SeaGlide_TEAM	Water Pressure	Lesson #4 (60 minutes)

Description:

Students will take the role of a naval engineer. Recently, their supervisor challenged the department to design a submarine that was capable of maneuvering through the water, similar to a plane, and be piloted by a single person. As a reward, those that design this submarine will receive a large stipend and promotion. With their team, the student will design a submarine that can maintain its depth in the water, that can be piloted by a single person, and that can glide in the water similarly to an airplane.

Adapted from Buoyancy & Pressure in Fluids: Soda Bottle Cartesian Diver.

Students will be able to:

- Use a Cartesian diver and interpret how it works by using terminology such as density, buoyancy and pressure.
- Explain the physics of the Cartesian diver behavior based on an understanding of Pascal's law and Archimedes' principle.

Students will understand:

One of the largest problems with underwater expeditions and diving has been the pressure exerted by water as you decreased in depth. However, with the invention of submarines, this problem has become maneuverable. The concept of fluid pressure remains an important part of the engineering design process regarding submarine and underwater robot design. Through this lesson, students are learning how pressure affects their SeaGlide through inquiry and experimentation.

Key Definitions & Concepts: [1]

- **Bernoulli's Principle**: States that an increase in the speed of a fluid occurs simultaneously with a decrease in pressure or with a decrease in the fluid's potential energy.
- **Fluid**: Any liquid or gas (generally any material that cannot sustain a tangential, or shearing, force when at rest) that undergoes a continuous change in shape when subjected to such a stress.
- **Buoyancy**: The ability of an object to float in a liquid.
- **Density**: A measurement of the compactness of an object.
- **Mass**: A measurement of the amount of matter in an object.
- **Mass Density:** Mass per unit volume of a substance.
- **Pressure**: A measurement of force per unit area.
- **Volume**: A measurement of the amount of space an object occupies.

Standards: [Copied from: 2]

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.

- Students will be performing experiments to test how an fluid's weight and pressure affect the force exerted on the hull of a submarine. The exploration activities serve to have student make observations and devise explanation for how pressure affects

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

- Through the elaboration of this lesson, students design a submarine that meets the demands of the students' supervisor. Students communicate the science behind their submarine's design in the form of a proposal and an email, demonstrate their knowledge of the material and defend the effectiveness of their designed solution.

Background Information

Prior Knowledge:

- Gravity is the driving force for an object's weight
- All objects are subject to gravity
- Density is the amount of mass occupying a given volume or space
- Buoyancy is a measure of how much force is required for an object to be suspended inside a liquid

Science Practices: [Copied from: 3]	Core Ideas: [Copied from: 4]	Cross Cutting Concepts: [Copied from: 5]
• Planning & Carrying Out Investigation • Engaging in Argument from Evidence	• Forces & Motion • Developing Possible Solutions	• Stability & Change

Possible Preconceptions/Misconceptions:

Students may have difficulty working with the ideal gas law and connecting it to the Cartesian Diver. The ideal gas law should be a new topic for students, causing them to experience frustration when working with it. The instructor should emphasize to students that they are only identifying patterns within the equation in relation to the Cartesian Diver. Once the instructor has clarified that students are not meant to "plug and chug" using the ideal gas law, students should respond better and be able to solve the final questions within the *Cartesian Diver* analysis questions.

Lesson Plan - 5E(+) Model

Engage: [1]

The instructor will begin by asking students to guess how much the air in the classroom weighs. The instructor will then ask students how they can figure out the weight of the air molecules in the classroom. Following the *Instructor's Guide*, the instructor will work with students to determine the weight of air molecules in the classroom. The instructor will then connect the weight of air molecules around them to the weight of water molecules around a scuba diver. This activity should take 15 minutes.

Explore:

Part I: Introduction

The instructor will prompt students by asking what technology was invented to aid in diving underwater (see *Instructor's Guide* for assistance). The instructor will guide students in a discussion towards the understanding that diving inventions are able to withstand increased pressure. The instructor will then introduce students to the Cartesian Diver. The purpose of introducing the Cartesian Diver is to demonstrate the phenomenon of the Cartesian Diver, which students will be analyzing later on in the lesson. This activity should take 10 minutes.

Part II: *Benchmark Lesson:* Cartesian Diver Activity [1]

Students will work on the *Cartesian Diver* activity and the associated worksheet in pairs. Students will be observing how the Cartesian Diver is affected by the pressure exerted by the water and other outside forces. This activity serves as a direct connection to the SeaGlide, which will be impacted by water pressure, similar to the Cartesian Diver. Students will be writing down their observations and interpretations of the phenomenon. Afterward, students will be answering analysis questions that extend their observations and generate explanations for the phenomenon using ideas from previous lessons. This activity should take 10-15 minutes.

Part III: *Investigation Lesson:* Physics of the Cartesian Diver [1], [6]

After students finish answering the analysis questions from the *Cartesian Diver* worksheet, the instructor will go over questions 6 and 7 with students. These questions invoke higher-level thinking in students by requiring them to apply physics concepts to their understanding of the Cartesian Diver. The instructor will ask students to state their answers and explain them, prompting students to not only recite but also verbalize their understanding of the activity. This activity serves to introduce students to the important physics properties that will affect their SeaGlide. This activity should take 10 minutes.

If students are having difficulty understanding the physics concepts associated with the Cartesian Diver, the instructor can show students the following Fun Science Demos video on the Cartesian Diver: Cartesian diver Video | Fun Science Demos. This video will extend the activity to 15 minutes total.

Explain:

Throughout the exploration of this lesson, students will engage in discussions and activities that seek to discover their understanding of the topic at-hand as it relates to fluid pressure forces. Instructors should informally ask questions to promote thoughtful discussion that is designed to aid in addressing any questions or concerns that some students may have. Students are expected to formalize their answers throughout the entirety of the lesson via the worksheets, the activities and the exit ticket.

Elaborate:

The instructor will distribute the letter from the *Director of the Engineering Division* and the *Submarine Design: Revision* activity sheet. Through this activity, students must refer back to their submarine designs and proposals from prior lessons. Students will be working individually to revise their submarine designs with the knowledge they learned about pressure. Afterward, they must write to their Captain about their design revision that explains how pressure on the hull will be addressed in the format of an email. This gives the students an additional opportunity to verbalize their understanding of the unit as a whole. Allow students until the last 5 minutes of class to complete this activity. Students should return their revision email during the start of the next class meeting for grading.

Evaluate:

In the last 5 minutes, students will complete an exit ticket, prompting them to apply what they learned about pressure. The questions elicit higher-level and deep content understanding in students by focusing on the effects and impacts of pressure rather than calculating it. These questions serve to test student understanding of how pressure will impact their SeaGlide and how hull shape will affect their underwater robot.

Throughout this lesson, there are both formal and informal evaluations. The informal evaluations occur throughout the exploration portions via leading and open-ended questioning, as well as the open class discussions. The informal evaluations will allow for the teacher to gauge surface-level understanding of the students. By surveying the students during completion of the worksheets and activities, teachers will be able to hear and to address any misconceptions or misunderstandings as necessary. The formal evaluations of this unit are the compilation of the worksheets, the *Submarine Design* activity, and the exit ticket.

Enrich:

This lesson can be extended to an aeronautical engineering class. The concepts of fluid pressure can be expanded on, as well as the physics background supporting it. Pressure exerted by a fluid is a unique phenomenon that relies heavily on the logical and mathematical properties described in physics. Oftentimes, these mathematical properties require advanced knowledge of the Calculus series, like derivatives.

All associated documents are attached below

Reference *Annotated Bibliography* on the very last page of this packet

Instructor's Guide [1]

Engagement:

Who wants to take a guess at how much the air in this classroom weighs? (Listen to a few student answers and then move on.) To calculate how much the air in this classroom weighs, we need to determine a few things. Who knows what information we need in order to begin? (Listen to student answers until all correct answers have been stated. Write the correct answers on the classroom board.) We need to know the volume of the classroom—that means we need to know its length, width and height measurements. What else? We need to know the density of air at room temperature.

Who will volunteer to measure the length, width and height of the classroom? (Choose three to six volunteers to measure the classroom dimensions in metric units.) Who wants to volunteer to calculate on the board how much the air weighs? (Choose a volunteer or two to work the problem on the board. Draw on the board a table titled, "Densities of Various Gases" and include any gases you wish, such as the Table 1 example.)

Gas	Density (kg/m^3)
air 0 °C	1.293
air 20 °C	1.205
carbon dioxide 0 °C	1.977
carbon dioxide 20 °C	1.842
hydrogen 0 °C	0.0899
nitrogen 0 °C	1.2506
nitrogen 20 °C	1.165
oxygen 0 °C	1.429
oxygen 20 °C	1.331

An example calculation using L = 15.85 m, W = 13.4 m and H = 3.66 m as classroom dimensions results in the following volume, mass and weight:

$$volume\ (V) = L * W * H = (15.85\ m) * (13.4\ m) * (3.66\ m) = 777.35\ m^3$$

$$mass\ (M) = V * density\ (\rho) = (777.35\ m^3) * (1.205\ kg/m^3) = 936.71\ kg$$

$$weight\ (W) = M * gravity\ (g) = (936.71\ kg)\ (9.81\ m/s^2) = 9189.09\ N \sim 2{,}000\ pounds!$$

Verify the student's calculations because the weight of air in each classroom will be different than the example calculation provided since it depends on the room size. Ask students what they think about the weight of the air in the room.

Who remembers the relationship between mass and volume? (Listen to student answers and guide them into a conversation about the air in the classroom and the density relationship.) Students are expected to answer that as mass increases and volume remains constant, then the density will increase.

Now that we know how much the air around us weighs, imagine how much the water around a scuba diver weighs! What do scuba divers have to help control the pressure from the surrounding water? Think about Archimedes' principle and buoyancy. What do scuba divers have that controls their buoyancy? (Expected possible answers: Scuba divers use weighting systems, diving suits, and buoyancy compensators to control buoyancy.)

Instructor's Guide [1]

Exploration: Introduction Discussion

What are some examples of engineered devices that can dive deeper than scuba divers? (Expected possible answers: Submarines and remote operated vehicles (ROVs or "robots").) How are they able to dive deeper than scuba divers? (Answer: They are designed to withstand higher pressures.) What are submarines and ROVs used for and why are they important? (Possible answers: They are essential to helping us investigate deep-water regions that humans are unable to survive; they can reach depths much greater than satellite and shipboard technologies; they enable exploration of abysmal ocean communities and the discovery of new species.)

Name:____ Date:_______________

Cartesian Diver [1]

Objectives

- To demonstrate understanding of Pascal's Law and Archimedes' principle.
- To use a Cartesian diver based on understanding of density, buoyancy and pressure.

Definitions

- Volume: ____

- Mass: ____

- Density: ____

- Buoyancy: ____

- Pressure: ____

Relationship Question

What is the relationship between volume, mass and density?

Materials

- 1-liter bottle with cap filled with water
- bowl of water
- Cartesian diver (ketchup packet)

Procedure

1. Fill the bottle with water.
2. Using the bowl of water, adjust the amount of water and air inside the Cartesian diver so that it barely floats.
3. Place the Cartesian diver inside the bottle, making sure the bottle is filled to the top with water.
4. Screw the cap on the bottle so it is closed securely.
5. Squeeze the bottle and observe what happens to the Cartesian diver.

Questions

1. What happens when the bottle is squeezed?

2. What happens when the bottle is released?

3. What variables affect an object’s ability to float?

4. Use the variables you listed in question 3 to explain the relationship between the forces being exerted on an object in a fluid and an object’s ability to float.

5. How do Pascal’s law and Archimedes’ principle apply to the Cartesian diver?

6. Use the ideal gas law to explain the relationship between volume and pressure when the bottle is pressurized and explain why the Cartesian diver sinks.

   ideal gas law: $PV = nRT$

   Where P = pressure, V = volume, n = number of moles of gas, R = universal gas constant, and T = temperature

7. BONUS: Provide a few examples of how these principles are used in real-world science, engineering and/or technology.

DEPARTMENT OF THE NAVY
NAVAL SEA SYSTEMS COMMAND
2531 JEFFERSON DAVIS HWY
ARLINGTON, VA 2242-5160

Greetings Cadet,

Your submarine designs have been sufficient in meeting all of the requirements thus far. However, before we can celebrate, one more obstacle remains: the pressure. Previous submarine designs have been crushed due to the amount of pressure that they underwent while in the water. How will you address this?

Contact me in an email, stating how you would address the above concerns and defend your answers. The NAVY needs the best and safest ships possible to ensure our missions are successful.

Director, Engineering Division

Name:____ Date:_________________

Submarine Design Revision Email

Directions:

Your team designed a submarine that meets the requirements your captain put in place. Now, you must write an email to them, stating how the submarine operates and meets the requirements by incorporating your new knowledge of water pressure. Below is a rubric for your revision.

Design Requirements:

- Hull design of the ship
- Ability to withstand the pressure exerted by water on the hull of the submarine

Revision Email Requirements:

- Explanation of the design including:
  - What aspects were changed, and why
  - How the submarine meets the design requirements
  - How the submarine is comparable to an airplane
- Scientific evidence to support explanations
- Incorporation of new topics learned about water pressure

Rubric:

Points	0 - 1	2 - 3	4 - 5
Design	The submarine does not meet any of the design requirements **and** does not share any of the characteristics with an airplane	The submarine meets some of the design requirements **AND/OR** shares some of the characteristics with an airplane.	The submarine meets all design requirements and shares the characteristics of an airplane to move through the water.
Explanation	The email offers no factual scientific evidence to support the design requirements **and** does not provide proper logic for changes made.	The email offers some factual scientific evidence to support the design requirements **AND/OR** provides logic for changes made partially correct.	The email offers factual scientific evidence to support how it will meet the design requirements and provides proper logic for changes made.
Grammar/ Spelling	The proposal has many grammatical/spelling mistakes that negatively impacts the proposal.	The proposal has some grammatical/spelling mistakes that negatively impacts the proposal.	The proposal has little to no grammatical/spelling mistakes that negatively impacts the proposal.
Creativity (**BONUS**)	The design has little to no unique designs or decals, or does not combine an airplane to the submarine.	The design is unique, contains decals, and combines the best parts of an airplane to a submarine.	

Name:____ Date:________________

Submarine Design Revision Email

Comments:	
	Design:__________
	Explanation:__________
	Grammar/Spelling:__________
	Creativity (**BONUS**):__________
	TOTAL:_________

Name:____ Date:________________

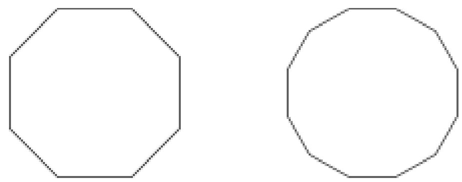
Submarine Design Proposal: Grade

Comments:	
	Design:__________
	Explanation:__________
	Grammar/Spelling:__________
	Creativity (**BONUS**):__________
	TOTAL:_________

Name:____ Date:_________________

Exit Ticket

1. Two shapes can be used in a submarine design. Compare and contrast the two shapes by answering the questions below. Defend your answer.
    a. If the hulls with the following shapes below were placed underwater, indicate the direction of pressure from the surrounding water by using arrows.

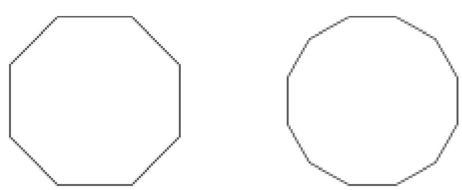


    b. Which shape would be the most effective hull? Defend your answer.

Name:____ Date:_________________

Exit Ticket

1. Two shapes can be used in a submarine design. Compare and contrast the two shapes by answering the questions below. Defend your answer.
    a. If the hulls with the following shapes below were placed underwater, indicate the direction of pressure from the surrounding water by using arrows.



    b. Which shape would be the most effective hull? Defend your answer.

Name:______________Answer Key_______________________ Date:_________________

Cartesian Diver [1]

Objectives

- To demonstrate understanding of Pascal’s Law and Archimedes’ principle.
- To use a Cartesian diver based on understanding of density, buoyancy and pressure.

Definitions

- Volume - A measurement of the amount of space an object occupies.
- Mass - A measurement of the amount of matter in an object.
- Density - A measurement of the compactness of an object.
- Buoyancy - The ability of an object to float in a fluid.
- Pressure - A measurement of force per unit area.

Relationship Question

What is the relationship between volume, mass and density?

($\rho = m / v$)

Materials

- 1-liter bottle with cap filled with water
- bowl of water
- Cartesian diver

Procedure

1. Fill the bottle with water.
2. Using the bowl of water, adjust the amount of water and air inside the Cartesian diver so that it barely floats.
3. Place the Cartesian diver inside the bottle, making sure the bottle is filled to the top with water.
4. Screw the cap on the bottle so it is closed securely.
5. Squeeze the bottle and observe what happens to the Cartesian diver.

Questions

1. What happens when the bottle is squeezed?

   The Cartesian diver sinks to the bottom of the bottle.

2. What happens when the bottle is released?

   The Cartesian diver rises back up.

3. What variables affect an object's ability to float?

   Density of the object, density of the fluid, surface area, pressure, volume

4. Use the variables you listed in question 3 to explain the relationship between the forces being exerted on an object in a fluid and an object's ability to float.

   Volume and density are inversely proportional.

   Density and pressure are proportional.

   When pressure is applied, the volume of air and the density increases; therefore, the object becomes denser than the surrounding fluid and sinks.

5. How do Pascal's law and Archimedes' principle apply to the Cartesian diver?

   Pascal's law states that a pressure applied at any point on a confined incompressible fluid is transmitted equally throughout the fluid. When the bottle is pressurized (squeezed) the pressure within the entire bottle and Cartesian diver is increased. Archimedes' principle applies because the Cartesian diver sinks when its density is increased.

6. Use the ideal gas law to explain the relationship between volume and pressure when the bottle is pressurized and explain why the Cartesian diver sinks.

ideal gas law: $PV = nRT$

Where P = pressure, V = volume, n = number of moles of gas, R = universal gas constant, and T = temperature

The pressure in the bottle is increased, therefore the volume of air trapped inside the Cartesian diver decreases. As the volume of air decreases, water is taken up into the Cartesian diver which increases the density of the Cartesian diver so it sinks.

7. BONUS: Provide a few examples of how these principles are used in real-world science, engineering and/or technology.

The concepts of Pascal's law, Archimedes' principle, the ideal gas law and the density-buoyancy relationship are important in science, engineering and technology applications such as fish physiology, scuba diving and various submersibles.

Most bony fish have a swim bladder that models a lung and enables fish to control their buoyancy, or height in the water column, without swimming. In contrast, non-bony fish such as sharks, store lipids to maintain buoyancy or employ dynamic lift, which is the use of the pectoral fins for constant swimming to maintain buoyancy.

Scuba divers use special equipment such as weighting systems, diving suits and buoyancy compensators to control their buoyancy. They use a weighting system so that they are negatively buoyant and sink by default; then they can then adjust their buoyancy compensator by adjusting the volume of gas in the bladder, which is taken from the diver's air tank or mouth.

Submersibles enable the exploration of depths much greater than can be reached via satellite and shipboard technologies; these creative submersible and remotely operated vehicle (ROV) inventions enable people to explore very deep ocean communities and discover new species. Additional examples include a Galileo thermometer, high-pressure systems like autoclaves (laboratory instruments that sanitize lab equipment), deep sea drilling.

Name:_______________Answer Key_________________________ Date:__________________

Submarine Design Revision Email

Directions:

Your team designed a submarine that meets the requirements your captain put in place. Now, you must write an email to them, stating how the submarine operates and meets the requirements by incorporating your new knowledge of water pressure. Below is a rubric for your revision.

Design Requirements:

- Hull design of the ship
- Ability to withstand the pressure exerted by water on the hull of the submarine

Revision Email Requirements:

- Explanation of the design including:
  - What aspects were changed, and why
  - How the submarine meets the design requirements
  - How the submarine is comparable to an airplane
- Scientific evidence to support explanations
- Incorporation of new topics learned about water pressure.

Expectations:

Students are expected to have designs that are very similar to their previous design. However, greater emphasis on hull design should be present in the explanation.

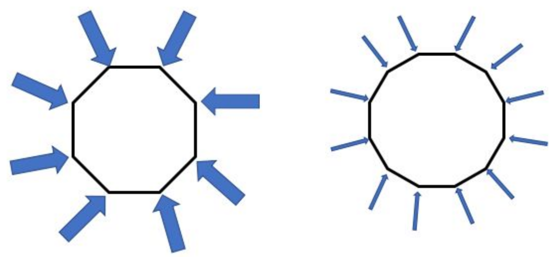
The shape of the hull must be circular so that water pressure is being evenly distributed around the hull. Students must clearly explain and address this because if the hull does not have equally-distributed pressure, then it will be crushed under the weight of the water.

The submarine design should appear similar to an airplane, with a hull, propeller, and wings. Depending on student design, it can have stripes or decals. These provide bonus points for students in the creativity category.

Name:____ Date:_________________

Exit Ticket

1. Two shapes can be used in a submarine design. Compare and contrast the two shapes by answering the questions below. Defend your answer.
    a. If the hulls with the following shapes below were placed underwater, indicate the direction of pressure from the surrounding water by using arrows.



    b. Which shape would be the most effective hull? Defend your answer.

    The most effective hull would be made with the 12-sided polygon. Submarines require a hull that can withstand the pressure from the surrounding water, thus a shape with many sides should be used. The 12-sided polygon can more evenly distribute the pressure from the water than the octagon. Therefore, the 12-sided polygon is the more effective hull.

Annotated Bibliography

[1] Sappington, E., & Taylor, M. (2019, March 7). Buoyancy & Pressure in Fluids: Soda Bottle Cartesian Diver - Activity. Retrieved March, 2019, from https://www.teachengineering.org/activities/view/uoh_fluidmechanics_lesson01_activity1

This reference was used for excerption purposes. This reference aided in the completion of the instructor's guide, lesson activities, and analysis questions. The definitions were directly excerpted from this reference within this lesson. The TeachEngineering introduction and Cartesian diver worksheets were directly excerpted for this lesson. The introduction served to develop the necessary scientific information needed to teach this lesson. The activities also serve to provide hands-on learning experiences for students. TeachEngineering is useful in employing hands-on and inquiry-based activities to help students learn.

[2] Nsta. (n.d.). Access the Next Generation Science Standards by Topic. Retrieved January 18, 2019, from https://ngss.nsta.org/AccessStandardsByTopic.aspx

This website was used in each lesson in the Ocean Conditions module to select proper national set standards for science subjects that each lesson is centered around.

[3] Nsta. (n.d.). Science and Engineering Practices. Retrieved January 18, 2019, from https://ngss.nsta.org/PracticesFull.aspx

This website used in every lesson in the Ocean Conditions module to find Standards for Science and Engineering Practices that are applicable in each lesson.

[4] Nsta. (n.d.). Disciplinary Core Ideas. Retrieved from https://ngss.nsta.org/DisciplinaryCoreIdeasTop.aspx

This website was used in each lesson in the Ocean Conditions module to select appropriate disciplinary core ideas set forth by the NSTA that are at the center of each lesson.

[5] Nsta. (n.d.). Crosscutting Concepts. Retrieved from https://ngss.nsta.org/CrosscuttingConceptsFull.aspx

This website was used in each lesson in the Ocean Conditions module to selecting appropriate crosscutting concepts set forth by the NSTA that apply to each science lesson.

[6] Funsciencedemos. (2013, September 30). Density and the Cartesian Diver. Retrieved March, 2019, from https://www.youtube.com/watch?v=16Ak30_VukA

This reference was used as an educational tool to demonstrate the Cartesian Diver and explain how it relates to density. FunScienceDemos is a useful resource when integrating demonstrations, whether hands-on or visual only, to explain natural phenomenon in the classroom.