PRESSURE & DENSITY | EDUCATOR

Links to Next Generations Science Standards |

MS-PS1-4: Develop a model that predicts and describes changes in particle motion, temperature, and state of a pure substance when thermal energy is added or removed.

MS-ESS2-1: Develop a model to describe the cycling of Earth's materials and the flow of energy that drives this process.

MS-ESS2-4: Develop a model to describe the cycling of water through Earth's systems driven by energy from the sun and the force of gravity.

Links to Common Core Standards |

CCSS.ELA-LITERACY.RST.6-8.9: Compare and contrast the information gained from experiments, simulations, video, or multimedia sources with that gained from reading a text on the same topic.

CCSS.MATH.CONTENT.6.EE.9: Represent and analyze quantitative relationships between dependent and independent variables.

S T E M

Supplement Video |
https://www.youtube.com/watch?v=VDQTBbpJ0qE
https://vimeo.com/154181564 (password: exploration)

Pacing | 2 - 3 Class Periods (45 min each)

Background Needed | Density, Pressure, Ocean Exploration, ROVs, Nautilus Exploration Program

Assessment | STEM Project & Task rubric provided

Materials/Resources |

Station One- Cartesian Diver

For the tank:
- 1 clear empty two liter soda bottle with tight fitting cap

For the diver:
- 1 glass eye dropper
- Water- enough to fill the soda bottle
- Paper towels - for wiping up spills
- Tweezers - helpful for removing unsuccessful divers from bottles so they can be readjusted.

Station Two- Golf Ball Float
- Kosher (pickling) salt
- Golf ball
- Clear container
- Water
- Food coloring

Station Three- Ice Cubes and Density
- Baby oil
- Vegetable oil
- Ice cubes
- Food coloring

Station Four- Compression with Depth
- Before & After photographs of styrofoam cups lowered on the ROVs
- Dimension data sheet about cup size and dive data (provided in module below)
- Graph paper

Station Five- Layering of Water/ Stratification
- Clean, plastic soda bottle, with cap
- Vegetable oil
- Food coloring
- Alka-seltzer tablets
- Flashlight
- Water

This clump weight is used when the ROV Engineers need to stretch out the cable for tests or maintenance. The heavy weight keeps the wire under tension as it lowers to deep depths without the vehicles attached.

PRESSURE & DENSITY | EDUCATOR

Set The Stage!

- Set up each station the day or morning before you plan to run the stations lab.
- As students work at each station, circulate the classroom using informal questioning to gather information on where students' general thinking is.
- At the end of the stations lab, ask students to develop a short paragraph explaining the concept behind each station and report out their summary of what was occurring at each station.

Overview

In teams of four or five, students will rotate through five stations set up at various points around the classroom. Teams will spend approximately 7-8 minutes at each station. Teachers will direct students to move to the next station with a cue of their choice (verbal, musical, flicking lights on and off, etc.). Each station demonstrates a key concept about seawater, density and/or pressure in the ocean. At the end of all the rotations, students will work with their teammates to summarize their findings and make connections to ocean exploration and ROV technology. The five learning stations include:

- Cartesian Diver
- Golf Ball Float Challenge
- Ice Cubes and Density
- Compression with depth: Styrofoam descends
- Layering of Water/Stratification

Objectives and Learning Outcomes

- Students will explain how differences in density between freshwater and saltwater may affect the buoyancy of ROVs.
- Students will explain the relationships between pressure and density in the ocean and how those affect ROVs.

Guiding Questions

1. What is density?
2. How do the densities of freshwater and saltwater compare?
3. How does the density of seawater affect the buoyancy of objects, including ROVs?
4. How is the pressure different at sea level and above sea level? How does pressure change with depth in the ocean?

Activity/Tasks

Students will investigate:

- Cartesian Diver
- Golf Ball Float
- Ice Cubes and Density
- Compression with Depth
- Layering of Water/Stratification

Extensions & Adaptations

Introductory |

- Students can research examples of density around them, such as the differences between solid water, liquid water and water vapor and use these examples to explain how various Earth processes work, such as the water cycle.
- Students can research adaptations of marine animals that allow them to survive at great depths and give a brief report on their chosen species.

Advanced |

- Have students use a graduated cylinder and balance to measure mass and volume of various liquids and then solve for density. Students can also use the displacement method in a graduated cylinder or beaker to measure the volume of a solid. Students can graph their results and use their data to explain why some objects of the same size or dimensions can have different densities.

Lesson Set-Up

✓ Teachers should set up each station the day before or morning of the lab.

- **Cartesian Diver Station**
  1. Fill an empty, clear 2-L soda bottle with water. Leave space at the top (about 2 cm) so there is room for air.
  2. Fill a glass eye dropper (the diver) about 1/4 full with water. You may need to play with the amount of water in the dropper to make it work. *See note below for material substitutions.*
  3. Insert the diver into the bottle. The eye dropper should float.
  4. Screw the cap on tightly.
  5. Squeeze the sides of the bottle. Water should go into the dropper and the diver should sink.
  6. Release the sides of the bottle. The water should come out of the dropper and the diver should float back to the top.

DISCUSSION: How does a Cartesian Diver work? When you squeeze the sides of the bottle, you are increasing the pressure on the liquid inside. That increase in pressure is transmitted to every part of the liquid. That means you are also increasing pressure on the eye dropper itself. Since water is not nearly as compressible as air, you notice the changes within the air-filled space of the eye dropper. Squeeze hard enough and you will push some more water up inside the dropper. The air inside the dropper squeezes tighter as more water is forced in. Now, water is much denser than air. So when you push more water inside the dropper, you increase its overall density. Once its density is greater than that of its surroundings, it will sink. Release the pressure on the bottle's sides and you stop forcing water inside the eye-dropper. The air inside it will now push out the extra water again, and the eye-dropper will rise.

NOTE: Ketchup packets also make excellent Cartesian Divers if you do not have access to glass eye droppers. Close the packet inside a soda bottle and follow the same instructions.

- **Golf Ball Float Station**
  1. Fill a clear container 1/2 full with water.
  2. Add kosher salt until no more salt dissolves.
  3. Add golf ball to the salt solution.
  4. Gently add freshwater on top of the saltwater solution.
  5. Add some food coloring to the top of the freshwater.

DISCUSSION: The food coloring will help students see that the freshwater sits on top of saltwater. The golf ball floats on the saltwater (which is more dense) and sinks through the freshwater (which is less dense).

Added Online Resources

- Shrinking Cups in the Deep Blog **http://nautl.us/1TLYMFs**
- Photo Album: Hercules: the Mighty ROV of Nautilus **http://nautl.us/1WPSYwF**
- Science Friday Lesson: High Pressure in the Deep Ocean **http://nautl.us/1qMvACB**

Lesson Set-Up Continued

- **Ice Cube Station**
  1. Add two drops of food coloring to a clear, empty container.
  2. Fill half of the container with vegetable oil and fill the remainder of the container with baby oil. Leave a small amount of space on the top of the container.
  3. Observe the way the two oils interact.
  4. Gently drop an ice cube into the container. It sits right in the middle of the container without sinking to the bottom or floating to the top
  5. Wait for the ice cube to begin melting.
  6. Record observations.
  7. Reset station to the way you found it at the beginning.

DISCUSSION: This demonstration is all about density. The baby oil settles on top of the vegetable oil because the baby oil is less dense. Frozen water (ice) is less dense than liquid water, which is why it floats. As the ice melts, the dense liquid water sinks to the bottom of the container.

- **Compression with Depth**
  1. Provide photographs for students to see examples of styrofoam cups that have been attached to the ROV and carried far below the ocean's surface to different depths (see student sheet). *Note: Styrofoam cups are attached to Argus to stay safely away from Hercules many thrusters and science instruments.*
  2. Provide graph paper (or computer graphing software) so that students can graph atmospheric pressure vs. vehicle depth using the following data (this data is approximate- pressure varies with density of saltwater):

DEPTH (METERS)	PRESSURE (ATM)
10	1
500	50
1000	100
2000	200
4000	400

DISCUSSION: Pressure increases by about 1 atm per 10 m of depth in the ocean. Hercules was designed and constructed to withstand high pressure of ocean depth. For example, most electronics on Hercules are enclosed in titanium housings. These titanium housings are hollow tubes filled with electronic circuits and wiring. Weaker materials would buckle under the forces of deep ocean pressure. The cylindrical shape is ideal because it evenly distributes pressure across a circular surface while still providing flat end caps which make sealing electronic connectors and attachments simple. Electrical components that can not be fully enclosed in a titanium housing are encased in compartments filled with mineral oil. This oil is ecologically harmless and also compresses very little even under high pressure.

Instructional Notes, Thoughts & Ideas

Lesson Set-Up Continued

- **Layering of Water/Stratification Station**
    1. Fill a clean, plastic soda bottle ¾ full with vegetable oil.
    2. The remainder of the bottle should be filled with water, almost to the top.
    3. Next, add 10 drops of food coloring. Observe.
    4. Break the Alka-Seltzer tablet into pieces. About 8 pieces will work best.
    5. One at a time, drop the bits of Alka-Seltzer into the bottle. Observe.

DISCUSSION: Oil and water don't mix because they have different densities. Water is more dense than oil, meaning in two equal volumes water's molecules are more tightly packed than oil's molecules. This explains why the water sinks beneath the oil. Also, water molecules are polar, meaning molecules of water are more attracted to each other than they are attracted to oil molecules. Another way to think of this is that water molecules stick to each other but don't stick to oil. The Alka-Seltzer tablets react with water to create carbonation- bubbles of carbon dioxide (CO_2) gas. As carbonation rises, colored water gets attached to the bubbles and is carried to the surface. CO_2 gas is less dense than both water and oil. When the bubbles pop and the gas is detached from the colored water, the dense water falls back to the bottom of the bottle.

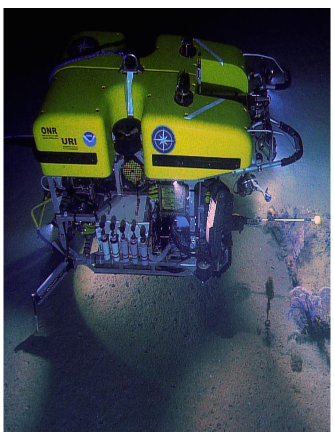
WRAP IT UP!

After student teams have circulated through all five stations, have them prepare a short "report" to share with the rest of the class about their findings. Have each group report out to summarize their discoveries. See suggested rubric for assessment.

PRESSURE & DENSITY | STUDENT

Learning Goals

- Explain how differences in density between freshwater and saltwater may affect the buoyancy of ROVs.
- Explain the relationships between pressure and density in the ocean and how those affect ROVs.



Introduction |

Density of a substance is the measure of how much mass (kg) is contained within a given volume (m^3). The more mass contained within a given volume, the higher the density. Fluids also have density which can be increased by dissolving additional material into the fluid, i.e. adding salt to tap water. The density of seawater is greater than that of freshwater, because seawater contains many dissolved salts and minerals. Salt adds mass to the water and makes it more dense without really changing the volume. Density of a substance can also be changed by reducing the volume it's contained within, i.e. squishing the same amount of material into a smaller space. With increased pressure, solid materials compress very little, fluids compress only slightly, but gases are highly compressible.

This activity will also explore the effects of pressure, an important part of your daily life although you might not spend much time thinking about it. Your body has evolved to function under normal surface air pressure. To picture air pressure, imagine adding together the weight of all the air molecules in a vertical column above your head all the way up to the height of the entire atmosphere, out to the edge of space. The total weight of those molecules totals 14.7 pounds per square inch, or a unit called 1 atmosphere (atm). If you descend into the ocean, more things stack above you pushing down. The farther you descend into the ocean, the weight of seawater stacked on top of you increases; this is water pressure. Diving 10 meters/ 33 feet into seawater, you are subjected to another 14.7 pounds on each square inch, or an additional 1 atm of water pressure. Each time you descend another 10 meters, the pressure increases 1 atmosphere. In our everyday life, we don't feel changes in pressure on most of our body because the fluid in our bodies compresses very little. Air filled spaces, like our eardrums, compress and expand significantly with pressure changes. This is why we have to equalize our ears when diving below the ocean's surface or as we fly in airplanes far up in the atmosphere or when the weather changes.

Density and pressure are important concepts to understand when learning about ocean exploration and ROV technology. The deeper an ROV dives into the ocean, the greater the pressure from all sides. Technology must be specially engineered to handle the stresses of pressure. ROV *Hercules* can travel to depths of 4,000 meters (13,123 feet or nearly 2.5 miles) below the ocean surface! In the deepest parts of the ocean (11,000m), the water pressure is equivalent to an elephant's weight balanced entirely on a postage stamp!

In this activity, you will work in small groups as you rotate through five demonstration stations with tasks to help you investigate the various dynamics of pressure and density in the ocean.

Helpful Resources:

- Shrinking Cups in the Deep Blog ***http://nautl.us/1TLYMFs***
- Photo Album: Hercules: the Mighty ROV of Nautilus ***http://nautl.us/1WPSYwF***
- Science Friday Lesson: High Pressure in the Deep Ocean ***http://nautl.us/1qMvACB***

Guiding Questions |

1. What is density?

2. How do the densities of freshwater and saltwater compare?

3. How does the density of seawater affect the buoyancy of objects, including ROVs?

4. How is the pressure different at sea level and above sea level? How does pressure change with depth in the ocean?

Station One: Cartesian Diver

As you complete the procedure below, consider how pressure and density are related. Why does the diver sink? Why does the diver float?

- **Materials (per group):**

For the tank:
1 clear empty two liter soda bottle with cap
For the diver:
1 glass eye dropper
Water – enough to fill the soda bottle
Paper towels – for wiping up spills
Tweezers – helpful for removing unsuccessful divers from bottles to be readjusted

Problem: How do density and pressure affect the Cartesian diver?
Hypothesis:

Procedure:

1) Fill an empty, clear 2-L soda bottle with water. Leave a small space at the top (about 2 cm) so there is room for air.
2) Fill a glass eye dropper (the diver) about 1/4 full with water. You may need to modify the amount of water in the dropper to make it work.
3) Insert the diver into the bottle. The eye dropper should float.
4) Screw the cap on tightly.
5) Squeeze the sides of the bottle. What changed? Release the sides of the bottle. What changed?

Conclusion: Describe what you observed in words or in a drawing. How did squeezing the bottle affect the diver?

Station Two: Golf Ball Float

Materials (per group):
Kosher (pickling) salt
Golf ball
Clear container
Water
Food coloring

Problem: How does adding salt to water affect the way a golf ball floats?
Hypothesis:

Procedure:
1) Fill a clear container 1/2 full with water.
2) Add kosher salt to the container and stir to dissolve until no more salt dissolves.
3) Add golf ball into the salt solution.
4) Gently pour freshwater on top of the saltwater solution.
5) Add four drops of food coloring to the top of the freshwater.

Conclusion: What can you conclude about the density of saltwater vs. freshwater?

Station Three: Ice Cube Station

Materials:
Baby oil
Vegetable oil
Ice cubes
Food coloring
Clear, empty container

Problem: What will happen to an ice cube placed in a container with baby oil and water?
Hypothesis:

Procedure:
1) Add two drops of food coloring to a clear, empty container.
2) Fill half of the container with vegetable oil. Then gently fill the container with baby oil, leaving a small amount of space on the top of the container.
3) Observe the way the two oils interact.
4) Gently drop an ice cube into the container.
5) Wait for the ice cube to begin melting.
6) Observe.

Conclusion: Draw and label a diagram of what you observed. Explain how density is involved in this demonstration.

Station Four: Compression with Depth

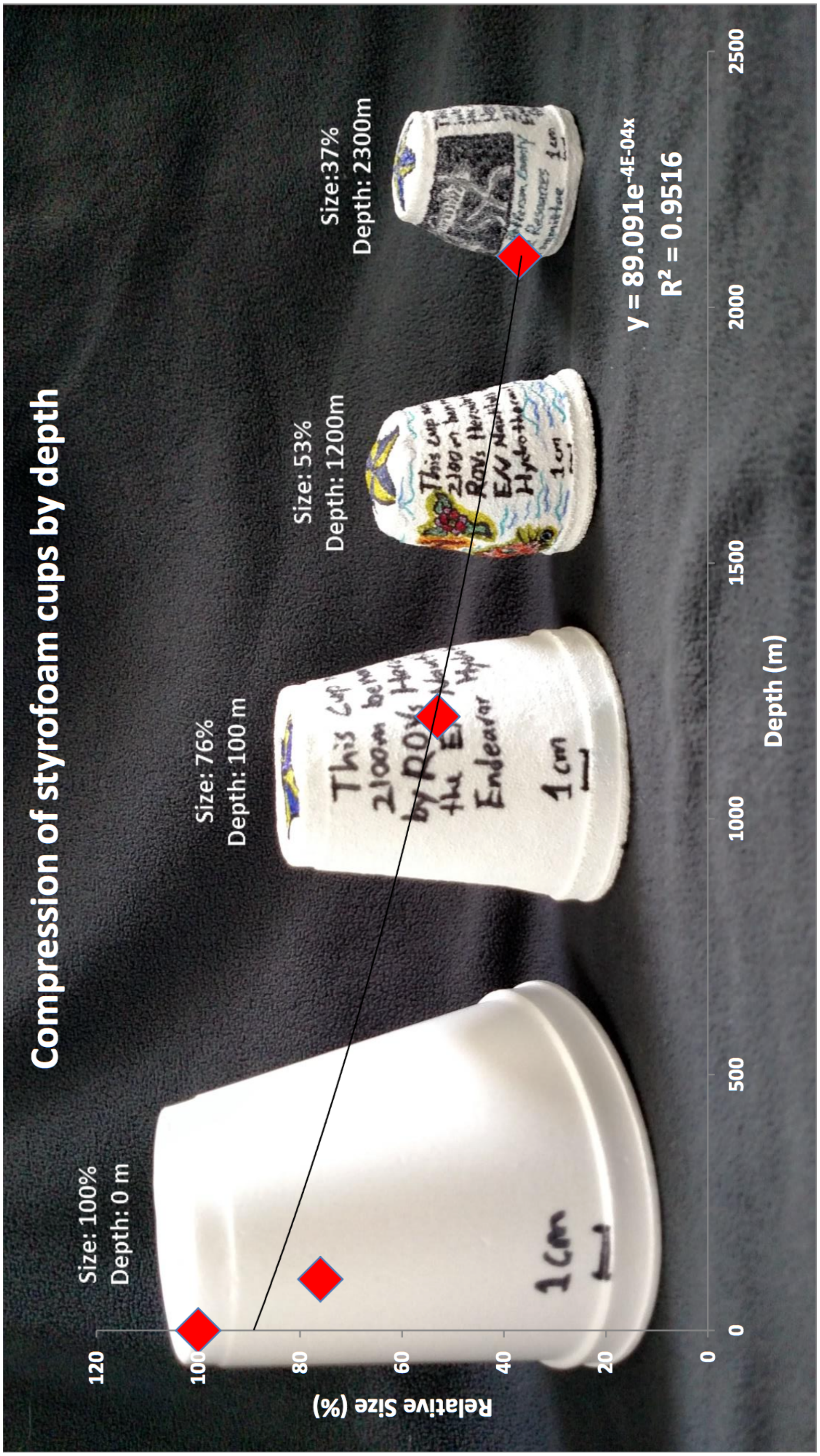
Materials:
Photographs of cups that have gone down on Hercules (before and after)
Data about depth of Hercules and size of cups
Graph paper

Problem: How does pressure change with depth in the ocean? How does this pressure change affect compressible material like styrofoam cups?
Hypothesis:

Procedure:
1) Examine the diagram showing styrofoam cups that have been attached to the ROVs and carried under the ocean's surface to different depths. *Diagram is on next page.*
2) On a piece of graph paper, create a graph showing pressure (y-axis) vs. depth (x-axis) using the following data:

DEPTH (METERS)	PRESSURE (ATM)
10	1
500	50
1000	100
2000	200
4000	400

Conclusion: Use your graph to describe the relationship between pressure and ocean depth.


Compression of styrofoam cups by depth
Size: 100%
Depth: 0 m
Size: 76%
Depth: 100 m
Size: 53%
Depth: 1200m
Size:37%
Depth: 2300m
$y = 89.091e^{-4E-04x}$
$R^2 = 0.9516$
Relative Size (%)
0
20
40
60
80
100
120
Depth (m)
0
500
1000
1500
2000
2500

Station Five: Layering of Water/Stratification Station

Materials:
Clean, plastic soda bottle, with cap
Vegetable oil
Food coloring
Alka-Seltzer tablet
Water

Problem: How are the bubbles in this demonstration affected by density?
Hypothesis:

Procedure:
1) Fill a clean, plastic soda bottle ¾ full with vegetable oil.
2) The remainder of the bottle should be filled with water, almost to the top.
3) Next, add 10 drops of food coloring. Observe.
4) Break the Alka Seltzer tablet into pieces. About 8 pieces will work best.
5) Drop the broken bits of Alka Seltzer, one at a time, into the bottle. Observe.

Conclusion: Why do the bubbles behave the way they do? What is the relationship to density? Draw a picture.

WRAP IT UP!

Take five minutes to develop a short summary of your group's findings. How does the relationship between pressure and density relate to deep ocean technology? Be prepared to share your results with the class.

PRESSURE & DENSITY | ASSESSMENT

STEM Project & Task Rubric

OBJECTIVE	CRITERIA			
	4 Exemplary	3 Commended	2 Emerging	1 Developing
Knowledge & Understanding |	Student consistently, correctly and thoroughly answers all questions. Uses an abundance of relevant vocabulary and is able to explain relationships within the content using examples. Can apply the content to other topics or real life.	Student is able to consistently answer most questions correctly. Uses an adequate amount of relevant vocabulary. Can explain relationships within the content and can apply content to other topics or real life.	Student is able to answer some questions correctly. Uses some relevant vocabulary. Student does not elaborate on relationships within the content or make connections between the content and real life.	Student is able to answer a few questions correctly. Inconsistently uses relevant vocabulary. Student does not elaborate on relationships within the content or make connections between the content and real life.
Content Organization, Methodology & Analysis |	Student effectively organizes complex ideas, concepts, and information to make important connections and distinctions. This may include detailed, labeled and thorough procedures, data tables, graphs, diagrams and/or analyses.	Student is able to organize ideas, concepts, and information to make connections and distinctions. This may include mostly detailed, labeled and thorough procedures, data tables, graphs, diagrams and/or analyses.	Student attempts to organize ideas, concepts and information to make some connections and distinctions. Student is able to provide basic procedures, data tables, graphs, diagrams and/or analyses.	Student has difficulty organizing ideas, concepts and information to make connections and distinctions. Student is unable to provide basic procedures, data tables, graphs, diagrams and/or analyses.
Self-Directed Learner |	Student is actively engaged in the learning process; consistently contributes to class discussions and asks clarifying questions. Seeks out and shares additional resources with the class or teacher. Advocates for his/her learning needs.	Student is engaged in the learning process. Often contributes to class discussions and asks clarifying questions. Advocates for his/her learning needs.	Student is inconsistently engaged in the learning process. Sometimes contributes to class discussions or asks clarifying questions. Inconsistently advocates for his/her learning needs.	Student is weakly engaged in the learning process. Rarely contributes to class discussions or asks clarifying questions. Rarely advocates for his/her learning needs.
Technological Tools |	Use of digital resources is always appropriate for the task. Willing to learn and use technology for inclusion of charts, graphs, pictures, etc. to amplify the message.	Use of digital resources is appropriate for the task. Willing to use technology for inclusion of charts, graphs, pictures, etc. to amplify the message.	Use of digital resources is sometimes appropriate for the task. Inconsistent use of technology for inclusion of charts, graphs, pictures, etc. to amplify the message.	Use of digital resources is rarely appropriate for the task. Inconsistent use of technology for inclusion of charts, graphs, pictures, etc. to amplify the message.
Collaboration Skills |	Consistently works effectively and respectfully with a diverse group of learners. Actively checks with others for understanding and how he or she may be of help. Student listens when others speak and incorporates or builds off of the ideas of others.	Works effectively and respectfully with a diverse group of learners. Checks with others for understanding and how he or she may be of help. Student listens when others speak.	Sometimes works effectively and respectfully with a diverse group of learners. Sometimes checks with others for understanding and how he or she may be of help. Student listens when others speak.	Has difficulty working effectively and respectfully with a diverse group of learners. Rarely checks with others for understanding and how he or she may be of help. Student may talk over other students or does not listen when others speak.
Total Score:	**Comments:**			

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...	Who did you engage in your teaching?
❏ Classroom ❏ After school program / Club meeting ❏ Fair / Festival / Event ❏ Museum / Science Center ❏ Other. Tell us more:	# 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!