtract the “Starting Volume” from the “Ending Volume” to find the volume of the irregular shaped object. Record the volume of the object in the table.

Name of Object	Starting Volume (mL)	Ending Volume (mL)	Volume of Object (mL)
1.			
2.			
3.			
4.			
5.			
6.			
7.			
8.			

LESSON

3 Connecting Volume and Mass

Lesson Objectives

The students will be able to:

- Understand that 1 cm^3 of water = 1 mL of water = 1g of water.
- Understand that objects submerged in water displace a volume of water equal to the object's weight in grams.

Time Required

One 50-minute class period

Materials

- Centimeter cubes from Lesson 2
- Double pan balance
- Aquarium or other large, transparent tank
- Graduated cylinder
- Clear prisms (1L)
- Digital scales

Standards Addressed

- Next Generation Science Standards: 5-PS2-1

Key Terms

maximum capacity, volume, cubic centimeter, liter, milliliter, gram, displacement

Lesson Summary

In this lesson, students will build off of their knowledge about volume from Lesson 2. Students will understand that for water, not only does 1 cm^3 = 1 mL, but 1 cm^3 = 1 mL = 1 g. This lesson provides students with an introduction of what they will need to know for their Engineering Design Challenge in order to make sense of maximum capacity.

Background

Teacher Background

This lesson, which is heavily demonstration-based, takes a lot of patience in balancing the container of water and making sure that the amount poured into it is correct. Because of the "wow" factor associated with this demonstration, students will remain a captive audience.

This lesson shows students what Archimedes's principle is all about and introduces them to the idea of density. While this unit is not aimed at covering density to a great level of detail, this lesson introduces the idea in terms of maximum capacity and whether or not a given object sinks or floats in water.

Before the Activity

You will need a double pan balance, a graduated cylinder, colored water, and various gram masses totaling 1,000 grams, and a 10 - 20 gallon aquarium (or other large clear container) filled halfway with water. This is for activities 1 and 2. This should be set up in the front of the classroom for demonstration purposes. This can be adapted to be a small group activity if you have the equipment.

Classroom Instruction

Introduction

1. Have students recall what they know about measuring volume by **asking**, *Name some ways we can measure volume.* You may mention that students can refer to their *Engineering Notebooks* to remind themselves. Student answers should reflect their knowledge gained from Lesson 2 such that they offer the formula for measuring the volume of a prism (V = L x W x H), using a graduated cylinder to measure the volume of a liquid, and using the displacement of a liquid to measure the volume of an irregular object. In this process, be sure to ask students what units are used to indicate volume.
2. **[Optional]** Have students draw a picture to show that 1 mL is equal to 1cm^3. Students should share this with their table groups and then shared to the whole class.
   - **Note:** This should be used if students are struggling to understand this concept.
3. **Say:** *Today we're going to learn more about volume and how there is a force associated with putting objects into water. This will help us to understand maximum capacity - what you need to learn in order to address the National Guard's engineering design challenge.*

Activity

Activity 1

1. In this brief activity, students will revisit how to measure the mass of an object using either a digital scale or triple-beam balance.

Connecting Volume and Mass

- **Note:** This activity can be skipped if students are very familiar with measuring mass. Digital scales (when available) make this lesson quicker to implement. Small adaptations must be made if using triple-beam balances.)

2. Have student groups grab a cup of the centimeter cubes used in Lesson 2. Ask students to recall the volume of these cubes [1 cm^3= 1 mL]. If you did not use Lesson 2 in your class, quickly have students use a ruler to measure the volume of these cubes to determine that they are in fact 1 cm^3.
3. Tell students that these cubes are special - they each weigh 1 gram. Discuss with students that this means that not only is the volume of each cube equal to 1cm^3 = 1 mL, but each one weighs 1 gram. Ask students if they know of any other substance like water in terms of its density.
   - **Note:** If your students know about density, feel free to use this term. Otherwise, density does not need to be introduced here.
4. Have students put all centimeter cubes back in their cup to test this theory. Remind students of how to use the digital scale to measure the mass of the cubes, first by zeroing the scale while the empty cup is on it.
5. Discuss with students how this information might be helpful when it comes to the engineering design challenge. Remind students to take notes in their Engineering Notebooks. Students should be able to connect between what they learned in Lesson 2 such that the volume displaced by the cubes (in cm3 or mL) is equal to the weight of cubes in grams.
   - **Note:** If students struggle with this, have them consult their worksheet from Lesson 2.

Activity 2 - Archimedes's Principle

6. This activity is a big demonstration for students to watch. If you have abundant resources, this activity can be modified such that groups of students perform the activity with enough materials. It worked well with a demonstration.
   - **Note:** You will want to have two clear rectangular prisms that are 1 liter in volume (10 cm x 10 cm x 10cm). Math departments often have these in sets. These prisms usually have the height demarcated in 1 cm increments. If not, you will want to mark the prism with a marker. Alternatively you could mark the volume for each cm of height for example 1cm = 100cm^3, 2 cm = 200cm^3 etc.)
7. Use a double pan balance and place a one liter rectangular prism on each pan, adjust it so they are in perfect balance. Place a 100 g mass into one of the prisms - Measure 100 mL of colored water using a graduated cylinder and pour it into the other prism. The two should now be in balance.
8. After adding the water, the students should see that the water level should be at the 1 cm height mark. This is a good opportunity to reinforce the calculation of volume 10 cm x 10 cm x 1 cm = 100cm^3= 100mL
9. **Say:** *As you can see 100 mL of water = 100 cm^3 of water, which equals 100 grams of mass.*
10. Continue adding mass to one side and water to the other in increments, discussing this relationship as you go, until you reach 1,000 mL = 1,000 cm^3 = 1,000g (1 kg).
11. Ask students to recall what they know about displacement. [An object displaces a volume of water equal to the volume of that object that is below

Assessments

Pre-Activity Assessment
Students recall what they know about volume.

Activity Embedded Assessment
As students are making observations about the balance, be sure to call on a variety of students to check for understanding. You may want to enforce some think-pair-share into this activity to make sure that all students are participating.

Remind students to record their observations in their Engineering Notebooks.

Post-Activity Assessment
Ask students how what they learned today would be helpful in their ultimate mission of watercraft design and maximum passenger occupancy. Have students brainstorm ideas at their tables and share out the groups' ideas.

Ask students to write their ideas in their Engineering Notebooks.

DUPLICATION MASTERS
- none

EDUCATOR RESOURCES
- none

Connecting Volume and Mass

the waterline.]

12. Next, place one of the empty 1 L prisms in the aquarium that is full of water. It should easily float. Now place the 100 gram weight or equivalent 100-gram object in the center of the prism. Have the students observe that it sinks to the 1 cm mark on the prism. The prism has displaced 100 cm^3 of water and it supports 100 grams of mass.
13. Continue adding mass and observing the waterline until you reach the maximum capacity of the prism. Let the prism sink and ask students why that might have happened. (Note: This is a preview of Day 3 in Lesson 4)
14. **Ask**: *Why does something float/sink?"*
    - Have students calculate the mass/volume of the empty prism and also of the prism when it finally sank.
    - Have students revisit the introduction to the lesson and consider what this is for water, knowing that 1mL = $1cm^3$ = 1g.
    - Let students discuss and answer the question [Because its mass/volume, its density is less/more than the density of the medium that it is floating in (water).]
    - Remind students to document their notes and explanations in their Engineering Notebooks.

Closure

1. Ask students how what they learned today would be helpful in their ultimate mission of watercraft design and maximum passenger occupancy. Have students brainstorm ideas at their tables, keep notes in their *Engineering Notebook*, and share out the groups' ideas.

Connecting Volume and Mass

LESSON 3

LESSON 4 Forces and Buoyancy

Lesson Objectives

The students will be able to:

- Understand the relationship between the volume of an immersed object and the upward force (buoyant force) exerted by the water on that object.
- Use graphs to understand this relationship.
- Understand different types of forces including balanced, unbalanced, and buoyant forces.

Time Required

Three 50-minute class periods

Materials

- Tubs of water
- Spring scales
- Sets of empty plastic water bottles of various sizes,
- [Optional] Video file: http://bit.ly/2arLfRt
- [Optional] Script for making your own video
- Buoyancy-Volume System (see below for details) (one per four-person group, eight total for thirty-two students)
- Plastic container
- Prism
- Spring scales (1 per 4-person group, 8 total for 32 students in class)

Standards Addressed

- Next Generation Science Standards: 5-PS-1, MS-PS2-1, MS-PS2-2
- Common Core State Standards - Mathematics: 6.RP.1, 6.RP.3 (a,d), 6.EE.6, 6.EE.9, 6.SP.4

Key Terms

force, balanced force, mass, weight, buoyancy, displacement

Lesson Summary

Students will first learn about forces before experiencing the buoyant force on objects that are immersed in water. This content is pertinent for their work on the engineering design challenge in which students need to understand that there is a force that pushes up on objects that appear to be “resting” on water. They will intuit that the greater the volume of the object below the water-line, the greater the upward force on the object. Students will use spring scales to estimate the magnitude of the buoyant force and rotate through a variety of lab stations to learn more about buoyancy. Students will also be able to determine that the buoyant force is equal to the weight of the water displaced (Archimedes’ principle); this can either be accomplished by a demonstration, small group activity, or a video. Students will display their data using graphs and/or pictorial representations, which will be used to make predictions of the upward force on different objects.

Background

Teacher Background

For simplicity, this lesson will describe force in units of grams; if working with advanced students, you may choose to use the accepted unit of Newtons. This makes a nice connection to the fact that 1mL volume of water is equal to 1 gram. The actual unit of metric unit of force is the Newton(mass x acceleration due to gravity, $1N \rightarrow 1\ kg{\cdot}m/s^2$). In the activity and optional video described in Day 3 the distinction between force and mass is made briefly, but if your students already have this background you may want to use units of Newtons throughout. Students at this age often struggle to understand the difference between mass and weight, so the distinction of using grams instead of Newtons depends on the ability level of your students.

In Lesson 3, students learned that the mass of an object in grams was equal to the volume of water displaced in mL (i.e., if an object has a mass of 100 g, it would displace 100 mL of water when submerged). In this lesson students develop this idea further by focusing on the upward force of the water on an object. In Lesson 3 when weights were placed in the plastic box (rectangular prism) it was perfectly balanced by the upward force of the water. As with all balanced forces the net force was zero. In this lesson, students will learn a way to measure the upward force directly, using a spring scale - and also measure it indirectly by calculating the volume of displaced water. They will experience this both qualitatively (Day 2) and quantitatively (Day 3). This is very powerful, and is the key to the main goal of the unit in being able to predict the maximum occupancy of the prototype watercraft. If students are able to calculate the volume of their watercraft, then they know the amount of volume of water the watercraft can displace. Using this information, students can then determine the buoyant force and maximum capacity of the watercraft.

After the activities in Day 2, students will understand that it takes more force to push the larger container, the container with the greater volume, all the way under the water. They will also notice that the farther they pushed a container into the water, the greater the force required. In Day 3, they will be collect data to show a relationship between the volume of an object that is below the waterline, and the force of the water pushing up. This is similar to the demonstration done in Lesson 3 (Archimedes’s Principle).

Forces and Buoyancy

For Day 3, you have the option of having students do the activity in small groups (how it is written), do it as a demonstration, or show a video for students to document data. If the activity is done as written, when the empty prism is placed in water, the water line is actually just above the bottom of the prism due to the weight of the prism, and a small volume of the prism is submerged. The water line should be considered the zero line. So, when you place a 100-gram weight into the prism, the volume below the water line will read as greater than 1centimeter. This may be confusing to students, but they should start from the zero line/water line when measuring the height. For a plastic 10 cm^3 prism listed in the materials list, the zero line is at approximately 1 cm. You may wish to draw the zero line on the container and the increments of 1 cm from the zero line to the top of the prism. Or, you may want to tape a ruler onto the prism. Also, you may want to make a Styrofoam grid at the bottom of the prism to create slots for the weights. Alternatively, you can use stacks of 40 pennies taped together as weights. 40 pennies that are dated after 1982 is equal to 100 grams (one penny weighs 2.5 grams).

- For the video: The simple device in the video shows a rectangular prism (box) being pulled further and further below the water. At each mark on the container have students calculate the volume of the box that is below the surface, and record the amount of force needed to pull the box into the water. Since the box is not moving at the time we are doing the recording, the forces are balanced. The force of the pull is balanced by the push upwards of the water. These two forces are equal. Therefore, the force the spring scale is recording is equal to the buoyant force of the water. During the video, have students record the height of the water and the buoyant force as shown on the spring scale. The optional Video Data Table Graph worksheet should be used for this. You also have the option of recreating the video using the script (or use this if you plan to do a demonstration).

Before the Activity

- For Day 2: Have large tubs of water set out and make available empty plastic bottles of different volumes: 237mL, 500mL, 1,000mL, and 2,000mL. Make sure they all have caps. Other objects that you use in this activity will need a place to attach a spring scale. Duct tape may be used on larger objects. You may want to use duct tape and/or wire to make a loop at one end of the object so that the item can be suspended from a spring scale.
- For Day 3: Have large clear tubs of water set out for groups of four students. Students will work together during a hands-on experience. Students will use a spring scale to measure the amount of “push” needed to submerge a square container at increasing depths. They will also add 100-gram weights, one at a time and measure the volume of displaced fluid each time another weight is added.
- Optional for using video: Set up aquarium with the pulley spring scale and plastic box similar to what is shown in the video file. By creating this system, students can get a hands on experience without doing the full activity.

Assessments

Pre-Activity Assessment

Day 1
Displacement review

Day 2
Connecting buoyancy to Engineering Design Challenge

Day 3
Understanding the relationship between buoyancy and volume

Activity Embedded Assessment

Day 1
Force Notes Worksheet, Push or Pull Activity

Day 2
Buoyancy Lab Worksheet

Day 3
Buoyancy and Volume Worksheet (Data Table and Graph), Maximum Occupancy Practice Worksheet, Note-taking in Engineering Notebook

Post-Activity Assessment

Day 1
Daily Reflection, Exit Slip

Day 2
T-P-S of pushing different volume bottles underwater

Day 3
Exit Slip, Science Concept Flowchart

DUPLICATION MASTERS

- 4.a. Force Notes
- 4.b. Buoyancy Notes
- 4.c. Buoyancy Lab Rotation
- 4.d. Volume vs Buoyancy Lab
- 4.f. Calculating Maximum Occupancy

EDUCATOR RESOURCES

- 4.e. Video Script

LESSON 4

Forces and Buoyancy

Classroom Instruction

Day 1 - Forces

Note: During the first day of this lesson, students will learn the basics of forces.

Introduction

1. As students enter the room, have a word scramble of "displacement" on the board for them to unscramble. Once students have done this, ask:
2. Can someone explain what this term means?
3. What did we learn about this in class yesterday?
4. Allow students to explain what they did to understand displacement to measure the volume of an object.

Activity - Force Notes

1. **Say:** *Today, we will be learning some basics about forces in order to finish up our learning of the science concepts needed for our engineering design challenge. First, who can tell me what they know about forces?* [Push or pull **Ask:** *How might knowing about forces connect to our Engineering Design Challenge?* [Forces acting on the watercraft] **Say:** *Yesterday we saw how when we added mass to the clear prism in the aquarium, there was a certain level at which it sank. This is what we call maximum capacity, that is, the maximum amount of mass the container could hold before sinking. This is related to both volume and forces, which we'll learn more about today. Most objects have more than one force acting on them. If you had just one force acting on you, you would be pushed or pulled at a faster and faster speed like a rocket. Right now, as you sit there, you have at least two forces on you, and they are balanced. Can anyone identify those two forces?* [Downward force of gravity, upward force of the chair] **Say:** *Can you feel the forces? Because these forces are balanced, you have no change in your motion, but you know they are there. We call the sum of all the forces acting on an object the Net Force. Think of a big net capturing all the forces acting on the object."*
2. Hand out copies of the *4.a Force Notes*.
3. Go through these notes with students.
4. Have students find a partner to demonstrate different forces on one another using their hands: 1) one person pushes and stops, 2) other person pushes and stops, 3) both push equally (net force of zero). Repeat 1-3 with pulling.
5. Remind students to take notes and record observations in their *Engineering Notebooks*.

Closure

1. Daily reflection - Have students write about experiencing forces with a partner. *How might knowing about forces connect to our Engineering Design Challenge?*
2. Remind students to document their observations in their *Engineering Notebooks.*
3. **Engineering notebook prompt:** Ask students to draw a picture of a rectangular prism-shaped watercraft floating in water and carrying two people. Tell students the depth of the watercraft under water, dimensions of the watercraft, the weights of the watercraft and each person, and ask students to draw all of the forces acting on the watercraft using arrows to show the

direction of the forces.

Day 2 - Buoyancy Lab Rotation
Introduction

1. **Say:** *Yesterday we learned a bit about forces. Today we are going to explore one force in particular - the buoyant force, also known as buoyancy. Simply put, buoyancy is the upward force water exerts (makes) on objects. How might this help us with our engineering design challenge?* [The watercraft sits on the water, so there must be a force that keeps it afloat].
    - **Note:** Have students attempt to make this connection, but if they aren't getting it at the beginning, assess their understanding after the station rotation.

Activity

1. Pass out spring scales to table groups (4 students) and have students practice using them to measure the force for various objects. If you have them all measuring the same item, such as a can of soda, you can make sure they are zeroing the scale and measuring correctly.
2. Once students are comfortable using the spring scales, have students work with a partner for the next part.
3. **Say:** *I want your partner to gently lift up on the can of pop while it is hanging from the spring scale. What happens to the measurement on the spring scale?*
4. Discuss balanced forces with the students. **Say:** *The spring scale is pulling up with a force of ___ grams, and the force of gravity is pulling down with the same amount of force of ___ grams. The forces are balanced and so the object doesn't change its motion.*
5. Remind students to take notes in their *Engineering Notebooks*.
6. Have students consider the following questions, using the spring scales and cans of soda.
    - *Can your partner make the can of soda weigh half as much?*
    - *Can they make it read zero?*
    - *When they make the spring scale read half the amount, how much force is your partner applying?*
    - *When they make the spring scale read zero, how much force are they applying?*
    - *How did you calculate that answer?*
7. Use the front of the room to demonstrate pushing down on a can of soda in a large body of water (e.g., clear plastic tub, aquarium tank). **Say:** *When I put the can of soda in the water, the water will push up on the can too. That force is called the buoyant force. You can think of it as an "invisible hand" that pushes up on the can while the can pushes down on the water. The amount of that force can be calculated the same way.*
8. Hand out the *4.b. Buoyancy Notes* worksheet. Go over the notes with students.
9. Hand out the *4.b. Buoyancy Lab Rotation.* Explain the four columns:
    - The name of the object
    - The object's weight (force) out of the water.
    - The weight (force) of the object when suspended in the water.
    - The buoyant force calculated by subtracting the weight of the object in

water from the weight when out of the water.

10. Describe to the students the different stations that you have set up around the room. Tell them that for each object/station, they should be filling in a row in their table.
    a. Station 1: Can of pop
    b. Station 2: a brick
    c. Station 3: a water bottle full of sand
    d. Station 4: a water bottle full of iron filings
    e. Station 5: a screw driver
    f. etc, as many items and stations you want to use

    Note: Students can rotate to different stations with different sized containers, this way you can have appropriate sized tubs for each size of object. You can also have students make a t-table for their qualitative observations or just keep track of this information on their worksheet.
11. Have students complete each station to fill out the *4.c. Buoyancy Lab Rotation* worksheet. The students arrive at the station and suspend the object from the spring scale. They record the weight in grams/Newtons (whichever you see as appropriate for your students). Next they suspend the object in the bucket of water while it is still on the spring scale. The weight of the object is less than it was when recorded suspended in the air. They record this new value. Finally they subtract the difference. This difference is that the upward force exerted by the water and it is known as the buoyant force. Repeat the process at each of the stations.

Closure

1. **Say:** *In the lab there are different water bottles next to tubs of water. Your first task is to go back and submerge (push) these containers under water. Try pushing them slowly, and as you do so make observations about the force it takes to submerge them.*
2. After 5 minutes or less have students come back together and Think, Pair, Share the observations that were made. Remind students to record their observations in their *Engineering Notebook*. Guide this conversation so that students recognize that it took more effort/force to push the larger bottles under water. You can also guide them to identify that the deeper they pushed the containers into the water, the more difficult it became to do. For students who let go of the bottle while it was underwater, causing it to "jump" out of the water, ask to them explain why this might have happened [the buoyant force on the bottle pushed it out of the water].

Day 3 - Connecting Volume and Force
Introduction

1. **Say:** *Today we are going to try to quantify (use numbers to explain) the phenomenon (experience) from yesterday when you pushed the different sized containers under water. You noticed that it took more force to push the larger container, the container with the greater volume, all the way under the water. You also noticed the farther you pushed a container into the water the greater the force required. Why do you think that is?*
    - **Note:** This introduction should be similar regardless of whether you choose to do this as a demonstration, small group activity, or show the video.)
2. Remind students to record their observations and keep notes in their

Engineering Notebooks.

Activity 1 - [Small group version or modify to do as a demonstration]
Note: Various worksheet templates (*4.d. Volume vs. Buoyancy Lab*) have been provided to accompany this activity. If you do this activity as a small group activity or a demonstration, use *4.d. Volume vs. Buoyancy Lab* version (a), (b), or (c) as you deem appropriate. Each group of 4 should have a large, clear bin filled 2/3 with water, a 10 centimeter cube prism, and ten 100-gram weights. The 10-centimeter cube prism should have clearly labeled 1-cm marks from the bottom to the top made with a permanent marker. Additionally, you may tape a clear plastic ruler to the prism.

3. Explain the activity (below) to students. Before allowing them to work in their groups **ask**: *How will you know when the maximum capacity has been reached?*
4. Have students complete the table, calculating the volume the box under water (the volume of the displaced fluid). To measure the buoyant force, have students remove all of the weights, push down with the spring scale until the box height under water is 2 cm. Note amount of force (Newtons) read on the spring scale. Holding at this height, the forces are balanced. This means that the amount of force you are pushing down with is equal to the buoyant force that is pushing up on the prism.
5. Student steps:
   - Have students calculate the area of the base of the prism and measure the height of the prism, and have students calculate the volume of the prism. This should be recorded on their worksheet.
   - Have one group hold the clear, cube-shaped prism in the large container of water. Do not push down on it, but keep it steady, holding it with both hands on opposite sides. Note to the students that the water line or the zero line is at approximately 1 cm. This is due to the weight of the prism itself, which students can calculate if they wish.
   - Have another student add one 100-gram mass to the prism. The student should place the first weight in the center of the base for balance. Have students
   - Another student should be in charge of data recording. Have this student write down the how many centimeters of the prism is submerged or is below the waterline using the *4.d. Volume vs Buoyancy Lab* worksheet.
   - Have the second student continue to add 100-gram weights to the prism and collect the data. (Note: Balancing these can be tricky).
   - The student data collector should note the height of the box under water. Students should continue to add the masses one at a time, noting the height of the box under water after each additional mass, until the maximum capacity has been reached.
   - Have students graph their data.
   - **[Optional]** In addition, to help students better understand buoyant force, have students measure the weight of the volume of the prism that is under water. They can do this by using a balance. Have students weigh the empty prism and zero the scale. Then, have students add water to the prism to the height of 2 cm. Have students discover that the weight of this water is equal to the buoyant force as measured by the spring scale. This buoyant force is equal to the weight of the displaced water, or the volume

Lesson Objectives
The students will be able to:
•

Time Required

Materials
- **Per classroom:**
- **Per group:**
- **Per student:**

Standards Addressed
•

Key Terms

of the prism that is under water.

Activity 1 [Video version]

6. Watch part 1 of the video. During this time, students should record the height of the box underwater using the *4.d. Volume vs. Buoyancy Lab (d)* worksheet.
7. After part 1, have students calculate the volume of the box that was submerged at each instance.
8. Make a graph of volume versus buoyant force using the graph on the bottom of the worksheet.
9. Allow students to make sense of this graph and the end of the previous days' activity in which they felt the difference in force for different volumes of water. Allow them to conclude that the bigger the volume under water, the more buoyant force there is pushing up on a submerged object.
   - Note: A best fit line graph would work the best.
10. Show students the aquarium/pulley device and allow them to experience it.
11. **Say:** *In the lab is a device that is similar to the device shown in the video. I would like you and your partner to get familiar with this device and see how accurately you can measure the force required to pull the container under water to different depths. As you do this try to find ways that errors or mistakes might be made if one was not careful. Also how would you calculate the volume of the part of container that is underwater? Make sure to write your notes on this in your Engineering Notebook. These ideas and skills will be necessary for the next part of our investigation where we will determine the relationship between volume and buoyancy.*

Activity 2

12. After the lab activity or video compare results. **Ask**:
    - *Did everyone get the same result?*
    - *What was the range?*
    - *Why didn't we get the same answers?*
    - *Does error happen when professional scientists conduct data collection?*
13. **Say**: *Due to the difficulty in measuring with a high degree of accuracy it is okay to not have your line go through every point. We found a strong relationship between buoyancy and volume submerged. We will use what is called a "Best Fit Line graph" .*
14. Return to the pop bottles that were set up from the previous day and compare the 500 mL bottle to the 2L bottle.
15. Have students use their graph to estimate the buoyant force on these two bottles when they are fully submerged. Confirm this.

Activity 3

16. Have students make a claim about the relationship between volume of immersed object and the upward force exerted by the water on that object. They can document this in their *Engineering Notebooks*. Specifically, guide them to a point where they understand that the greater the volume, the greater the upward force and that the buoyant force is equal to the weight of the water displaced.
17. **Ask:** *How does this information relate to what we learned about maximum capacity?"*Allow students to answer this question before then **asking**, *"How does all of this information help us understand our engineering design*

challenge?"

18. [Optional] Provide students with various sizes of watercraft prototypes made out of aluminum foil only. Allow them to work in groups to practice calculating maximum capacity using the *4.f. Calculating Maximum Occupancy* worksheet.

Closure

1. **[Optional]** Have students revisit their notebook prompt from Day 1 of Lesson 4 and add to it by asking them to calculate the maximum capacity of the watercraft given the dimensions of the watercraft and the mass of the people.
2. To close, have students connect science concepts learned so far to each other and to the Engineering Design Challenge. This can be done via a flowchart in their *Engineering Notebook*.
   - **Note:** It may be a good idea to make a flowchart of these interconnections to visualize how these concepts are related.

Name_______________________ Date___________ Period _____

4.a. Force Notes

Force

- A ____________________ or ____________________
- Measured in ____________________
- What forces are being exerted on the football?

Strength and Direction of Forces

- ____________________ are used to show force
- Longer arrow = ____________________
- Shorter arrow = ____________________

Net Force

- The ____________________ of all the ____________________ acting on an object
- Depends on the directions of the ____________________ applied to an object

Find the Net Force

- Must specify the ____________________
- ____________________ force = ____________________ direction as reference direction
- ____________________ force = ____________________ direction of reference direction

Forces in the same direction example	Forces in the opposite direction example

LESSON 4

Name____________________________________ Date____________ Period _____

4.a. Force Notes

Balanced Forces

- ______________________ forces acting in ______________________ directions on an object
- ______________________change in ______________________ (cancel each other out)
- Net force = ______________________

Unbalanced Forces

- ______________________ forces (do not cancel each other out)
- Net force ______________________ = 0
- Motion ______________________ (object accelerates or ______________________ down)

Friction

- Force that ______________________ motion between 2 surfaces
- Depends on the:
    - Types of ______________________
    - ______________________ between the surfaces

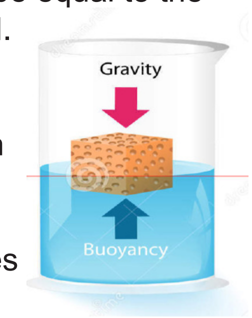
Mass	Weight
The amount of matter in an object	The downward force of an object due to its mass and the gravitational attraction of Earth

Name____________________________________ Date___________ Period _____

4.b. Buoyancy Notes

<table>
<tr><th>Questions</th><th>Buoyancy Notes</th></tr>
<tr><td></td><td>**Displacement** - The amount of water pushed out of the way by a volume of the object.

Buoyancy - The upward force of water on an object.</td></tr>
<tr><td></td><td>The buoyant force of water will be equal to the weight of water that is displaced.



Since buoyancy is a force it is measured in Newtons. But often here on earth we often think of weight and mass as the same. For simplicity we may sometimes use grams as a convenient measure of buoyancy.</td></tr>
<tr><td colspan="2">**Lab Rotation Summary**</td></tr>
</table>

LESSON 4

Name________________________________ Date___________ Period _____

4.c. Buoyancy Lab Rotation

Object	**Weight** (grams**)	**Weight in Water** (grams)	**Buoyant Force** (the difference between column B and C)
1.			
2.			
3.			
4.			
5.			
6.			
7.			

LESSON 4

Name________________________________ Date____________ Period ______

4.d. Volume vs Buoyancy Lab (a)

Base of Box (cm^2) 10 cm x 1 cm	**Height of Box Underwater** (cm)	**Calculation** (Base x Height)	**Volume of Box Underwater** (cm^3)	**Buoyant Force** (N)
10 cm^2	1 cm	10 cm^2 x 1 cm	10 cm^3	
10 cm^2	2 cm			
10 cm^2	3 cm			
10 cm^2	4 cm			
10 cm^2	5 cm			
10 cm^2	6 cm			
10 cm^2	7 cm			
10 cm^2	8 cm			
10 cm^2	9 cm			
10 cm^2	10 cm			

Buoyant Force (Newtons)

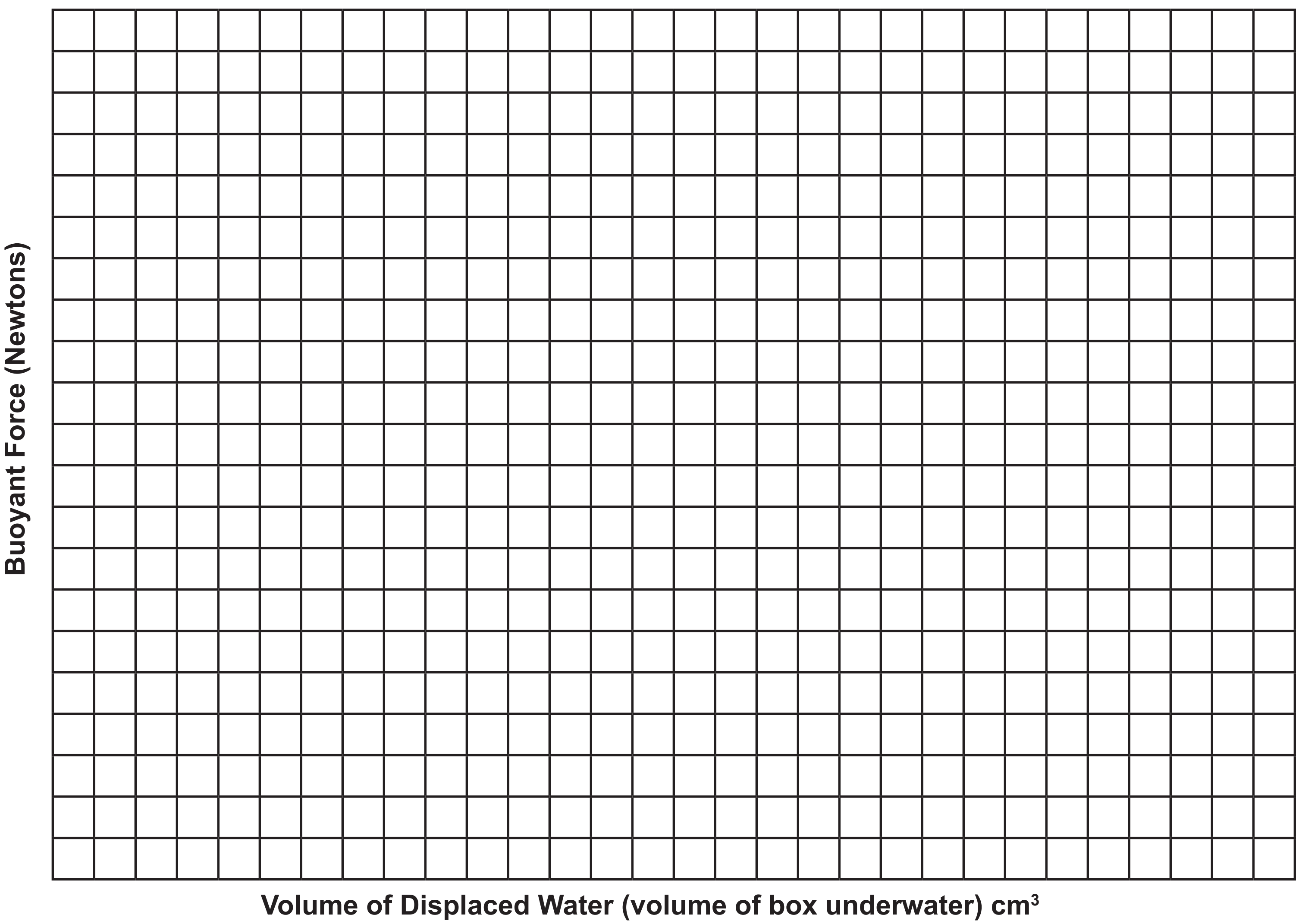
Volume of Displaced Water (volume of box underwater) cm^3

LESSON 4

Name________________________________ Date___________ Period _____

4.d. Volume vs Buoyancy Lab (b)

Base of Box (cm^2) 10 cm x 1 cm	**Height of Box Underwater** (cm)	**Calculation** (Base x Height)	**Volume of Box Underwater** (cm^3)	**Buoyant Force** (N)
cm^2	1 cm		10 cm^3	
	2 cm			
	3 cm			
	4 cm			
	5 cm			
	6 cm			
	7 cm			
	8 cm			
	9 cm			
	10 cm			



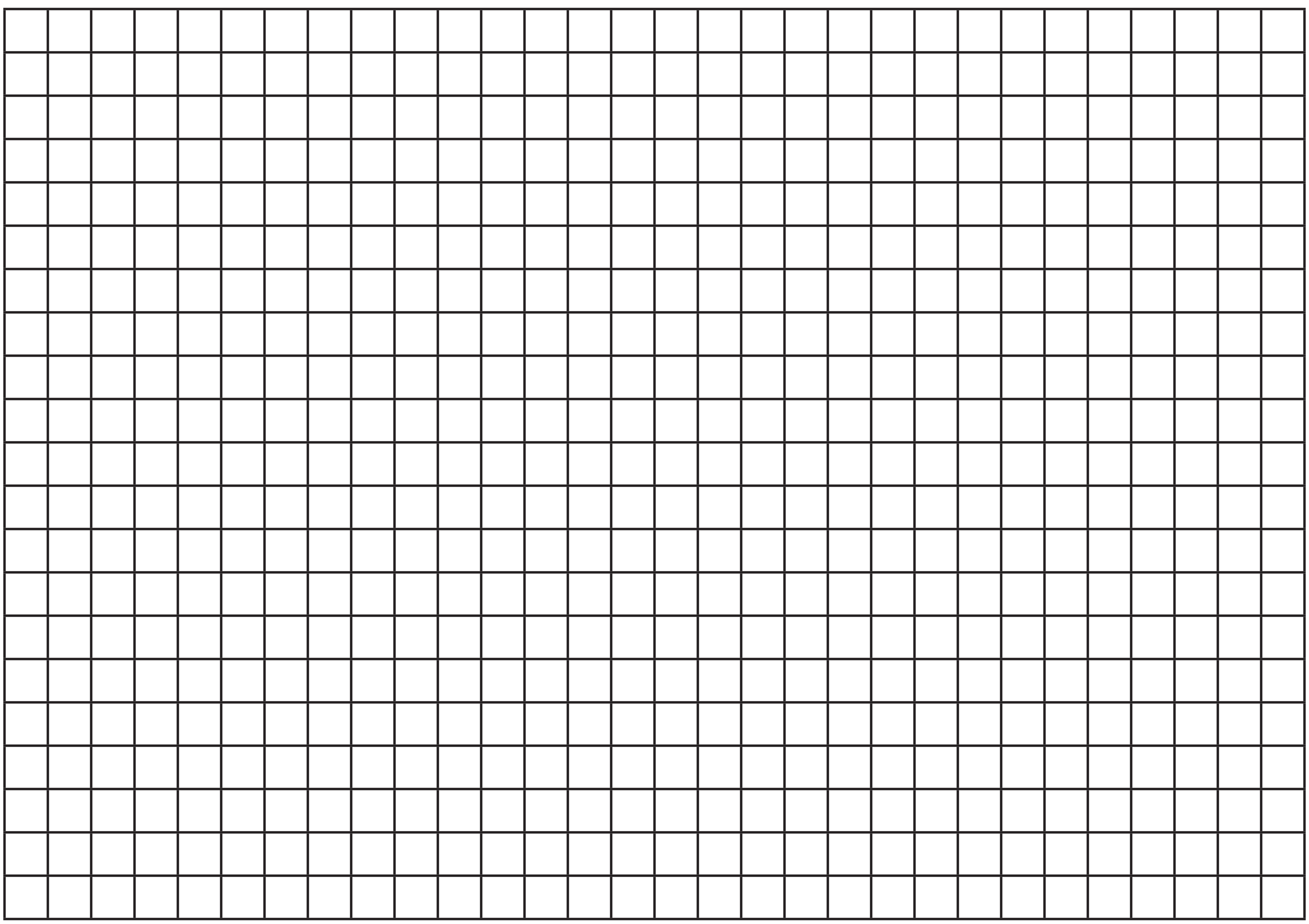
LESSON 4

Name______________________________ Date__________ Period _____

4.d. Volume vs Buoyancy Lab (c)

Base of Box (cm^2) 10 cm x 1 cm	**Height of Box Underwater** (cm)	**Calculation** (Base x Height)	**Volume of Box Underwater** (cm^3)	Calculation of Buoyant Force (kg x 9.8 m/s^2)	**Buoyant Force** (N)
cm^2	1 cm				
	2 cm				
	3 cm				
	4 cm				
	5 cm				
	6 cm				
	7 cm				
	8 cm				
	9 cm				
	10 cm				

Buoyant Force (Newtons)



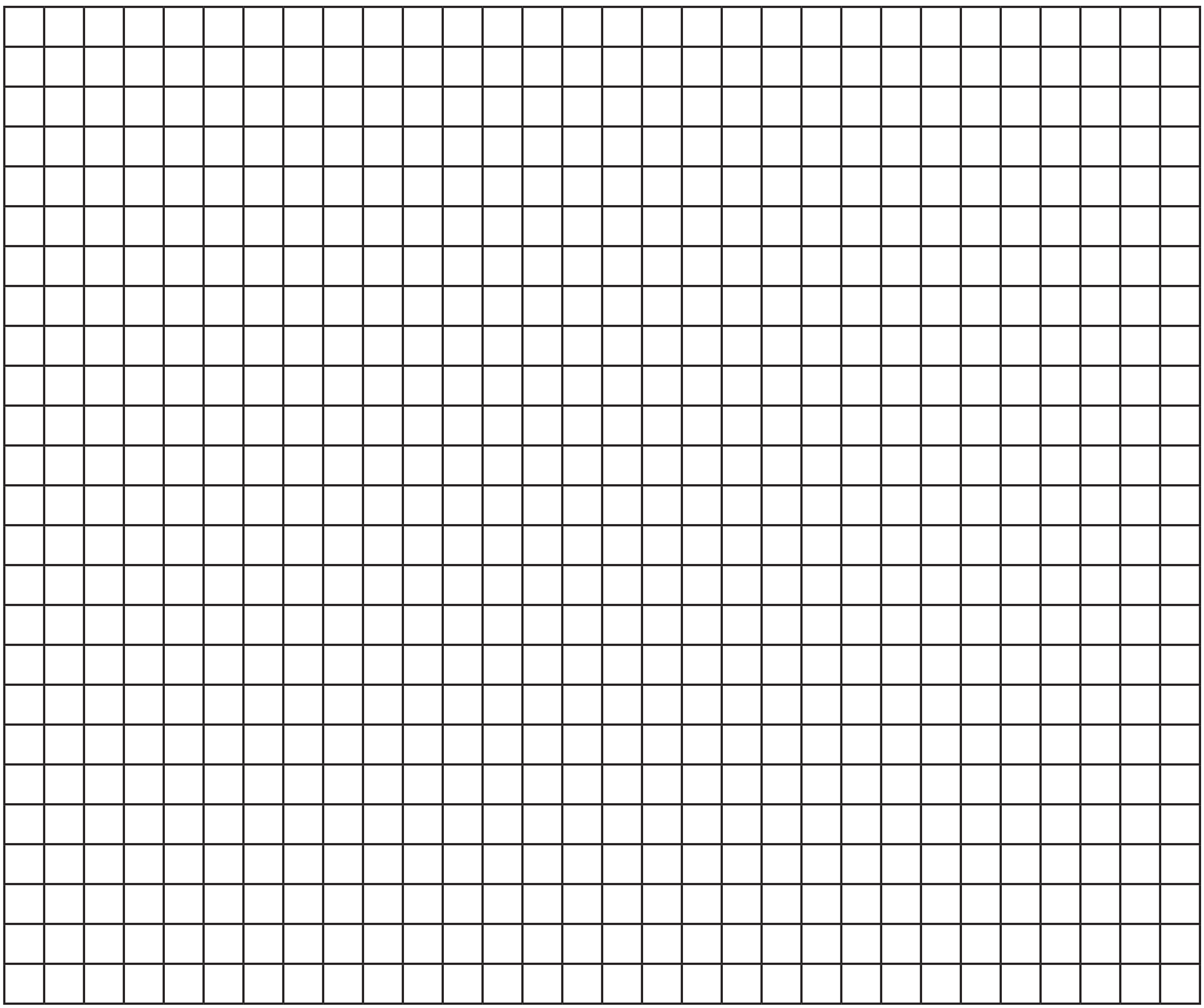
Volume of Displaced Water (volume of box underwater) cm^3

LESSON 4

Name______________________________________ Date____________ Period _____

4.d. Volume vs Buoyancy Lab (d)

Base of Box (cm^2) 14 cm x 15 cm	**Height of Box Underwater** (cm)	**Calculation** (Base x Height)	**Volume of Box Underwater** (cm^3)	**Buoyant Force** (N)
210 cm^2	5 cm	210 cm^2 x 5 cm	1,050 cm^3	
210 cm^2	7 cm			
210 cm^2	9 cm			
210 cm^2	10 cm			
210 cm^2	12 cm			
210 cm^2	15 cm			



Buoyant Force (Newtons)

Volume of Displaced Water (volume of box underwater) cm^3

4.e. Video Script

Buoyancy and How it Relates to Volume

Here is a little device that allows me to pull a container underwater and since I can't be under water pulling a force straight down, I used a pulley. So, the pulley just changes the direction of the force. It really doesn't change the force much.

At the top, I am going to attach one of our spring scales. So we can actually quantify the amount of force it takes up pull this container under water.

Now, I can tell, qualitatively, that the farther under water I pull the container, the harder it is to hold it at that point.

Right now, the forces are balanced. I know that because the containers are not moving.

When there's no force on it, it's just sitting in the water and the only force down is its weight and the weight of the rope.

My assistant is not pulling on the rope at all right now.

So, if we look at this, its just a little bit above the zero.

That means when we're doing our measurements, I'll always have to go a little bit above the line with the number.

I am going to have _____________

____________ is going to start pulling on her spring scale.

And we are going to stop when it right above the 5.

Okay, stop right there.

Alright.

(Music...pause...) (Show the container in the tank...)

Then zoom in on the spring scale...it is perfectly 10.

___________ is going to continue pulling. She's going to get it a little above the seven. So, a little more, ____________, a little bit more...stop right there.

The spring scale reads 13.5.

Then, ___________ pulls to a little bit above 9.

4.e. Video Script

Spring scale…number of Newtons reads 18
___________ pull to a little above the 10.

Spring scale reads (max) 20 N.

___________ pulls to about 12

Spring scale reads 25.5

15

spring scale reads 31 newtons.

Now we need to find the volume of our container.

Since it is a prism, it is base x height.

We know the height. Let's find the area of the base. I line up my rule with the zero and it looks like in this direction it is 14 cm almost exactly.

All right, lets do the other direction. Line up one side with the zero. We have 15 cm, so our base is 14 x 15.
Buoyancy part II: The cylinder

OK, now I am going to try this with a different shaped container. This is a cylinder. So it's a different base times the height and same thing. This is a little bit off because I didn't take into account the weights of the rope but right now there is no force on this. So it's a little above the mark I had on there for zero.

And I'm going to start …halfway is about 6 cm of height and our Newton scale is reading at 5 Newtons.

To 8 cm of height and it is at 9.5 Newtons

Buoyance part III the brick

Here is another way to consider buoyancy. And we know the block is going to sink but does that not mean that there is no buoyant force? Well let's find out?

16.2 N weight of the brick.

When we put the brick in the water. The deeper we go into the water.

9 Newtons.

LESSON 4

Name______________________________ Date__________ Period _____

4.f. Calculating Maximum Occupancy

1. Define volume:

2. Volume of rectangular prism: ________________ x ________________ x ________________

3. Define mass:

Maximum Occupancy = Total Volume of Object - Mass of the Object

Volume of Object (watercraft)	**Mass of Object** (make sure the scale is at 0g before you put it on)	**Maximum Occupancy** (volume - mass)	**Mass on Pennies you Put In** (keep object on scale and press on/zero button before you put pennies in container)	**What happened? How close to the water level where you?** (draw a picture)

LESSON 5

Engineering Design Challenge

Lesson Objectives
The students will be able to:

- Use an engineering design process to design, build, and test a watercraft prototype to be used in flood conditions
- Work in teams to come up with a watercraft design
- Develop communication skills by working with small groups
- Calculate the maximum capacity of their watercraft prototypes using their knowledge of volume and buoyancy
- Reflect using their Engineering Notebooks.
- Use evidence-based reasoning to communicate with their client.

Time Required
Five to ten 50-minute class period (organized into a seven day lesson)

Materials
- See Overview

Standards Addressed
- Next Generation Science Standards: 3-PS2-1, 3-PS2-2, 3-5-ETS1-2, 3-5-ETS1-3, MS-PS2-1, MS-PS2-2, MS-ETS1-2, MS-ETS1-3, MS-ETS1-4
- Common Core State Standards - Mathematics: 6.G.2, 6.G.4

Key Terms
engineering design process, prototype, maximum capacity, evidence-based reasoning

Lesson Summary
In this lesson, students will follow an engineering design process to apply concepts of mass, volume, maximum capacity, and buoyant forces to plan, try, test, and decide on a watercraft prototype. Students work in teams where they have an assigned role/task that is necessary in order for their team to succeed. If possible, these teams should not compete within one class, but should compete across different hours (i.e., if you teach three sections of 6th grade science, have each of these classes compete with one another). Students end their work with writing a brief report back to the client to explain what they did, which should include the specifications of their watercraft. In this, students use evidence-based reasoning to convince their client that they or their class created the best prototype possible.

Background
Teacher Background
This lesson is made up of several activities to help students through the Engineering Design Challenge of designing a prototype of a watercraft for the National Guard to use to rescue people in a flood.

Before the Activity
- For this lesson, it is best to have students at lab stations or tables in different parts of the room so that groups of 4 can work together. Organizing the materials ahead of time is extremely helpful. You may want to have “hours” for the materials store such that students need to carefully plan for purchasing their materials; this allows you to free yourself up and check on student progress as they work. An example of prices for materials is found in the *5.k. Material Cost Sheet.* This particular example includes “Trip to the junk yard,” which could be used as a way to recycle materials between the materials testing day and the prototype building day. Other ideas are to have “sales” on materials that require students to do some extra calculations on the prices. This may be used for advanced students.
- As students are working on the initial materials testing and building their prototypes, you will need to have a large testing station available to them. For the initial materials testing, these can be small stations around the room (e.g., plastics tubs filled with water). For the final testing, this should be large enough for students to be able to see when gathered around. You may want to use something bigger than the plastic container used in Lessons 3 and 4. Aquariums and stream tables make great alternatives.

Grouping Information: For the Engineering Design Challenge, students will work in groups of four. As an engineering team, this group of four students will take on roles that are required for the success of their watercraft: Watercraft Designer, Keep it Together Crew, Straw Sealers, and Math Masters. It should be stressed to students that while they are assigned one of these roles, they are all supposed to aid in the building of the watercraft. Each member of the team is required to accomplish this goal. A description of each role is found below.

a. **Watercraft Designer:** Tests different types of watercraft shapes and designs.

Having pre-made shapes would be helpful so that these students could spend more time doing controlled tests. Students in this role could also test different weights of aluminum foil. The heavier brand could be set at a higher price so groups should have data on how much of an advantage the thicker foil would be.

b. **Keep it Together Crew:** Test different ways to keep materials together such as hot glue, duct tape, masking tape, waterproof tape. Another task that this group can do is to test folded aluminum for leaks. For example, can the fold be taped to let in less water.

c. **Straw Sealers:** Test different ways to seal the straws and keep water from entering in. Straws should be weighted down below the surface of the water for a specified amount of time

d. **Math Masters:** Works on calculating the volume of the different shaped objects that could be used, such as the film canisters and bubble straws. This individual can also be the accuracy checker on keeping track of costs and budget.

- When students do their initial testing, there are two ways to structure this. The first way is that the brainstorming and testing that happens on Days 1 and 2 is done with students of "like" roles (i.e., all of the Watercraft Designers work together to come up with ways to test different watercraft designs). This is more of a jigsaw approach so that when the teams come back together, each person is contributing something different. The second way is to keep the teams of four together so that the students are in constant communication with one another to assure the success of their watercraft. Both of these methods lead to the development of successful teamwork and communication.
- If choosing for students to work in "like" roles: Students who are math masters can be given inexpensive calipers to accurately measure the diameter of the straws and the film canister. As this tends to monopolize the teacher's time it could make it difficult for the other three groups to succeed. It would be helpful if the math masters could be lead through their task with an instructional video. They may enjoy the challenge of that and can check their answer with the teacher at the end of process. Teams should either have their plan of attack pre-approved by the teacher before doing the testing or at the very least have well constructed data tables prior to their testing. You could require them to have quantitative evidence for each of their claims, prior to reporting back to their group

Engineering Notebook

- Encourage students to take notes each day to document what they have done and are learning.
- Each day also has specific questions to assess students' throughout their design process and opportunity for feedback.

Classroom Instruction

Day 1

Introduction

1. Before you begin, prepare for materials/mini test
   - **Note:** For this initial testing, you may or may not choose to enforce a budget. You may want to strongly suggest to students that they should take note of the materials they need so they can plan accordingly.
2. Revisit the goals/letter, class competition: Review the letter from the National Guard (*1.a. Client Memo*) that you shared with students in Lesson 1. Make

Assessments

Pre-Activity Assessment

Day 1

Evidence Based Reasoning Idea Graphic (insert into Engineering Notebook)

Activity Embedded Assessment

Teacher observations of try, test, retest in teams.

Post-Activity Assessment

Day 1

Engineering Notebook Questions (Plan)

DUPLICATION MASTERS

- 5.a. Engineering Notebook Daily Goals
- 5.b. Helpful Background Information
- 5.c. Materials Testing
- 5.d. Design Brainstorming
- 5.e. Prototype Report
- 5.f. Class Data
- 5.g. Evidence-Based Reasoning Graphic
- 5.h. Memo to the National Guard
- 5.j. Company Credit Card
- 5.k. Material Cost Sheet

EDUCATOR RESOURCES

- 5.i. Client Memo Rubrics 1 & 2
- 5.l. Teacher Observation Protocol: Try Lesson
- 5.m. Teacher Observation: Test Lesson
- 5.n. Teacher Observation: Retest Lesson

sure to identify the criteria/constraints and the information needed in the final report. Go through the timeline for the challenge. Ask students what more they need to know; write out a list from class ideas.

3. **Say:** *Today we will be starting our engineering design challenge. You will learn about the different materials that will be available to you, including the cost of these materials. Just like engineers, you will be given a budget, so it is important to plan accordingly.*

Activity

1. Share the *5.b. Helpful Background Information* handout with students as a "quick reference guide" of the science content they have learned that may help them along the way. You may want to hand out the version of the vocabulary list that is complete with definitions if you have time constraints or if students have trouble writing.
2. Share the list of materials with the students (*5.k. Materials Cost Sheet*) and go through the cost of each material.
3. Provide students with information of the different roles as described above. Allow students to decide in their group what role they would like. Encourage students to play to their strengths such that if someone is really good at math, they should be the Math Master of their group. Remind students that each member of their team is important for success; each team's success is important for the class since they will be competing with students from the other classes. Be sure to remind students that just because they have one job, they are all contributing to the final design of the watercraft.
4. Once students have decided what job they would like to be in charge of, have students start to brainstorm their ideas for their mini tests. Students should use the first page of *5.c. Materials Testing* to start planning for materials testing. This can either be done in like groups of with their 4-person team.
5. Have students decide what is needed to collect evidence/data table for students to share their individual testing findings using the second page of *5.c. Materials Testing* as a guide.

Closure

1. Before the end of class, have students make their first entry in the *5.a. Engineering Notebook Daily Goals* sheet (and have them attach these in their notebooks). Have them write down the learning goals for today and provide a reflection on how they met these goals. Each student will need at least 2 copies of the *5.a.* sheet.

Day 2: Implement mini-tests, focus on accurate data collection / analysis.
Introduction

1. **Say:** *Yesterday we started brainstorming what tests we need to conduct in order to understand our materials. This testing will also help us to understand what materials will help our watercraft float and how we can create a watercraft with a large maximum capacity.*
2. Provide students with a few minutes to write down their goals for the day in their *5.a. Engineering Notebook Daily Goals* sheet. Students should write something that reflects the materials testing.

Activity

1. Have students briefly talk in their teams, continuing brainstorming and making final decisions about collecting evidence for their individual test. This information should end up in their *5.c. Materials Testing* worksheet (page 1).
2. Allow students to test their assigned task at different stations in the room while completing page 2 of *5.c. Materials Testing*. Encourage students to talk to others who are working on the same task/role or others that are in their 4-person group.
   - **Note:** During this time the teacher can work with the math masters on some of the higher level volume problems, such as the volume of cylinders (straws and film canisters).
3. Collect *5.c. Materials Testing* sheet for students to share their individual testing findings with their group and the class.

Closure
1. Before students leave, have them reflect on what they did today in their *5.a. Engineering Notebook Daily Goals* sheet and plan ahead for tomorrow.

Day 3: Reflect on Initial Testing
Introduction
1. **Say:** *Yesterday you each worked on small investigations to help prepare you for your engineering design challenge. Today, we will have time to share what we learned from these investigations. Remember - while you are working in small groups, you are all part of a team. Each team's success adds to the success of the class.*
2. Have students write down a goal for today in their *5.a. Engineering Notebook Daily Goals* sheet.

Activity
1. Have students share out their results from the previous day's materials testing. This should first be done within the 4-person teams for students to share what each of them accomplished. This should then transition into a class-wide share out. It is recommended to do this by job description so that everyone has a chance to share what he/she found with the individual testing.
2. Once students have shared their successes and failures, have each four-person team brainstorm ideas for their watercraft prototype. This can be done on a separate piece of paper or using the *5.d. Design Brainstorming* worksheet. Make sure that students know to clearly label their designs with materials.
3. Have the students narrow down their brainstorm ideas into one design that they will move forward with as a team. Have them complete the *5.g. Evidence-Based Reasoning Graphic* for their team idea and attach it to their notebooks.
4. Once students have completed a prototype drawing/sketch, have them work on a shopping list. This should be more of a back and forth if using a budget as students will need to carefully plan their materials. Introduce students to the *5.j. Company Credit Card* and the *5.k. Material Cost Sheet* if using a budget.

Closure
1. Before students leave, have them reflect on what they did today in their *5.a.*

Engineering Notebook Daily Goals sheet and plan ahead for tomorrow.
2. Have students answer the following questions in their *Engineering Design Notebooks*:
   - What are the pros and cons of each of your solutions?
   - Which solution did your team choose and why?

Day 4-5: Plan, Try, Test
Note: Students may find that if they choose to use film canisters, the watercraft may be lopsided in terms of balance. If using two canisters, have the lids pointing in opposite directions for better balance.
Tip: To help keep track of materials, provide each 4-person team with a plastic or paper bag to store their materials between days.

Introduction
1. Have students write down a goal for today in their *5.a. Engineering Notebook Daily Goals* sheet.

Activity
1. If needed, have four-person teams continue brainstorming; draw/sketch design, plan their budget.
2. As each group finishes these planning stages, check off on their plan (optional: You can be their manager) before they start to buy materials and build their prototype. Allow 2 days for students to build. Use a blank sheet of paper for students to practice their calculations of volume and maximum capacity of their watercraft (this will eventually be part of their *5.e. Prototype Report*). Make sure to have digital scales set up for students to find the mass/weight of their watercraft.
3. Allow students to build their design. As they are building, use the *5.l. Teacher Observation Protocol: Try Lesson* to assess students as they work.
4. At the end of building, make sure that all groups have completed their *5.e. Prototype Report* (with the exception of the mission evaluation), complete with a detailed sketch of their watercraft, volume calculations, force diagram, and maximum capacity. (Note: You may choose to have groups check each others' work as a way to build up the class as a team)
5. Allow students to test their watercraft in an aquarium or other transparent container filled with water to test for balance.

Closure
1. At the end of each building day, make sure students reflect on what they did that day in their *5.a. Engineering Notebook Daily Goals* sheet and plan ahead for tomorrow.

Day 6: Official testing of Prototypes (Test)
Note: Testing station should be big enough for all students to see how each watercraft fares in the water. You can make this more relevant if you have small people or animals (e.g., toy figurines) that students can "save" with their watercraft. You should be sure to label these with their masses.

Introduction
1. Remind students that today is testing day and that before they can test, they

need to make sure that everyone in their group has completed their *5.e. Prototype Report* (with the exception of the mission evaluation) and that it should include a final sketch of the watercraft, a list of the materials included, the total volume of their watercraft, the mass of the watercraft, and the predicted maximum capacity.

2. **[Optional]** Students should also indicate the “safety factor” in their prediction. This is an error that you can decide since the volume estimates may be off. You may want to suggest an error of 10g.

Activity

1. Once all students have completed filling out the *5.e. Prototype Report*, have them gather around the testing station.
2. For each watercraft that is tested, use small weights to fill the watercraft to the maximum capacity within the limits of the safety factor. For watercraft that stay afloat, add small masses (pennies work well) until they just begin to sink to see how close the maximum capacity prediction was. While this testing is going on, be sure to ask students about their calculation of the maximum capacity. For watercraft in which the maximum capacity is significantly higher than the students’ prediction, have the class decide if this should be counted as successful; correctly calculating the maximum capacity is part of the challenge!

    Note: To simulate a more realistic flood situation, you could create waves in the water by your hand, a strong fan, or an underwater motor. Also, make sure students are not too careful when placing things in the watercraft.
3. As they are testing, use the *5.m. Teacher Observation Protocol: Test Lesson* to assess students as they work.
4. At the end of testing, count all watercraft that were successful and have students include the class data on the *5.f. Class Data* worksheet (this will be part of the memo sent to the client)

Closure

1. Have students complete the *Mission Evaluation* portion of their *5.e. Prototype Report.*
2. Have students reflect on what they did today in their *5.a. Engineering Notebook Daily Goals* sheet.
3. Have students answer the following questions in their *Engineering Notebook*:
    - *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 test results? 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.)

Day 7: Redesign
Introduction

1. Tell students that they will be redesigning their watercraft based on their testing results and things they have learned along the way. Help them undertsand where they are in the design process.
2. Have students write down a goal for today in their *5.a. Engineering Notebook Daily Goals* sheet.
3. Allow students to reflect on their engineering design process by pairing groups together before allowing for time for whole class reflection.

Activity

1. Review the engineering design process with students. **Ask:** *What steps did you take to get to where you are now with your watercraft design?* Help students identify the steps in the design process.
2. Have students reflect on all designs from their class. Then have them choose the class' best design and improve it through redesign.
3. Have student teams draw/sketch their redesign and plan their budget in the engineering notebook or on the *5.d. Design Brainstorming* sheet (then attach to their notebook).
4. As each group finishes these planning stages, check off on their redesign plan before they start to buy materials and build their prototype.
5. Allow students to build their redesigned watercraft. As they are building, use the *5.l. Teacher Observation Protocol: Try Lesson* to assess students as they work.
6. At the end of building, make sure that all groups have completed another *5.e. Prototype Report* (with the exception of the mission evaluation), complete with a detailed sketch of their watercraft, volume calculations, force diagram, and maximum capacity.
7. Have students retest their design. As they are testing, use the *5.n. Teacher Observation Protocol: Retest Lesson* to assess students as they work.

Closure

1. Have students complete the *Mission Evaluation* portion of their *5.e. Prototype Report.*
2. Have students reflect on what they did today in their *5.a. Engineering Notebook Daily Goals* sheet.

Day 8: Discussion (Decide), Reflections, and Wrap-Up
Introduction

1. Allow students to reflect on their engineering design process by pairing groups together before allowing for time for whole class reflection. Make sure to highlight the iteration on the design process because of their redesign.

Activity

1. Have students use the *5.g. Evidence-Based Reasoning Graphic* page to plan their *5.h. Memo to the National Guard.* Once they have mapped this out, have them complete their *5.h. Memo to the National Guard.* Remind students that they are to use complete sentences in their final memo and provide thoughtful

comments to improve their design. Students should use their observations and notes from their testing to provide claims, evidence, and reasoning in their letter. Rubrics are included as educator resources to help you assess student memos (*5.i. Client Memo Rubrics 1 & 2*)

Closure

1. Allow time for students to reflect in their *5.a. Engineering Notebook Daily Goals*.
2. Ask them to answer the following questions in their notebooks individually, then in their teams:
   - *How has your understanding of the problem changed during the design process?*
   - *How has your understanding of how to design a solution changed during the design process?*
   - *How do engineers solve problems?"*
3. **[Optional]** To close this unit, have students discuss or write a few paragraphs reflecting on their overall experience during this unit.
   - *What did they like?*
   - *What didn't they like?*
   - *How could it be made better?*
   - *How does each student think he/she did as part of a team?*
   - *How did their team work together?*
   - *Describe successes and challenges that the team faced.*
4. **[Optional]** As an extension, address the fact that students created a model prototype of a watercraft that is much smaller than the actual watercraft. See if students can explain how to scale up and calculate the actual size and maximum capacity of their watercraft.
   - *What is the average weight of a person, and how many people can their watercraft actually save if scaled up to actual size?*
   - *What is the actual material that could be used to create the watercraft?*

   This information could be added to their final reports to the client or could be part of their closing reflection.

LESSON 5

Name________________________________ Date__________ Period _____

5.a. Engineering Notebook Daily Goals

Date	Goal	Reflection

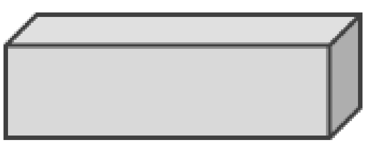
LESSON 5

Name________________________________ Date__________ Period _____

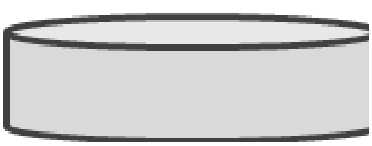
5.b. Helpful Background Information

Vocabulary Word	Definition
1.	A push or a pull applied to an object
2.	The sum of all the forced acting on the object (the total force)
3.	Equal forces acting in opposite directions on an object, no change in motion, net force = 0
4.	Unequal forces, net force does NOT = 0, the motion changes
5.	Force that opposes motion between two surfaces
6.	Upward force of water on an object
7.	Volume of water pushed out of the way by an object
8.	The weight of the fluid (ex: water) that an object displaces is equal to the buoyant force pushing up on an object

Calculate Volume



Length x Width x Height (L x W x H)



Measure mL water it can hold

Straws and Canisters

38 cm^3

Base x Length of straw

.95 cm^2 x ________

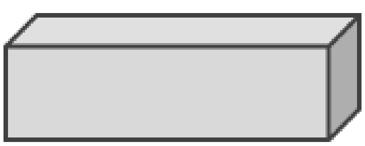
LESSON 5

Name________________________________ Date__________ Period _____

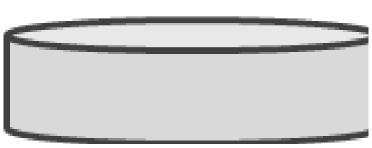
5.b. Helpful Background Information

Vocabulary Word	Definition
1. Force	A push or a pull applied to an object
2. Net Force	The sum of all the forced acting on the object (the total force)
3. Balance Force	Equal forces acting in opposite directions on an object, no change in motion, net force = 0
4. Unbalance Force	Unequal forces, net force does NOT = 0, the motion changes
5. Friction	Force that opposes motion between two surfaces
6. Buoyancy (Buoyant Force)	Upward force of water on an object
7. Displacement	Volume of water pushed out of the way by an object
8. Archimedes' Principle	The weight of the fluid (ex: water) that an object displaces is equal to the buoyant force pushing up on an object

Calculate Volume



Length x Width x Height (L x W x H)



Measure mL water it can hold

Straws and Canisters

38 cm^3

Base x Length of straw

.95 cm^2 x ________

LESSON 5

Name________________________ Date__________ Period _____

5.b. Helpful Background Information

The volume of a rectangular prism (a box) can be calculated using **L x W x H** (Length x Width x Height)	The volume of a cylinder is **Base x Height**
The base of a cylinder can be calculated using the formula **π x r^2** where r = the radius	**Buoyant Force** is the upward push of water on an object
The volume of an object that is underwater **displaces** and equal volume of water	**Archimedes' Principle** The weight of the fluid that an object displaces is equal to the Buoyant Force
Units of Volume 1 cm^3 is the same as 1 mL **1 cm^3 = 1 mL**	1 mL of water has a mass of 1 gram **1 mL (H_20) = 1 gram** **1 cm^3 (H_20) = 1 gram**
Net Force Means the total forces acting on an object	When the net forces are balanced there is no change in an object's motion
If the buoyant force up to greater than the combines weight of the watercraft and its load, **the watercraft will float**	**If you can calculate your watercraft's volume, you can calculate the buoyant force up on it and determine its maximum capacity**

LESSON 5

Name__________________________________ Date___________ Period _____

5.c. Materials Testing

You will be assigned to test specific materials for your engineering team. It is your responsibility to take accurate and exceptional data and report all information back to your team.

1. What materials are your responsible for testing?

2. What questions need to be answered from your testing?
   A.

   B.

   C.

3. Brainstorm ideas on how to answer those questions:

4. List the data you will be collecting:

5. Make a plan for testing your materials. Create a data table to use on the next page.

LESSON 5

Name________________________________ Date____________ Period ______

5.c. Materials Testing

Use the plan you developed and test the materials you are responsibly for. Make sure you keep excellent records of your results during the testing test. Remember – your team and the class are depending on you!

Data Table
Important Observations

Summary of Tests

Write a summary of what you learned from your tests.

LESSON 5

Name________________________________ Date____________ Period ______

5.d. Design Brainstorming

Idea 1 (include labels)	**What materials are needed?**
Idea 2 (include labels)	**What materials are needed?**
Idea 3 (include labels)	**What materials are needed?**

LESSON 5

Name______________________________ Date__________ Period _____

5.e. Prototype Report

Detailed drawing of watercraft with labels, measurements, and descriptions

Maximum Occupancy Calculations

Total **volume** of watercraft: _______

Total **mass** of Watercraft: _______

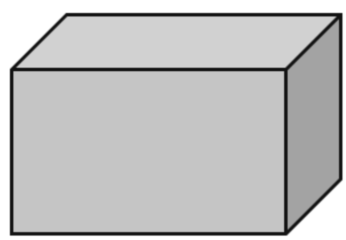
Predicted maximum occupancy: _______________

Results: How much mass did your prototype hold?

____

Force Diagram

Draw all the forces acting on the watercraft when it is placed in water:



Mission Evaluation

1. How close was your prediction to your results?

2. List 3 specific improvements you could make to your prototype.
   a.

   b.

   c.

LESSON 5

Name_________________________________ Date____________ Period ______

5.e. Prototype Report

Watercraft Segment (list and draw a picture)	**# Used**	**Total Volume of Segment**
	Total Volume of Watercraft	

LESSON 5

Name________________________________ Date____________ Period _____

5.f. Class Data

Group	Total Volume of Watercraft (cm^3 or mL)	Mass of Watercraft (g)	Maximum Occupancy (cm^3 or mL)	Results (over, under, or just right)
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Class Results Summary

Total number of watercraft ______________________________

Number of successful watercraft ______________________________

Percent of class successful ______________________________

LESSON 5

Name______________________________ Date__________ Period _____

5.g. Evidence-Based Reasoning Graphic

Problem

Problem Constraints

Problem Criteria

Solution	**Evidence**
Draw a labeled sketch of your watercraft prototype.	*Provide multiple pieces of evidence for why your design should be picked.*

Reasoning

Explain how your evidence influenced your design. Explain how the criteria and constraints were or were not met. Explain how your design best meets the needs of the client.

LESSON 5

Name________________________________ Date__________ Period _____

5.h. Memo to the National Guard

From: _______________________________

To: LTC Diamond, Minnesota Army National Guard

Subject: Project – Flood Rescue Mission

Dear LTC Diamond,

Attached to this memo you will find my team's final report on our watercraft prototype. Overall, my hour was very successful! _________ out of __________teams were able to use mathematics and science to correctly calculate the maximum capacity of their watercraft.

Mathematics and science were very important in succeeding in this challenge. For example, mathematics was important for the following reasons:

____

____

____

____

Science was important for the following reasons:

____

____

____

____

All of our hour's designs are first prototypes, which require redesign and further testing. We will let you know of important improvements. I have identified the following **three** ways my team's watercraft could be improved. I have also explained specifically how each change would improve the watercraft.

LESSON 5

Name________________________________ Date__________ Period ______

5.h. Memo to the National Guard

1. ____

____

____

____

2. ____

____

____

____

3. ____

____

____

____

Thank you for giving us this interesting opportunity, and thank you for the work you do with the National Guard.

Sincerely,

____

5.i. Client Memo Rubric 1

Page 1: Use the TAG + C format to summarize the following prompts: • To be successful in the mission why was it important to apply mathematics concepts? • To be successful in the mission why was it important to apply science concepts? • Identify 3 specific improvements you could make to the design of your watercraft.	
INCLUDE THE FOLLOWING IN EACH SUMMARY	**POINTS**
Transition words	5 4 3 2 1 0
Gives at least 3 examples and supporting detail from the mission	5 4 3 2 1 0
Conclude your thoughts	2 1 0
Page 2: All parts of the back page are complete including:	
Maximum occupancy calculations, class data, force diagrams	3 2 1 0

Page 1: Use the TAG + C format to summarize the following prompts: • To be successful in the mission why was it important to apply mathematics concepts? • To be successful in the mission why was it important to apply science concepts? • Identify 3 specific improvements you could make to the design of your watercraft.	
INCLUDE THE FOLLOWING IN EACH SUMMARY	**POINTS**
Transition words	5 4 3 2 1 0
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Maximum occupancy calculations, class data, force diagrams	3 2 1 0

Page 1: Use the TAG + C format to summarize the following prompts: • To be successful in the mission why was it important to apply mathematics concepts? • To be successful in the mission why was it important to apply science concepts? • Identify 3 specific improvements you could make to the design of your watercraft.	
INCLUDE THE FOLLOWING IN EACH SUMMARY	**POINTS**
Transition words	5 4 3 2 1 0
Gives at least 3 examples and supporting detail from the mission	5 4 3 2 1 0
Conclude your thoughts	2 1 0
Page 2: All parts of the back page are complete including:	
Maximum occupancy calculations, class data, force diagrams	3 2 1 0

Page 1: Use the TAG + C format to summarize the following prompts: • To be successful in the mission why was it important to apply mathematics concepts? • To be successful in the mission why was it important to apply science concepts? • Identify 3 specific improvements you could make to the design of your watercraft.	
INCLUDE THE FOLLOWING IN EACH SUMMARY	**POINTS**
Transition words	5 4 3 2 1 0
Gives at least 3 examples and supporting detail from the mission	5 4 3 2 1 0
Conclude your thoughts	2 1 0
Page 2: All parts of the back page are complete including:	
Maximum occupancy calculations, class data, force diagrams	3 2 1 0

5.i. Client Memo Rubric 2

Front of Letter	**0**	**1**	**2**
Overall complete	Nothing to almost nothing	Missing items	All sections complete
Improvements	Not done	Non specific (ex: more tape)	Complete ideas - specific design change
Back of Letter	**0**	**1**	**2**
Prototype drawing	Not done or very poorly done in multiple ways	Missing labels, incomplete or sloppy	All views neat and labeled
Calculations	Note done	Partially done	Complete and correct
Buoyant force diagram and summary	Not done	Incomplete	Accurately depicts forces and all parts compete
		Total score	**____ / 10**

Front of Letter	**0**	**1**	**2**
Overall complete	Nothing to almost nothing	Missing items	All sections complete
Improvements	Not done	Non specific (ex: more tape)	Complete ideas - specific design change
Back of Letter	**0**	**1**	**2**
Prototype drawing	Not done or very poorly done in multiple ways	Missing labels, incomplete or sloppy	All views neat and labeled
Calculations	Note done	Partially done	Complete and correct
Buoyant force diagram and summary	Not done	Incomplete	Accurately depicts forces and all parts compete
		Total score	____ / 10

LESSON 5

Name_______________________________________ Date______________ Period ______

5.j. Company Credit Card

Accountant's Name: ____

Budget = $100.00

Item	Number Needed	Cost	Total From Budget/ Store Signature

Accountant's Name: ____

Budget = $100.00

Item	Number Needed	Cost	Total From Budget/ Store Signature

LESSON 5

Name____________________________________ Date____________ Period ______

5.k. Material Cost Sheet

Budget for watercraft prototype: $100.00

Material	Cost	Maximum Limits
Aluminum foil	$25	2 pieces (10" x 10")
Film canisters	$20	2 canisters
Large bubble tea straws	$10	N/A
Small drinking straws	$5	N/A
Stir sticks/Popsicle sticks	2 for $5	N/A
Tape	6" for $10	N/A
Glue session	$10 per session	N/A
Junk yard trip	$10	3 pieces

Budget for watercraft prototype: $100.00

Material	Cost	Maximum Limits
Aluminum foil	$25	2 pieces (10" x 10")
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Small drinking straws	$5	N/A
Stir sticks/Popsicle sticks	2 for $5	N/A
Tape	6" for $10	N/A
Glue session	$10 per session	N/A
Junk yard trip	$10	3 pieces

5.I. Teacher Observation Protocol: Try Lesson

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

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

Part 1: Behaviors

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

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

Notes:

☐ Team has made appropriate progress on their solution.

☐ Team is struggling to make their solution.

Notes:

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

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

Notes:

5.I. Teacher Observation Protocol: Try Lesson

Part 2: Question Prompts

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

1. Can you tell me about your solution? What are you designing?

2. What were some of the other solution ideas you generated? How well did they address the problem?

3. How did you decide to move forward with this idea? What evidence do you have that your design will solve the problem for the client?

5.m. Teacher Observation Protocol: Test Lesson

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

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

Part 1: Behaviors
Testing

- ☐ All team members are on-task to test solution.
- ☐ One or more team members are not on-task.

Notes:

- ☐ Team has made appropriate progress on testing and analysis.
- ☐ Team is struggling to test or analyze their solution.

Notes:

- ☐ Team has identified how to improve solution.
- ☐ Team is struggling to consider improved performance.

Notes:

5.m. Teacher Observation Protocol: Test Lesson

Part 2: Question Prompts

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

4. What did you find out from testing?

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

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

5.n. Teacher Observation Protocol: Retest Lesson

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

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

Part 1: Behaviors Testing Improved Solution

- ☐ All team members are on-task to retest solution.
- ☐ One or more team members are not on-task.

Notes:

- ☐ Team has attempted to improve performance of solution.
- ☐ Unclear what improvements team made.

Notes:

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 to support 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?

