FUTURE U.

Semi-Autonomous Propulsion

Objectives

Students wil be able to:

- **Explain** and **demonstrate** the difference between potential and kinetic energy.
- **Research** the impact of energy use on the environment.
- **Evaluate** and **compare** factors that impact propulsion.
- **Design** and **construct** a model boat that takes these factors into consideration.
- **Analyze** their boat propulsion's performance and **optimize** it accordingly.

Lesson Overview

Students will be tasked with helping Boeing develop a line of model boats designed to boost children's interest in STEM. They will be introduced to one of the autonomous undersea vessels that Boeing has created, and they will brainstorm the different capabilities that autonomous watercrafts likely hold. Students will then be instructed to focus on the autonomous feature of propulsion, and they will participate in hands-on activities as they explore how to create self-sustaining propulsion and investigate propulsion designs that minimize environmental impact. Students will apply what they have learned to create a self-propelling model boat, which they will ultimately test and optimize.

This lesson focuses on:

Engineering Design Process

- Designing Solutions
- Refine or Improve
- Communicating Results

21st Century Skills

- Communication
- Collaboration
- Critical thinking
- Creativity

Timing

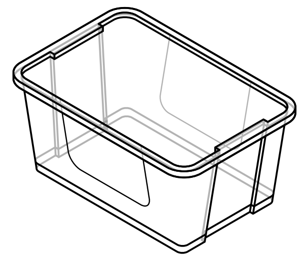
Three 45–60-minute class periods

Materials

DAY 1

- Computer or device with the ability to project, one for the instructor
- Image 1 to project: Echo Voyager
- Cotton balls, one for each student
- Cup/glass of water

- Closed bottle/can of a carbonated drink
- Devices with internet access, enough for half the class
- Green Energy Handout, enough for half the class
- Boat Demonstration:
    - 20-ounce empty plastic bottle*
    - Half of a drinking straw*
    - Masking tape*
    - Water
    - Alka-Seltzer tabs
- 2 41 quart storage containers for each day's water demonstrations (long containers are preferable so boats have space to move)
- Pitcher, to help fill the storage container with water



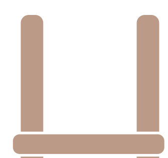
*In advance of class, make a small hole in the bottom of the plastic bottle (opposite the cap), and press part of the straw through the bottle, so it is half in the bottle and half out. Then place masking tape on the outside of the bottle to secure the straw in place.

DAY 2

- 2 storage containers (same as the one used in Day 1), filled about one-third full with water
- Towels to place under the storage containers
- Hot glue gun and glue
- Materials needed for Activity 1: Propulsion & Potential Energy:
    - 10 of the following:
        - Activity 1: Propulsion & Potential Energy handout
        - Boat frame* (as described below)
        - 12 inch-piece of string
        - 3 rubber bands of different sizes
        - 1 craft stick (like this Jumbo natural craft stick)
        - Scissors

        **Before you arrive, use craft sticks and hot glue /super glue to construct at least ten boat frames that look like the model here.

        
- Materials needed for Activity 2: Propulsion and Mass:
    - Painter's tape, a couple rolls for the class to share
    - 10 of the following:
        - Activity 2: Propulsion and Mass handout
        - Ruler
        - Golf ball
        - Ping pong ball

- Straw
- Stopwatch or timer that record time to the millisecond*

  *These can also be accessed online if stopwatches are not available

- Design-a-Propulsion System handout, enough for half the class

DAY 3

- Handout 3: Boat Box Slip, enough for half the class
- 2 storage containers (like the one used in Days 1 and 2), filled about one-third full with water
- Towels to place under the storage containers
- 10 boat frames (can be re-used from Day 2)
- Craft sticks, at least 40
- Reusable spoons, at least 30
- Hot glue gun and hot glue, for the class to share
- Scissors, a few pairs for the class to share
- Aluminum foil, for the class to share
- Rubber bands of various sizes
- Any other available materials that students could use to make a boat propeller!

Have you ever wondered . . .

Will there be self-driving, autonomous boats and ships in our future?
It's likely! Not only has Boeing developed the Echo Voyager, which will serve as a prototype for a series of unmanned ships developed for the U.S. Navy, but autonomous boats and ships are being explored elsewhere as well. Researchers at MIT are experimenting with a small 3D-printable boat that they're envisioning could be used to ferry people and goods around cities with canal or river systems. These researchers also hope that their autonomous vehicles could be designed to position themselves together to form floating bridges, space for pop-up markets, etc. And that's not all: It's possible that one day soon autonomous tugboats will be able to guide large ships into tight ports using sensor-based computer systems.[1] In addition, the Norwegian countries of Finland and Sweden are paving the way for autonomous ferries and container ships.[2] As countries around the world begin to explore autonomous water vessels, more and more opportunities for this industry arise.

Do water vessels impact the environment?
The shipping industry transports more than eighty percent of the world's trade, and other types of boats and ships are used for everything from fishing and exploration to cruising and defense. One large shipping vessel produces as much sulfur (which hurts both air quality and the environment) as 50 million cars, and the shipping industry as a whole is responsible for more than two percent of all global emissions. For this reason, the United Nations is asking all maritime emissions to be cut by at least 50 percent by 2050. It hopes to achieve this through a "propulsion revolution" in which hybrid and battery-powered ships and wind propulsion help the world move toward green, zero-carbon water vessels.[3]

Make Connections

How does this connect to students?

While fully autonomous, self-driving vehicles can't yet be purchased in the United States, technology is heading there. In the meantime, today's cars and trucks already have varying degrees of self-automation, and self-driving prototypes are a work in progress. As these self-driving land vehicles become more prevalent, the development of similar sea vehicles is also picking up speed.

Thankfully for job seekers, the field of autonomous vehicles (whether on land or sea) requires a wide range of STEM expertise. From software and robotics to engineering, mathematics, and design, diverse skills are needed to produce these vehicles—which will open the door to a variety of career prospects and future opportunities for students upon graduation![4]

How does this connect to careers?

Marine Engineer: Marine engineers design, build, and repair equipment used in the ocean, as well as aboard boats and ships. Propulsion systems are one example of equipment that a marine engineer may be responsible for designing, monitoring, and optimizing!

Mechanical Engineers: design, develop, manufacture, and/or install mechanical systems across all industries. In the maritime industry, mechanical engineers may work to manage a boat's performance and ensure that all of its systems function optimally.

Marine Biologists: Marine biologists' study marine life—from microscopic species to entire populations of larger sea animals. These scientists also study the effects of human activity on marine life and may provide suggestions or solutions to minimize their impact.

How does this connect to our world?

While the shipping industry is crucial for the world's economy, there are areas within the industry that would benefit from improvement. Shipping, for instance, is a major contributor to global greenhouse gas emissions. In addition, according to a study by Allianz, more than 75 percent of all maritime accidents are caused by human error.

Therefore, it makes sense that companies around the world are leaning toward autonomous sea vehicles as a solution to cut emissions, improve safety, and embark on unmanned missions. From Boeing's underwater vessels to Finland's development of the world's first autonomous ferry and Sweden's quest to produce a fully-autonomous and fully-electric container ship, the world has begun to explore the capabilities of autonomous and environmentally-friendly water vehicles.[2]

Sources

[1] "Forget Robo-Cars and Hit the Water on an Autonomous Boat." Wired. https://www.wired.com/story/self-driving-ships-boats/.

[2] "Massive Cargo Ships Are Going Autonomous. Here are the Companies & Trends Driving the Global Maritime Industry Forward." CB Insights. https://www.cbinsights.com/research/autonomous-shipping-trends/.

[3] "UN calls for shipping 'propulsion revolution' to avoid 'environmental disaster.'" UN News. https://news.un.org/en/story/2019/10/1050251.

[4] "How to prepare students for jobs in the self-driving-car industry." EdSurge. https://www.edsurge.com/news/2019-02-28-how-to-prepare students-for-jobs-in-the-self-driving-car-industry.

Blueprint for Discovery

Instructor Prep: This lesson requires a variety of materials. Before each class session begins, take time to organize the materials that will be needed. If one session has more than one station or activity, separate these materials in advance.

DAY 1

1. Begin class by projecting Image 1: Echo Voyager. Explain that this is a Boeing undersea vehicle called the Echo Voyager. It is a completely autonomous, unmanned boat, which means it can drive and control itself without anyone onboard!
2. Challenge students to brainstorm: In order to be autonomous and unmanned, what must this boat be able to do by itself? Keep a list on the board as students share their thoughts. Before moving on, make sure that the idea of propulsion or the ability to move through water has been recorded. If not, hint at this quality with a question such as: Does an autonomous boat always stay in one place?
3. Quickly read through the list that the class developed to recap their thoughts. Then share the students' challenge: They are about to imagine that they have been recruited by Boeing to develop a line of semi-autonomous model boats. The boats will be designed for children to use to make them excited about STEM!

   Go on to explain that when something is semi-autonomous, it can operate by itself under some conditions but also may need a degree of human help. The model boat that the students create will be semi-autonomous in terms of propulsion (or its ability to drive itself forward). Students will therefore investigate factors that impact a boat's propulsion before they begin creating their models.
4. Ask students: In order for a boat to move—whether it's on its own or with help—what must the boat possess? Help students arrive at *energy*.
5. Explain that there are two types of energy and ask for input* on what these two types of energy are. Eventually write *Kinetic Energy* and *Potential Energy* on the board and explain:
   - **Kinetic** energy is energy of motion. In other words, kinetic energy is the energy that something possesses as it moves.
   - **Potential** energy is stored energy. In other words, the more stored energy something has, the more *potential* it has to move!

     *Note: This will be a good way to judge if students already have a grasp on kinetic and potential energy. If students seem to have a working knowledge of these concepts, you can move through them quickly. If they don't, you may want to spend a little more time.
6. To lead the class in demonstrating these two forms of energy, distribute a cotton ball to each student and provide the following prompts:
   - Place the cotton ball somewhere where it has potential energy.
   - Now, place the cotton ball somewhere where it has a bit less potential energy.
   - Show me what it looks like when the cotton ball has kinetic energy.

   Then, collect the cotton balls before moving on.
7. Next, shake a closed bottle or can of a carbonated drink and place it down in front of you. Directly next to this drink, place a glass of water. Ask the class to point to which one has more potential

energy, and then ask for a student volunteer to explain why. Students should be able to explain that the carbonated drink has more potential energy because it contains bubbles that are waiting for the bottle to be opened so they can move to the surface.

8. Wrap up the energy conversation by asking students to share how these energy types may be related to their challenge of developing a model boat that can move by itself. Guide students in arriving at the conclusion that the boat must be able to convert its potential energy to kinetic energy in order to move and propel itself through the water!
9. Divide students into pairs and pass out one Green Energy handout to each pair. As you do, explain that the energy for water vehicles can come from various sources. When considering an energy source, it's important to consider the impact it may have on the environment. Then review the instructions on the handout, answer questions as needed, and ensure students know where to find devices to complete this activity.
10. Give the class about 15 minutes to complete the handout. As students work, prepare the materials needed for the baking soda boat demonstration, and fill the storage container about one-third full of water.
11. When about 15 minutes have passed, instruct students to gather around the water-filled container. Explain that you have one idea for a self-propelling boat. As you demonstrate the following, instruct students to apply what they just learned and think about *how* this boat is propelled:
    - Pick up your bottle/straw combination, unscrew the cap, and ask a student volunteer to pour about a cup of water into the bottle.
    - Drop an Alka-Seltzer tab into the bottle's opening and screw the cap back on as quickly as possible.
    - Immediately place the "boat" into the container of water and watch it propel itself around.
12. Then discuss the following two questions:

    (Once students have shared their responses, summarize the answers below.)

    - What caused the boat to propel or move forward?
        - Answer: A reaction occurred that created bubbles that wanted to escape from the bottle, which propelled the boat forward. More specifically, baking soda is a base and vinegar is an acid. As they tried to neutralize each other, carbon dioxide formed. (This is exactly what happens in the classic volcano demonstration, too!) This carbon dioxide took the form of bubbles, which escaped out of the bottle, through the straw, and ultimately propelled the boat.
    - Is this an environmentally friendly model?
        - Answer: This would *not* be a good example of an environmental-friendly model. If students think about the three types of energy that they just learned about (fossil fuels, wind turbines, and solar energy), this is most similar to fossil fuels—which also produce carbon dioxide when burned!
13. Conclude class by previewing that next session students will begin to explore how to best build a model boat that self-propels *and* is kind to the environment!

DAY 2

1. Begin class by reminding students of their challenge: to help Boeing develop a line of self-propelling model boats that get children excited about STEM!

2. Explain that today, the class will participate in two activities designed to help them investigate propulsion ideas for their model boat.
3. Divide students into groups of three, and distribute one boat frame and one Activity 1: Propulsion & Potential Energy sheet to each group. Then review the following:
    - The handout's directions are clear, and students should carefully follow each step.
    - Students should handle their boat frame carefully. A hot glue gun is available if repairs are needed.
    - Show the class where they can find the supplies needed for this activity. Also point to the water-filled containers and explain that groups will have to take turns as they perform trials in these bins.
    - When a group completes the first activity, they should move on to the second activity. Show students where they can find the handout and materials for this activity.
4. Once you have answered any questions, encourage the groups to begin. Rotate through the classroom as students work and ensure they are staying on track. If groups have not shifted to the second activity after about 10–15 minutes, encourage them to wrap up and move on.
5. Once about 25–30 minutes have passed, regain the class's attention, and explain that when they wrap up their work on the second activity, they should put all of their materials back where they found them. If time allows, they should then begin brainstorming for their own model boat. Show students where they can find their Design-a-Propulsion System handout, and challenge students to complete Step 1 before the end of the class session.
6. When there are five minutes left, ask any remaining groups to begin cleaning up and explain students will design and build their model boats next session!

DAY 3

1. As the class session begins, ensure all groups have a copy of the Design-a-Propulsion System handout. Then review/complete Step 1 together, regardless of whether groups have already completed it themselves.
2. Once you have reviewed the class's key take-aways, read through Steps 2 and 3 and explain that groups will have about 30-35 minutes to complete these steps. As you review the directions:
    - Encourage groups to spend the majority of their time on Step 3. While sketching an idea for their boat design is important, they won't know if their design will work until they actually begin building it!
    - Reiterate the importance of testing and optimization. The goal of Step 3 is not to initially build a perfect boat. The goal is to initially build a boat that may be able to propel itself and then continually make changes until it does!
    - Show students where they can find the day's construction materials and briefly review what is available before you instruct groups to begin!
3. When there are about 15 minutes left in class, distribute one Boat Box Slip to each group, and explain that this slip is a draft of what will be included with the boat when it is distributed, so children will understand how their boat works and why they were designed as they were. Explain that:
    - In the first column, students should include step-by-step instructions, so children know how to operate the boat. Encourage students to work "potential energy" and "kinetic energy" into their instructions.

- In the second column, students should consider how their boat would be “green” if it was a real boat. In other words: How would it get its energy in an environmentally-friendly way?

4. When there are a couple minutes left in class, conclude with a brief review of the boat-building process and what students learned as they constructed their own model boats. Ask groups to share what they changed, and how they modified their designs to optimize their boat’s performance.
5. Wrap up by thanking the class for their hard work and creativity over the last few class periods and remind students that as they begin to consider future career paths, there are many STEM careers that focus on propulsion, oceanography, and marine transportation!

Extend

Groups can exchange boats and boat slips with each other and follow the slip’s directions to operate the boat. Groups can then debrief together and provide suggestions and recommendations on how to: 1) Improve the operating instructions, 2) Improve the boat’s performance, and/or 3) Be more environmentally friendly.

National Standards

Next Generation Science Standards

Engineering Design:

- 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.

Motion and Stability: Forces and Interactions:

- 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.

Common Core English Language Arts Standards

Writing

- W.4: Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.

Speaking & Listening

- SL.1: Prepare for and participate effectively in a range of conversations and collaborations with diverse partners, building on others' ideas and expressing their own clearly and persuasively.

Green Energy handout

1. Open a web browser on your device and go to climatekids.nasa.gov/power-up/.
2. Read the webpage once all the way through.
3. Then read the article again, this time stopping to fill out the chart below.
4. If time remains and you have finished the chart below, you may play Power Up.

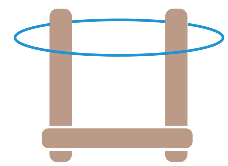
Power Source	In a sentence or two, how does this power source work?	What are the **benefits** of this type of energy?	What are the **risks** of this type of energy?
		Include details from the article, as well as your own thoughts and inferences.	
Fossil Fuels			
Wind Turbines			
Solar Panels			

Activity 1: Propulsion & Potential Energy

Directions: Gather the materials listed below. Then work as a group to complete Steps 1–6!

Materials Needed

Boat frame	1 piece of string
3 rubber bands (of different sizes)	1 craft stick
Scissors	



1. Pick up the string and rubber bands and stretch each one lightly. Then discuss with your group: Do these have different amounts of potential energy, or the same? Why?
2. Tie the string in a loose loop around the open end of the boat frame.
3. Place the extra craft stick through the middle of the loop of string and turn it in a circle. You are creating the boat's propeller, so think about which way you should turn the craft stick so that the boat will move forward. Turn the craft stick around the string in this direction until you can't turn it any further.
4. Hold on to the craft stick and string so they don't come unwound, and place your boat frame at one end of the water container. Then release the craft stick and see what happens! Measure how far it moves and describe how it moved in the second column of the propulsion chart below.
5. Remove the string and repeat Steps 2-4 with all three rubber bands.
6. Use Column 3 to rank how well the string and rubber bands were able to propel your boat frame, based on your measurements and observations. Was your hypothesis correct? Why or why not?

Material	**Propulsion Observations** How far was your boat propelled? How would you describe its movement?	**Propulsion Ranking** 1 = Best; 4 = Worst
String	Distance Propelled: Other Notes:	
Smallest Rubber Band	Distance Propelled: Other Notes:	
Medium Rubber Band	Distance Propelled: Other Notes:	
Largest Rubber Band	Distance Propelled: Other Notes:	

Activity 2: Propulsion & Mass

Directions: Newton's Second Law of Motion states that Force = Mass x Acceleration. Gather the materials listed below, and then complete Steps 1–6 to investigate how this law can be applied to boat propulsion.

Materials:

- Ruler
- 2 pieces of painter's paint
- Stopwatch
- Ping Pong Ball
- Golf ball
- Straw
- 2 notebooks

1. Decide which group member will take the following roles:
   - **Assembler:** You will be in charge of setting up the experiment.
   - **Force:** You will create the experiment's force by blowing into a straw.
   - **Timer:** You will be in charge of operating the stopwatch.
   - **Recorder:** You will be in charge of taking notes throughout the experiment.
2. The **Assembler** should:
   - Use tape to create a starting line and finish line on the floor or a table, 12 inches apart.
   - Lay the notebooks on either side of the track, between the starting and finish lines.
   - Place a ping pong ball on the starting line.
3. The **Force** should take a deep breath and practice exhaling steadily through one of the straws onto the ping pong ball, so that the ping pong ball is pushed from the starting line to the finish line. The **Timer** should keep track of how long this takes.

   The **Force** should practice this several times until rolling between the two points takes about the same amount of time each time.
4. Once your group has a steady force, begin the experiment:
   - Perform three trials to see how long it takes the **Force** to push the ping pong ball from the starting line to the finish line. The **Timer** should time how long each trial takes, and the **Recorder** should record it in the chart below. Be sure to record the time to the millisecond! (e.g., 1.003 seconds)
   - Then, repeat the experiment with the same steady **Force**, but this time the **Assembler** should replace the ping pong ball with the golf ball. The **Timer** and **Recorder** should continue to time and record each trial in the chart below.

	How long did it take to cross the finish line?			
	Trial 1	**Trial 2**	**Trial 3**	**Average**
Light Mass: Ping Pong Ball				
Heavy Mass: Golf Ball				

5. When all trials are complete, work together to calculate the average time for each ball.
6. Discuss the questions below as a group.
   - What effect did mass have on acceleration (e.g., the trial times)?
   - How can the equation Force = Mass x Acceleration be used to help you construct a boat that can accelerate quickly?

Design-a-Propulsion System

Directions: Follow the steps below as you begin to design, build, and optimize your model boat.

Step 1: Review your Activity 1 and Activity 2 handouts and think about what your group learned that could help you build a powerful and semi-autonomous propeller system. What should you keep in mind as you begin to design your own boat?

Step 2: Use your boat frame as a starting point, and work with your group to sketch your own model boat design. Your boat must meet two criteria:

- It must be able to propel itself.
- It must be environmentally friendly. (Consider: If this were a real boat, where would it get its energy?)

Step 3: Use your plan to help you build your boat. As soon as you think it may able to propel itself, test it in water to see how it performs. Then consider how you can make it even better.

Try to perform at least two different tests and optimize (or improve) your boat each time.

Boat Box Slip

Boat Name: ______________________________

I run by myself! You can give me energy by…

If I were a real boat, I would be kind to the environment because…

Boat Name: ______________________________

I run by myself! You can give me energy by…

If I were a real boat, I would be kind to the environment because…