ENGINEERING DESIGN CHALLENGE

RUBBERBAND THRUSTERS | EDUCATOR

Links to Next Generations Science Standards |

MS-ETS1-2: Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.

MS-ETS1-3: Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.

MS-PS3-5: Construct, use, and present arguments to support the claim that when the kinetic energy of an object changes, energy is transferred to or from the object.

Links to the NEED Project Curriculum |

For Upper Elementary Level: Elementary Science of Energy

For Secondary Level: The Secondary Science of Energy

S T **E** M

Pacing | Variable

Background Needed | Basic properties of motion

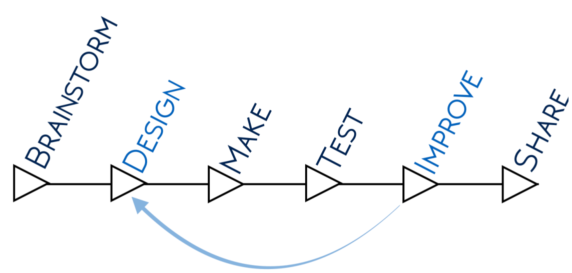
Materials/Resources |

- Craft sticks / Cardstock / Cardboard
- Paperclips
- Propellers
    - Available for purchase from PITSCO Education (http://www.pitsco.com/clubs_and_competitions/4h/Propeller_Assembly) or Kelvin Education Supply (http://kelvin.com/nose-hook-propeller-6-in-dia/)
    - For an added challenge- make your own propellers from a soda can or plastic bottle (http://www.sciencetoymaker.org/plane/propeller.htm)
- Long rubber bands (7-inch file bands work well)
- Masking tape or hot glue
- Stopwatch
- Race track materials
    - Fishing line
    - Stable structure (classroom chairs or playground equipment)

The Challenge

Students will design and build a model thruster that utilizes a propeller to race itself along a racetrack as fast as possible. Students will document and compare solutions to identify the best characteristics from the tested designs that can be combined into more successful solutions. The concepts used to design the models in this challenge are analogous to the six thrusters used to maneuver ROV *Hercules* underwater.

Students will use the **Engineering Design Process: Brainstorm, Design, Make, Test, Improve, Share** to design their model thrusters.



Objectives & Learning Outcomes

- Students will understand the engineering design process.
- Students will be able to discuss basics of propulsion using STEM vocabulary.
- Students will produce a thruster model powered by a rubber band and propellor to race down a racetrack as fast as possible.
- Students will understand how modifications to their design produce changes in the speed it can move.

Links to Common Core Standards |

CCSS.ELA-LITERACY.WHST.6-8.4: Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.

CCSS.ELA-LITERACY.WHST.6-8.7: Conduct short research projects to answer a question, drawing on several sources and generating additional related, focused questions that allow for multiple avenues of exploration.

CCSS.MATH.CONTENT.7.EE: (See Extensions) Solve real-life and mathematical problems using numerical and algebraic expressions and equations.

Background for Educators |

Forces are acting on objects at all time. When unbalanced forces act on a object, the object will move. Motion is affected by the magnitude of those unbalanced forces. Some forces such as gravity tend to increase an object's motion. Other forces such as friction, air or water resistance tend to cause an object's motion to decrease. Motion can be quantified by measuring the distance an object travels or the time it takes for an object to move.

Isaac Newton *(1643- 1727)* was a mathematician and physicist who explained the motion of objects. In his 1st Law of Motion he explained that objects tend to stay at rest or in motion unless an unbalanced force acts on it. In this challenge, the forces of friction, air resistance, and thrust will have the largest effects on the motion of the model.

Wind the propeller, twisting the rubber band, to store potential energy. When released, the propeller rapidly unwinds generating thrust, pulling the thruster along a low-friction racetrack. Students witness potential energy transformed into kinetic energy. The moment of force, torque, can cause rotation that flips thrusters upside down on the racetrack. Modify designs to counter this force by introducing drag resistance. Attaching a cardboard body to the model adds drag perpendicular to the force of the uncoiling preventing inversions.

If needed, use these demos from Curiosity Machine to illustrate key concepts.

Potential Energy is energy stored in a system.

> *Explanation Action:* Fill a balloon with air. Have students note the air now inside the balloon. Ask students to explain why the air in the system is potential energy.

Kinetic Energy is the energy of motion.

> *Explanation Action:* Release the balloon and have students explain the kinetic energy as your balloon loses air.

Newton's Third Law: For every action there is an equal and opposite reaction.

> *Explanation Action:* Ask students to explain the action (air being released from a balloon) and reaction (balloon moving in the opposite direction of the released air).

Thrust is a propulsive, or forward-moving force. Thrust occurs when air is pushed in the direction opposite to movement.

> Explanation Action: Refill the balloon and ask the students if it is possible to control the direction of the force exerted by aiming the balloon. Have students tell you how to get the balloon to go in a specific direction when released and then test their idea.

ENGINEERING DESIGN CHALLENGE

RUBBERBAND THRUSTERS | EDUCATOR

Extensions & Adaptations

Introductory |

- *Allow students to work in pairs or groups;*
- *In the test stage, have pairs of students compare their designs (rather than as a whole class).*
- *Limit the amount of materials students can use.*

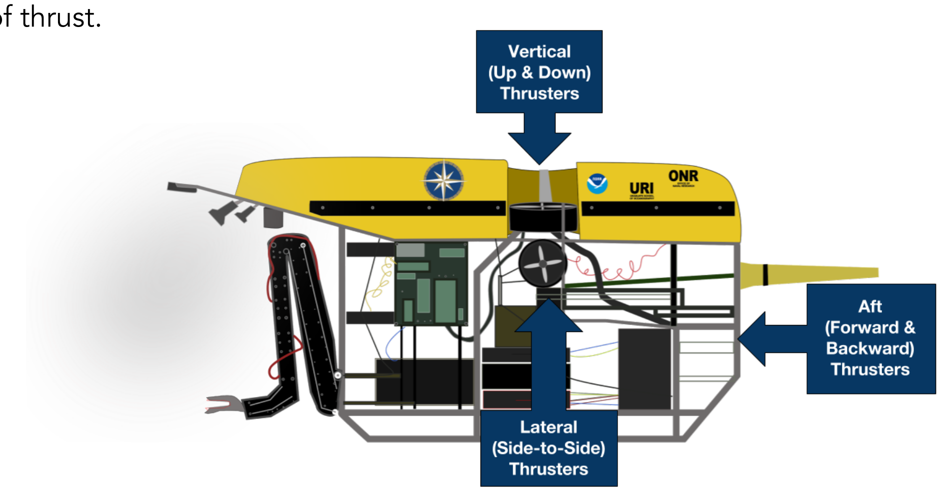
Advanced |

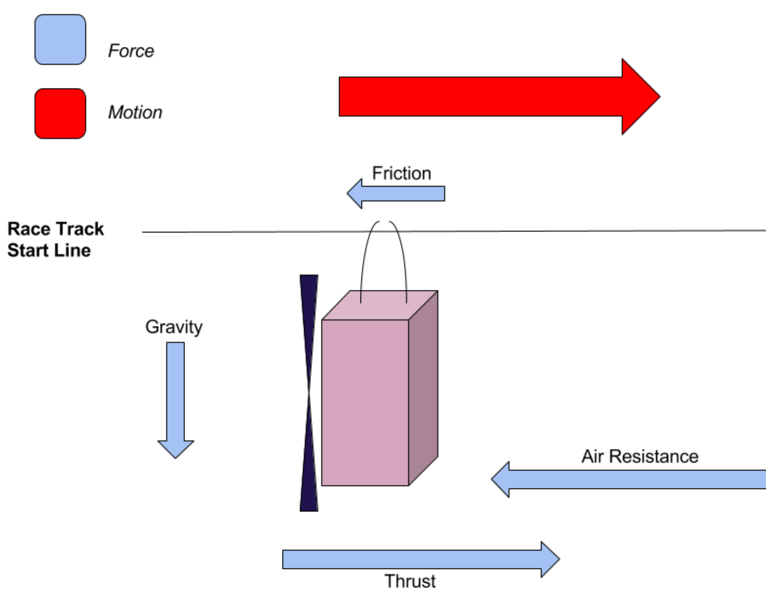
- *Engineer your propeller from a plastic bottle or soda can. Visit* http://www.sciencetoymaker.org/plane/propeller.htm
- *Ask students to increase the speed of their thruster. Can they increase it by 50%? How will they redesign to complete this task?*
- *Challenge students to design a thruster capable of carrying weight. How would they redesign their thruster to move 10 quarters at the same rate as the unweighted thruster?*
- *Find the kinetic energy (in joules) of the thruster by finding the mass of the thruster, the velocity of the thruster (velocity = distance/time), and using the kinetic energy equation:* $KE = 1/2mv^2$

Real-World STEM | Thrusters on E/V *Nautilus*

ROV *Hercules* has six thrusters powered by a hydraulic system.

- Four 11-inch diameter ducted thrusters (2 Aft & 2 Vertical) each provide 900N or 200lbf thrust.
- Two 9-inch diameter ducted thrusters (Laterals), each provide 450N or 100lbf thrust.





Note: the propellor in this sketch is pushing the design. Propeller angle determines whether they function best pushing or pulling. Students will have to experiment to with their models to orient the propeller(s).

Advanced Concept Background

"How Propellers Work" by Quicksilver Propellers from Mercury Marine.
http://legacy.qsprops.com/about/how-propellers-work/

Challenge Preparation |

SAFETY | Teachers should implement their own classroom policy for lab safety. Spinning propellers can pose a hazard. Ensure the thruster testing racetrack is highly visible or safely above everyone's head. Pulling downward on the thruster model while it is hooked onto the racetrack may cause it to be flung off the line upon being released. This can be dangerous when the propeller is rapidly unwinding.

1. Read the educator's introduction and watch the challenge videos.
    1. Maneuvering ROV Hercules with thrusters - http://nautl.us/2l58ioJ
    2. Basic Design Introduction - http://nautl.us/2lxyudH
2. Plan and build your own thruster model. This will be a good example to show students and will help you to answer their questions
3. Gather materials students will need to complete the design challenge. Feel free to experiment adding additional materials to diversify the designs. Lightweight materials like cardboard tubes or poster board work well in place of popsicle sticks. Display materials centrally. Students should pick their build materials and explore various options.
4. Print out student worksheets and data sheets. If you want to race models against others, print tournament brackets. [https://www.printyourbrackets.com/fillable-tournament-brackets.html]
5. Prepare a thruster racetrack for design trials.

    Students can make thrusters at their desks but you will need at least one racetrack to test student designs. Side-by-side racetracks will allow for bracket-style racing trials and faster student trials.

    Tie fishing line to two chairs set apart to create a taut, horizontal line. Consider student height and also traffic through the area when selecting your track placement. Recommended track length is 25-30 feet. If outdoor playground equipment is available, you can create larger race tracks. Mark a starting line and finish line along the track so student timers can collect accurate data.

BRAINSTORM

Challenge Introduction |

Show students the video of ROV Hercules moving along the seafloor. [http://nautl.us/2l58ioJ] Ask students why and how they think thrusters work. Have they seen this idea in any other things?

Introduce engineering design process and any concepts needed for students to create a thruster model. Introduce the design challenge. Show students materials they can use to build their prototypes.

> Optional- introduce materials in segments detailing the important parts of a thruster (mounting attachment, body, propeller). Or show students your prototype if they need help understanding how to get propeller motion directed down a racetrack.

If would like students to research the ROV *Hercules* thruster system or other thruster concepts, have them complete it at this time.

Define the following terms:

Force
- something that causes a change in the motion of an object; a push or pull

Motion
- the action or process of moving or being moved

Resistance
- force which an effort force must overcome in order to do work on an object; a hindrance preventing motion

Thrust
- a propulsive, or forward-moving force

Potential Energy
- energy an object has because of its position, rather than its motion

Kinetic Energy
- energy of a system or object because of its motion; the energy of movement

Newton's First Law
- an object in motion will remain in motion until acted upon by another force. an object at rest will stay at rest until acted upon by another force.

Newton's Third Law
- for every action, there is an equal and opposite reaction.

1. Brainstorm examples of potential energy and kinetic energy in your life everyday and list them below. Answers will vary.

Potential Energy	Kinetic Energy
1. Fire door propped open	1. A ball bouncing down stairs
2. Mousetrap loaded with the spring	2. Cars and trucks driving down the road
3. Textbook perched on the edge of a table	3. Running kids moving across the playground

2. In the examples below, circle the actions and draw a box around the reactions. Remember Newton's Third Law of Motion states that for every action, there is an equal and opposite reaction.

An octopus expels water out of its siphon, propelling itself away from ROV *Hercules*.

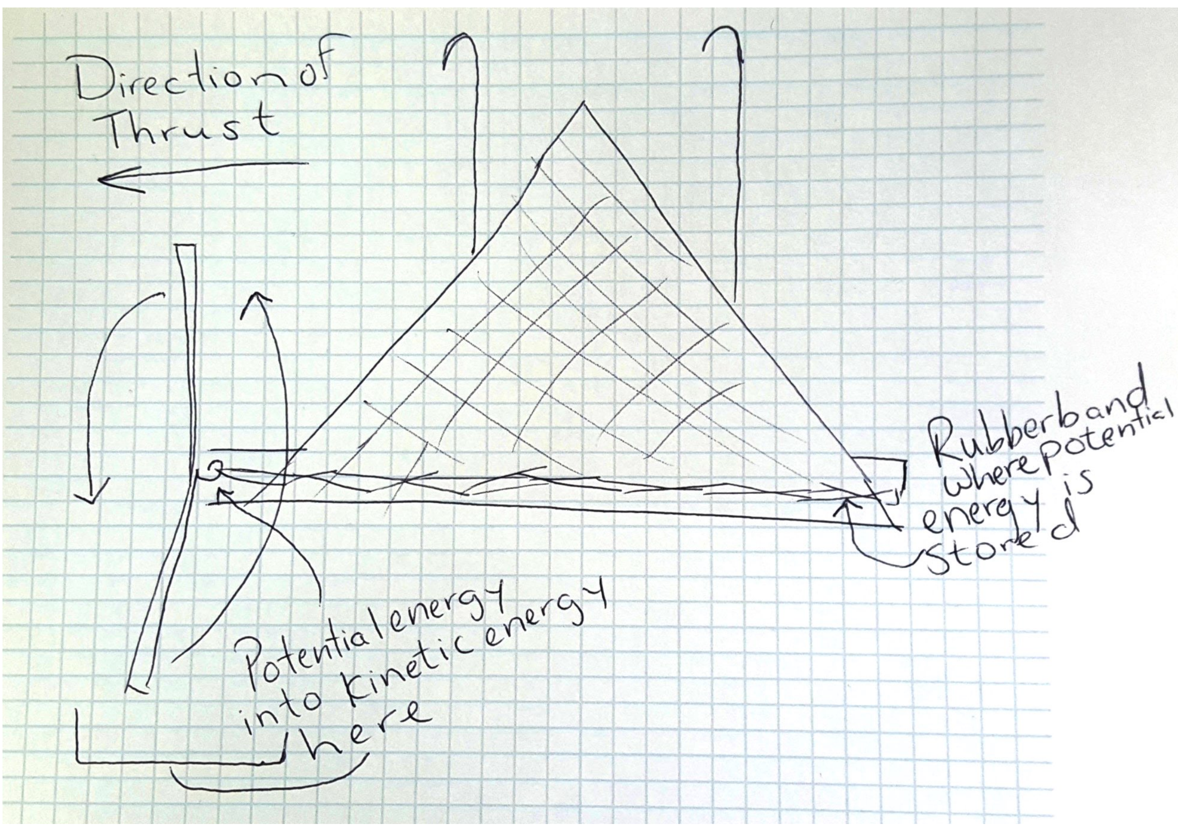
2-ton ROV *Hercules* moves backwards after nudging a boulder.

The floor pushes against her foot as a student steps into the *Nautilus* control van.

DESIGN

Students will examine the provided materials and draw their design plan. Instructions ask students to label the important parts of the thruster [Body, Propeller(s), and Mounting frame- used to attach the thruster to the ROV or to the racetrack]. Students should also label their drawing the following.

- Where potential energy is stored.
- Draw and label an arrow to show the path of potential energy transferring into kinetic energy.
- Draw and label an arrow to show the direction of thrust.



Students will complete the progress questions. This is a good time for group collaboration or share out if some groups are struggling.

Progress Questions I

5. How will your model will transfer potential energy into kinetic energy?

Answers may vary. The twists in the rubberband store potential energy. When the propeller is released the unwinding rubber band moves the propeller. Kinetic energy of the thruster is the energy it contains when it's in motion.

6. Which end of your model will face the finish line? And what would happen if you turned your design around?

The end with the propeller. If the design was turned around it would travel backwards in the direction of the starting point.

7. Compare your design to two other classmates' designs. What are the similarities? What are the differences? After observing your classmates' designs, what is one thing that you think might work well that you haven't tried?

Answers will vary.

MAKE

Build Your Thruster Model!

If students are having trouble getting started, have them start building a mechanism that allows the propeller to spin (rubber band and propeller with something in between to hold the far end of the band. Once that is finished, have students add other parts to their design.

TEST

Students will test their thruster models along the racetrack. Time each thruster from the start to finish line. Students will complete two trials so they can average their speed along the track. If you built side-by side tracks, use tournament brackets to determine the fastest designs. Consider standardizing the number of rubber band winds to help ensure the models are the tested variable rather than the potential energy differences.

Editable student data sheet: Race Trials Data Sheet [http://nautl.us/2lNmozG]

Encourage students to record notes on their data sheets about what worked well for their design and other models. What elements of their design need improvement?

IMPROVE

The redesign process can be student directed or led as a large-group discussion. Encourage students to think critically about how to make improvements to their designs or about elements they would add to their design if allowed to use any materials. Lead the discussion beginning with any of the following questions.

> *What worked well? What challenges did you encounter? What would happen if your thruster was larger? What if it was smaller? What if it weighed more or less? Did all parts of your thruster function like you planned? What materials might help your thruster move faster? What other engineers' ideas inspired you?*

Ask students to make at least one modification to their thruster's design then return to the test track and complete Section II of the data sheet.

SHARE

Individually or in small groups, students should answer the reflection questions.

8. Overall, what patterns did you see that made the models successful?

   Answers will vary.

9. When potential energy was transferred into the model, what happened to the kinetic energy?

   The kinetic energy increases over time. As the force of the thrust from the spinning propeller overcomes air resistance and friction the thruster will begin to move.

10. Did the kinetic energy of the model change over time? Use evidence to describe how.

    As the thruster moves faster the kinetic energy also increases. The thrust force reduces as it runs out of potential energy. It is slowed down by air resistance and friction with the racetrack. Kinetic energy decreases as energy is spread out as heat from friction on the racetrack and into movement of air molecules that are pushed from the propeller.

11. What do you think is greater - air resistance or water resistance? Give evidence to support your claim.

Water resistance is greater than air resistance. Water and air have different densities and weight. Water weighs more than air and can require a higher amount of energy to move compared to air. Ex: it takes more energy to move your hand through water than air.

12. If you were modifying your design for use underwater, what changes would you consider?

The model would need to be waterproof. Streamlining the model would reduce water resistance by decreasing drag. The propellor would also need more potential energy behind it to power its motion and create kinetic energy through the thicker medium (water).

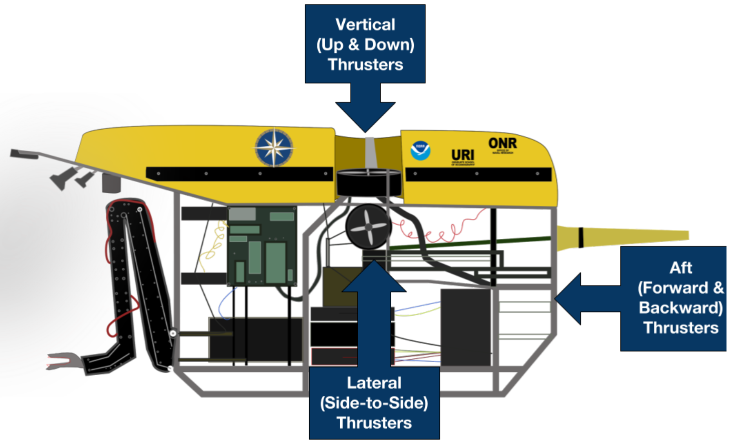
ENGINEERING DESIGN CHALLENGE

RUBBERBAND THRUSTERS | STUDENT

Learning Goals

- Understand the engineering design process.
- Learn the basics of propulsion using STEM vocabulary.
- Make a thruster model powered by a rubber band and propellor to race down a racetrack as fast as possible.
- Understand how modifications to a design produce changes in the speed it can move.

The Challenge |

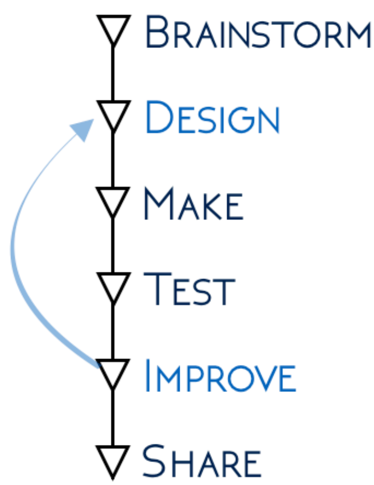


We're counting on you, engineer, to build the most powerful thruster possible to help propel the remotely operated vehicle (ROV) *Hercules* along the seafloor.

Before taking your skills to sea, you will build a thruster model in your classroom. Successful designs will use a propeller to race along a track as fast as possible!

Use the engineering design process to design the most successful solution to the challenge - a thruster to race against your fellow engineers.

All engineers will document their designs and compare solutions to identify the similar successful characteristics. The best part of this challenge is that there is no wrong answer in how to construct your model!



The Basics |

A thruster is a propulsion device built into or mounted onto a ship or a machine to provide it with the capability to be maneuverable. ROV *Hercules* has six thrusters which pilots use to "fly" the robot during exploration—two aft thrusters to maneuver forward and backward, two vertical thrusters to maneuver up and down, and two lateral thrusters to maneuver side-to-side. Watch this animation to see the thrusters moving the ROV *Hercules* along the seafloor. [http://nautl.us/2l58ioJ]

ENGINEERING DESIGN CHALLENGE

RUBBERBAND THRUSTERS | STUDENT

Real-World Problem Solving

While preparing for a ROV launch, one item on the engineer's checklist is to inspect the thrusters. All must spin freely with nothing like fishing line caught in them. *Hercules'* six thrusters are paired: two forward, two thrusters side-to-side and two vertical.

Imagine the forward thruster on the left side (port side) of ROV *Hercules* stops. When you thrust forward, only the right side spins. The ROV turns itself left instead of going straight. What would you do in this situation?

Tips from the Corps of Exploration

"As a pilot you compensate for the turning by using the lateral thrusters. Lateraling to push the vehicle from the left at the same time you use the forward thruster will compensate for that overpowering turn."

-Josh Chernov
ROV Team Leader

BRAINSTORM

Getting Started. Define the following terms:

Force

Motion

Resistance

Thrust

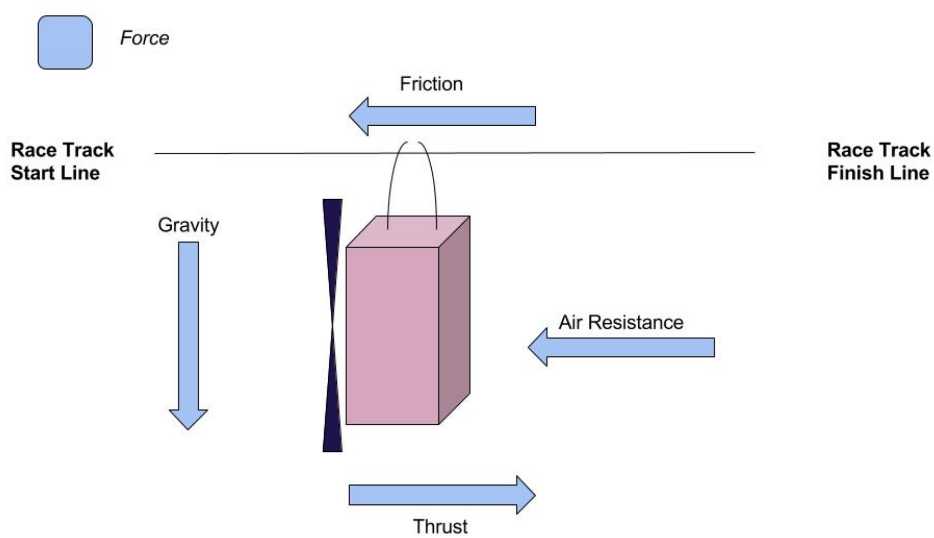
Potential Energy

Kinetic Energy

Newton's First Law

Newton's Third Law

Examine the basic forces in this challenge. Circle the force which needs to be the largest for your thruster to reach the finish line.



1. Brainstorm examples of potential energy and kinetic energy in your everyday life and list them below.

Potential Energy	Kinetic Energy
1.	1.
2.	2.
3.	3.

2. In the examples below, circle the actions and draw a box around the reactions. Remember Newton's Third Law of Motion states that for every action, there is an equal and opposite reaction.

   An octopus expels water out of its siphon, propelling itself away from ROV *Hercules*.

   2-ton ROV *Hercules* moves backwards after nudging a boulder.

   The floor pushes against her foot as a student steps into the *Nautilus* control van.

DESIGN

3. Examine the provided materials and draw your design plan including the key components of a thruster listed below.

Body	Propeller(s)	Mounting frame (to attach the thruster to the ROV or to the racetrack in this challenge)

4. Label the following on your drawing:
   - Where potential energy is stored.
   - Draw and label an arrow to show the path of potential energy transferring into kinetic energy.
   - Draw and label an arrow to show the direction of thrust.

Progress Questions |

5. How will your model will transfer potential energy into kinetic energy?

6. Which end of your model will face the finish line? And what would happen if you turned your design around?

7. Compare your design to two other classmates' designs. What are the similarities? What are the differences? After observing your classmates' designs, what is one thing that you think might work well that you haven't tried?

MAKE

Build Your Thruster Model!

TEST

Time to Race!

Complete Section I of the data sheet with data from racing your thruster.

IMPROVE

What worked well? What challenges did you encounter? What would happen if your thruster was larger? What if it was smaller? What if it weighed more or less? Did all parts of your thruster function like you planned? What materials might help your thruster move faster? What other engineers' ideas inspired you?

Make at least one modification to improve your thruster's design. Return to the test track and complete Section II of the data sheet.

SHARE

Reflection Questions |

8. Overall, what patterns did you see that made the models successful?

9. When potential energy was transferred into the model, what happened to the kinetic energy?

10. Did the kinetic energy of the model change over time? Use evidence to describe how.

11. What do you think is greater - air resistance or water resistance? Give evidence to support your claim.

12. If you were modifying your design for use underwater, what changes would you consider?

How Large is Nautilus Nation?

Tracking the reach of Ocean Exploration Trust's education programs is essential in ensuring we are funded to continue making discoveries and inspiring the next generation of explorers.

Name: **My Community (City, State):**

Email Address:

School's Name:

Instruction date: **Grade level instructed:**

Subject area:

My education space is a...

- ❏ Classroom
- ❏ After school program / Club meeting
- ❏ Fair / Festival / Event
- ❏ Museum / Science Center
- ❏ Other. Tell us more:

Who did you engage in your teaching?

Students

Community Members

Select all the OET materials you used in your instruction:

- ❏ STEM Learning Modules. Which ones? ______________________________
- ❏ Digital Resource Library materials. Which ones? ______________________________
- ❏ Nautilus Live website: photo albums ☐ highlight videos ☐ live stream
- ❏ Meet the Team STEM mentor profiles
- ❏ Facebook (NautilusLive) ☐ Twitter (@EVNautilus) ☐ Instagram (@nautiluslive)
- ❏ Other. Tell us more: ______________________________

____

What made working with OET resources valuable to your instruction (select all that apply)?

- ❏ Hands-on activities ☐ STEM career connections
- ❏ Easy to use lessons ☐ Standards-based lessons
- ❏ Website resource access ☐ Real world application of curricula topics
- ❏ Excitement of cutting-edge discoveries / Unfamiliarity of deep ocean
- ❏ Another reason. Tell us more: ______________________________

____

Using OET resources increased my confidence in teaching my science, technology, engineering, or math subjects.	☐ Yes	☐ No
OET provided me with helpful and relevant teaching resources.	☐ Yes	☐ No
Using OET resources increased my awareness of STEM careers.	☐ Yes	☐ No
If yes, how so? How can we improve?		

Please scan this document or snap a picture of it with your phone. Email the feedback or questions to education@oet.org. You can also submit feedback online: http://nautl.us/2cp3PNu

Thank You For All You Do!