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The Science of Sound and Musical Instruments

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I serve as a Magnet School Curriculum Facilitator and Teacher at East Rock Global Magnet School. We pride ourselves because of our diverse population and our global studies curriculum, which introduce students to various cultures around the world at an early age. Not only are children introduced to the cultures of these various countries, but through our partnership with the Yale School of International Studies, graduate students teach Russian, Chinese, Swahili, Japanese and Portuguese to our students. I am particularly excited about participating in the Yale New-Haven Institute Seminar, "Sound and Sensibility: Acoustics in Architecture, Music and the Environment" for several reasons. First, I have always wanted to write a unit focusing on culture, and when I approached several colleagues to work as a team they were receptive. Even though my unit concentrates on the science of sound, the units written by my colleagues focus on culture and the musical instruments associated with the cultures of Brazil and Africa. Secondly, I am looking forward to the production that we are planning for the school utilizing the units we create. Throughout these units, we will discuss the role of music in the cultures of Brazil and Africa.

The curriculum unit, "The Science of Sound and Instruments" can be used with students in grades 4 through 7 with minor adaptations. This unit is one portion of three other units written in this book. It will serve as the science behind sound and will discuss how the instruments introduced in the other units make music or sound.

"The Science of Sound and Instruments" will be composed of the following sections:

I. The Components of Sound

II. Sound Waves

III. Structure of the Ear

(A) Outer Ear
1. Pinna
2. Auditory Canal

(B) Middle Ear
1. Eardrum
2. Ossicles
3. Eustachian Tube

(C) Inner Ear
1. Semicircular Canals
2. Cochlea

IV. Hearing

V. How Musical Instruments Create Music

As you can see from the outline above, the paper will be divided into three different sections. Section I, The Components of Sound, will introduce students to the concepts which allow sound to occur. They will also discover the role each of these components in producing sound through basic experiments found in the lesson plans at the end of the unit. Section II, Sound Waves, will discuss how sound waves behave in the environment and the role they play in hearing. Section III, The Structure of the Ear, will focus on how we hear and perceive music. The students will be introduced to each part of the ear and discover how they all work together in order to hear sounds. Section IV, Hearing, briefly discusses what happens once sound reaches the ear. Section V, How Musical Instruments Create Sound, will explore the different instruments mention in the units written by Doreen Canzanella, Judith Dixon and Jackie Porter units. Lesson plans and simple scientific experiments utilizing those instruments will also be included in this unit.

Upon completion of the unit, the students will be able to:

(1) Identify the components of sound.
(2) Describe the relationship between pitch and frequency.
(3) Explain the terms sympathetic vibrations and resonance.
(4) Perform simple experiments about the world of sound.
(5) List the three sections of the ear and the structures associated with each area.
(6) Using a diagram of the ear, identify the main structures of the ear.
(7) Explain the process of hearing.

The Components of Sound

Sound is created through vibrating objects going through a medium (air) in the forms of sound waves. These sound waves reach the eardrum causing them to vibrate. Then the brain perceives these vibrating waves as sound. The phenomenon of hearing sounds like a complicated process, believe me it is! However, the curriculum unit, "The Science of Sound" will attempt to simplify the process so that it can be utilized in the third to fifth grade classroom.

When an object such as a drum vibrates, it produces sound. The sound causes the molecules in the air to move back and forth. This motion called sound waves vibrates in all direction within the atmosphere.

Sound waves within the atmosphere are invisible, but there are several ways in which you can demonstrate movement of sound within your classroom. (See Lessons I on sound waves.) This simple experiment uses water as the medium in which the waves travel through. This is a simulation of vibrations traveling in the atmosphere as sound waves. The sound waves would then reach the eardrum.

Sound waves travel at different rates of speed and have different intensities and frequencies. The frequency of a sound wave is determined by the number of times an object, or sound waves it produces, vibrates in one second. Scientist measures frequency in units called Hertz. Hertz are the number of times a sound wave cycle passes a given point each second.

The frequency that sound vibrates determines the pitch of that sound. If a sound wave vibrates rapidly, it will produce a higher pitch. If a sound wave vibrates slowly, it will produce a lower pitch. The experiment in the second lesson demonstrates this phenomenon.

Blowing across the top of the bottles containing different amounts of water causes a column of air to vibrate inside the bottle to vibrate and the vibration produces sound waves. The strong flow of air travels down into the bottle and expands. When it reaches the surface of the water it is reflected back towards the opening. The back and forth movement of these air molecules across the opening of the bottle reaches the atmosphere and produce sound.

The flow of air in the bottles with the less water has to travel farther inside the bottle producing a larger air column, which causes the air to vibrate slower. The slow vibration produces a lower pitch. Likewise, the flow of air in the bottles with more water has to travel a shorter distance inside the bottle producing a smaller air column, which causes the air to vibrate faster. The faster vibration produces a higher pitch. High pitches have high frequencies and short wavelengths. Low pitches have low frequencies and longer wavelengths.

All objects have a natural frequency or period of vibration. If we consider the strings on the inside of the piano, we will find that it is composed of string or wires with its different lengths and thickness. Each of the wires has been tightened so that they will vibrate at a definite frequency. But the string can also vibrate without being struck because anything vibrating near it at the same rate, as its own natural vibration rate will set a string into motion. This action is called sympathetic vibration.

In order to demonstrate sympathetic vibration of an object in the classroom, a simple pendulum can be used. Once the pendulum is set into motion, it has a natural frequency. You can set up additional pendulums at the same length and it will have the same frequency as the first pendulum. But if you place two or more pendulums, hang them on the same source and just swing one of the pendulums the other ones will begin to swing. This happens because the other pendulums feel the vibration on the source that the first pendulum is hanging because they have the same natural frequency as the first pendulum. This is an excellent example of sympathetic vibration. See experiment in Lesson IV if you would like to do this experiment in your classroom.

In the atmosphere vibrations of one object at its natural frequency produce vibrations in another object with the same natural frequency. This phenomenon is called sympathetic resonance. The best known example of resonance occurring in nature is the opera singer hitting a note that shatters the glass. Resonance occurs when small vibrations of one object at its natural frequency produces large vibrations in another object with the same natural frequency. A better understanding of resonance and sympathetic resonance can be achieved by performing the experiment in Lesson IV at the end of this unit.

Sound Waves

Sound waves have different characteristics. Perceived pitch is determined by frequency, or by how fast an object vibrates back and forth. Frequency is the number of times that an object, or sound wave it produces, vibrates in one second. The higher the frequency of an object, the higher the pitch. The normal human ear can hear sounds with frequencies between 20 and 20,000 vibrations per second. Each vibration is considered to be one Hertz.

The amount of energy flowing in the sound waves is referred to as the intensity of sound. The loudness of the sound is based on the strength of the sensation received by the eardrum and sent to the brain. The same intensity of sound may produce different degrees of loudness for different people. Intensity and loudness of a sound depend on four factors: (1) how far the distance is from the source of the sound (especially in outdoor situations), (2) the amplitude of the vibration, (3) how dense the medium is through which the sound travels, and (4) the area of the vibrating object.

The intensity and loudness of a direct sound decrease as the distance increases between a person and the source of the sound. This happens because sound waves move out from their source in all directions. The energy flowing in the sound waves spreads over a greater area and decreases the farther away the sound travels.

The amplitude of vibration is the distance that a vibrating object moves as it vibrates. The larger the amplitude of vibration of a sounding body, the louder and more intense the sound. The amplitude of a sound wave is the degree of motion of air molecules within the wave, which correspond to the extent of rarefaction and compression that accompanies the wave.

In air, the forward movement of vibrating objects pushes molecules together. This is called compression. When the vibrating object moves back in the opposite direction, the air is separated, causing the molecules to move farther apart. This is called rarefaction. The amplitude of a sound wave can be expressed in terms of absolute units by measuring the actual distance of displacement of the air molecules, or the pressure differential in the compression and rarefaction, or energy involved.

One way of explaining this phenomenon is to use the tuning fork as an example. As we know the vibrating prongs of a tuning fork produce sound. As the sound of the tuning fork move forward in one direction, it compresses the air molecules in front of it. Then the tuning fork swings in the opposite direction, and the space that it just occupied is nearly empty of air molecules. The surrounding air molecules begin to crowd into the partly empty space, but the tuning fork, swinging forward again, compresses them once more. This process of compressing and rarefying the air around the tuning fork continues as long as the tuning fork vibrates.

The compressed air molecules are pushed against those that are a little farther away from the tuning fork. This push, or impulse, moves farther and farther outward, compressing air molecules as it travels. A space of rarefied air follows each compression. Thus, the vibrating tuning fork sends a continual series of alternating compressions and rarefactions through the air. Each pair of compressions and rarefactions makes up one sound wavelength.

The Structure of the Ear

To better understand the total functioning of the human ear, it is best to divide the ear into three distinct regions: the outer ear, middle ear and the inner ear. The outer ear includes the pinna and the auditory canal; it ends at the tympanum or the eardrum. The middle ear includes the tympanum and the ossicles which are three small bones that are attached to the to the eardrum. The inner ear is made up of the semicircular canals and the cochlea.

The pinna is the flappy visible part of the ear. It collects sound (especially high frequencies) and directs it to the auditory canal. The pinna also allows us to determine the direction in which the sounds hear are traveling. The auditory canal acts as a funnel sending sound directly to the middle ear, via the eardrum. It is a tubular passageway lined with delicate hairs and small glands that produce a wax-like secretion called cerumen. The cerumen traps and keeps dust and dirt away from the eardrum. This keeps the eardrum from hampering its ability to vibrate.

The eardrum separates the outer ear from the middle ear. The eustachian tube is a small, narrow passageway, which connects the middle ear to the throat and the back of the nose. The primary job of the estachian tube is to keep the eardrum intact by equalizing the pressure between the middle and outer ear to prevent them from rupturing. Sometimes the estachian tube closes when it begin to feel pressure within the middle ear. This usually happens when pressure changes due to altitude occur. For example when a plane takes off or land the tube will automatically closes. Swallowing or chewing gum can open the tube.

A good way to demonstrate how the eardrum and the eustachian tube work is to have students make a replica of the eardrum and the auditory canal. This can be done using a toilet paper roll, rubber band and a piece of rubber or a balloon. Have the students stretch the rubber tightly over one end of the tube and secure it with a rubber band. Instruct the students to speak into the open end of the tube and feel what happens to the rubber. They will find that the rubber or the balloon vibrates. The eardrum reacts in the same manner. Sound vibrations enter the ear canal and hit against the eardrum.

The eardrum is attached to three bones called the ossicles. These bones are shaped like a hammer, an anvil and a stirrup. These bones are named according their shape, the hammer shaped bone is called the malleus, the anvil shaped bone is called the incus and the one shaped like a stirrup is called the stapes. If you show the students a model or drawing of the middle ear, they will clearly see how the bones in the ossicles received their names. This is also a good way to get the students to memorize the names and where the bones are located in the ear.

The hammer is located in the eardrum, and the stirrup fits into a membrane that fronts the inner ear. Vibrations from the eardrum move the hammer. Then the motion of the hammer moves the anvil, which moves the stirrup. As the sound vibrations pass from the eardrum to the ossicles it is amplified just before it passes through the oval window into the inner ear. The inner ear is protected from loud noises and pressure changes by two small muscles called the tympani and the stapedius. They protect the middle and inner ear from damage by contracting and limiting the movement of the ossicles.

The ossicles in the middle ear leads into the complex inner ear. The three main parts of the inner ear include the cochlea, the vestibule and the three semicircular canals. The cochlea is a coiled tube that looks like the shell of a snail. It is further divided into three distinct fluid-filled canals along the length of the cochlea called the vestibular canal, the cochlear canal and the tympanic canal. There is a partition between the cochlear canal and the tympanic canal called the basilar membrane. Within the basilar membrane is the is the spiral shaped organ of the Corti. There are sensory cells in the organ of Corti have several rows of hairlike projections that are attached to nerve cells. Each hairlike projection contains cilia that are bent when the basilar membrane receives sound vibrations from the middle ear. From here they are sent to the brain via the auditory nerve. The brain interprets these vibrations as specific sounds.

The best way to help students understand how the sensory cells in the organ of Corti work and to remember the terms is to have them imitate to actions of the inner ear. This can be done by having the students stand close together in an open area with their hands above their heads. Have them pretend that they are hair cells, and that their arms are hairs. Tell the students that they simulate the bending and swaying of the hairs in the organ of Corti. Instruct them that when a loud sound is heard they will bend low and if a soft sound is heard they will sway and stand tall. This is what occurs before they are sent to the brain via the auditory canal.

The second main structure of the inner ear, the vestibule, has very little to do with hearing. Its primary job is to help the body maintain balance and orientation through constantly monitoring the sensation of movement and position. The vestibule is made up of two sacs called the utriculus and the sacculus. There are special sensory areas in the wall of the utriculus, which sends impulses to the brain distinguishing the position of the head. The sensory areas have hairlike particles embedded in gelatin covered with mineral particles. The mineral particles exert pressure on the sensory cells according to the position of the head. The cells then send a specific pattern of nerve impluses to the brain. The structure of the sacculus resembles that of the utriculus. It also aids in body orientation and plays a small role in the function of hearing.

The third main structure of the inner ear is the three semicircular canals. Movement is detected from these tubes and a signal is sent to the brain. These canals direct balance as the body moves in a straight line or turns in different directions. Each of the canals contains sensory areas with hair cells that project into a cone-shaped cap of gelatin. One canal is horizontal and detects horizontal movement like turning and spinning. The other two semicircular canals are in a vertical position and detect vertical movement such as jumping or falling.

The ways in which each of the canals reacts depend on the inertia of the fluid inside. As our bodies change motion, the fluid in the canal lags behind causing the hair cells in the canal to bend. As the hair cells bend, they send nerve impulses to brain causing the canals to respond to the movement of the body. This can be demonstrated by using a half gallon plastic milk bottle filled halfway with water. By sloshing the water around in the container. The kids will get an idea of the inertia effect.

To help students better understand the importance of these balancing organs in the ear simple experiments can be performed that affects the impulses sent to the brain. Simply have the students spin around and around and tell them to walk along a straight line. If they spun fast enough, they will have trouble doing this simple task. After giving them a few seconds to regain their balance, have them spin around again and then change the direction in which they are spinning. They should also have difficulty in performing this particular task. At the end of these two exercises, have the students discuss the importance of the organs in the inner ear.

Hearing

Humans hear primarily by detecting sound waves, which enters the pinna and are and magnified by the auditory canal. Sound waves are then directed towards the tympanic membrane. The pressure of the air molecules cause the tympanic to vibrate. This causes the malleus on the other side of the membrane to move. The handle of the malleus strikes the incus causing it to vibrate. The vibrating incus moves the stapes in and out and vibrates the oval window.

The sound wave is transferred to the oval window and given support from the ossicles. They are particularly helpful because the fluid in the inner ear is more difficult to move than air; therefore the sound must be amplified. As the vibrations pass from the large area of the eardrum through the osscicles, which have a smaller area, their force is much more concentrated and causes the sound to become amplified. Once the sound wave reaches the inner ear from the oval window it sets up pressure changes that vibrates the vestibule. To relieve this pressure, the membrane of the oval window bulges in and out. The basilar membrane moves because of the alternating changes of pressure in the fluid of the canals. The organ of Corti also moves causing the hairlike projections to bend. As the hairlike projections bend, they stimulate the sensory cells to transmit impulses along the auditory nerve to the brain.

The Science of Sound and Instruments

Much of what we know about music and how tension, length, and thickness affect the frequency of vibrating strings can be accredited to the Greek philosopher Pythagoras. He discovered that if one string vibrates with twice the frequency of an identical string, we hear the higher frequency as once octave higher in pitch than the lower frequency. This can be demonstrated by playing the middle C on a piano, then the next C to the right. That pitch will be one octave higher because the second C will resonate with the middle C and increase its amplitude. Pythagoras also found that whole number ratios of frequencies produce sounds that are harmonious to the human ear. That is the reason we found the two different C notes on the piano to be pleasing to the ear. Even the musical scale is based on the frequency ratios of sound.

As we investigate musical instruments, we will discover that some type of vibrating system produces all musical sounds. The strings on the guitar, or the air column in the clarinet, and the head of the drum are examples of vibrating systems. The vibrating systems on most musical instrument are made up of two or more vibrating systems working together to produce sounds loud enough to be heard by the human ear. Examples of instruments with two or more vibrating systems include the membranes of leather stretched across the tensioning loop of a drumhead, the strings and the sounding board of a piano. Other examples are the strings and the body of a guitar or violin, or the reed and air column of the air column of the clarinet.

A vibrating string produces very little sound. Therefore, most string instruments have a sounding board. Your students can investigate how the sounding board increases the intensity of a sound by stretching a rubber band between your finger and thumb. Pluck the rubber band and describe the loudness of the sound. Then have the students place the same rubber band around a pie plate and pluck the rubber band. They will find that the sound of rubber band is much louder.

The sounding board on musical instruments increases sound in the exact same manner. The vibration made on the sounding board is called forced vibration because the natural frequency of the board usually does not match the frequency of the vibrating string. As the two frequencies match when the string is plucked, resonance amplifies the sound.

Wind instruments depend on the vibration of a column of air to produce sound. The column of air vibrates when wind is blown into or across an instrument. There are two types of wind instruments, brass and woodwind instruments. Brass instruments are played by vibrating the lips and pressing them against the mouthpiece of the instrument. This causes the air column to vibrate and create sound. Woodwind instruments such as the clarinet need a reed to make the air columns vibrate. The column of air vibrates in the flute and piccolo when air is blown across a hole. Higher or lower pitch can be produced in these instruments by making the air column shorter or longer.

Most percussion instruments produce sound when the material stretched over a hollow container vibrates when struck by a stick, mallet or hand. However, some percussion instruments are solid and vibrate when it is struck by another object. The piano is also considered a percussion instrument because the strings are set into motion or vibration by a hammer, which acts on the bridge of the piano, which cause the sounding board to vibrate. The percussive instruments produce pitch either by tightening the stretched material, or by using thinner or smaller pieces of material.

Lesson Plans

Lesson I: Making Sound Waves Visible

Materials Needed

Tuning fork
Bowl or Cake pan
Water
Rubber Mallet

Procedures

(1) Strike the tuning fork against a rubber mallet and hold it in the air. Observe what happens to the tuning fork.

(2) Fill the bowl almost to the top with water.

(3) Strike the tuning fork against the mallet once again and stick it into the bowl of water. Observe what happens to the water in the bowl.

Conclusion

What happened when you struck the tuning fork against the mallet? What happened when you struck the tuning fork against the mallet and placed it in the bowl of water?

Explanation

Once the mallet is struck by the tuning fork it vibrates and produces sound. The vibration coming from the tuning fork causes the water to move out in wave formation.

Lesson II: Frequencies of Different Sounds

Materials Needed

- Metal ruler
- Wood ruler
- Plastic ruler
- Large rubber band
- Small rubber band

Procedures

(1) Place the metal ruler on your desk so that about half of it is sticking out from the edge of your desk.

(2) While your partner holds the ruler in place, press down firmly on the edge of the ruler and release the ruler. Observe how fast the ruler vibrates and the sound it makes.

(3) Repeat steps 1 and 2, with about three-fourths of the ruler is sticking out from the edge of the desk.

(4) Using the ruler made from wood, repeat steps 1, 2, and 3.

(5) Using the ruler made from plastic, repeat steps 1, 2, and 3.

Conclusion

Did you notice a difference in the sound and how fast the rulers vibrated (frequency) when you had it half and three-fourths of it hanging off the side of your desk? Explain. Were there any differences between how fast the rulers vibrated (frequency) and sound of the different rulers? Explain. What did you find out from this experiment?

Explanation

Vibrations caused the sounds produced by the rulers. The speed at which the vibrations occurred determines its frequency. The length of a vibrating object affects it pitch. The materials an object is made of affects its frequency.

Lesson III: Making Musical Sounds by Changing Pitch

Materials Needed

Eight empty plastic or glass bottles that are the same size
Water
Pencil

Procedures

(1) Arrange the bottles in a row and fill the first one close to the top with water. Blow across the top of the bottle and observe the sound (pitch) coming from the bottle.

(2) Fill the next bottle with a little less water than the first bottle. Blow across the top of the bottle and observe the sound (pitch) coming from the bottle.

(3) Fill the remaining bottles with less water than the previous bottles. Blow across the top of the bottle and observe the sound (pitch) coming from the bottle.

(4) Now tap on the first bottle with a pencil. Observe the sound (pitch) coming from the bottle.

(5) Tap on the remaining bottles and observe the sound (pitch) coming from each of the bottles.

Conclusion

What did you notice about the pitch coming from the bottles as you blew on each one of them in descending order? Was there a difference in the pitch when you blew on the bottles than when you tapped on the bottle? Explain your answers.

Explanation

Different sounds are produced by changing the length of the object, or air volume through which the air vibrate. Shorter air columns produce higher pitches that longer air columns. When the glasses are tapped, they react in the same manner.

Lesson IV: Sympathetic Vibration

Materials Needed

Four pieces of string 1 meter long
Two items to support the string (chairs or tables will work perfectly)
Three identical objects to be suspended from a piece of string

Procedures

(1) Attach one piece of string as tightly as possible between two chairs.

(2) Take the three remaining pieces of string and tie them at equal lengths apart on the string between the two chairs.

(3) Tie the weights at different heights to each of the three strings. Make sure that the knot can be easily undone.

(4) Once the weights are hanging in a still position. Swing the first weight from side to side like a pendulum.

(5) Observe and record what happens to the other weights along the string.

(6) Take turns swinging the other weights at separate interval and record what happens.

Conclusion

What happened to the other two weights when you swung the first weight? When you swung the other two weights? Why did this happen?

Explanation

When one of the pendulums along the line is set into motion, the other ones felt the tiny vibrations (resonance) traveling down the string. The second pendulum will begin to vibrate or swing (sympathetic vibration) because it is on the same natural frequency as the first pendulum. The same action causes the third pendulum to move.

Lesson V: Resonance

Materials Needed

A variety of pots and pans
String

Procedures

(1) Tie a piece of string around the handles of each of the pots and pans. Make sure they are secure.

(2) Tie each of the pots and pans to a strong support system. Make sure they are secure and will not fall during the experiment.

(3) Once all of the pots and pans are hanging safely and you are sure there is no chance of them falling continue with step four.

(4) Label each pot and pan A, B, C, etc..., until all the items are labeled.

(5) Sing a steady loud note into each of the pots and pans for a few seconds. Record your observations for each letter on a chart.

Conclusion

Did some of the pots or pans resonate better than others? If so, which ones? Do you think that the materials in which the pots and pans were made of make a difference in their resonating qualities? If so which ones?

Explanation

The students should hear a sound reflecting from the pans. Because some materials resonate better than others, the students may not hear anything when they sing a single note into a pan.

Teachers' Annotated Bibliography

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