Stirring up Sound

Discovery of Sound in the Sea (www.dosits.org)

Inquiry Questions:

- What adjectives do you use to describe sounds?
- What do you know about the way sound travels through water?
- Do things sound different underwater than they do in air?
- Do the properties of water affect the way sound travels through it? Why or why not? If you think it does change, how do you think it changes?

Introduction:

Sound is a wave, similar to the ripples on a pond or the ocean waves you might see crashing on a beach. Instead of being a wave on the ocean surface, sound is a wave that travels through a medium, such as air or water. How fast sound travels through a medium, called the speed of sound, determines the delay between when a sound is made and when it is heard. Sound travels five times faster in seawater than in air. The speed of sound in seawater is not a constant value, however. It varies slightly from place to place, season-to-season, morning to evening, and with water depth. In the simplest situations, sound will also travel in a straight line. In the ocean, however, interactions between the sound and water make the transmission of sound much more complicated. These effects include reflection, bending (refraction), and scattering.

Objectives:

- To demonstrate how the temperature of water affects the speed of sound.
- To demonstrate how dissolved particulates and bubbles scatter sound.

Materials:

- 2 mugs
- 2 metal teaspoons
- 2 plastic straws
- 2 thermometers
- graduated cylinder
- very hot (boiling) water
- ice water
- instant coffee

Procedure:

1) Break into groups of 3 and predict how sound may or may not change as the properties of water change. Write down your predictions.
2) Design an experiment to test your predictions.
3) Design a data table to record your observations.
   Hint: Include a column in your table to record time.
4) Discuss your results with your group.

5) Write a one-paragraph summary of your conclusions.
6) Share your group's findings with the class.

Discussion Questions:

1) How did your group design your experiment? Why?
2) What properties of water did you investigate? Why?
3) If your group tested the differences in sound between boiling water and ice water, what did you observe? Why?
4) How do you think temperature affects sound in the global ocean?
5) If your group tested the differences in sound between still water and bubbling water, what did you observe? Why? Did you observe a change based on the size of the bubbles?
6) How do you think bubbles affect sound in the global ocean?
7) If your group tested the differences in sound between plain water and coffee, what did you observe? Why? Did you observe a change over time?
8) What effects do you think climate change and warming oceans may have on the way that sounds move through the ocean?

Vocabulary:

<u>Absorption</u>
The conversion of acoustic energy to heat energy.

<u>Frequency (Pitch)</u>
The number of cycles of a wave per second. Expressed in units of Hertz (Hz).

<u>Hertz</u>
The unit of frequency; the number of cycles, or wavelengths, in a second (cycles/second).

<u>Intensity</u>
The average amount of sound power (sound energy per unit time) transmitted through a unit area in a specified direction. The unit of intensity is watts per square meter.

<u>Loudness</u>
How loud a person perceives a sound to be. Not the same as the intensity of the sound. The perceived loudness varies with frequency.

<u>Medium</u>
A substance or material that carries or transports the wave from its source to other locations. In the open ocean, the medium through which the wave travels is the ocean water.

<u>Scattering</u>
When the path of a sound wave is broken up by objects, the sea floor, or the sea surface.

<u>Wave</u>
A disturbance caused by the movement of energy through a medium.

<u>Wavelength</u>
The length of one cycle of a wave (one crest and one trough).

TEACHER STRATEGIES

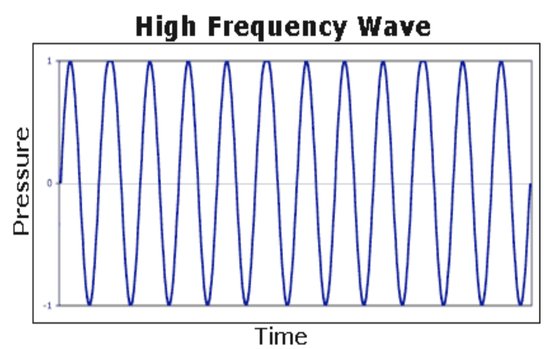
Background Information:

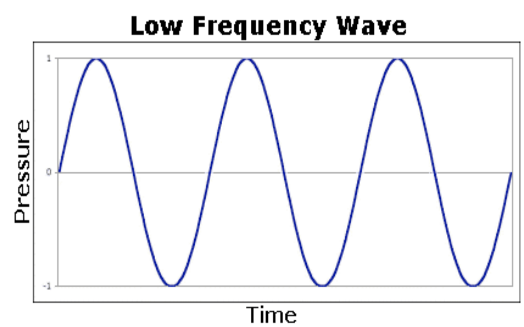
How do you characterize sound? (http://www.dosits.org/science/sound/characterizesound/)
If you had to describe a specific sound to a friend, what words would you use? Perhaps you would describe a sound with the words loud or soft; high-pitched or low-pitched. These words describe, or characterize, how we perceive sounds. Scientists, on the other hand, describe sounds with characteristics that can be measured using instruments. We can relate characteristics that scientists measure to the words we use to describe the sounds we hear. When we talk about loud or soft, scientists talk about the **intensity**, or **amplitude**, of the sound. When we talk about the pitch of a sound, scientists use the word **frequency**.

Perceived Characteristic	Physical Characteristic
Loudness	Intensity
Pitch	Frequency

<u>Frequency or Pitch</u> (http://www.dosits.org/science/sound/characterizesound/frequency/)
High-pitched or low-pitched refer to the frequency of a sound wave. You've heard the word "frequency" before, perhaps in sentences such as: "How frequently do you eat ice cream?" or the dentist might ask you, "How frequently do you brush your teeth?" Your answer is how often you do these activities in a given amount of time. Your responses could be, "I eat ice cream once a week", or "I brush my teeth twice a day."

Because sound travels in a wave, we can relate the characteristics that scientists use to describe sound, such as **frequency**, to a picture of a wave. A wave has a repeating pattern. One such repetition is known as a **wave cycle**. When talking about sound, frequency means the number of cycles of sound in a second. The diagram to the right shows a **high frequency wave** (top) and a **low frequency wave** (bottom), plotted as pressure versus time. The high frequency wave has completed twelve cycles over the time shown. The low frequency wave has completed only three cycles over the same time.





The unit used to measure frequency is named Hertz, which is defined to be the number of cycles in one second. (This unit is named after Heinrich Hertz, a famous 19th century physicist.) If you increase the frequency of sound (there are more cycles in a second), you get a higher pitched sound. When you decrease the frequency, you get a lower pitched sound.

How does sound move underwater?

<u>Speed of Sound</u> (http://www.dosits.org/science/soundmovement/speedofsound/)
Sound moves about 1500 meters per second in seawater (sound moves much more slowly in air, at about 340 meters per second). The speed of sound in seawater varies by a small amount (a few percent) from place to place, season-to-season, morning to evening, and with water depth. Although the variations in the speed of sound are not large, they have important effects on how sound travels in the ocean. What makes the sound speed change? It is affected by the oceanographic variables of temperature, salinity, and pressure (depth). The speed of sound in water increases with increasing water temperature, increasing salinity, and increasing pressure.

<u>Sound Scattering</u> (http://www.dosits.org/science/soundmovement/soundmove/scattering/)
Seawater has bubbles, suspended particles, organisms, and many other things in it. How does this affect sound as it travels through seawater? Have you ever used a flashlight? Most of the time, the flashlight creates a circle of light on objects that you point it towards, such as the ground. However, what happens when it is foggy out? You may have noticed that you can now see the beam of the flashlight. What is different? When it is foggy out, the air contains many water molecules, and the light from the flashlight is scattered in all directions off the water molecules. This makes the beam of the flashlight visible. When the light is scattered, it does not travel as far. Therefore on foggy nights the headlights of a car do not project as far as on clear nights.

The same thing happens to sound in the ocean to sound (remember, seawater has bubbles, suspended particles, organisms, and many other things in it). The amount of scattering is affected by the size of the object (the scatterer) and the wavelength of the sound. An object will be a significant scatterer if its size is comparable to or bigger than the wavelength of the sound. If the object is much smaller than one wavelength of the sound, the sound will tend to travel around the object in its path and not be significantly affected. That is why researchers use high frequency sound to look for small objects, such as fish, in the ocean.

<u>Sound Absorption</u>
(http://www.dosits.org/science/soundmovement/soundweaker/absorption/)
You have heard the word "absorb" in many contexts. Think of a sponge. If you spill grape juice, you clean it up by wiping a wet sponge over the grape juice spill. The sponge has just absorbed the grape juice. The same thing happens to sound. As sound travels through a medium such as water, it gets absorbed - caught by the molecules within the medium. The amount of absorption depends on the frequency of the sound. A high frequency sound has many cycles in a second, and the particles in the medium are therefore vibrating very rapidly. Just as when you rub your hands together very rapidly, this produces more heat than if you rub your hands together slowly. Since the molecules get their energy to vibrate from the sound wave, the sound wave will run out of energy sooner when it is a high frequency sound. This means that, under the same conditions, a high frequency sound won't travel as far as a low frequency sound.

Approximate Time Required:
One class period. Teacher may want to introduce the topic the preceding day.

Prior Preparation:
Gather all materials. *SAFETY CONCERN*: very hot (boiling) water will be used in the students' experimental design. Depending on the grade level, this may be something the teacher distributes to each working group. Students should otherwise be monitored when handling the hot water.

Set up each experimental station with 2 mugs/beakers (ceramic coffee mugs are preferable), 2 metal teaspoons, 2 plastic straws, and 2 thermometers. Paper towels may also want to be provided to wipe up any spills that may occur.

- Ceramic mugs or beakers will work better than glass.
- The mugs or beakers should come from the same set- you may want to ting on each of the glasses prior to the class period to make sure they all sound "similar" when empty.

When students are filling their mugs, make sure they only fill them, at most, ¾ of the way full of water (if they fill them too high, things will be get very messy).

- Students should use a graduated cylinder to measure out the amount of water added to each mug. This way, the water level is kept consistent across experiments.
- If possible, include some type of measurement bar inside each mug so students can then record the height of their water levels.

Students may need to empty their mugs after each experiment (or they may want to repeat the same experiment); if a sink is not available, a bucket may be necessary for students to dispense of their wastewater.

Teachers may want to download free online software that display the frequencies of sound as they are created. Although these frequencies will be that which is measured in the air, not under water, it still offers an opportunity to visualize the differences in the sounds produced. Students could also guess which sound is being shown (e.g. that in hot water, vs. that in cold water). Suggestions for free, downloadable, visualization software:

- (Mac) Audacity - http://audacity.sourceforge.net/
- (PC) Overtone Analyzer Free edition - http://www.sygyt.com/en/free-spectrum-analyzer

Instructional Strategies:
Begin a class discussion with the inquiry questions provided (~ 15min).

Break students into groups of three. Promote role-designation within student groups (if groups conduct more than one experiment, encourage students to rotate rolls).

Once the students have started their experiments, move among the groups and guide students to:

- Use the metal teaspoons to tap on the mugs to create sound. Encourage students to clink their spoons or stir rods on the inside or inside/bottom of the cup.

- Investigate how sound differs between the mug containing hot water and the mug containing cold water. Encourage students to think about how the water temperature may be changing with time (hot water cooling, ice water warming), and how this may affect the sounds produced. Students may need longer than 1 minute to observe a change.

- Compare sound production in plain, hot water, vs. water that has had instant coffee added to it. Students should also continue to stir/produce sound for at least one minute after they have added the instant coffee and make note of how sound changes over time.

- Use the plastic straws to blow bubbles in the water and also vary the force they used to blow air through the straw (this will change the size of the bubbles produced).

***NOTE:** If students produce sounds by tapping the inside of their mugs while stirring, it is important to note that the act of stirring in and of itself can change the frequency of the sound produced (stir and tap on the outside, don't stir and tap on the outside). When you are stirring, there is movement of the water, which could cause a slight Doppler effect to the clinking sound. It is also likely that having the spoon in the water causes scattering of sound and makes a difference in the frequency of the clink. Effects are very subtle compared to the other things students may be looking at, however, it is something to keep in mind.

Sample experimental design:

Hot vs. cold water:

1) Students work in groups of three. One can be in charge of the hot water, another can be in charge of the cold water, and the last student can record results.
2) Add boiling water to one mug (no more than ¾ full); add ice water to the other mug (no more than ¾ full).
3) Tap on the inside of each of the mugs with the metal teaspoons. How do the sounds differ? Record results.

Plain hot water vs. coffee (adapted from <u>Sound Science</u>, 1991*):

1) Students work in groups of 3. One student will be the "stirrer", another a "scooper", and the last will record the results.
2) Fill one mug ¾ of the way full with very hot water.
3) Take a metal teaspoon and gently stir the water, clinking the spoon against the side and/or bottom of the mug. Listen to the pitch of the clinking (how high or low it sounds). Record observations.
4) Continue stirring/clinking. Another student takes the other metal teaspoon to take a scoop of instant coffee and pour it into the water. Note what happens to the pitch of the clinking sound.

5) Continue stirring/clinking for another minute. How does the pitch of the clinking sound change? Record observations.

* Adapted from: "Changing Pitch". *In*: Sound Science. Written by Etta Kaner. Addison-Wesley Publishing Company. 1991. Pp 28-29.

No bubbles vs. bubbles (adapted from Sound Science, 1991*):

1) Students work in groups of three. One will be the sound producer, another will be in charge of blowing bubbles, and the last student will record results.
2) Fill one mug ¾ of the way full with tap water.
3) Tap one of the metal teaspoons against the side of the mug. Describe the sound produced and record results.
4) Blow bubbles into the mug of water using one of the plastic straws. Describe how the sound changed and record results.
5) Vary the force used to blow air through the straw. Describe how the size of the bubbles changes with different force and how the sound also changed. Record results.

* Adapted from: "Changing Pitch". *In*: Sound Science. Written by Etta Kaner. Addison-Wesley Publishing Company. 1991. Pp 28-29.

Sample data tables:

Hot vs. cold water

	Description of the "clinking sound"			
Sound production in the mug containing cold water:				
Sound production in the mug containing hot water:				
Stirring hot water, after one minute:	**15 seconds**	**30 seconds**	**45 seconds**	**1 minute +**
Stirring cold water, after one minute:	**15 seconds**	**30 seconds**	**45 seconds**	**1 minute +**
Water temperature, cold water:				
Water temperature, hot water				

Plain hot water vs. coffee:

	Description of the "clinking sound"			
Stirring, hot water only:				
Stirring, instant coffee added:				
Stirring, one minute after coffee was added:	**15 seconds**	**30 seconds**	**45 seconds**	**1 minute**

No bubbles vs. bubbles:

	Description of the "clinking sound"	
Sound production in calm water:		
Sound production in water with bubbles:		
	Large bubbles	**Small bubbles**

Answers to Discussion Questions:

1) How did your group design your experiment? Why?
All reasonable answers are acceptable, as long as an explanation is provided.

2) What properties of water did you investigate? Why?
Temperature, the introduction of particulate matter, and the introduction of bubbles into the water. Underwater sound speed is affected by the oceanographic variables of temperature, salinity, and pressure (depth). The speed of sound in water increases with increasing water temperature. Seawater has bubbles, suspended particles, organisms, and many other things in it that also affect how sound will travel through water.

3) If your group tested the differences in sound between boiling water and ice water, what did you observe? Why?
Tapping a metal teaspoon against the mug with the boiling water produced a higher pitched sound than tapping the spoon against the mug with the ice water. The speed of sound in water increases with increasing water temperature. High frequency (high pitched) sounds travel faster than low frequency (low pitched) sounds.

4) How do you think temperature affects sound in the global ocean?
Most of the change in sound speed in the surface ocean is due to changes in temperature. Sound speed at the ocean surface is fast because the temperature is high from the sun warming the upper layers of the ocean. As water depth increases, the temperature gets colder and colder until it reaches a nearly constant value. Since temperature is now constant (of about 2°C for depths below roughly 1000 m), the pressure of the water has the largest effect on sound speed.

5) If your group tested the differences in sound between still water and bubbling water, what did you observe? Why? Did you observe a change based on the size of the bubbles?
The pitch of the clinking sound decreases when bubbles are introduced. Bubbles scatter underwater sound, causing its speed to slow. Low frequency (low-pitched) sounds travel slower than high frequency (high-pitched) sounds. The amount of scattering is affected by the size of the object (in this case, the bubbles) and the wavelength of the sound. An object will be a significant scatterer if its size is comparable to or bigger than the wavelength of the sound. If the object is much smaller than one wavelength of the sound, the sound will tend to travel around the object in its path and not be significantly affected. Blowing with more force through the straw (and creating bigger bubbles) caused the pitch of the clinking sound to become lower than blowing with less force (small bubbles). This was because the sound wave created by the clinking spoon could travel around the smaller bubbles, whereas the larger bubbles scattered more sound, slowing the sound wave down. Low frequency (low-pitched) sounds travel slower than high frequency (high-pitched) sounds.

6) How do you think bubbles affect sound in the global ocean? How do you think scientists could use this effect to study the weather?
Breaking waves and rainfall create bubbles. Bubble clouds have been found to extend 10 meters or more (33 feet or more) below the surface when winds are strong. If scientists are measuring the speed of sound in the upper ocean, changes in the sound speed can be

correlated to rainfall events or wind speed through the type of sounds they hear. The sounds vary based on the size and amount of bubbles in the water (http://www.dosits.org/people/studyweather/measurerainfall/ and http://www.dosits.org/people/studyweather/measurewind/).

7) If your group tested the differences in sound between plain water and coffee, what did you observe? Why? Did you observe a change over time?
When the coffee is added to the boiling water, the pitch of the clinking sound becomes lower. The particles of instant coffee actually have tiny air bubbles attached to them. Thus, when the coffee dissolves in the hot water, the air bubbles are released into the water. Bubbles scatter sound. The air bubbles slow down the sound waves of the clinking spoon, and slower sounds have a lower pitch (low frequency sounds). As students continue to clink and stir up the water, the coffee dissolves and the air bubbles rise to the water surface and escape. The pitch of the clinking sound gradually rises, returning to the original pitch when the sound waves were traveling through water only.

8) What effects do you think climate change and warming oceans may have on the way that sounds move through the ocean?
One way the ocean will respond to global climate change is with a change in temperature. The average temperature of the ocean will rise as global climate warms. In warmer water, sound travels faster.

Extensions:

General extensions

- If you are able to measure how high the water level is in each mug, this offers an opportunity to talk about the differences in wavelength. In mugs with a lower level of water, there is less water for the sound to travel through, and hence, the sound has a shorter wavelength. This shorter wavelength results in a higher-pitched sound. Students can adjust the level of the water and listen to the pitch of the sound change as they add/remove water from their mugs.
- Experiment with other materials that dissolve in water and produce bubbles. These could include Alka-Seltzer or Efferdent tabs.
- Experiment with salt water. Use "instant ocean" or sea water in one mug, and tap water in another mug and see what happens. Are sounds produced different? Why or why not? If not sound difference is noted, try to significantly increase the salinity of the water and see if that causes a change.

Grades 9-12

Calculate the speed of sound in each mug (one will contain hot water, the other cold water):
Measure the temperature of the water. Use the simplified equation from Mackenzie, 1981, to calculate the speed of sound in the water. We assume that depth (z) is 0 and salinity (S) is also zero and that we can measure temperature (T) reasonably accurately.

Speed in water z(0), S(0) =

1448.96+(4.591xT)+(-0.05304xT2)+(0.0002347xT3)+(1.34x(0-35))+(-0.0163xTx(0-35))

What is the difference in speed between the mugs? Does it change over time (as the mugs cool/heat)?

There are more accurate algorithms to calculate the speed of sound but this one is simple enough to use without a spreadsheet and is close enough for the purposes here.

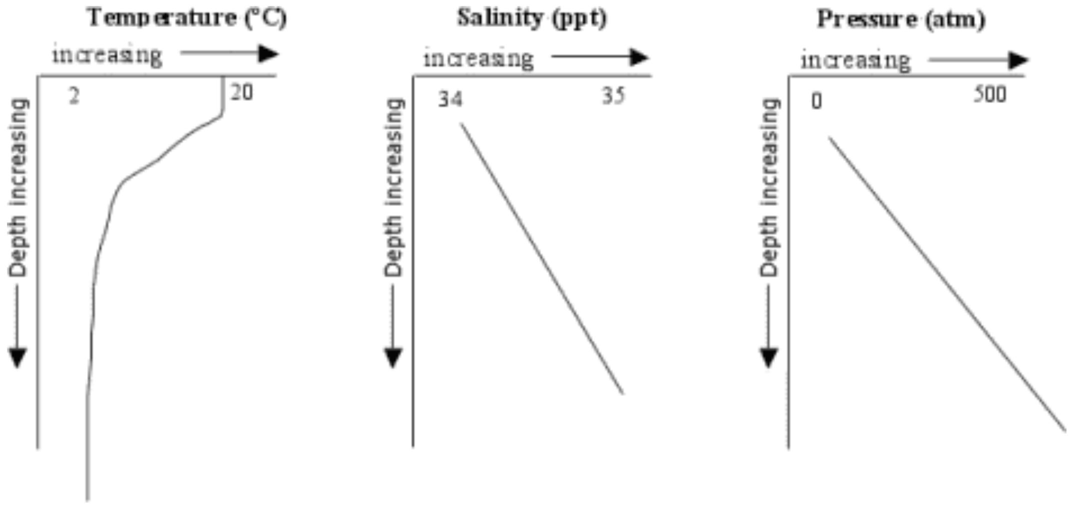
Reference:

Mackenzie, Kenneth V. (1981). "Discussion of sea-water sound-speed determinations". Journal of the Acoustical Society of America 70 (3): 801–806.

Investigating the change of an oceanographic variable with water depth: profiles
(http://www.dosits.org/science/soundmovement/speedofsound/)

Sound speed is affected by the oceanographic variables of temperature, salinity, and pressure. We can look at the effect of each of these variables on the sound speed by focusing on one spot in the ocean. When oceanographers look at the change of an oceanographic variable with water depth, they call it a profile. Similar to the profile of your face that gives a side view of your face, an oceanographic profile gives you a side view of the ocean at one location from top to bottom.

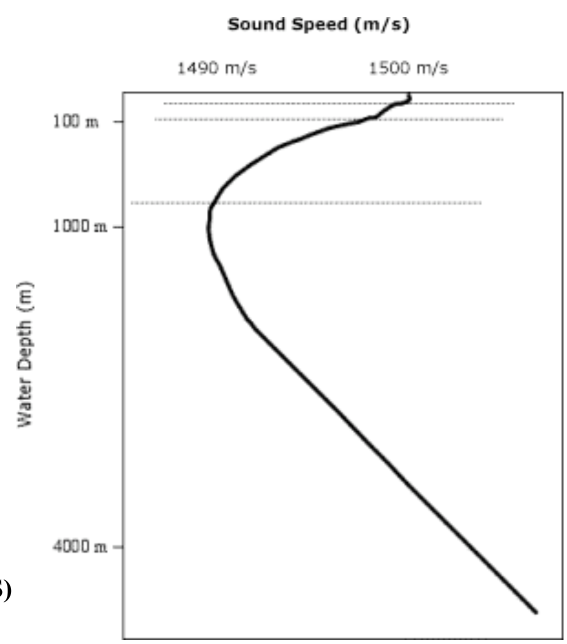
It looks at how that characteristic of the ocean changes as you go from the sea surface straight down to the seafloor.



Displayed above are the basic profiles for a site in the deep, open ocean roughly halfway between the equator and the North or South pole. In these profiles, temperature decreases as the water gets deeper while salinity and pressure increase with water depth. Here we are referring to the ocean pressure due to the weight of the overlying water (equilibrium pressure), not to the pressure associated with a sound wave, which is much, much smaller. In general, temperature usually decreases with depth, salinity can either increase or decrease with depth, and pressure always increases with depth.

Have students draw an example temperature profile, salinity profile, and pressure profile, using data available from NOAA's National Ocean Data Center's World Ocean Database (http://www.nodc.noaa.gov/OC5/SELECT/dbsearch/dbsearch.html). To retrieve data, search for data that contains geographic coordinates, temperature, salinity, and pressure. For the geographic coordinates, use the "Rubberband selection coordinates" feature to draw a small box somewhere in the middle of the ocean (close to the equator)- keep the box relatively small, as you will retrieve a lot of data! Data will be exported to an ftp site and then can be imported into Microsoft Excel.

Once students have drawn their temperature, salinity, and pressure profiles, discuss them as a class and compare results. Students should show a decrease in temperature with depth, a slight increase or decrease in salinity with depth, and an increase in pressure with depth. Knowing that the speed of sound increases with increasing temperature, salinity, and pressure, ask the students what they think a sound speed profile would look like for their part of the ocean? Instruct students to draw a sound speed profile given the temperature, salinity, and pressure profiles they created. A typical sound speed profile for the deep, open ocean in mid-latitudes is shown to the right.



The decrease in sound speed near the surface is due to decreasing temperature. The sound speed at the surface is fast because the temperature is high from the sun warming the upper layers of the ocean. As the depth increases, the temperature gets colder and colder until it reaches a nearly constant value. Since the temperature is now constant, the pressure of the water has the largest effect on sound speed. Because pressure increases with depth, sound speed increases with depth. Salinity has a much smaller effect on sound speed than temperature or pressure at most locations in the ocean. This is because the effect of salinity on sound speed is small and salinity changes in the open ocean are small. Near shore and in estuaries, where the salinity varies greatly, salinity can have a more important effect on the speed of sound in water.

Standards Addressed:

Ocean Literacy: Essential Principles and Fundamental Concepts

Essential Principle 3: The ocean is a major influence on weather and climate.
b. The ocean absorbs much of the solar radiation reaching Earth. The ocean loses heat by evaporation. This heat loss drives atmospheric circulation when, after it is released into the atmosphere as water vapor, it condenses and forms rain. Condensation of water evaporated from warm seas provides the energy for hurricanes and cyclones.

Essential Principle 5: The ocean supports a great diversity of life and ecosystems.
d. Ocean biology provides many unique examples of life cycles, adaptations and important relationships among organisms (symbiosis, predator-prey dynamics and energy transfer) that do not occur on land.

f. Ocean habitats are defined by environmental factors. Due to interactions of abiotic factors such as salinity, temperature, oxygen, pH, light, nutrients, pressure, substrate and circulation, ocean life is not evenly distributed temporally or spatially, i.e., it is “patchy”. Some regions of the ocean support more diverse and abundant life than anywhere on Earth, while much of the ocean is considered a desert.

Essential Principle 6: The ocean and humans are inextricably interconnected.
e. Humans affect the ocean in a variety of ways. Laws, regulations and resource management affect what is taken out and put into the ocean. Human development and activity leads to pollution (point source, non-point source, and noise pollution) and physical modifications (changes to beaches, shores and rivers). In addition, humans have removed most of the large vertebrates from the ocean.