# Carrying Cargo

**Subject:**
Science
Math

**Strand:**
Engineering Design
Geometry

**Grade:**
9-10

**Estimated Instructional Time:**
3-4 class periods, 50 minutes each

**Related Kit(s):**

- Boats

**Abstract:**
Students will be engaged in a hands-on activity to test the efficiency of various cargo boat designs. In testing, students will collect data using 3D-printed boat models and determine which design is superior in terms of total cargo mass. Students will explore scientific approaches, engineering design, and mathematical applications, namely developing a procedure to select a boat while meeting several constraints. In part 2 of the activity, students will have the opportunity to design their own boat prototype using Tinkercad.

## Learning Objectives

Students will:

- Directly and accurately measure ship and cargo mass.
- Evaluate competing design solutions and explain why some are more effective than others.
- Design an improved boat model.
- Write a coherent and formal response to the client, justifying their boat design and clearly conveying their multistep design procedure.
- Define criteria and constraints of the problem using the former to evaluate competing design solutions.

## Content and Practice Standards

### Next Generation Science Standards

*HS-ETS1-3*

Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.

### NGSS Science and Engineering Practices

2. Developing and using models
4. Analyzing and interpreting data
8. Obtaining, evaluating, and communicating information

### Common Core State Standards

*CCSS.MATH.CONTENT.HSG.MG.A.3*

Apply geometric methods to solve design problems (e.g., designing an object or structure to satisfy physical constraints or minimize cost; working with typographic grid systems based on ratios).*

*CCSS.ELA-LITERACY.WHST.9-10.4*

Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.

### Florida Standards

*MAFS.912.G-MG.1.3*

Apply geometric methods to solve design problems (e.g., designing an object or structure to satisfy physical constraints or minimize cost; working with typographic grid systems based on ratios).

*LAFS.910.WHST.2.4*

Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.

*SC.912.N.1.1*

Define a problem based on a specific body of knowledge, for example: biology, chemistry, physics, and earth/space science, and do the following:

2. Conduct systematic observations,
*(Write procedures that are clear and replicable. Identify observables and examine relationships between test (independent) variable and outcome (dependent) variable. Employ appropriate methods for accurate and consistent observations; conduct and record measurements at appropriate levels of precision. Follow safety guidelines).*
6. Use tools to gather, analyze, and interpret data (this includes the use of measurement in metric and other systems, and also the generation and interpretation of graphical representations of data, including data tables and graphs),
*(Collect data or evidence in an organized way. Properly use instruments, equipment, and materials (e.g., scales, probeware, meter sticks, microscopes, computers) including set-up, calibration, technique, maintenance, and storage).*
9. Use appropriate evidence and reasoning to justify these explanations to others.

## Guiding Questions

- How can geometric shapes be identified in real-world objects such as boats?
- What formulas should be used to calculate the volume of various shaped objects?
- How can you determine whether two shapes can hold the same volume?
- How can geometric methods be used to help find the most efficient boat shape to carry cargo?
- What are some examples of how scientific observations might differ from casual/everyday observations?

## Prior Knowledge

**Purpose:**

The main purpose of this activity is to help students to explore scientific approaches (e.g., data collection), engineering design (selecting/designing a boat while considering constraints), and mathematical applications (e.g., recognizing geometric figures in real-world objects) to select and design a boat model that meets certain physical and cost constraints. Students will also learn how boat design (e.g., shape, density) can have an effect on how the boat fares in the water (e.g., buoyancy, drag).

**Concepts:**

Students will test each boat model in at least two trials and record data on model mass, cargo mass, stability, steering, and cargo carrying efficiency. Weight, mass, displacement, stability, and volume are therefore important concepts for this lesson. Students should also be aware of the method in which scientific observations are conducted, that is, using systematic observations, writing clear and replicable procedures, proper use of instruments, and use of appropriate evidence and reasoning when explaining the methods to others.

**Background Reading: What's Happening to a Boat in the Water?**

*Modified from the NOAA Ocean Education Service activity "Boat Building Challenge"*

Water tends to maintain a level surface. When you put an object into water, gravity pulls the object down, which displaces some of the water, meaning that some of the water is pushed aside. Now the surface of the water is no longer level. Gravity pulls the displaced water down, and causes an upward force on the object. [Note: This upward force is due to pressure, which is higher at the bottom of the boat compared to that at the top.] This upward force is equal to the weight of the water that the object displaces, and is called buoyancy. Buoyancy depends upon the volume of liquid displaced as well as the density of the liquid. Density is the ratio of mass to volume. It is easier to float in the ocean than in fresh water because seawater is denser than fresh water, thus your buoyancy is greater in the ocean.

The amount of fluid that an object displaces depends upon the weight of the object: more weight means more fluid displaced, which means more buoyancy. Increasing the amount of surface area in contact with fluid increases the effect of friction as the object moves through the fluid. Boat designers have to consider buoyancy as well as friction when deciding on the shape of a boat's hull. A boat designed for speed must have enough displacement to stay afloat, but surface area has to be minimized to decrease the effects of friction. Note that it is only the surface area that is in contact with the water that creates friction. On the other hand, an object designed to carry a heavy weight, such as a cargo boat, must be designed with greater power to overcome the effects of increased friction. However, drag caused by the shape of the boat is likely more important than simple friction.

Displacement occurs when an object is immersed in a fluid, pushing it out of the way and taking its place. The volume of the fluid displaced can then be measured, and from this the volume of the immersed object can be deduced (the volume of the immersed object will be exactly equal to the volume of the displaced fluid).

Boat hulls are designed to have a maximum displacement greater than the weight of the boat (and its intended cargo). As mentioned, increasing boat volume increases the maximum possible boat buoyancy (while affecting mass and density as well), but not necessarily the buoyant force for a given cargo load. Should the force of gravity pushing down on the boat exceed the boat's maximum displacement (which is equal to the force pushing up on the boat or buoyancy) the boat will sink. If there is no longer sufficient water displacement to counteract the force of gravity on the pieces of the hull, the boat will sink.

## Procedure

### Assessment and Review of Prior Knowledge

Ask the following questions to assess prior knowledge and get students to start thinking about the concepts:

- What happens to the water when you push an object into it?
  *Displacement—the water is pushed aside.*
- What determines if an object floats?
  *An object will float if its density is less than the density of the substance it is placed in.*
- If an object is submerged completely, how is the volume of the object related to the volume of water that is displaced?
  *The values will be equal.*

If students need a review on the volume formulas, there are several good websites that provide this information, such as MATHguide.

For scaffolding Part 2 of the lesson, in which students calculate the volume of their cargo hold, it may be helpful to show video examples.

- "Volume of a Composite Shape," Khan Academy (YouTube)
- "Volume through Decomposition," Khan Academy (YouTube)
- Real-world application: "Volume in Engineering," Annenberg Learner
  Watch the Part B video where an engineer describes how he calculates the volume of irregular objects.

### Days 1 and 2

You will need to have the sample boat models (one of each type) printed before class for each group to test. It is highly recommended to test the boats before class by using the boat launcher to launch them into a tub of water. You will likely need to adjust the launcher or the amount of water in the tub to get the best results. Affix the launcher in place so that it will remain the same for all students.

Provide each student a copy of the Background Reading on boats and ask them to highlight vocabulary they don't understand. Ask students which words they highlighted and ask if anyone knows what the word means. Some students may be more familiar with boats than others. The included vocabulary sheet can be printed or shown on the overhead as needed.

Pass out Reading Passage 1, which is a Request for Proposals (RFP) from a shipping company that is requesting proposals from engineering teams to develop a procedure to choose a cargo boat design. Have students take a couple minutes to read the passage or read the passage aloud and have students follow along.

Pass out Data Set 1 and ensure that students understand all the terminology.

Ask students the Readiness Questions to ensure understanding of the RFP and to be sure that they know what the client is asking them to do.

- What is the problem?
  *Seago Shipping Services needs a new fleet of boats and they need to fulfill several requirements, such as carrying as much cargo as possible.*
- Who is the client?
  *Seago Shipping Services*
- What does your team need to do?
  *Select the best boat for the client's purposes; be sure the boat meets the technical requirements and respond in writing with a step-by-step procedure of how to select a boat*
- What things do you need to include in your written response to the Request for Proposals?
  *Step-by-step procedure of how to select a boat, fill in the blank columns in the data tables, show our calculations*
- Do you think there is more than one correct answer to this problem? Why or why not?
  *Yes, because different factors can be prioritized differently*

Have each student examine the 3D-printed boat models. Ask students to think individually about what boat would work best for the client and why.

After giving students some time to think and write down some ideas on their own, group students in teams of three to four. One suggested method is to group students heterogeneously by math ability. Have each team member select a role. Roles can include moderator, recorder, timekeeper, etc.

Students are told that they will get to test each boat type and collect the data. In their notebooks, ask students to discuss their ideas in their group and make predictions about how each boat will perform when tested (e.g., amount of cargo it can hold, stability, steering).

Each group will then test the different boats in at least two trials and record the following data:

- Model Mass: Either use a digital scale or submerge boat in water (displacement)
- Cargo Mass (carrying capacity): The mass of the maximum amount of cargo (e.g., paperclips) that can fit in the boat without sinking
- Stability: Weights (e.g., paperclips) are hung from the side peg (either side) and the end peg (not at the same time). The resulting mass will represent the mass the boat can withstand before capsizing

- Steering: A rank (e.g., best to worst) of each boat according to how straight the boat glides when launched
- Cargo Efficiency: The ratio of maximum cargo to boat mass

See the included Data Set Keys for an example of two trials for each of the boat types.

After their data is recorded in the Testing table, students will use that data table to fill in the middle table, Calculations. They will then fill out the third table, Data Table, using the tables above.

Next, students will use the third table to develop their procedure for selecting the best boat for the client. The more time students have for this, the more they will discuss and revise their solutions in iterative modeling cycles.

As students are working, circulate to each team to ask the Guiding/Reflective Questions to prompt students to think about their decisions.

- Why do you think that?
- How do you know if you've solved the problem?
- What are the most important things to consider in your procedure?
- What are the reasons for your team's boat design?

After students have determined their step-by-step procedure for selecting a boat, they will write back to the client detailing their procedure and decision.

**Days 2 and 3**

Students will finish their work for part 1 of the problem, as needed.

Pass out Reading Passage 2 and Data Set 2; ensure that students understand what they need to do.

Ask students the Readiness Question for Part 2:

- What is the client asking your team to do now?
  *Design a new boat, provide an updated procedure for selecting a boat, include the rationale for the boat design, fill in the tables and provide calculations for your work*

Tell students that they will have the opportunity to design their own boat in Tinkercad, and that their design will be printed out so they can test it. Students should examine the four boat models and brainstorm what modifications are needed to best meet the client's needs.

Students should receive grid paper to begin sketching their prototype; what design they think will best meet the client's needs. As teams are drawing, the teacher can circulate and ask guiding questions about their models (e.g., why did you choose this shape?).

Provide students with an overview of Tinkercad. It may be helpful to familiarize students with the platform before this activity.

Each team should access the boat model templates in Tinkercad. When finished drawing, students should translate their drawings to Tinkercad by modifying one of the provided models.

Print students' designs before the start of the next class.

**Day 4**

Set up the classroom for testing the boats. Hand out the 3D printed boats that each team designed in the previous class session.

Provide student teams with the Data Tables that they filled out in Part 1 so they can compare their new design to the original four boat models. Students should test their new boat design and fill out the data tables for Part 2. They should write their procedure for selecting a boat as specified in the second RFP.

As students are working on testing their boat and writing back to the client, circulate to each team to ask Guiding/Reflective Questions.

You may want to have students present their designs and procedures to the class to conclude the activity. In this case, if teams finish early, ask them to begin preparing to present their work.

Students can reflect on their solutions by answering Reflection questions.

- How did your procedure change after designing your own boat prototype? Why or why not?
- After seeing your classmates' designs, how would you modify your team's boat design and why?

Summative assessment using the attached rubric can take place to determine to what extent students have met the learning objectives for this activity.

The following section provides instructions on testing the 3D models. It will be helpful to include this as a handout for the students.

### Instructions for Testing the 3D Models

Boat Mass Testing instructions:

- Obtain and turn on a digital scale.
- Place the boat on the scale and record its mass/weight.

  - A distinction should be made between weight (mass • gravity) and mass. You'll have the mass or weight of the water displaced depending upon the scale used.
    - If your scale measures mass, you already have the desired value.
    - If you only have access to scales that measure weight (lbs.), divide the measured value by gravity ($9.8 \frac{m}{s^2}$) to calculate mass.
- If a scale is not available, the following procedure should be used. Students should submerge the boat (the entire boat should be below water with no pockets of trapped air) in a graduated cylinder partially filled with water, measuring the increase in volume. Students would then multiply the volume of displaced water by the density of water ($1 \frac{g}{cm^3}$) to find the boat's mass. ($1\ mL = 1\ cm^3$)
  For example:
  - Displaced water volume = 5 mL (measured value)
  - Density = $1 \frac{g}{cm^3} = 1 \frac{g}{mL}$
  - Boat mass = Displaced water mass = (water density) • (displaced water volume) = $(1 \frac{g}{mL}) \cdot (5\ mL) = 5\ g$

Cargo Testing Instructions:

- Fill the tub with water so it is at least 10-15 cm deep.
- Write down how much mass (g) you think each design will carry, given the mass of the boat itself.
- Place the boat on the water so it floats. If it does not float, stop here. Record the results.
- Place weights, one at a time, into the boat, being careful to evenly distribute the weights as they are placed. Continue placing weights (keep in mind any constraints) until just before the boat begins to take on water (or when the waterline is even with the upper edge of the boat's hull).
- Gather the weights from the tub and weigh them. The resulting mass/weight is the maximum cargo load for the boat. Record this value. *Make sure you are measuring dry weights, in case any have gotten wet.*
- In your notes, record whether this value was less than, equal to, or more than you expected. Also include any other testing notes of interest.
- Calculate the ratio of maximum cargo to boat mass (efficiency). Record this value in the table.

Stability Testing Instructions:

- Fill the tub with water so it is at least 10-15 cm deep.
- Write down how much mass (g) you think each peg will carry, given the mass of the boat itself.
- Place the boat on the water so it floats. If it does not float, stop here. Record the results.

- For each model, you must test one side peg (either will work) and the end peg. Each should be tested independently (first test the side peg and record the value, then test the end peg and record the value). Values should be used in conjunction to determine total stability.
- To test, incrementally add mass to the selected peg. Continue increasing mass until the boat begins to take on water. (Paperclips or small hanging weights can be used to complete this step.)
- Remove the clips/weights from the peg and weigh them. The resulting mass/weight will represent the mass the boat can withstand before capsizing. Record this value. *Make sure you are measuring dry weights, in case any have gotten wet.*
- In your notes, record whether this value was less than, equal to, or more than you expected. Also include any other testing notes of interest.

Steering Testing instructions:

- Fill the tub with water so it is at least 10-15 cm deep.
- Rank (write down, in order from best to worst) each boat according to how straight the boat glides when launched.
- To give a better idea of how each boat will respond when loaded, place 5 g of cargo in the hollowed centers before testing.
- The provided boat launcher (ramp) is intended to hook onto the edge of your tub. Use tape to affix the launcher in place if needed. Each boat will be placed at the top of the boat launcher and released. The boat should slide down the ramp and be "launched" into water. Each boat should be ranked according to how straight it progresses through the water.
  - (Water levels and/or tub design may create issues with the launcher. In the event the launcher does not operate as desired, hold the launcher in an appropriate position. Use the same position for all subsequent launches. Each boat should be launched as "straight" into the water as possible. The launcher should be angled enough so that the boat will begin to slide due to its own mass only. No additional force is required.)
- Record your ratings. In your notes, record whether this value was worse than, equal to, or better than you expected. Also include any other testing notes of interest.

## Further Recommendations

If the teacher has less time to implement Part 2 of the lesson, the following suggestions may help to reduce class time for this component:

- Students may skip re-writing their procedure, and instead write about how their procedure changed or why it did not change.

## Required Materials

Materials needed (per group):

- MyStemKits.com Boats kit (each kit contains four boats plus a boat launching ramp)
- Scale (used to measure the mass of each model and corresponding carrying capacity)
- Ruler (to measure boats)
- Bin/tub (to be filled with water for boat testing)
- Masses (small hanging weights or paper clips used to test boats; we have found that large paperclips work best)

Print out copies of the student materials included with this lesson. Ideally, each student should have their own copy (Background Reading, Client Letter 1 and 2, Instructions for Testing the 3D Models, Data Set 1 and 2).

## Accommodations and Extensions

### Accommodations

Testing the boats can be completed as a class to minimize time needed and simplify the required calculations.

Additional discussions can be led by teachers, as needed, to resolve any issues that may arise.

Supplemental reading can be read aloud by teachers.

### Extensions

Students can use their knowledge of the volumes of three-dimensional shapes to approximate the volume of each boat. Students will need to determine which formula to apply to approximate the volume of each boat, and fill out the appropriate column in the data table. Be sure to delete the given volume values in the table first (13.5 $cm^3$ for each boat).

L = Length
W = Width
D = Depth
H = Height
b = base
r = radius

Rectangular prism: $L \cdot W \cdot D$
Triangular prism: $\frac{1}{2} \cdot b \cdot H \cdot D$
Cylinder: $\pi \cdot r^2 \cdot D$
Sphere = $\frac{4}{3} \cdot \pi \cdot r^3$
Pyramid (equal sides) = $\frac{L \cdot W \cdot D}{3}$
Cone = $\frac{\pi \cdot r^2 \cdot D}{3}$

To better emphasize the geometry standard, you can instruct students to design a different shaped cargo hold that will hold the same amount of cargo as the boat they designed in Part 2. *What is your design for a different shaped cargo hold that will hold the same amount of cargo as your boat? Be sure to show your work and specify the geometric shape of your boat's cargo hold as well as the new shape.*

## Review

- What happens to the water when you push an object into it?
  *Displacement—the water is pushed aside.*
- What determines if an object floats?
  *An object will float if its density is less than the density of the substance it is placed in.*
- If an object is submerged completely, how is the volume of the object related to the volume of water that is displaced?
  *The values will be equal.*

- How do you calculate volume for various 3-dimensional shapes?
  *If students need a review on the volume formulas, there are several good websites that provide this information, such as MATHguide.*

## What's Happening to a Boat in the Water?

*Modified from the NOAA Ocean Education Service activity "Boat Building Challenge"*

Water tends to maintain a level surface. When you put an object into water, gravity pulls the object down, which displaces some of the water, meaning that some of the water is pushed aside. Now the surface of the water is no longer level. Gravity pulls the displaced water down, and causes an upward force on the object. [Note: This upward force is due to pressure, which is higher at the bottom of the boat compared to that at the top.] This upward force is equal to the weight of the water that the object displaces, and is called buoyancy. Buoyancy depends upon the volume of liquid displaced as well as the density of the liquid. Density is the ratio of mass to volume. It is easier to float in the ocean than in fresh water because seawater is denser than fresh water, thus your buoyancy is greater in the ocean.

The amount of fluid that an object displaces depends upon the weight of the object: more weight means more fluid displaced, which means more buoyancy. Increasing the amount of surface area in contact with fluid increases the effect of friction as the object moves through the fluid. Boat designers have to consider buoyancy as well as friction when deciding on the shape of a boat's hull. A boat designed for speed must have enough displacement to stay afloat, but surface area has to be minimized to decrease the effects of friction. Note that it is only the surface area that is in contact with the water that creates friction. On the other hand, an object designed to carry a heavy weight, such as a cargo boat, must be designed with greater power to overcome the effects of increased friction. However, drag caused by the shape of the boat is likely more important than simple friction.

Displacement occurs when an object is immersed in a fluid, pushing it out of the way and taking its place. The volume of the fluid displaced can then be measured, and from this the volume of the immersed object can be deduced (the volume of the immersed object will be exactly equal to the volume of the displaced fluid).

Boat hulls are designed to have a maximum displacement greater than the weight of the boat (and its intended cargo). As mentioned, increasing boat volume increases the maximum possible boat buoyancy (while affecting mass and density as well), but not necessarily the buoyant force for a given cargo load. Should the force of gravity pushing down on the boat exceed the boat's maximum displacement (which is equal to the force pushing up on the boat or buoyancy) the boat will sink. If there is no longer sufficient water displacement to counteract the force of gravity on the pieces of the hull, the boat will sink.

**Seago Shipping Services**
3953 Canal Road
Tampa, FL 33603
(555) 354-8394

**Introduction**
Seago Shipping Services is soliciting proposals from engineering teams for a shipping vessel to transport our cargo across the sea. We are an international shipping company that depends on our boats to transport heavy loads of cargo as fast and cost-effectively as possible.

**Purpose of this Request for Proposals**
Our company's current vessels are becoming older and more prone to costly repairs. It is time to update our fleet, and therefore we are requesting proposals for a new vessel so we can build the best design to refurnish our fleet. We would like to begin replacing our fleet as soon as possible.

**General Background Information**
Our routes take us across the Gulf of Mexico to several countries in South America. Occasionally we will also ship our cargo to several countries on the west coast of Africa. Therefore, the vessels that we use will be required to operate across long distances.

**Proposal Requirements – Instructions to Bidders**
Technical requirements and information:

- An efficient, hydrodynamically sound vessel is ideal (or low friction and able to realistically travel through the water)
- Cargo needs to sit inside the hull of the vessel (below the deck, rather than on it)
- Maximize carrying capacity (hold as much cargo as possible)

Boat models and a data table have been provided for your consideration. Please test the models to finish filling out the data table. Use this data to decide which boat would best meet our needs. Engineering teams should respond to this RFP by providing written documentation which details your step-by-step procedure used to select a vessel and a ranking of the four boat models from the first to last choice based on your procedure. Be detailed, as we will need to be able to follow your thought process to select among various boat designs in the future.

*Note: Scale is 1cm = 10 meters*

**Seago Shipping Services**
3953 Canal Road
Tampa, FL 33603
(555) 354-8394

**Addendum**
We would like to thank each engineering team who sent us a proposal. All of the proposals were well-received and it will be a difficult decision to select which team's boat to build.

Before that, however, we need to amend our Request for Proposals. We recently added a new shipping route that will take us beneath several bridges. We are concerned current designs will not accomplish this task safely. Therefore, we have revised one of our technical specifications that you must now consider.

**Revised Technical Requirements and Information**
Technical requirements and information:

- An efficient, hydrodynamically sound vessel is ideal (or low friction and able to realistically travel through the water)
- Cargo needs to sit inside the hull of the vessel (below the deck, rather than on it)
- Maximize carrying capacity (hold as much cargo as possible)
  - Boat will be traveling beneath bridges, so the height of the boat must be 60 meters or less. *Note: Scale is 1 cm = 10 meters*

Also, we have some good news – we have a budget increase and extra time for the boat to be built. Therefore, cost and time to build can be eliminated from your decisions this time.

Please design a boat that satisfies all requirements listed above and respond with an updated response to this RFP. Bidders should respond to this RFP by providing written documentation that details your engineering team's step-by-step procedure of how to select the best boat, keeping in mind this new requirement. We will need to be able to follow your procedure and thought process to select a boat to build. Include your rationale for your new boat design. Your team must also submit your testing information (e.g., data tables and calculations) for your new boat design. Be sure your new design still has side pegs and an end peg to allow for testing the stability.

In summary, please submit the following:

- Written documentation that details your engineering team's step-by-step procedure of how to select the best boat
- According to your procedure, state which boat is the one we should build, with a ranking of the boats in order that we should build them from 1 to 5 (the 4 boat models plus your new design)
- Scaled drawing of your boat design
- Rationale for your new boat design (what design decisions did you make and why?)
- Data tables and calculations for boat testing (e.g., cargo hold volume, stability, carrying capacity)

Name: ______________________________ Date: ________________

## Testing

| Boat | Carrying Capacity 1 (g) | Carrying Capacity 2 (g) | Carrying Capacity Average | Boat Mass 1 (g) | Boat Mass 2 (g) | Boat Mass Average (g) | Stability – side peg | Stability – end peg | Stability Average (g) | Steering | Steering | Steering Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | | | | | | | | | | | | |
| B | | | | | | | | | | | | |
| C | | | | | | | | | | | | |
| D | | | | | | | | | | | | |

## Calculations

| Boat | Efficiency (%) | Boat Volume ($cm^3$) | Boat Density ($\frac{g}{cm^3}$) |
|---|---|---|---|
| A | | 13.5 | |
| B | | 13.5 | |
| C | | 13.5 | |
| D | | 13.5 | |

MyStemKits.com

## Data Table

(Values in this table should be used to develop your step-by-step procedure.)

| Boat | Cost ($\$ \times 10^6$) | Build Time (Months) | Stability | Steering | Carrying Capacity (g) | Efficiency (%) |
|---|---|---|---|---|---|---|
| A | 146.33 | 29-34 | | | | |
| B | 125.54 | 21-25 | | | | |
| C | 128.48 | 17-20 | | | | |
| D | 119.55 | 22-26 | | | | |

**Terminology:**

*Stability:* Weights (e.g., paperclips) are hung from the side peg (either side) and the end peg (not at the same time). The resulting mass will represent the mass/weight the boat can withstand before capsizing. The location of the weight is crucial; in particular, its position relative to the boat's center of mass.

*Steering:* A rank (e.g., best to worst) of each boat according to how straight the boat glides when launched

*Carrying capacity (cargo mass):* The mass of the maximum amount of cargo (e.g., paperclips) that can fit in the boat without sinking

*Efficiency:* The ratio of maximum cargo to boat mass

MyStemKits.com

Name: ______________________________ Date: ________________

## Testing

| Boat | Carrying Capacity 1 (g) | Carrying Capacity 2 (g) | Carrying Capacity Average | Boat Mass 1 (g) | Boat Mass 2 (g) | Boat Mass Average (g) | Stability – side peg | Stability – end peg | Stability Average (g) | Steering (rank compared to the 4 boat models) | Steering (rank compared to the 4 boat models) | Steering Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| New design | | | | | | | | | | | | |

## Calculations

| Boat | Efficiency (%) | Boat Volume ($cm^3$) | Boat Density $\left(\frac{g}{cm^3}\right)$ |
|---|---|---|---|
| New design | | | |

MyStemKits.com

## Data Table

(Values in this table should be used to develop your step-by-step procedure.)

| Boat | Stability | Steering | Carrying Capacity (g) | Efficiency (%) |
|---|---|---|---|---|
| New design | | | | |

What is your procedure and rationale for your new boat design? Did your procedure change now that you developed your own boat? Please explain.

What are the shape and dimensions of your new boat's cargo hold?

**Terminology:**

*Stability:* Weights (e.g., paperclips) are hung from the side peg (either side) and the end peg (not at the same time). The resulting mass will represent the mass/weight the boat can withstand before capsizing. The location of the weight is crucial; in particular, its position relative to the boat's center of mass.

*Steering:* A rank (e.g., best to worst) of each boat according to how straight the boat glides when launched. Students may need to test the other four boat models in order to compare steering with the new boat model and determine how each one ranks from 1 to 5.

*Carrying capacity (cargo mass):* The mass of the maximum amount of cargo (e.g., paperclips) that can fit in the boat without sinking

*Efficiency:* The ratio of maximum cargo to boat mass

*Boat volume:* Students can calculate this using the appropriate volume formula or by using displacement.

MyStemKits.com

# Instructions for Testing the 3D Models

**Boat Mass Testing Instructions:**

- Obtain and turn on a digital scale.
- Place the boat on the scale and record its mass/weight.
  - A distinction should be made between weight (mass • gravity) and mass. You'll have the mass or weight of the water displaced depending upon the scale used.
    - If your scale measures mass, you already have the desired value.
    - If you only have access to scales that measure weight (lbs.), divide the measured value by gravity ($9.8 \frac{m}{s^2}$) to calculate mass.
- If a scale is not available, the following procedure should be used. Students should submerge the boat (the entire boat should be below water with no pockets of trapped air) in a graduated cylinder partially filled with water, measuring the increase in volume. Students would then multiply the volume of displaced water by the density of water ($1 \frac{g}{cm^3}$) to find the boat's mass. ($1 \text{ mL} = 1 \text{ cm}^3$)
  For example:
  - Displaced water volume = 5 mL (measured value)
  - Density = $1 \frac{g}{cm^3} = 1 \frac{g}{mL}$
  - Boat mass = Displaced water mass = (water density) • (displaced water volume) = $(1 \frac{g}{mL}) \cdot (5 \text{ mL}) = 5 \text{ g}$

**Cargo Testing Instructions:**

- Fill the tub with water so it is at least 10-15 cm deep.
- Write down how much mass (g) you think each design will carry, given the mass of the boat itself.
- Place the boat on the water so it floats. If it does not float, stop here. Record the results.
- Place weights, one at a time, into the boat, being careful to evenly distribute the weights as they are placed. Continue placing weights (keep in mind any constraints) until just before the boat begins to take on water (or when the waterline is even with the upper edge of the boat's hull).
  - Gather the weights from the tub and weigh them. The resulting mass/weight is the maximum cargo load for the boat. Record this value. *Make sure you are measuring dry weights, in case any have gotten wet.*
- In your notes, record whether this value was less than, equal to, or more than you expected. Also include any other testing notes of interest.
- Calculate the ratio of maximum cargo to boat mass (efficiency). Record this value in the table.

**Stability Testing Instructions:**

- Fill the tub with water so it is at least 10-15 cm deep.
- Write down how much mass (g) you think each peg will carry, given the mass of the boat itself.
- Place the boat on the water so it floats. If it does not float, stop here. Record the results.
- For each model, you must test one side peg (either will work) and the end peg. Each should be tested independently (e.g. first test the side peg and record the value. Then test the end peg and record the value.) Values should be used in conjunction to determine total stability.
- To test, incrementally add mass to the selected peg. Continue increasing mass until the boat begins to take on water. (Paperclips or small hanging weights can be used to complete this step.)
- Remove the clips/weights from the peg and weigh them. The resulting mass/weight will represent the mass the boat can withstand before capsizing. Record this value. *Make sure you are measuring dry weights, in case any have gotten wet.*
- In your notes, record whether this value was less than, equal to, or more than you expected. Also include any other testing notes of interest.

**Steering Testing instructions:**

- Fill the tub with water so it is at least 10-15 cm deep.
- Rank (write down, in order from best to worst) each boat according to how straight the boat glides when launched.
- To give a better idea of how each boat will respond when loaded, place 5 g of cargo in the hollowed centers before testing.
- The provided boat launcher (ramp) is intended to hook onto the edge of your tub. Each boat will be placed at the top of the boat launcher and released. The boat should slide down the ramp and be "launched" into water. Each boat should be ranked according to how straight it progresses through the water.
    - (Water levels and/or tub design may create issues with the launcher. In the event the launcher does not operate as desired, hold the launcher in an appropriate position. Use the same position for all subsequent launches. Each boat should be launched as "straight" into the water as possible. The launcher should be angled enough so that the boat will begin to slide due to its own mass only. No additional force is required.)
- Record your ratings. In your notes, record whether this value was worse than, equal to, or better than you expected. Also include any other testing notes of interest.

*Beam:* The width of a ship.

*Bow:* The front of a vessel.

*Bulk cargo:* Not in packages or containers; shipped loose in the hold of a ship without mark and count. Grain, coal and sulfur are usually bulk freight.

*Buoyancy:* The upward force that is equal to the weight of the water that the object displaces.

*Capsizing:* When a ship is turning on its side.

*Cargo:* Freight loaded into a ship.

*Cargo tonnage:* Most ocean freight is billed on the basis of weight or measurement tons (W/M). Weight tons can be expressed in short tons of 2000 pounds, long tons of 2240 pounds or metric tons of 1000 kilos (2204.62 pounds). Measurement tons are usually expressed as cargo measurement of 40 cubic feet (1.12 meters) or cubic meters (35.3 cubic feet.)

*Density:* The mass of cargo per volume. Density is commonly measured in kilograms per cubic meter.

*Displacement:* The weight of the water that a ship displaces when it is floating. Since a floating body displaces its own weight in water (Archimedes' principle), displacement is the actual weight of the ship.

*Maximum displacement:* the maximum weight of water (which equals the weight of the boat with cargo) a boat can displace while staying afloat.

*Dock:* For ships, a cargo handling area parallel to the shoreline where a vessel normally ties up.

*Draft:* The number of feet that the hull of a ship is beneath the surface of the water.

*Hull:* the watertight body of a ship.

*Hydrodynamics:* the study of fluids, including gases.

*Keel:* The principal structural member of a ship, running lengthwise along the center line from bow to stern, to which the frames are attached.

*Mass:* A fundamental measure of the amount of matter in the object, mass is commonly measured in kilograms.

*Seaworthiness:* The fitness of a vessel for its intended use.

*Ship:* (1) A vessel of considerable size for deep-water navigation. (2) A sailing vessel having three or more square-rigged masts.

*Stern:* The end of a vessel. Opposite of bow.

*Volume:* The amount of three-dimensional space an object occupies. Volume is commonly measured in cubic meters.

*Waterline:* The point at which the hull meets the water surface.

*Most vocabulary is from the Maritime Administration [Glossary of Shipping Terms]*

MyStemKits.com

Student or Group Name: ______________________________

| Category | 1<br>Unsatisfactory | 2<br>Developing | 3<br>Effective | 4<br>Excellent |
|---|---|---|---|---|
| 1st Response Letter (20%) – method | Developed method is ineffective. Procedures do not accurately list the steps taken. | Developed method is logical but ineffective. Obvious effort but results incomplete. Procedures are listed but are not in a logical order or are difficult to follow. | Developed method is effective and logical but fails to account for all data or is insufficiently detailed. Procedures are listed in a logical order, but steps are not numbered and/or are not in complete sentences. | Developed method is effective and logical. Method accounts for all data and is thoroughly detailed. Procedures are listed in clear steps. Each step is numbered and is a complete sentence. |
| 2nd Response Letter (20%) – method | Developed method is ineffective. Little or no effort. | Developed method is logical but ineffective. Obvious effort but results incomplete. Failed to take Part 1 tests into consideration when designing new boat. | Developed method is effective and logical but fails to account for all data (considers some Part 1 tests but not all) or is insufficiently detailed. | Developed method is effective and logical. Method accounts for all data and is thoroughly detailed. |
| 1st and 2nd response letter (20%) | Writing is below grade level or no attempt was made. | Poorly-written letter in which ideas are inadequately organized and/or produced. | Decently-written letter in which ideas are organized and produced. | Well-written letter in which ideas are clearly organized and coherently produced. |
| Model design (20%) | Boat design was impractical or nonsystematic; little or no effort was made. | Boat design was somewhat impractical and not very systematic; design solutions have little explanation and lack detail; few calculations are shown, and only some of the clients' requests are met. | Boat design was mostly logical and systematic; design solutions are explained, but more detail may be needed; some calculations are shown, and most of the clients' requests are met. | Boat design was logical and systematic; design solutions are explained, calculations shown, and all of the clients' requests are met. |
| Model testing (20%) | Data not taken carefully or not taken in a reliable manner. | Some data were taken in a careful, reliable manner or data were taken only once for each test. | Most data were taken more than once in a careful, reliable manner. | All data taken more than once in a careful, reliable manner. |

MyStemKits.com

## Data Set 1 Sample Answer Key

*This represents one possible solution.*

### Testing

| Boat | Average Carrying Capacity (g) | Average Boat Mass (g) | Stability | | | Steering Rank |
|---|---|---|---|---|---|---|
| | | | Side | End | Rank | |
| A | 49.57 | 13.45 | 6.27 | 13.14 | 1 | 2 |
| B | 39.00 | 11.54 | 1.86 | 6.44 | 4 | 1 |
| C | 30.56 | 11.81 | 5.21 | 7.81 | 2 | 3 |
| D | 29.45 | 10.98 | 4.25 | 6.83 | 3 | 4 |

*Stability values were averaged, then ranked. This is only one means for ranking.*
*Steering values were based solely on perceived performance.*

### Calculations

| Boat | Efficiency (%) | Boat Volume ($cm^3$) | Boat Density $\left(\frac{g}{cm^3}\right)$ |
|---|---|---|---|
| A | 368.55 | 13.5 | 0.996 |
| B | 338.25 | 13.5 | 0.854 |
| C | 258.76 | 13.5 | 0.875 |
| D | 268.21 | 13.5 | 0.813 |

*Boat density* = $\frac{\textit{average boat mass}}{\textit{boat volume}}$

*Efficiency = the ratio of maximum cargo to ship weight* $\left(\frac{\textit{average carrying capacity}}{\textit{average boat mass}} \cdot 100\right)$

### Data Table

| Boat | Cost ($ × $10^6$) | Build Time (Months) | Stability | Steering | Carrying Capacity (g) | Efficiency (%) |
|---|---|---|---|---|---|---|
| A | 146.33 | 29-34 | 1 | 2 | 49.6 | 369 |
| B | 125.54 | 21-25 | 4 | 1 | 39.0 | 338 |
| C | 128.48 | 17-20 | 2 | 3 | 30.6 | 259 |
| D | 119.55 | 22-26 | 3 | 4 | 29.5 | 268 |

MyStemKits.com

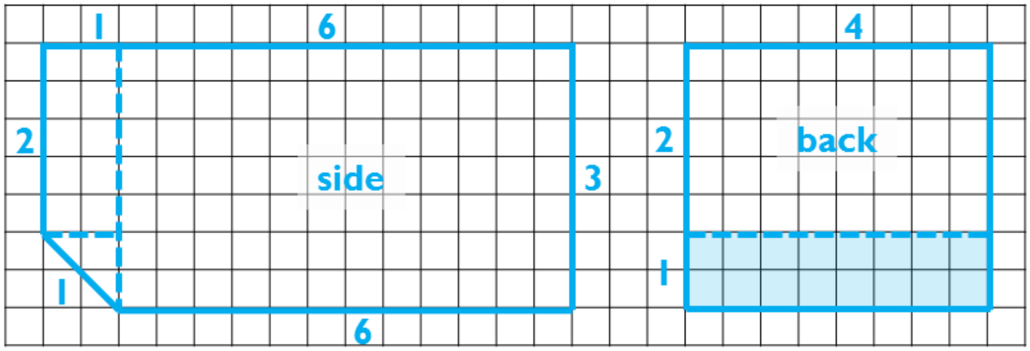
## Data Set 2 Key

Note: 85,000 tons is scaled to 8.5 g. Boat C is capped at this value, as it is the maximum allowed. If another unit is used, values will need to be converted.

1. What is your procedure and rationale for your new boat design? Did your procedure change now that you developed your own boat? Please explain.
   There are no specific answers for students' response to this question; however, students must justify their estimates in the table based on their findings from testing the boats and measure their new boat design correctly.

2. What are the shape and dimensions of your new boat's cargo hold?
   Students may select any size or shape of boat as long as it is justified. However, the boat height may not be above 60 meters (where 1cm = 10m) according to the updated stipulations in Reading Passage 2.

3. Extension Question (see Extension ideas): What is your design for a different shaped cargo hold that will hold the same amount of cargo as your boat? Be sure to show your work and specify the geometric shape of your boat's cargo hold as well as the new shape.
   - Students should recognize that they will need to calculate the volume of their boat design.
   - Students should then figure out the shape of their boat, considering: a) whether their boat hull is a complex solid, and if so which shapes, and b) whether the hull is an irregular object, in which case they may estimate the volume based on a regular object.
   - A worked example can be found on the following page.
     - The student designed a boat shape that is a complex solid, consisting of a triangular prism, a small rectangular prism, and a large rectangular prism.
     - After calculating the volume for this boat (e.g., 82 $cm^3$), students will select another shape and calculate the dimensions so that the volume is equal to 82 $cm^3$. In the example, a cylinder is selected since it was not one of the original shapes. It is not specified that students also need to hold to the constraint of height = 60 meters or less (specified in Reading Passage 2); this can be up to the teacher or students' discretion.




Triangular prism: $\frac{1}{2} \cdot b \cdot H \cdot L = ½ \cdot 1 \cdot 1 \cdot 4 = 2\ cm^3$

Small rectangular prism: $L \cdot W \cdot H = 1 \cdot 4 \cdot 2 = 8\ cm^3$

Large rectangular prism: $L \cdot W \cdot H = 6 \cdot 4 \cdot 3 = 72\ cm^3$

$$\begin{array}{r} 2 \\ 8 \\ \underline{+\ 72} \\ V = 82\ cm^3 \end{array}$$

Cylinder: $V = \pi r^2 \cdot H$

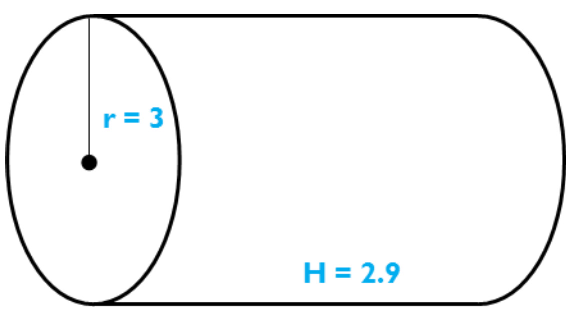
$82 = \pi r^2 \cdot H$, where either $r \leq 3$ or $H \leq 6$

$r = 3$

$82 = \pi \cdot 9 \cdot h$

$\frac{82}{9\pi} = H = 2.9$

$r = 3$




$3.14 \cdot 9 \cdot 2.9 = 82\ cm^3$

MyStemKits.com