Regional Class Research Vessel

Oregon State University

Exploring the Application of Sound in Ocean Acoustics
Human Sonar Simulation

Grades: 4-12

Content areas: **Physics, Technology, Marine Sciences**

Next Generation Science Standards: **4-PS4, MS-PS4-2, HS-PS4-1, HS-PS4-5**

Lesson time: **90-120 minutes, or 2-3x 45 minute periods for 3 full rounds**

Disciplinary Core Ideas:

- **Wave Properties**
- **Sound Wave Mediums and Changes**
- **Technologies Based on Wave Interactions with Matter**

Crosscutting Concepts:

- **Similarities and Differences in Patterns**
- **Structures can be Designed for a Particular Function**
- **Science and Engineering in Research and Development**

Science and Engineering Practices:

- **Asking Questions and Defining Problems**
- **Analyzing and Interpreting Data**
- **Engaging in Argument from Evidence**

Contact:

SMILE Program

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http://smile.oregonstate.edu/

DESCRIPTION:

In this lesson, students will enact a SONAR system like the ones being developed by the Regional Class Research Vessel Program at Oregon State University on RV Taani, RV Gillbert R. Mason, and RV Narragansett Dawn. These lessons go well with other RCRV Outreach and Education activities available here!

MATERIALS:

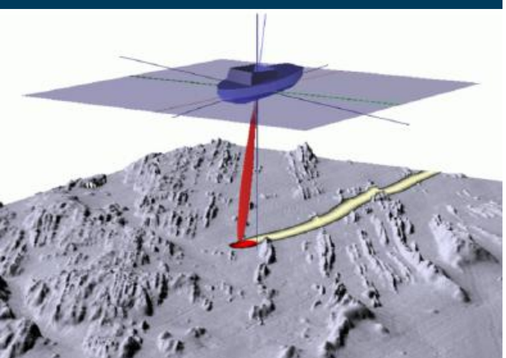
- Student Powerpoint
- Markers, Pens, Crayons for map making
- Student Worksheets
- 2 rooms or 1 room that can be divided (make it so youth making the map cannot see youth making the sound wave and seafloor)
- Items to make the seafloor (table, chairs, things to use for physical barriers)
- Scientific Calculator (to compute properties of a sound wave in water)
- Student groups of 2-4 students
- Amplitude cards for students to pick up during round 2
- Frequency and Return cards for student to pick up during round 3

OUTCOMES:

- Students will learn about Sound wave properties
- Students will learn about Sound Waves and their application in SONAR
- Students will enact RV Taani's SONAR system to map the seafloor
- Students will qualitatively communicate the properties of waves and their application in collecting and communication information by SONAR systems.

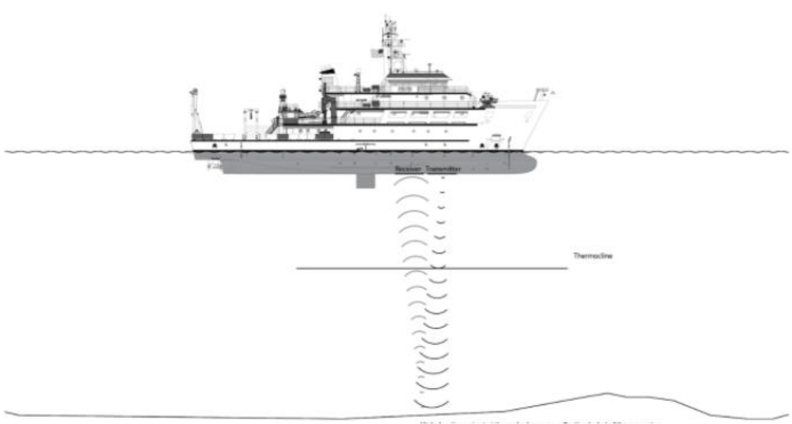
Exploring the Application of Sound in Ocean Acoustics
Human Sonar Simulation

Guiding Question:
How can we apply the properties of sound to make inferences about the seafloor and the location of marine organisms in the water column?



BACKGROUND INFORMATION:

SONAR [SOund NAvigation and Ranging] works because of the physical properties of sound waves moving through water. Sound needs a medium to move through. Water is a very good medium, especially because Ocean Researchers know how sound waves operate in seawater. For example, on the RV Taani, if the ship sends out a fixed sound, or a ping, with a known wavelength, amplitude, and over a known amount of time, we can infer a lot about the distance between the ship and the seafloor, and the characteristics of the seafloor. Scientists can make these inferences by comparing the sound wave the ship sent out and how it interacted with the water and seafloor, and then by comparing their findings to other data sets. With this information, we can map the seafloor! The rich history of SONAR is a classic example of Research and Development. SONAR, as we know it today, was developed for two main industry needs 1) for ships to know where they are in relation to other vessels in the open water and 2) for ships to know water depth below the ship. Technologies to fill these needs came out of exploring the properties of sound underwater and measuring seafloor depths. These technologies were widely applied in shipping, warfare, exploration, and oceanography, and are now widely used in marine sciences (oceanography, hydrographer, conservation), industry (oil, shipping, tourism), and recreation (fishing, sailing, exploration).

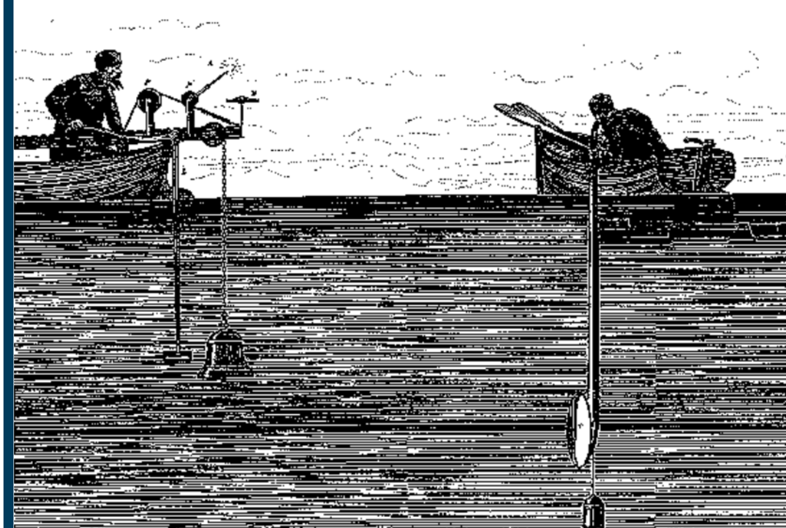


SOUND AND RANGING BETWEEN SHIPS:

"If you cause your ship to stop, and place the head of a long tube in the water and place the outer extremity to your ear you will hear ships at a great distance from you"

- Leonardo Da Vinci, 1490

It is well known that sound travels underwater better than visible light. In 1822, Daniel Colloden used a bell ringing underwater to calculate the speed of sound in Lake Geneva, Switzerland, as shown in the sketch:



Later, in the early 1900's, small ships used a Ranging System. The system was a combination of an underwater bell, a hydrophone (an underwater receiver), and a fog horn. Ships could hear each other's horn and bell through their hydrophones. This system allowed the crews on each ship to determine their approximate distance from each other by listening to the timing between sounds.

SOUND AND SEAFLOOR MAPPING AND WATER DEPTH:

The ability to determine features of the seafloor made traveling by ship safer and more reliable, and greatly improved our understanding of the seafloor. The simplest way to map seafloor depth is to lower a weight on a rope into the ocean until it lands on the seafloor. While very practical, this method is laborious and time consuming. . In the 1920s SONAR [SOund NAvigation and Ranging] was first used to determine water depths. A working sonar system requires four basic elements:

1. A sound wave source (transmitter+ping)
2. A sound wave receiver
3. A timer
4. Some sort of time plotting/recording chart

In a working sonar system, an energy source sends out a sound wave. The amount of time required for the sound wave to travel downward, bounce off the seafloor, and return to the receiver at the ocean surface is measured. Using this two-way travel time and the velocity of sound in water, it is possible to rapidly determine the depth of the ocean. Also, by knowing other features about the sound wave or ping, such as amplitude and frequency, we can infer what may be in the water column and the composition of the seafloor. This is done by accounting for absorption as a change in amplitude and reflection as a change in time.

HINT: In Round 1 students make inferences based on Time by converting Time to Depth.
HINT: In Round 2 students make inferences based on Amplitude differences between the transmitted and returned wave.
HINT: In Rounds 3 students make inferences based on 2 sound waves that are transmitted at different frequencies and returned at different times.

Please watch the video here for a deeper understanding of how SONAR is used to help ships "see" underwater.:

https://oceanservice.noaa.gov/facts/sonar.html

Because the rate of attenuation of sound in water varies with its frequency, only low frequencies can reach deep ocean depths, and only certain frequencies can "see " objects that are in the water column. To account for this, the RV Taani can send out 5 different frequency waves at a time! When choosing a sonar frequency for an application, the general rule of thumb is to use the highest frequency wave (kHz) as you can for the depth you want to investigate.

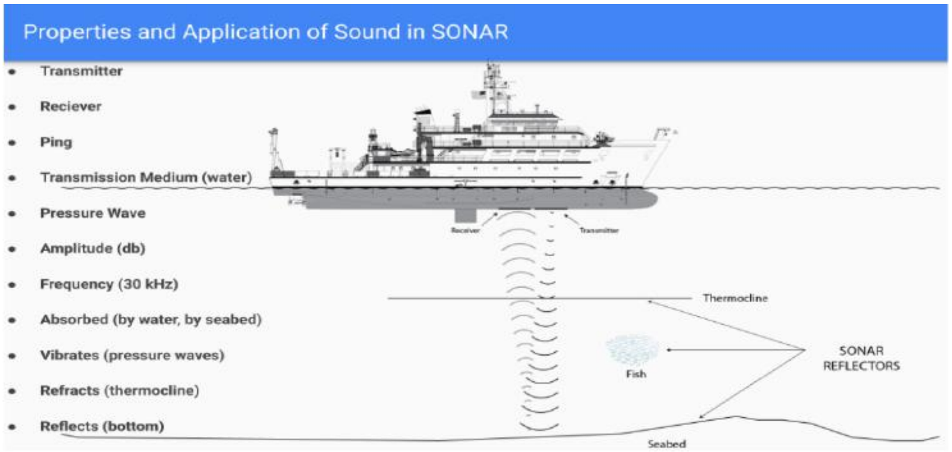
See the chart below for some of the frequencies used in seafloor mapping.

Frequency	12 kHz	30 kHz	100 kHz	300 kHz
Typical attenuation	1dB/km	5dB/km	30dB/km	65dB/km
Typical range	11000m	5000m	1000m	200m

Exploring the Application of Sound in Ocean Acoustics
Human Sonar Simulation

RV TAANI SONAR MODELS:

Below is a model of the RV Taani's SONAR [SOund NAvigation and Ranging] system. The Taani is equipped with a Singlebeam and a Multibeam SONAR. In our simulation we will be exploring the application of a Singlebeam SONAR.



DEFINITIONS AND PARTS OF RV TAANI SONAR MODEL:

(1) Transmitter: The sound source that creates a pressure wave that vibrates the water

(2) Receiver: A hydrophone that captures the vibrations and the characteristics of the returning sound wave

(3) Transmission Medium (ocean water): The matter that the sound moves through. The properties of water: temperature, density, and salinity, impact characteristics of the median and influence the physical properties of the sound wave that return to the receiver. Such as, the speed of the sound waves through cold and warm water, or salty or fresh water.

(4) Amplitude (db): Amplitude, in physics, is the maximum displacement or distance moved by a point on a vibrating body. In ocean acoustics, amplitude is the strength of the pressure wave generated by the transmitter. This information can be used to infer what the seabed is made of, e.g. mud or rock

Definitions continue on the next page:

DEFINITIONS AND PARTS OF RV TAANI SONAR MODEL CONTINUED:

Frequency (Hz): How many waves, or vibrations, per unit of time (Hz= 1/s, KHz - 1000/s) are generated by the transmitter. The RV Taani's Singlebeam SONAR is 12 KHz, and the vessels' Multibeam SONAR 30 KHz. This is what gives the sound it's pitch, high or low.

Singlebeam SONAR: A transmitter that only sends 1 ping out at a time that can be aimed in any direction below the ship, but is generally transmitted straight down and used to track the bottom.

Multibeam SONAR: A transmitter that sends up to 300 pings out at a time. These narrowly focused pings (or beams) are arranged in a fan pattern perpendicular to the direction of travel. This arrangement of beams allow the ship to image objects off to the side(s) of the vessel.

Ping: A ping is when the transmitter creates a sound for a length of time. It is a particular sound at a fixed frequency and amplitude for a specific length of time. Fixed means that the properties of the sound wave are predetermined. The returning sound wave is then compared to the outgoing ping to infer characteristics of the seafloor and aquatic organisms.

Pressure Waves: Vibrations in the water created by the amplitude of the sound generated by the ping of the transmitter.

Refraction: When the sound wave changes between two mediums of different density the wave will bend. This occurs in the ocean when the wave travels from warmer fresher water to saltier colder water at a thermocline. High to low refraction goes towards normal, and from lot to high away from normal. Refraction is a minor issue when using a Singlebeam SONAR to sample because the instrument is sampling directly below the ship.

(5) Reflection: The portion of the initial pressure wave that returns to the receiver

Absorption: A pressure wave is absorbed when the sound wave vibrates an object. The properties of that object determine how much energy is lost by the wave before it returns to the transmitter. Seafloor greatly impacts.

Exploring the Application of Sound in Ocean Acoustics
Human Sonar Simulation

PARTS OF OUR SIMPLIFIED HUMAN SONAR MODEL:

Transmitter (RV Taani) -> Ping -> Absorb (seafloor) ->Reflect (seafloor) -> Receiver (RV Taani)

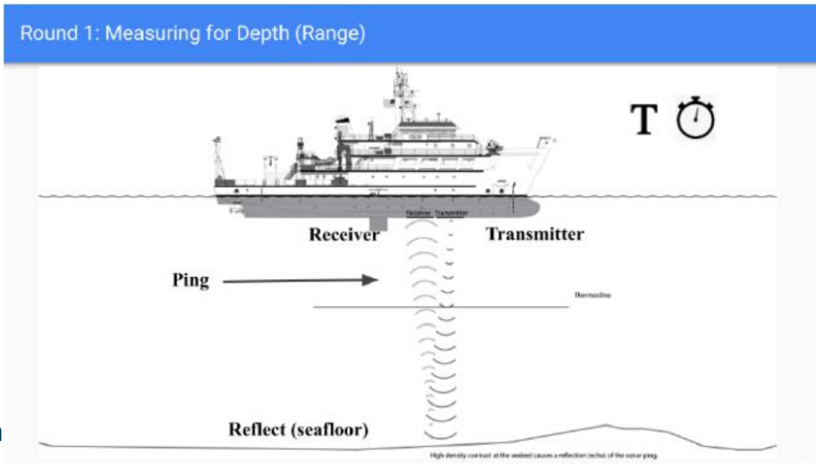
MODEL FOR ROUND 1

Measuring Time:

Transmitter (RV Taani) -> Ping ->Reflect (seafloor) -> Receiver (RV Taani)

Ocean researchers can infer the ocean depth by timing how long it takes a known sound wave, or ping, to travel from the ship to the seafloor and back. To calculate Water Depth you use this formula:

Depth = Speed of Sound x [(Two Way Travel Time)/2].



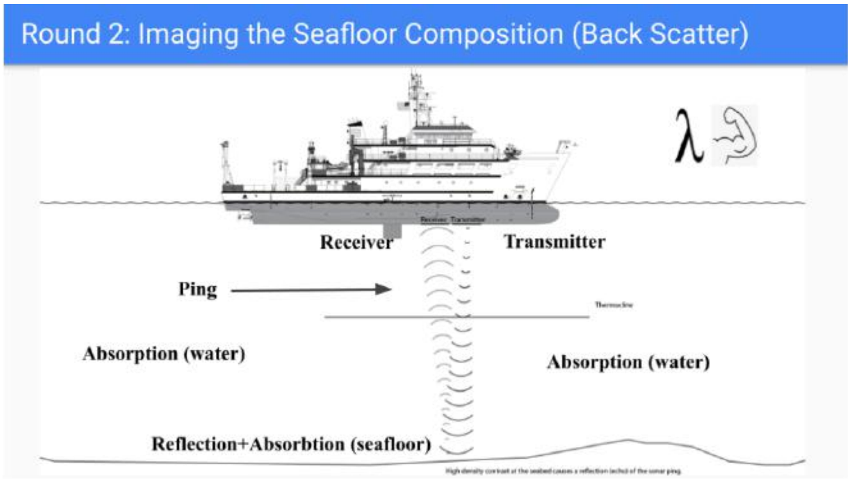
We need to divide the travel time by two because we do not know when the sound wave hit the seafloor and was reflected back up. If we wanted to measure one way travel time, we would need to place a receiver at the seafloor. In this round we are having students measure their travel time of a known distance. Students convert their travel time to steps per second or meters per second. Then after timing each return ping students use the formula below to calculate depth.

Formula for Round 1: Speed of Human ([steps or meters] / second) x [(Two Way Travel Time)/2]

MODEL FOR ROUND 2

Measuring Amplitude:

Transmitter (RV Taani) -> Ping ->Absorb (water) -> Reflect and Absorb (seafloor) -> Absorb (water) -> Receiver (RV Taani)



Ocean researchers can infer the hardness of the seafloor based on how the amplitude of the sound wave interacts with the seafloor. A lower amplitude return means that energy from the sound wave was absorbed by the seafloor (e.g. mud). A similar amplitude return means that the energy from the sound wave was reflected back from the seafloor inferring that the surface is hard (e.g. rock).

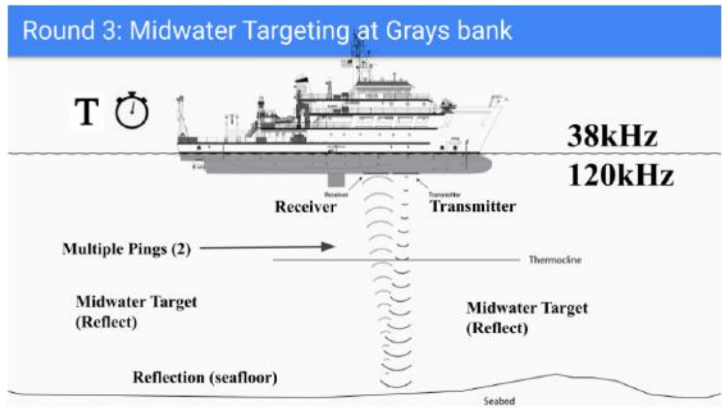
MODEL FOR ROUND 3

Measuring Multiple Returns (Time and Frequency):

Transmitter (RV Taani) -> 2 Ping s->0 or more Reflect and Absorb (targets) -> 2 Reflect and Absorb (seafloor) -> Receiver (RV Taani)

Ocean researchers can infer the sea life in the water column and at what depth based on how frequencies interact with that object in the water column below the ship. 38kHz is used to identify fish with larger amounts of air in their bodies (an air bladder). 120 Hz is used to find fish with smaller air bladders and bubbles in the water column and/or seeping from the seafloor.

*There is refraction, absorption, and reflection occurring at more places in our model, such as particles in the water, aspects of the seafloor, but these are the main ones that will impact our seafloor maps.



PROCEDURE:

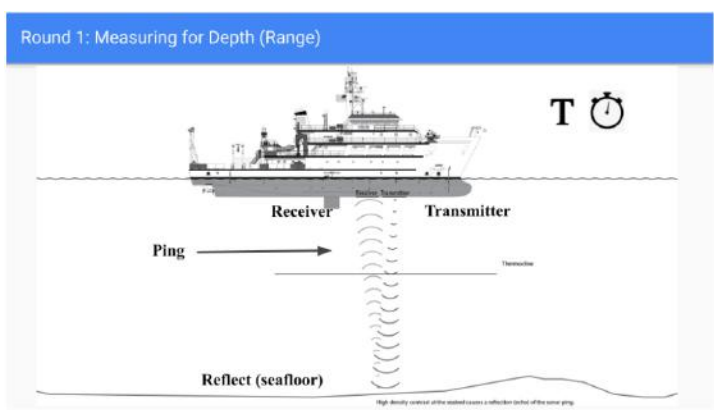
Introduce SONAR using an example that you feel your students would relate too. This can be two cups attached to one string, highlighting echolocation in dolphins, or another technology, like smoke signals or morse code, that people use to communicate information over long distances. Introduce aspects of the wave they may know and are familiar with. Then review the terms provided.

STARTING THE SIMULATION:

1. Have students watch the video on SONAR and look at the model for Round 1.

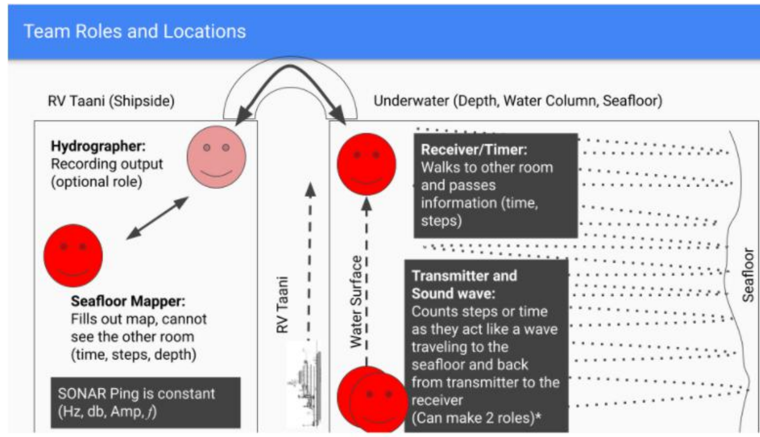
   Ask them to explain what is happening at each part of the model. If students use gestures, ask them to explain why they are using them.

   a. You can also use the blank model provided and ask students to apply the terms to the model and discuss similarities and differences of each.



STARTING THE SIMULATION CONTINUED:

2. Divide students in groups of 3-5 and introduce the roles for each team member.
    a. Let students know they will be doing 15 pings to measure the depth of part of the ocean. 15 pings means they will be doing 15 readings per round.
    b. Decide on team roles and who will be in what locations.
        i. It can be helpful to have 1 person convert the data and 1 person graph the data, while the other team members collect and pass of the data.



Round 1 - Time and Depth

1. Have each group establish their 'sound waves' travel time.
    a. Review how the seafloor mapper and hydrographer will convert time to depth.
2. Separate the seafloor mapper and the hydrographer into another room or space where they cannot see the "seafloor"
    a. show them the tools they have (chart, calculator)
    b. show them an example conversion
    c. Depth = Speed of Human x ([two way travel time/2])
3. Separate the transmitter, soundwave, receiver and timer and have them help you to rearrange the room into a seafloor.
    a. You can use the model floor provided
        i. a simple slope right to left with a rock pile at the far right end.
    b. You can create a more complex seabed with trenches and dropoffs
4. Have students compare their maps.
5. Let students know they will be adding to their maps for rounds 2 and 3.
6. If your class used the sample provided, let students know they sampled Grays Bank off the coast of Oregon!

Exploring the Application of Sound in Ocean Acoustics
Human Sonar Simulation

Round 2 - Amplitude Changes and Backscatter:

1 .Let students know that "Backscatter" is a measurement of returned acoustic energy. The amplitude of the sonar ping is reduced (some energy is absorbed) when sound waves interact with the seafloor. By measuring the amplitude of the returned pings, and comparing multiple pings, they can infer the hardness of the seafloor that was imaged

2. Review the model for Round 2 and ask students to discuss what has changed.

3. Review the team roles for Round 2 and ask students if they would like to change roles

   a. Let students know they will be collecting and comparing cards to see the changes in amplitude to infer the composition of the seafloor.

4. Before rooms are separated into different rooms, ask each team to decide how they will record changes in amplitude and the hard/soft-ness of the seafloor below each ping

   a. Researchers use a black and white color gradient

      i. black is used for soft because soft things absorb sound, so if the return amplitude is much lower than the original ping the sound wave is reflecting off mud or plant life

      ii. white is used for hard things because white reflects, sound, so if the return has a slightly lower amplitude than the original ping the sound wave is reflecting off a hard surface like rock

5. Divide the group and run the simulation for 15 pings adding to their seafloor map.

6. Have students compare their maps.

Round 3 - Midwater Targeting at Grays Banks:

1 .Let students know that “Midwater Target” is a phenomenon when sound waves are interacting with objects, biotic and abiotic, in the water column or near the seafloor. Scientists also use specific frequency waves if they are looking for a specific fish or object.

2. Review the model for Round 3 and ask students to discuss what has changed.

   a. Let students know they are sending out 2 pings, meaning 2 sound waves this round.

   b. let students know they will be collecting and comparing cards to see return times by frequency. Students need to convert return time to depth and mark the incident on their map

      i. Tell students to track

         1 . 38Hz return in Red

            a. This frequency is used by marine biologists to locate fish that have large amounts of air in their bodies.

         2 . 120Hz return in Blue

            a. This frequency may be used to locate fish with less amounts of air in their bodies and bubbles in the water column and coming from the seafloor.

3.Review the team roles for Round 3 and ask students if they would like to change roles.

4. Before rooms are separated into different rooms, ask each team to decide how they will record the returns of specific frequencies on their map

   a. Objects in the water appear as a function of time and how much of the sound wave was reflected.

5. Divide the group and run the simulation for 2 frequencies for 15 pings adding to their seafloor map.

6. Have students compare their maps.

Exploring the Application of Sound in Ocean Acoustics
Human Sonar Simulation

WRAPPING-UP:

Once students have refined their maps in their teams, post them on the walls around the room. Ask students to post sticky notes with questions or insights on each team's maps. Review the questions and share them with the entire class. Let students know that this is the process of creating data sets to gather more information to build a better module and understanding of the seafloor. Oceanographers, Hydrographers, Seafloor Mappers, and others build oceanographic data sets through years and years of data collection to gain a better understanding of the seafloor and its interaction with Earth's systems by applying the properties of sound waves. This same process of study is used in the imaging of objects, Earth, and the universe by applying the properties of sound waves.

CONCERNS:

Communication time can be an issue. If OK, students can use text messages to communicate the recorded data. There can also be issues of crowding. Stress to students that this is a walking activity.

SCAFFOLDING/EXTENSIONS:

Sunken Ship and a Treasure Hunt:

This activity can be framed as exploring a sunken ship and going on a treasure hunt. You can have students do the following:

1 .Have students map the depth of a "seafloor" area they know and all can see.
- a. This will let the team figure out all of their roles before jumping into the adventure.
- b. Tell them we are practicing what we will do on our adventure before we go out to sea.
- c.Have student use hand motions to act out each part (Transmitter -> Ping/Sound wave -> Seafloor (absorbed/reflected)-> Receiver)

2 . After the practice round, arrange a room with specific objects to make the seafloor "look like" the shape of a trench, cave, or something like that.
- a. Proceed to map depth

3 . Arrange amplitude cards for High to be where something metal and mard would be
- a. Ask students what they think it could be or where the chest may be located

4 . Tell students you are going to go back over the wreck to see if they can tell where the chest is.
- a.Have students remap a part of the ship
- b. Use a way to indicate VERY HIGH RETURN
  - i. Add a red dot to the round cards to indicate a very high return

5 . Have students make a map of their Sunken Ship and indicate where they think the chest is and why.
- a. This can be a great place to add the **Top 5 Vocab**.
- b. And add more terms as students need them to add more detail to their models

EXPLORING WAVES:

Students can explore Phet at University of Colorado. They have excellent physics simulators to explore the properties of light and sound waves.

http://phet.colorado.edu/sims/html/forces-and-motion-basics/latest/forces-and-motion-basics_en.html

SEABED 2030:

Seabed 2030 is a collaborative project between the Nippon Foundation and GEBCO. It aims to bring together all available bathymetric data to produce the definitive map of the world ocean floor by 2030 and make it available to all

https://seabed2030.org/faq

RCRV OUTREACH ACTIVITIES:

There are several more RCRV related activities available online. Helping Hand and Save the Soup both highlight ship technologies, and Ocean Careers and Holland Games highlight all the professions that make research as sea possible!

https://ceoas.oregonstate.edu/regional-class-research-vessel-outreach

Exploring the Application of Sound in Ocean Acoustics
Human Sonar Simulation

REFERENCES:

1. This site provides background information on SONAR

https://oceanexplorer.noaa.gov/technology/sonar/sonar.html

2.This site provides historical information on SONAR.

https://exploration.marinersmuseum.org/object/sonar/

3. This activity was developed from an activity by Kent M. Syverson, University of Wisconsin-Eau Claire.

https://serc.carleton.edu/NAGTWorkshops/oceanography/activities/72682.html

4. This activity used information provided by Dr. Chris Goldfinger at Oregon State University's College of Earth Ocean and Atmospheric Sciences

https://ceoas.oregonstate.edu/people/chris-goldfinger

5. Additional information on the RV Taani can be found here:

https://www.ship-technology.com/projects/r-v-taani-regional-class-research-vessel/ https://osu-wams-blogs-uploads.s3.amazonaws.com/blogs.dir/2967/files/2020/07/MT_July2020_pp.66-69.pdf https://ceoas.oregonstate.edu/regional-class-research-vessel-rcrv

ACKNOWLEDGEMENTS:

This lesson was developed as part of the RCRV Program and SMILE at Oregon State University funded by the National Science Foundation.
https://ceoas.oregonstate.edu/ships/rcrv/