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| ***Introduction*** |  |

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.

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| ***FL 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).
* SC.912.N.1.1: 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). 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). Use appropriate evidence and reasoning to justify these explanations to others.
* LAFS.910.WHST.2.4: Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.

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| ***Guiding Questions*** |  |

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

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| ***Learning Objectives*** |  |

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

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| ***Timeline*** |  |

Estimated number of class periods: *3-4*

Time per class period: *50 minutes*

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| ***Content Review*** |  |

**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 efficiency. Thus, weight, mass, displacement, stability, and volume are 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.

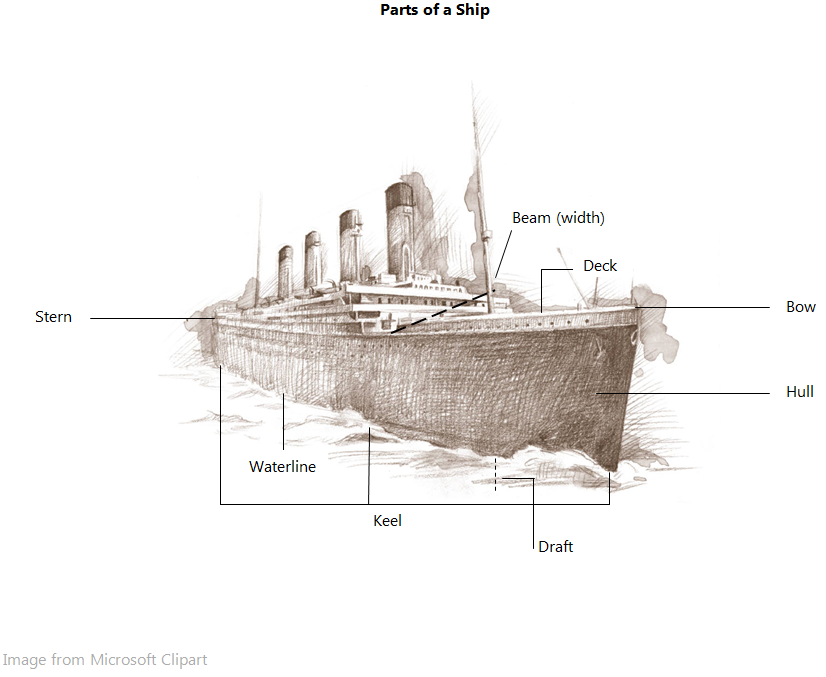
**Background Reading: What’s Happening to a Boat in the Water***Modified from:* [*http://oceanservice.noaa.gov/education/for\_fun/BoatBuildingChallenge.pdf*](http://oceanservice.noaa.gov/education/for_fun/BoatBuildingChallenge.pdf)

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 boats 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.



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| ***Procedure*** |  |

**Preparation**

* Materials needed:
  1. MySTEMKits.com Boat kit (each kit contains four boats plus a boat launching ramp)
  2. Scale (used to measure the mass of each model and corresponding carrying capacity)
  3. Ruler (to measure boats)
  4. Bin/tub (to be filled with water for boat testing)
  5. Mass (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 (Carrying Cargo SH.docx). Ideally, each student should have their own copy.

**Assessment and Review of Prior Knowledge**

* The teacher will 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? (*If the density of the object is less than the density of the substance it is placed in, the object will float*)
  + 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, for example: <http://www.mathguide.com/lessons/Volume.html>.
* 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.
  + Calculating the volume of a composite shape from the Khan Academy (via youtube): <https://www.youtube.com/watch?v=Q9vYvyvDzI8>
  + Calculating volume of irregular shapes via decomposition (Khan Academy): <https://www.khanacademy.org/math/cc-fifth-grade-math/cc-5th-measurement-topic/cc-5th-volume/v/volume-through-decomposition>
  + Real-world application: A video in which an engineer describes how they calculate the volume of irregular objects. (click on Part B video segments: [http://www.learner.org/courses/learningmath/measurement/session8/video.html#](http://www.learner.org/courses/learningmath/measurement/session8/video.html))

**Days 1 and 2**

* Before class begins, you will need to have the example boat models (one of each type) printed beforehand for each group to test.
* Provide a copy of the **Background Reading**, found above and in the document **Carrying Cargo SH.docx,** on boats to each student and ask students to highlight vocabulary they don't understand. Ask students which vocabulary was highlighted and ask if anyone knows what the word means. Some students may be more familiar with boats than others. The document called **Key Vocabulary.docx** can be printed or shown on the overhead as needed.
* Pass out **Reading Passage 1** (found in **Carrying Cargo SH.docx**) which is a Request for Proposals (RFP) from a shipping company that is requesting proposals from engineering teams 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** in the document called **Carrying Cargo SH.docx**). Ensure that students understand all 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, respond in writing with* *a step-by-step procedure of how the boat was selected*)
  + What things do you need to include in your written response to the Request for Proposals? (*step-by-step procedure of how we designed our 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. Individually, ask students to think 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, students are asked 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*: Use either 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 attachment "**Data Set 1 Answer Key**" 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, the teacher circulates to each team to ask the **Guiding/Reflective Questions** to prompt students to think about their decisions. The teacher acts as a facilitator during this time.
  + 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?
  + Do you agree or disagree with your classmates' ideas? Why or why not?
* 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.
* The teacher will pass out **Reading Passage 2**/**Data Set 2** (found in **Carrying Cargo SH.docx**) and ensure students understand what they need to do.
* The teacher can 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, provide approximations to fill out data set 2, and design a different shaped cargo hold that will hold the same amount of cargo as the boat you designed*).
* In teams, students work on the problem and respond to the client with the requested deliverables. The more time students have for this, the more they will discuss and revise their solutions in iterative modeling cycles.
* The teacher can circulate to each team to ask **Guiding/Reflective Questions** and to act as a facilitator.
* Teams write their updated procedure for selecting a boat, perform the necessary calculations, and sketch their boat prototype.
* The teacher 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?
  + After seeing your classmate’s designs, how would you modify your team’s boat design and why?
* **Summative assessment** using the attached rubric can take place to determine whether students have met the learning objectives for this activity.
* See the attachment "**Answer Key Part 2**" for a worked example and guidance for student answers on Part 2.
* The following section provides instructions on testing the 3D models. This is also included in the student handout file, **Carrying Cargo SH.docx**.

**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 m/s2) to attain 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 air pockets trapped) 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 (1g/cm3) to find the boat's mass. (1 mL = 1 cm3)
  + Ex. Displaced water volume = 5 mL (measured value)
  + Density = (1g/cm3) = (1g/mL)
  + Displaced water mass = Boat mass = (water density)\*(displaced water volume) = (1g/mL)\*(5 mL) = 5 g
* To test the cargo-carrying capacity of the design, students should gather their boat, some weights, a small aquarium or plastic tub, and water on which to float the boat.

**Cargo Testing instructions:**

* Place water in the tub/aquarium so it is approximately 10-15cm or more 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/aquarium and weigh them. The resulting mass/weight is the maximum cargo load for the boat. Record this value. The teacher should make sure the students are measuring dry weights, in case any have gotten wet.
* Write in your notes 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:**

* Place water in the tub/aquarium so it is approximately 10-15cm or more 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.
* Each model must be tested using: 1) one side peg (either will work) and 2) 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. The teacher should make sure the students are measuring dry weights, in case any have gotten wet.
* Write in your notes whether this value was less than, equal to, or more than you expected. Also include any other testing notes of interest.

**Steering Testing instructions:**

* Place water in the tub/aquarium so it is approximately 10-15cm or more deep.
* Rank (write down, in order from best to worst) each boat according to how straight the boat would glide if launched.
* To give a better idea of how each boat will react when loaded, place 5g in hollowed centers before testing.
* The provided boat launcher (ramp) is intended to hook onto the edge of your tub/aquarium. 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/aquarium design may create issues with the launcher. In the event the launcher does not operate as desired, simply 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 rating. Write in your notes whether this value was worse than, equal to, or better than you expected. Also include any other testing notes of interest.

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| ***Skills and Practices*** |  |

This lesson addresses the following STEM skills and practices:

* Developing and using models
* Analyzing and interpreting data
* Obtaining, evaluating, and communicating information

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| ***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 Question 1, where they are asked to provide numerical estimates of the carrying capacity, boat mass, stability, steering, and cargo hold volume. Instead, they will include their rationales for the boat design in their procedures for Question 3, which should include how their design affects these qualities.
* For Question 3, students may skip re-writing their procedure, and instead write about how their procedure changed or why it did not change.
* Question 4 may be skipped if you wish to emphasize more of the MEA design and rationale aspect than the modeling with geometry component. However, this lessens the alignment to MAFS.912.G-MG.1.3.

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| ***Required Materials*** |  |

3D Model: **MySTEMkits.com** **Boat Kit**

Additional Documents:

* **Student Handouts**  Carrying Cargo SH.docx
* **Sample answer key** Data Set 1 Answer Key.docx
* **Answer key part 2** Answer Key Part 2.pdf
* **Summative rubric** Assessment rubric.docx
* **Vocabulary** Key Vocabulary.docx

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| ***Review*** |  |

1. What happens to the water when you push an object into it? (*displacement - the water is pushed aside*)
2. What determines if an object floats? (*If the density of the object is less than the density of the substance it is placed in, the object will float*)
3. 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.*)
4. 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, for example:* <http://www.mathguide.com/lessons/Volume.html>.)

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| ***Accommodations & Extensions*** |  |

*Accommodations*

* Testing the boats can be completed as a class to minimize time and simply 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 c3 for each boat).]*
  + L = Length
  + W = Width
  + D = Depth
  + H = Height
  + b = base
  + r = radius
  + Rectangular prism: L x W x D
  + Triangular prism: ½ x b x H x D
  + Cylinder: pi x r2 x D
  + Sphere = (4/3) x pi x r3
  + Pyramid (equal sides) = (L x W x D)/3
  + Cone = (pi x r2 x D)/3
* Students can use online 3D design software (e.g., Tinkercad.com) to design their boat rather than graph paper. A 3D printer can be used to print their boats for testing.