Curriculum Units by Fellows of the Yale-New Haven Teachers Institute
2000 Volume V: Sound and Sensibility: Acoustics in Architecture, Music, and the Environment

Math and Science Objectives Taught Using Sound and Music Concepts

Curriculum Unit 00.05.04
by Mary Elizabeth Jones

Objectives

Discuss the relationship between frequency and wavelengths in a transverse wave and compressional (longitudinal) waves.

Use the relationship between wavelength, frequency and wave velocity to find one variable when two are given.

Illustrate the Doppler effect.

Analyze the role of noise as one type of pollution

Distinguish between noise and music.

Research the original scientists of math and sound.

Teach math concepts.

This unit is designed to be taught over one marking period to 6th grade math and science students. The unit is divided into three sections. The first section covers wave characteristics, sound velocity, pitch and frequency and the Doppler effect. The second section explores amplitude, sound pressure level, noise, and musical sounds. The last section focuses on persons involved in the origins of sound.

In order to make this unit meaningful to a math or science class, we must show a relationship between music, math and science. The Pythagorean Doctrine made the connection in this way. Geometry (math) as magnitude at rest. Astronomy (science) as magnitude in motion. Arithmetic as numbers absolute and music as numbers applied.

Students will discuss wave characteristics such as how sound waves travel and two types of wave motion. Students will learn to describe the transmission of sound through a medium and be able to recognize the relationship between amplitude, loudness and frequency of pitch.

Math skills will be taught using information compiled in science class.

Students will learn to apply specific formulas to solve problems. Opportunities will be provided for students to use math skills to measure, calculate, graph, and analyze data and complete mini-lab activities.

When is it music and when is it noise? Students will learn to recognize noise as a form of pollution and identify sounds that are considered noise both through frequency content and loudness. Students will be required to complete a report on the effects of noise on hearing and what can be done to protect their hearing.

Students will be required to research the original great scientists (such as Pythagoras and Thales) of sound and math along with their contributions. The research will be used to prepare a report.

Characteristics and types of waves

One of the first characteristics of a wave is that they can transport energy and information from one place to another through a medium, but the medium itself is not transported. A disturbance, or change in some physical quantity, is passed along from point to point as the wave moves. In the case of light waves or radio waves, the disturbance is a changing electric and magnetic field; in a sound wave, it is a change in pressure and density. In both cases, the medium reverts to its undisturbed state after the wave passes.

Two types of waves will be discussed in this section; transverse waves and compressional waves. A transverse wave is one in which the vibrations are at right angles to the direction the wave is traveling (ex. Waves on a rope). A compressional wave is one in which the vibration is in the same direction as the wave is traveling (ex. Sound waves in the air).

Transverse Waves

Have you ever seen stadium waves created by excited fans at a baseball game? Stadium waves, water waves, microwaves, sound waves and radio waves all have one thing in common. They all transfer energy from one place to another.

Water waves are probably the easiest type of wave to visualize. If you have been in a boat, you know that approaching waves bump against the boat but do not carry the boat along with them. The boat just moves up and down as the waves pass by. Like the boat, the water molecules on the surface of the lake move up and down, but not forward. Only energy carried by the waves moves forward.

Waves are rhythmic disturbances that carry energy through matter or space.

Water waves transfer energy through the water. Earthquakes transfer energy in powerful shock waves that travel through Earth. Both types of waves travel through a medium. A medium is a material through which a wave can transfer energy. This medium may be a solid, a liquid, a gas or a combination of these. Radio waves and light waves, however, are types of waves that can travel without a medium.

Two types of wave motion can carry energy. Figure 1 shows how you can make a transverse wave by snapping the ends of a rope up and down while a friend holds one end. Figure 2 shows how a compressional wave should look.

Notice that as the wave moves, some of the coils are squeezed together just as you squeezed the ones on the end of the spring. The crowded area is called compression.

The compressed area then expands, spreading the coils apart creating a less dense area. This less dense area of the wave is called a rarefaction. Does the whole spring move? Tie a piece of string on one end of the coils and observe the motion. The string moves back and forth with the coils. Therefore, the matter in the medium does not move forward with the wave. Instead, the wave carries only the energy forward.

Transverse waves have wavelengths, frequencies, amplitudes and velocities. Compressional waves also have these characteristics. A wavelength in a compressional wave is made of one compressional, and one rarefaction as shown in Figure 3. Notice that one wavelength is the distance between two compressions or two rarefactions of the same wave. The frequency is the number of compressions that pass a place each second. If you repeatedly squeeze and release the end of the spring three times each second, you will produce a wave with a frequency of 3 Hz.

The high, almost dense points of a wave are called crests; the lowest points are called troughs. Waves are measured by their wavelength. Wavelength is the distance between a point on one wave and the identical point on the next wave, such as from crest to crest or trough to trough.

Frequency and Pitch

Frequency is the number of waves that pass through a point in one second, expressed in Hertz (Hz). Pitch is the highness or lowness of a sound. The pitch you hear depends on the frequency of the sound waves. The higher the frequency, the higher the pitch; the lower the frequency, the lower the pitch. A healthy human ear can hear sound frequencies from about 20 Hz to 20,000Hz. As people age, they often have trouble hearing high frequencies.

Do high-pitched sounds travel at a different speed than low-pitched sounds? Let’s ask this question differently. If you were at an outdoor band concert (without electronic amplification) and the conductor gave the downbeat to the band, would the sound of the piccolo get to you before or after the sound of the tuba?1

Your experience will help to tell you that if there were much of a difference in the arrival times between high and low pitches, not only would it be difficult to keep the performance together, but also it would sound quite different up close to the band than further away. In fact, sound in the normal audible range travels at a constant speed independent of pitch.

Most people cannot hear sound frequencies above 20,000 Hz The frequency of the human voice range that carries information extends from about 250 to about 2000 Hz in a normal conversation. Bats, however, can detect frequencies as high as 100,000 Hz. Ultrasound waves are used in sonar as well as in medical diagnosis and treatment. Sonar, or sound navigation ranging, is a method of using sound waves to estimate the distance to, size, shape and depth of underwater objects.

Sound must have a medium (liquid, gas or solid) through which to travel. It cannot travel through a vacuum. A vacuum is a space that is empty of everything, even air. If you put a ringing alarm clock into a jar and pump the air out of the jar, the sound of the ringing will decrease as you pump out the air. When most of the air molecules are out of the jar, not enough molecules remain to form sound waves and the ringing sound stops.

Doppler

Imagine the sound you hear when a fire truck with its siren on rapidly approaches and then passes you. As the truck is moving toward you, the pitch of the siren sounds higher. The motion of the siren toward you compresses the sound waves closer together. This increases the frequency of the sound waves striking your ear. As a result, the pitch you hear is higher. As the siren moves away the waves are pulled farther apart. This decreases the frequency and you hear a lower pitch. This change in wave frequency is called the Doppler effect. The Doppler effect is observed when the source of sound is moving or when the observer is moving.

Amplitude

Water waves can be described by how high they appear above the normal water level. Amplitude describes wave height. Amplitude is the distance from the crest (or trough) of a wave to the rest position of the medium. See Figure 4. Amplitude relates to the amount of energy carried by the wave. Waves that carry great amounts of energy have large heights or amplitude; waves that carry less energy have smaller amplitudes.

When two waves of the same frequency reach the same point, they may interfere constructively or destructively. If their amplitudes are both equal to A, the resultant amplitude may be anything from zero up to 2 A. The same is true of a wave that reflects back on itself after hitting a hard surface.2

Wave Frequency

The frequency of a wave is the number of wave crests that pass one place each second. Frequency is measured in hertz (Hz). One hertz is the same as one wave per second. To increase the frequency of the wave in Figure 1, you move the rope up and down faster. As the frequency increases, the wavelength decreases.

Wave Velocity

Sometimes you may want to know how fast a wave is traveling. For example, earthquakes below the ocean can produce giant tidal waves. You would want to know how soon a tidal wave would reach you, if you needed to seek shelter. Wave velocity, (v) describes how fast the wave crests move.

Wave velocity can be determined by multiplying the wavelength and frequency. Wavelength is represented by the Greek letter lambda, ». If you know any two variables in an equation you can find the unknown variable. Velocity = wavelength x frequency.

For sound waves, the sound velocity does not change with frequency for a given medium.

Calculating the Movement of Sound

The two examples that follow show how you can use the above equation to solve for frequency or velocity.

Calculating the Frequency of a Wave

Problem: Earthquakes can produce three types of waves. One of these is a transverse wave called an s wave. A typical s wave travels at 5000m/s. Its wavelength is about 417 m.

What is its frequency?

Known

Information Velocity, v = 5000m/s

Strategy Hint: Remember, Wavelength, »= 417m

Hz= 1/s, so m/s divided by

m = 1/s = 1 Hz

Unknown Information frequency (f)

Equation to use v = » x f

Solution3 v = » x f, so f = v/»

= (5000m/s)/(412m) = 12 Hz

Calculating Velocity of a Wave

Problem: A wave is generated in a wave pool at a water amusement park. The wavelength is 3.2 m.

The frequency of the wave is 0.60 Hz.

What is the velocity of the wave?

Known

Information wavelength, »= 3.2 m

Strategy Hint: Another way frequency, f = 0.60 Hz

To express Hertz is 1/second,

Therefore, m x 1/s = m/s.

Unknown information velocity (v)

Equation to use v = » x f

Solution3 v = » x f = 3.2 m x 0.60Hz = 1.92 m/s

Class Activities

Activity 1. Transverse waves

Problem: Resonance: How can wave energy be stored?

Materials
small Slinky

stop watch

Procedure

1. You and a partner should pull on each end of the slinky until it stretches about I meter.

2. Hold one end of the Slinky motionless and shake the other end to make the slinky vibrate in one segment transverse to its length.

3. Count the number of vibrations the spring makes in 10 seconds.

4. Make a second wave by moving the end of the spring from side to side twice as fast as before. Look for the spring to vibrate in two equal segments. Each segment will move in opposite directions.

5. Try to make the spring vibrate in three equal segments.

Analyze

1. Draw pictures of the spring for each of the three forms of wave you made. How many transverse waves does each picture represent?

2. The spring can store energy when the wave is the right size to exactly "fit" onto the spring. That is, you produce a resonance. How many wavelengths fit onto the spring for each of the three forms of waves produced.

Conclude and Apply

3. If wave energy is to be stored in the spring, how must the length of the spring and the length of the wave compare?

4. Why could you store short wave energy in a long spring but are not able to store long wave energy in a short spring?

Answers to questions

1. Drawing should show

One half of wave.
One full wave
One and a half waves

2. The first-the spring holds one half of a wave. The second-the spring holds two halves of a wave. The third-

the spring holds three halves of a wave.

3. Wave energy can be stored in the spring if the spring is some whole number or half number of waves in length.

4. In order to store wave energy, the spring must be at least a half wavelength long.

Activity 2. Frequency of Sound Waves

Problem: What is the frequency of a musical note?

Materials
plastic pipe
rubber band
metric ruler

Procedure

1. Measure the length of the pipe and record it on the data table.

2. Stretch one end of the rubber band across the open end of the pipe and hold it firmly in place. Caution: Be careful not to release your grip on the ends of the rubber band.

3. Hold the rubber band close to your ear and pluck it.

4. Listen for a double note.

5. Slowly relax the tightness of the rubber band. Listen for one part of the double note to change and the other part to remain the same.

6. Continue to adjust the tightness until you hear only one note.

7. Exchange pipes with another group and repeat the experiment.

Data and Observation – sample data table

Sound Frequencies produced by an open Pipe

Length of Pipe = 0.2m
Length of wave = 0.4m
Frequency of sound = 855Hz

Analyze

1. The wavelength you obtained in step 6 is twice the length of the pipe. Calculate the wavelength.

2. Assume the velocity of sound to be 342 m/s. Use the equation frequency = velocity/wavelength to calculate the frequency of the note.

3. What was the wavelength and frequency of the sound waves in the second pipe?

Conclude and Apply

4. How does the length of a pipe compare with the frequency and wave?

length of the sound it can make? 5. A pipe organ uses pipes of different lengths to produce various notes. What other musical instrument uses lengths of pipe to produce musical notes?

6. If you listen closely, you can hear longer pipes produce certain higher frequency sounds. How is this possible?

Answers to questions.

1. Longest wavelength = 2 X pipe length

2. 32,200 cm/se = 805 Hz

40 cm

3. Answers will vary. Wavelength will increase and frequency decrease as the pipe become longer.

4. The longer the pipe, the longer the wavelength and the lower the frequency.

5. All horns and woodwinds as well as the human voice use a vibrating air column.

A xylophone uses open pipes to amplify the sound of the vibrating bars.

6. A series of shorter waves will “fit” the pipe if their wavelengths are 1 X, 2/3 X, ½ X, 2/5 X……the length of the pipe.

Compressional waves

Sound pressure level

In a sound wave there are extremely small periodic variations in atmospheric pressure to which our ears respond in a rather complex manner. The minimum pressure fluctuation to which the ear can respond is less then one billionth (10-9) atmospheric pressure. This threshold of audibility, which varies from person to person, corresponds to a sound pressure amplitude of about 2 x 10-5 N/m2 (Newton’s/meter 2) at a frequency of 1000 Hz. The threshold of pain corresponds to pressure amplitude approximately one million

(10^6) times greater, but still less than 1/1000 of atmospheric pressure.

A sound level meter, consisting of a microphone, an amplifier and a meter that reads in decibels, measures sound pressure levels. Sound pressure levels of a number of sounds are given in Table 2. Class exercise: students can obtain a feeling for different sound pressure levels by using a sound level meter.

Table 2 Typical Sound Levels

Jets take off (60 Meters) 120 dB
Construction site 110 dB intolérable
Shout (1.5 meters) 100 dB
Heavy truck (15meters) 90 dB very noisy
Urban street 80 dB

Automobile interior 70 dB noisy

Normal conversation (1 meter) 60 dB
Office, classroom 50 dB moderates
Living room 40 dB

Bedroom at night 30 dB quiet

Broadcast studio 20 dB

Rustling leaves 10 dB barely

audible4

The word sound is used to describe two different things: (1) and auditory sensation in the ear and (2) the disturbance in a medium which can cause a sensation.

Think of all the sounds that you've heard since you awoke this morning. Did you hear a blaring alarm, honking horns, human voices, and lockers slamming? Your ears allow you to recognize these different sounds. These sounds all have one thing in common. The vibration of objects produces them all. The vibrations of your vocal cords produce voice. The energy produced by these vibrations is carried to your friend's ear by sound waves traveling through a medium, air.

The speed of sound waves depends on the medium through which the wave travels and it temperature. Air is the most common medium you hear sound waves through, but sound waves can be transmitted through any type of matter. Liquids and solids are even better conductors of sound than air because the individual particles in a liquid or solid are much closer together than the particles in air.

Sound waves transmit energy faster in substances with smaller spaces between the particles. A research question for students: Can sound be transmitted if there is no matter? Astronauts on the moon would find it impossible to talk to each other without the aid of modern electronic communication systems. Since the moon has no atmosphere, there is no air to compress or expand.

The temperature of the medium is also an important factor in determining the speed sound travels. As the temperature of the substance increases, the molecules move faster and collide more frequently. This increase in molecule collisions transfers energy more quickly. Sound travels through air at 344 miles/second if the temperature is 20o C, but only 332 miles/second when the temperature is 0o C.

To better understand sound waves, consider a large pipe or tube with a loudspeaker at one end. Although sound waves in this tube are similar in many respects to the waves on a rope, they are more difficult to visualize, because we cannot see the displacement of the air molecules as the sound wave propagates. The pulse of air pressure travels down the tube at a speed of about 340 miles/second. It may be absorbed at the far end of the tube, or it may reflect back toward the loudspeaker (as a positive pulse or a negative pulse), depending on what is at the far end of the tube.

Reflection of a sound pulse in a pipe for three different end conditions is illustrated in Figure 5. If the end is open, the excess pressure drops to zero and the pulse reflects back as a negative pulse of pressure as shown in Figure 5b; this is similar to the “fixed end” condition.

In an actual tube with an open end, a little of the sound will be radiated; most of it however, will be reflected as shown. If the end is closed, the pressure builds up to twice its value, and the pulse reflects back as a positive pulse of pressure; this condition shown in Figure 5c is similar to the “free end” reflection. If the end is terminated with a sound absorber, Figure 5d, there is virtually on reflected pulse. Such a termination is called “no echo.”

Table 1 Speed of sound in various materials

Temperature Speed

Substance 0 meters/sec. Feet/sec.

Air 0 331.3 1087

Air 20 343 1127

Helium 0 970 3180

Carbon Dioxide 0 258 846

Water 0 1410 4626

Methyl Alcohol 0 1130 3710

Aluminum - 5150 16,900

Steel - 5100 16,700

Brass - 3840 11,420

Lead - 1210 3970

Glass - 3700-5000 12 – 16,0005

Wave movements in two and three dimensions

So far we have discussed only waves that travel in one direction (ex. along a rope or in a pipe). One-dimensional waves of this type are a rather special case of wave motion. Often, waves travel outward in two or three dimensions from a source.

Water waves are an example of two-dimensional waves. Many waves can be studied conveniently by means of a ripple tank in a laboratory. A ripple tank uses a glass-bottom tray filled with water; light projected through the tray forms an image of the wave on a large sheet of paper or on a projection screen. If the materials were readily available, this would be an excellent exercise for the students. Many calculations could be performed from the data collected.

Three-dimensional waves are difficult to make visible. For this unit we will not explore the techniques used to identify 3-dimension waves.

Multiple sources of sound

Sometimes we are concerned with more than one source of sound. The way in which sound levels add may seem a little surprising at first. For example, two different sources each of which would produce a sound level of 80 dB at a certain point will together give 83 dB at that point. Figure 6 gives the increase in sound level due to additional equal sources. It is not difficult to see why this is the case, since doubling the sound power raises the sound power level by 3 dB, and thus raises the sound pressure level 3 dB. Under some conditions, however, there may be interference between waves from the two sources and the doubling relationship will not hold true.

A Science and Math activity: The timer at a track meet starts the watch when he hears the sound of the gun rather than when he sees the flash of the gun being fired. If the gun were 200 m away from him, how much faster or slower would the recorded time be than the actual time?

SOLUTION: The speed of light is 300,000,000 m/s, so the light gets there virtually instantaneously. The speed of sound is about 330 m/s, so the timed speed will be 0.3 s faster than the real speed.

A Science and writing activity: You have just formed a new company, Ultrasonic Unlimited. Develop an advertisement for a product that uses this sound energy. SOLUTION; an encyclopedia will describe many uses including scientific, industrial, medical and residential.

Intensity and Loudness

The intensity of a sound wave depends on the amount of energy in each wave. This, in turn, corresponds to the wave’s amplitude. Intensity of a sound wave increases as its amplitude increases.

Loudness is the human perception of sound intensity. The higher the intensity and amplitude, the louder the sound. The intensity of a sound is measured in units called decibels (dB). Sounds with intensities above 120 dB may cause pain and hearing loss. Prolonged noise above 150 dB can cause permanent deafness. The roar of a racing car can be 125 dB, amplified music as high as 130 dB, and some toy guns 170 dB. Figure 7 shows some familiar sounds and their intensities in dB.

.

Noise

The most common kind of sound is noise. We are all surrounded by noise in our daily lives. Noise is defined as sound that has no pattern or defined pitch. Noise affects people in many ways. In addition to causing temporary and permanent hearing loss, noise interferes with speech communication, interrupts sleep, reduces human efficiency, and is believed to produce other physiological and psychological effects.

The effect of noise on the performance of various tasks has been the subject of several investigations in the laboratory and in actual work situations. When mental or motor tasks do not involve auditory (hearing) signals, the effects of noise on human performance have been difficult to assess.

Psychological effects of noise:

1. Steady noises below about 90 dB do not seem to affect performance.

2. Noise with appreciable strength around 1000 to 2000 Hz is more disruptive than low – frequency noise.

3. Noise is more likely to reduce the accuracy of work than to reduce the total quantity of work.

4. Noise appears to interfere with the ability to judge the passage of time.

5. There is a general feeling that nervousness and anxiety are caused by or intensified by exposure to noise.

Physiological effects of noise

Sudden noises are startling. They trigger a muscular reflex that may include an eye blink, a facial grimace or inward bending of arms and knees. These reflexes prepare the body for defensive action against the source of the noise. Sometimes these reflexive actions interfere with some tasks: sometimes they even cause accidents.

Constriction of blood vessels, reduction of skin resistance, change in heartbeat and secretion of saliva have been observed in human response to brief sounds. There is evidence that workers exposed to high levels of noise have a higher incidence of cardiovascular disorders such as ear, nose and throat problems and equilibrium problems than do workers at lower levels of noise.

@3H(after2H):Noise pollution When does noise become noise pollution? Noise pollution includes sounds that are loud, annoying or harmful to the ear. These sounds can come from sources such as jackhammers, a jet engine or highly amplified music.

Noise pollution can be harmful in several ways. Recall the way in which sound waves transfer energy through compressions and rarefactions. If the intensity of the sound wave is high enough, the energy carried can shatter windows and crack plastic.

When sound waves reach the human ear, the vibrations pass through various parts. Extremely intense vibrations can rupture the eardrum, but loudness-related hearing loss usually develops gradually. Your brain perceives sound when the auditory nerve carries a nerve impulse to the brain. The nerve is composed of many tiny nerve fibers surrounded by a fluid inside the ear. Hearing loss occurs when intense compressional waves traveling through the fluid destroys these nerve fibers. Loud sounds in the frequency range of 4000 to 20,000Hz cause most of the damage to these nerve fibers. Amplified music, motorcycles and machinery are sources of sound in this frequency range that often cause hearing loss after prolonged listening.

Controlling noise pollution (environmental acoustics)

Noise pollution can be controlled in a number of ways. Reducing the intensities of the sound waves from sources that cause noise pollution can decrease noise pollution. Acoustical engineers have quieted the noise made by many devices. For example, mufflers help quiet automobile engines. In buildings, thick heavy walls, well-sealed doors and windows, may be used to block sound. Builders use insulation to reduce sound. Industrial workers and other people exposed to intense noise should wear some form of ear protection to help prevent hearing loss.6

Musical sounds What is Music? Vibrations cause both music and noise, but there are some important differences. You can easily make a noise by just speaking a word or tapping a pencil on a desk, but it takes some deliberate actions to create music. Music is created using specific pitches and sound quality and by following a regular pattern.

A stringed musical instrument such as a guitar generates sound when you pluck a string. Plucking a string creates waves in the string. Because the ends of the strings are fastened, the waves reflect back and forth between the ends causing the string to vibrate at certain particular frequencies that are harmonically related to each other.

The guitar string, like most objects has a natural frequency of vibration. Plucking it causes the string to vibrate at its natural frequency.

If you were to play a note of the same pitch and loudness on a flute and on a piano, the sound wouldn’t be the same. These instruments have a different quality of sound. The quality does not refer to how good or bad the instrument sounds. Sound quality describes the difference among sounds of the same pitch and loudness. All sounds are produced by vibrations of matter, but most objects vibrate at more than one frequency. Distinct sounds from musical instruments are produced by different combinations of these wave frequencies.6

Mini-Lab: How can a hearing loss change the sounds you hear? To simulate a hearing loss, tune a radio station. Turn the volume down to the lowest level you can hear and understand. Turn the bass to maximum and the treble to minimum. If the radio does not have these controls, mask out the higher frequency sounds with heavy pads over your ears. Which voices are hardest to understand men's or women's? What letter sounds are the most difficult to hear, vowels or consonants? How could you help a person with a hearing loss understand what you say? Solution: Most hearing losses are in the higher frequencies of the speech range. Most affected are women's voices and consonant sounds. People with hearing losses should be spoken to face to face, at a steady, unrushed pace with a slight emphasis on consonant sounds.

Origins of Sound

The sounds of music and speech are deeply rooted in man's evolutionary past. The study of sound began in ancient times. As early as the 500’s B.C., Pythagoras, a Greek philosopher and mathematician, conducted experiments on the sounds produced by vibrating strings. Pythagoras is said to have invented the sonometer, an instrument used to study musical sounds. This philosopher of Samos and Crotona, and his master, Thales of Miletus (ca. 640-546 B.C.), were the intellectual pioneers who introduced and established mathematics in the culture of ancient Greece. Pythagoras is primarily remembered now for his espousal of the science of numbers: this doctrine shaped nearly all inquiries about the nature of sound for the next few centuries.

Pythagoras was also one of the first to insist that precise definitions should form the cornerstone for logical proofs in geometry, although he is better remembered in this field for the unhistorical association of his name with the already well-known theorem about sums of the squares on the side of a right triangle. His teacher Thales, the first of the seven Wise Men of Greece had already brought deductive rigor to bear on geometry by introducing the concepts of logical proof for abstract propositions.

The most enduring contribution Pythagoras made to acoustical theory was to establish the inverse proportionality between pitch and the length of a vibrating string.

Aristotle (384 – 322 B.C.) probably deserves to be called the first mathematical physicist, since he was deeply concerned with the whole range of natural philosophy and with the use of mathematical reasoning as a tool for examining nature. The relative velocity of transmission of light and sound periodically commanded the attention of philosophers and scientist until nearly the middle of the eighteenth century. In referring to the physical nature of sound Aristotle wrote “lightning comes into existence after the collision and the [resulting] thunder, though we see it earlier because sight is quicker than hearing.” This inverted notion that thunder causes lightning persisted for centuries.7

Two other historians of antiquity expressed proper conclusions concerning the relative velocity of the transmission of light and sound. Pliny the Elder (A.D. 23-79) observed, “it is certain that when thunder and lightning occur simultaneously, the flash is seen before the thunderclap is heard (this is not surprising, as light travels more swiftly than sound).”

In about 400 B.C. Greek scholar Archytas (428 – 347 B.C.) expressed the fundamental idea that sound is always produced by the motion of one object striking another. This statement was paraphrased in one way or another and repeated by almost every writer of ancient and medieval times who considered the generation of sound. About 50 years later, the Greek philosopher Aristotle suggested that sound is carried to our ears by the movement of air. From then until about A.D. 1300, little scientific investigation took place in Europe, but scientists in the Middle East and India developed some new ideas about sound by studying music and working out systems of music theory.

European scientist began extensive experiments on the nature of sound during the early 1600’s. About that time, the Italian astronomer and physicist Galileo demonstrated that the frequency of sound waves determines pitch. Galileo scraped a chisel across a brass plate, producing a screech. He then related the spacing of the grooves made by the chisel to the pitch of the screech,

About 1640, Marin Mersenne, a French mathematician, obtained the first measurement of the speed of sound in air. About 20 yeas later, the Irish chemist and physicist Robert Boyle demonstrated that sound waves must travel in a medium. During the late 1600's, the English scientist Sir Isaac Newton formulated an almost correct relationship between the speed of sound in a medium and the density and compressibility of the medium.

In the mid-1700's, Daniel Bernoulli, a Swiss mathematician and physicist, explained that a string could vibrate at more than one frequency at the same time. In the early 1800's, a French mathematician named Jean Baptiste Fourier developed a mathematical technique that could be used to breakdown complex sound waves into pure tones that make them up. During the 1860's, Herman von Helmholtz, a German physicist, investigated the interference of sound waves, the productions of beats and the relationship of both to the ear's perception of sound.8

Research Activity: Euclid of Alexandria (330-275 B.C.), Archimedes (ca. 287-212 B.C.), Galileo (1564-1642) and Plato (ca. 429-347 B.C.) are but a few of the great scientists of sound. Have student do research to get information on ancient scientist and modern day scientist who specialize in sound and acoustics.

Conclusion

This unit was written as part of a team of three teachers. Four disciplines, reading, music/band, math and science were covered. This is the math and science unit. The other two units were Music-Through the Basics of Reading by Pamela Tonge and "Banding" Together by making instruments by Sloan Williams.

We plan to teach these three units over one marking period using as many of the same students as possible. Upon completion of the teaching, we prepared a culminating activity. The participants in this activity, which will consist of a school-wide assembly, will be the students who made their instruments.

The assembly will consist of diverse entertainment from professional entertainers. Students will prepare poster board illustrations for each musical "family." Students will display completed instruments. One student from each "Family" will explain how their instruments make music. The students will perform at least one musical number together. They will also perform with the professional performers using the instrument they made. The performers will come from various ethnic backgrounds.

Students will report on the contributions of some of the first people to study sound.

The program will conclude with an International feast prepared for all the participants in the assembly. On the day of the assembly, everyone will be encouraged to dress in ethnic clothes.

Bibliography

Apfel, Robert E. Blind Architects & Blind Acousticians? A guide to the Principles of Sound Design. 1998, Apple Enterprise Press, New Haven, CT.

This text covers how far and fast sound travels. Shows how to design acoustical spaces and quiet spaces. Includes a case study of Philharmonic Hall.

Kock, W. E. Sound Waves and Light Waves. 1965. Doubleday, New York.

Text describes how sound waves and light waves travel. Explains sound pressure and sound velocity, pitch and frequency.

Rossing, Thomas D. The Science of Sound. 1990, Addison–Wesley.

This text covers advances topics including the perception and measurement of sound. It also explores the human voice and environmental noise.

Smith, Ballinger. Physical Science. Waves, Light and sound. 1998, Merrill Press, NY.

This textbook covers physical science. Chapter 18 introduced wave phenomena. The properties and behavior of transverse mechanical waves and properties of sound are covered.

Kryter, K.D. Noise and Man. 1970. Academic Press, New York.

This book explores the effects of noise on people. Explains how noise is defined and what can be done to protect you from the dangers of noise.

Hunt, Frederick E. Origins in Acoustics. The Science of Sound from Antiquity to the Age of Newton. 1978, Yale University Press, New haven and London.

This text covers the history of sound. The contributions of the persons first involved in science are discussed. The book starts with Pythagoras (570-497 B.C.) and ends with Boethius (A.D. 480-524).

End Notes

1Apfel, R.E. Deaf Architects & Blind Acousticians? A Guide to the Principles of Sound Design. Apple Enterprises Press. Page 6. 2Rossing, T.D. The Science of Sound. Addison-Wesley, 1990. Page 90. 3Smith, Ballinger. Merrill-Physical Science. Waves, Light and Sound. McGraw Hill, 1993. Page 461. 4Rossing, T.D. The Science of Sound. Addison-Wesley, 1990. Page 86. 5Rossing, T.D. The Science of sound. Addison-Wesley, 1990. Page 41. 6Smith, Ballinger, Merrill-Physical Science. Waves. Light and Sound. McGraw Hill, 1993. Pages 463-467. 7Hunt, F.V. Origins in Acoustics. The Science of Sound. Yale University Press. Pages 9, 15, 21, 22, and 23. 8World Book Encyclopedia. Sound. 1991 Edition. Scott Fetzer Company, Page 605.

Children Reading List

World Book Encyclopedia. “Sound.” Volume 18, 1991 Edition. Scott Fetzer Company. 1960.

This section of the encyclopedia deals with sound. Included is the human Voice, animal sounds and musical sounds. Frequency and pitch, intensity and loudness and the speed of sound is explained.

Reuben, Gabriel H. What is Sound? Chicago: Benefic Press. 1960.

This book is part of the What Is series. Sound is explained using illustrations and drawings. The text is written to be easily understood by young readers.

Kettelkamp, Larry. The Magic of Sound. New York: William Morrow and Company. 1982.

This book explains why and how we hear as we do and describes some of the applications of sound in contemporary life. Easy reading for young readers.

Newman, Frederick R. Zounds. New York: Random House, 1983.

This book is a guide to sound making. Readers learn how their voice works and how it can be used to make many kinds of sound.

Broekel, Ray. Sound Experiments. Chicago: Childrens Press, 1983.

This is a book of simple sound experiments that can be conducted using household materials.