The Physics of Music

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Academic Setting

I have been teaching for two years at Truman Middle School. Truman is located on the West Side of town. The population of this school is roughly 80.4% Hispanic, 4% Native American, 10.6% Anglo, 4% African American, .5% Asian and .4% other ethnicities. Out of the 650 students who attend Truman, 117 are living in poverty; that is nearly 20% of the student body. In addition, 12% of parents are unemployed and 9% are receiving public assistance. The free and reduced lunch program for A.P.S. is utilized by 79% of the students. It is also known that many of the parents have two jobs. Consequently, many of the children of these parents do not see them for days on end. This is a frightening prospect. Many teenagers are also taking care of younger siblings.

Academically, these students are also in need. With parents gone much of the time, there is little or no assistance or encouragement with homework. The educational background of these parents also has some bearing on how well these students perform academically. The Census Data of 1990 revealed 29% of adults 25 and older in the Truman community had not received a high school diploma. Of this 29%, 19% had 9-12th grade, and the remaining 10% had less than a ninth grade education. This is to be compared to Albuquerque in general where18% are without a diploma.

There is a very active gang life on the West Side. The administration is constantly watchful for all sorts of gang-related behavior. The dress code is one way of circumventing gangs and, with hope, the adults are able to identify gang-related behavior. Certain teens will wear a specific type of shirt to display their identification with a gang. People and children are resourceful. There are many different ways to distinguish one group from another. There are a few of ways gangs identify themselves: shave an eyebrow, comb hair in a certain way, tattoos, or marking ones belongings with a specific color or design. I think this is significant because the violence and peer pressure that my students are exposed to affects how much they can concentrate in class. As a result, I am competing for their attention. Music is a powerful tool to capture it.

A large percentage of the student body is non-English speaking. Many of the children at Truman speak Spanish in their homes and English at school. Some are proficient at English, yet others cannot speak or read the language that is predominately used in the United States. Truman test scores are very low in comparison to nation-wide reading and mathematics averages. The average reading level of all sixth, seventh and eighth graders is third grade. The same is true for our mathematics scores. Is education not being emphasized in the home? Or is it that many of the students are simply not familiar with the English language?

My class is a seventh grade math and science block. Basically, I have these students for 45 minutes to teach them mathematics and 45 minutes to teach them science; back-to-back, we have 90 minutes. If a lesson requires, I can teach science for the entire 90 minutes. The reverse is also true. Because the reading and mathematics' scores at Truman average at the third grade levels, the students need as many hands-on manipulatives as they can get. This is true for both math and science. It is also my philosophy that all learners need to have access to the three different types of learning styles: seeing, hearing and touching.

This curriculum unit is focusing on the physical aspects of sound, sound waves, and the exploration of this through music. This unit will be a three-week unit. Through class exploration, the students will discover how sound is made. They will discover different types of waves (i.e., transverse and longitudinal waves). Another way will be through the use of instruments and other common household objects. Science is a process of being a discoverer. One has to observe, question, hypothesize and conclude about one's experience. In life this is critical to becoming a fully functioning human. Adults are constantly making experiments to live better lives. What kind of pasta is better, faster or cheaper? What type of car should I buy given the amount of money I have to spend? Value judgements and day to day decisions are based on scientific process. This is an invaluable goal to teach children

Context and Background

Art and the study of physics are inventions that are solely human. Music, however, is a common medium for many living creatures. Birds and whales communicate with song. Lions, chimpanzees and other animals are soothed by tranquil melodies. Musical artifacts from Upper Paleolithic ritual sites have been found which are evidence of early musical ability in humans. Leonard Shlain has documented that as early as 35,000 years ago, musical instruments existed. Mankind is soothed by music. Music and physics entwined for the first time in the sixth century B.C.. Pythagoras of Samos is credited with first discovering pitch intervals (Sethares). Pythagoras discovered he could produce half the notes of an octave of music by dividing the string by whole numbers. Intervals in music, he demonstrated, had a mathematical, rational foundation (White 4).

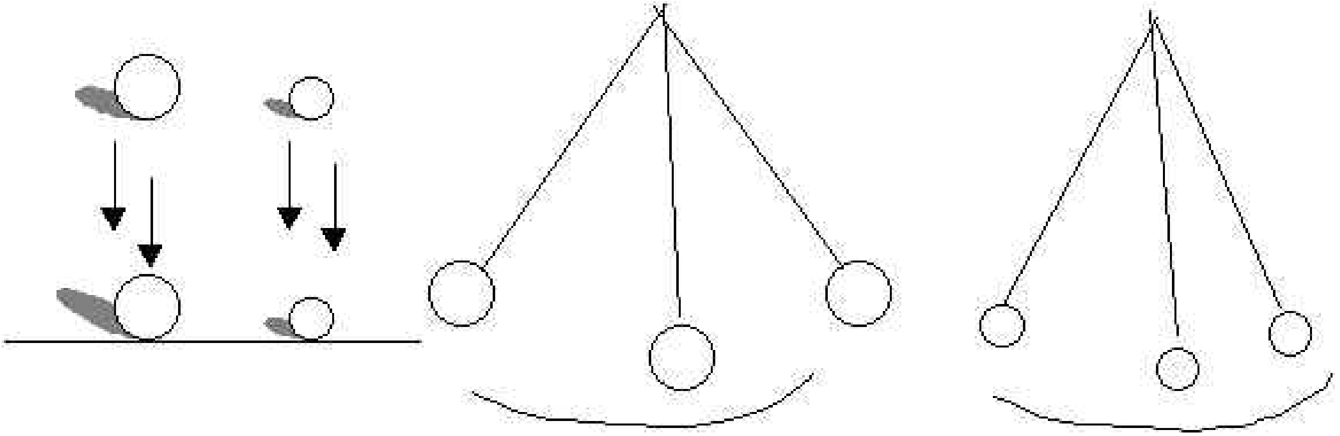
A solid understanding of waves and how they behave is a necessary conceptual need for seventh graders because it is an essential part of physical science. This is required by the *New Mexicos Science Scope and Sequence* which is aligned with the *New Mexico Standards for Excellence*, the *New Mexico Science Content Standards and Benchmarks*, and the *National Science Education Standards*. Conveying these abstract concepts to this age is a daunting task. Waves and their media form a significant part of physics. Water, earthquakes, light and sound all travel in waves. Waves are the vibration of material or electric and magnetic fields as in light. There are two different types of waves that are discussed in physics: longitudinal and transverse. This unit will explore sound waves and their importance to music. The most interesting sound for most seventh grade children (and adults) is music. I intend to connect these two with activities and hand-on experiments. What are waves? How are they created? What kind of waves make sound? What kind makes musical sounds?

Simple Harmonic Motion

The pendulum is a type of wave pattern. If you hang a fishing weight from the end of a piece of string, you have a pendulum. They can be found in grandfather clocks and cuckoo clocks. The to and fro motion of a pendulum is regular, but not very useful for all timepieces. For example it will not keep accurate time on your wrist (and they are much too large). Galileo discovered that the time a pendulum takes to swing to and fro through small distances depends on the length of the pendulum. There is an equation for the period of a pendulum. It is $T = 2??l/g$, where T is the period, l is the length of the pendulum, and g is the acceleration of gravity. The back and forth motion of the swing is called the period. The pendulum's period depends on the acceleration of gravity and length. It does not depend on the mass of the pendulum or on the size of the arc through which it swings.

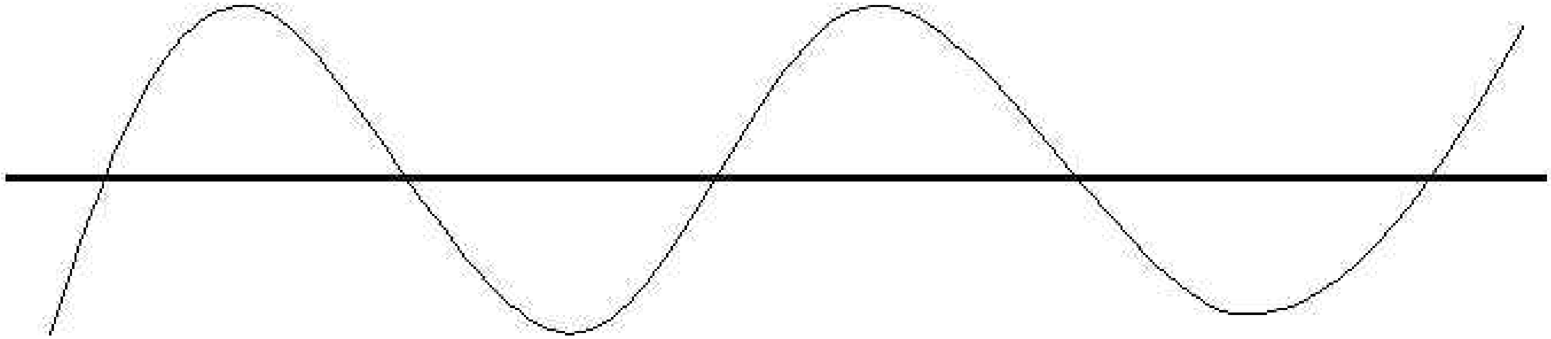
Drop two balls of different mass and they accelerate at g. Let them slide without friction down the

> same incline and they slide together at the same fraction of g. Tie them to string of the same length so they are pendulums, and they swing to and fro in unison. In all cases the motions are independent of mass. (Hewitt 325)



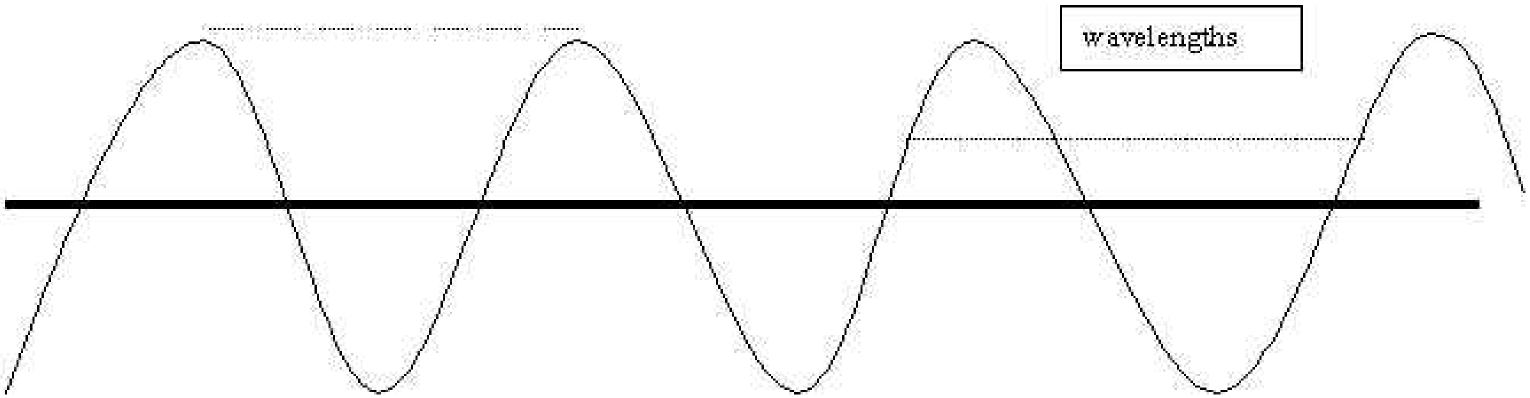
The back and forth motion, also called oscillatory motion of a swinging pendulum in a small arc, is called simple harmonic motion. If you place a funnel that leaks sand at the bottom of a pendulum, the sand will make a straight line. When you do the same with a moving onveyor belt, and the belt is moving at a constant speed, it will produce a sine curve. A sine curve is a visual representation of a wave.

A sine curve



In the ocean, a wave has high points called crests and low points called troughs. The middle is the starting point from which one measures the height or the depth of the wave. This distance is called the amplitude.

The wavelength is the length of the wave. A wavelength is the length of the distance from one trough to the next trough, or crest to crest. It is the distance between any successive identical parts of the wave.



Wavelengths are measured using a variety of units of measurement. Beach waves are measured in meters. Ripples in a pond are measured in centimeters, and light is measured in billionths of a meter (nanometers).

Frequency

Lothar Cremer explains the physics of the violin:

"Frequency is inversely proportional to the length of the string; control of pitch by the positioning of the finger of the left hand is based on this principle."

> The number of complete cycles per second is the frequency of a vibrating body. Paul Hewitt explains:
>
> "the frequency of a vibrating pendulum, or object on a spring, specifies the number of to-and-fro vibrations it makes in a given time (usually one second). A complete to-and-fro oscillation is one vibration."

If one oscillation occurs in one second, the frequency is one vibration per second. If two vibrations occur in one second, the frequency is two vibrations per second, and so on. A hertz (Hz) is the measure of a unit of frequency. It was named after Heinrich Hertz, who demonstrated radio waves in 1886. One vibration per second is one hertz, two vibrations is two hertz, etc... AM radio is in kilohertz (kHz, thousands of hertz). FM radio is in megahertz (MHz, millions of hertz). Radar and microwave ovens operate at gigahertz frequencies. A radio station set at 1200 on the AM dial broadcasts radio waves that have a frequency of 1,200,000 Hz. A station set at 102.5 on the FM dial broadcasts radio waves at a frequency of 102,500,000 Hz.

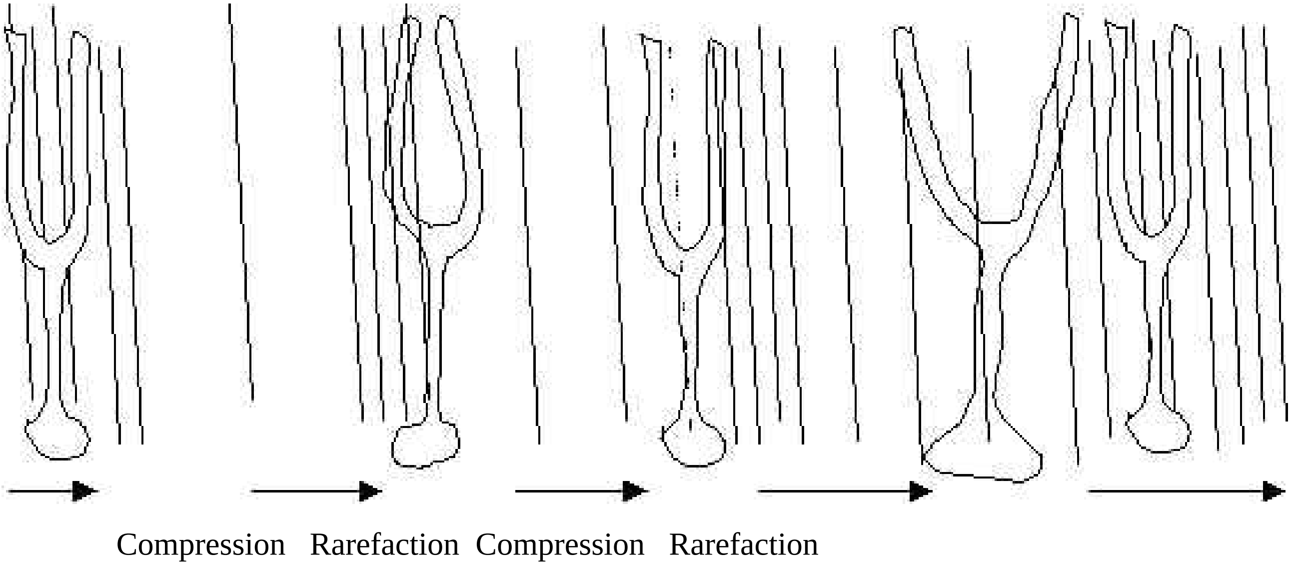
If an object’s frequency is known, one can calculate its period and vice versa. A pendulum that makes two vibrations in one second has a frequency of 2 Hz. The time needed then for one vibration is ½ second. If the vibration frequency is 4 Hz, then the period is ¼ second. The period and the frequency are the inverse of each other.

Sound Transmission

The vibration of matter causes sound. Sound requires matter in order to be propagated. Sound can be conducted through matter: solids, liquids and gases. It cannot occur in a vacuum like light can. The sound that is transmitted by air or any other gas can be demonstrated by suspending a bell in a jar. As the air is removed from the jar, the ringing of the bell becomes fainter and fainter. When a vacuum is obtained, no sound can be heard. Once the vacuum is broken again the ringing becomes audible again:

> The vibrating bell strikes air molecules, knocking them away from the metal surface. These molecules strike the adjacent air molecules, and they in turn strike others. Upon reaching the side of the jar, the glass walls are periodically bombarded by the molecules and set vibrating. The walls in turn set the outside air vibrating. Arriving at the observer’s ear, the disturbance strikes the eardrum, setting it into motion." (McLaughlin)

Another example of this is a tuning fork and how the sound transmits from one fork to the other.



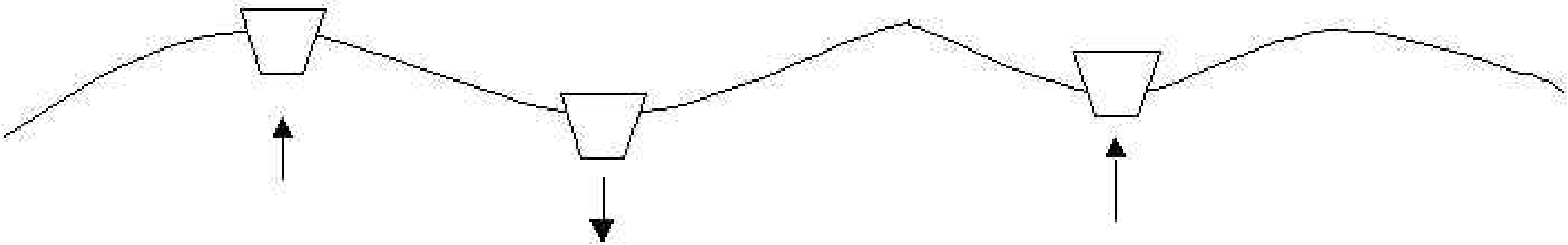
Particles in solids and liquids are closer together than in gases. Sound moves through them better because they are stiffer. This physical fact lies behind why musical instruments work the way they do. When an instrument is played, it makes the matter from which the instrument is made vibrate. This in turn vibrates the matter surrounding the vibration, usually air, and the sound travels to your ear.

Wave Motion

A wave in horizontally stretched rope is the most easily understood wave motion. Shake one end of a rope up and down and a rhythmic disturbance travels along the rope. The rope will return to its initial condition after the disturbance has passed. This is true for all mediums like water, air molecules, etc….

One of the most familiar waves, and one we can actually see, is a water wave. When a stone is dropped into a still pond, waves will travel outward in expanding circles. The centers of the circles are at the source of the disturbance. Many people believe that the water is actually moving toward the shore, when in fact it is not. It seems as though it is moving with the waves, since the water is splashed onto previously dry ground when the waves meet the shore. Barring other obstacles the water will run back into the pond. The surface of the water will have been disturbed, yet the water itself will have gone nowhere. A boat on the surface will bob up and down as the waves pass, but will end up where it started (White 38).

The corks will bob up and down, but will not move left and right.



Wave Velocity

There are times when one needs to know the velocity of a wave. For example, tidal waves can be enormous and can also be deadly. You will want to know how rapidly such a giant wave may strike land. One can calculate the velocity of a wave by multiplying the wavelength and frequency. Shown below is the formula for the velocity of a wave:

$$V = f \times \text{wavelength}$$

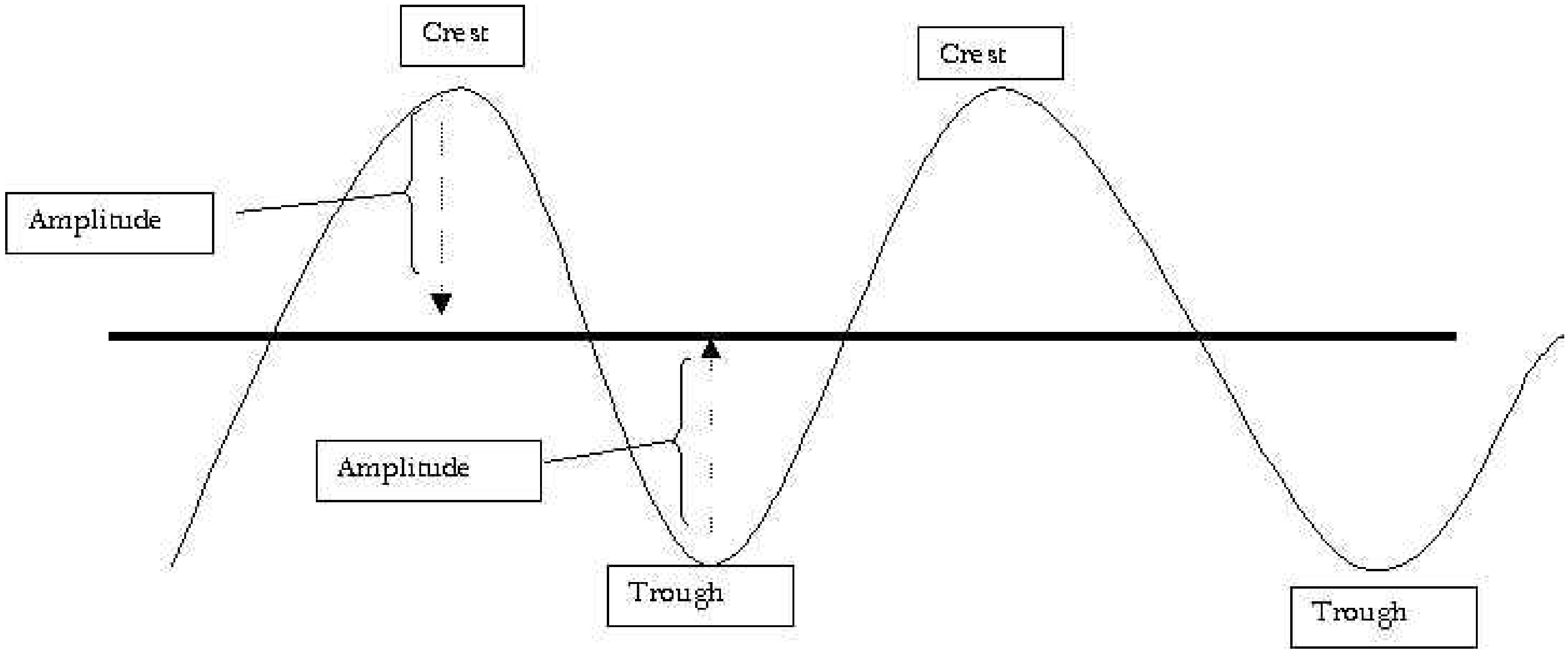
Where V is velocity and f is the frequency. If you have any two of these variables, you will find its remaining unknown variable. If you know thevelocity and the frequency, you can find the wavelength:

$$V = f \times \text{wavelength and } f = V / \text{wavelength; wavelength} = V / f\,.$$

For example if the frequency is eight and the velocity is 40 meters, one would apply algebra and divide the velocity by the frequency: 40 divided by eight equals five. The wavelength is five meters.

Transverse Waves

Waves are vibrations. They are disturbances in matter or space that carry energy in a rhythmical pattern. The two general types of waves are transverse and longitudinal. In a transverse wave, the disturbance moves at right angles to the direction the wave travels. This is an example of transverse wave:

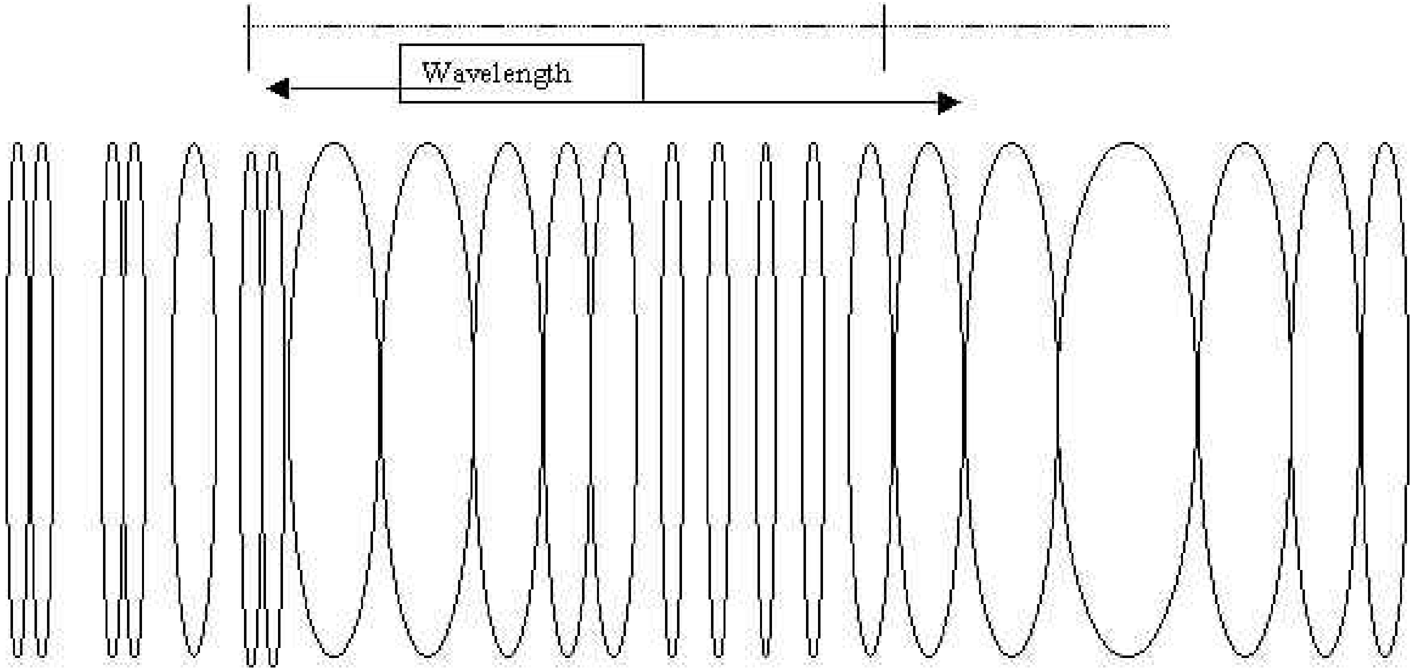


The wave motion moves up and down as it moves outward. Using a rope one could display what a transverse wave looks like. Let the rope lay on the floor and have two people hold the rope, one at each end. One person merely holds the end steady and the other moves the rope from side to side creating a disturbance. Transverse waves generally are vertical, however this example will get the point across. Ocean waves, light waves and some seismic waves are examples of transverse waves. The media do not move in the direction of the waves. In other words, in water waves the water does not move in the direction that the wave is going: it is disturbed but does not move in the horizontal direction that the wave is going.

The highest points of these waves are called crests and the lowest points are called troughs. The terminology of "crests" and "troughs" strictly applies only to specific waves. We use the same words for the other kinds of waves that do not have crests and troughs in the usual sense. A wavelength is the length of the distance from one trough to the next trough or from crest to crest. Amplitude is the height of the wave measured from the rest position as shown in the figure above. The wavelength has to move from one point to another over a period of time. The frequency of a wave is measured by the number of crests which pass a given place within a unit of time, usually a second.

Longitudinal Waves

A longitudinal wave vibrates in the same direction the wave is traveling. This is how sound and some seismic waves move. A Slinky is a reasonable example of this phenomenon. Lay a Slinky on a table and stretch it out about two yards. Push the Slinky in the direction of one end. You will see the wave pattern that is common to the longitudinal wave. It bunches up and then spreads apart like in a spring that is stretched and not stretched. This bunching and spreading of energy is compression and rarefaction.

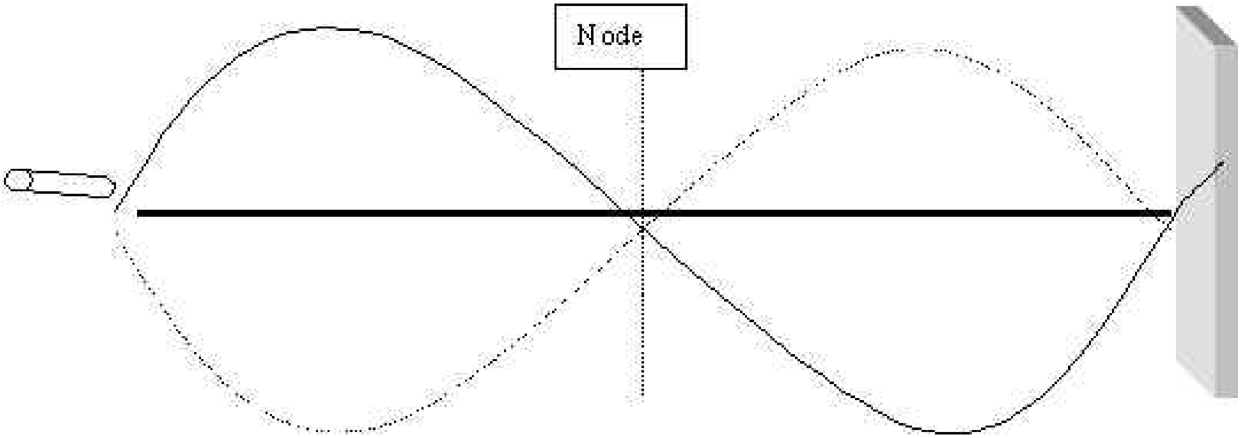


Compression Rarefaction Compression Rarefaction

The dense area of a sound wave is called the compression. The less dense space is called the rarefaction. The distance from one compression to the next measures the wavelength in the longitudinal wave. The same is true for rarefactions. Thus we can measure the frequency, by the number of compressions that pass a place each second.

Standing Waves

If we ties a jump rope to a wall and shake the free end up and down, we produce a train of waves in the rope. The wall, of course, will not move, so the waves are reflected back along the rope. A standing wave is caused when we shake the rope just right. The incident and reflected waves form, and parts of the rope, called the nodes, are stationary or "standing". Node are the areas of minimal or zero energy. Antinodes are the areas of maximum displacement and maximum energy.



(Hewitt 330)

Standing waves are the basis of stringed musical instruments. When a violin is struck, plucked, or bowed the string will make standing waves.

Sound

Loudness

Loudness is the perception of sound intensity. Amplitude and intensity when increased correspond to a louder sound. The amount of energy in each wave increases the intensity of a sound wave. This, in turn affects the amplitude. The amplitude increases as the sound wave increases. Michael Moravesik, in *Muical Sound: An Introduction to the Physics of Music*, explains "Loudness is related to the amplitude of the sound oscillations. The louder the sound the larger the amplitude is found to be."

Sound intensity is measured in decibels (dB). The faintest sound that can be heard by a human is 0 dB. One hundred twenty decibels can cause pain and permanent hearing loss because is it too intense. A cat’s purring is about 25 dB, a noisy restaurant is 80 dB, a chain saw is 115 dB (and nearing the pain threshold), and a jet plane taking off 150 dB (McLaughlin 510)

Another interesting phenomenon is the Doppler effect. One experiences this when one is standing still and a fire truck goes by. The siren is heard, as it is coming toward you, at a higher pitch than when it is going away. Why? If a sound is emitted from an object that is moving, the sound still moves at a fixed speed. The moving of the object, like a firetruck that is moving, is making the waves of sound appear closer together as it is approaching a stationary object. So an ambulance siren sounds higher as it is approaching you, and lower as it passes.

The most pleasant sound of all is music. What is music? It is sound which has a regular pattern, specific pitches and sound quality. There are many different kinds and styles of music. One person’s choice for music could be considered by another to be horrible noise. A plucked guitar string makes a sound. The vibration of the string is moving the air and making sound. The string is moving at its natural frequency. Most objects have a natural frequency. (Hewitt 329)

Reverberation

Light can be reflected from a mirror. Sound can be "reflected" too. Reverberation is the reflection of sound. A hall intended for musical or stage performances needs to have good sound reflection. If they do not have good sound reflection, then they may have "dead" places within the audience where one cannot hear the performance well. There are people who spend their life trying to improve the acoustics of performance halls.

An echo is the reflection of a sound. If you stand 50 yards away from a wall and clap your hands, you will hear the echo come back to you. Many animals like dolphins and bats use echo to find their way in the wild. Ultrasound is a high-frequency sound that enters the body and can detect the size and shape of a fetus or other object.

Implementation

Understanding waves and how they behave is a necessary conceptual need for seventh graders. This is required by the *New Mexico’s Science Scope and Sequence* which is aligned with the *New Mexico Standards for Excellence*, the *New Mexico Science Content Standards and Benchmarks*, and the *National Science Education Standards*. "Understand sources and properties of sound" is requirement 2.7 of the NMSS. Learners will describe the characteristics of sound waves (i.e., wavelength, frequency and amplitude). Waves and their media form a significant part of the study of physics. Water, earthquakes, light and sound all travel in waves. Waves are the vibration of material or electric and magnetic fields as in light. There are two different types of waves that are discussed in physics. This unit will explore sound waves and their importance to music. The most interesting sound for most seventh grade children (and adults) is music. I intend to connect these two by use of activities and hand-on experiments. What are waves? How are they created? What kind of waves make sound? What kind makes musical sounds?

This unit will take three week to implement. I have included samples of activities that will be used why teaching this unit but one thing I like to point out is that I generally have my students write in a journal about what they have learned. Most important is that they convey, in their own words what was discussed and discovered. This is a daily process.

The *New Mexico Science Scope and Sequence* requires seventh graders to explain motion using relevant terms (e.g., speed, velocity acceleration, and circular motion). Calculating the velocity of waves and pendulum action will be supported in this curriculum. We will cover Section 2.7: "Understand sources and properties of sound. Learners will describe the characteristics of sound waves (i.e., wavelength, frequency and amplitude).

All activities below focus on this benchmark.

1. Objective: to give a physical and visual example of a transverse wave.

   Materials: five, 20-ft. ropes

   Have two people hold the end of a rope. Have one person wiggle the rope side to side (or up and down) while the other holds their end stationary. The rope represents a transverse wave, as it would appear in water. It shows the crests, troughs, wavelengths, resting positions and amplitude. The class would have an opportunity for experimentation and discussion. I would ask them to give a definition of the crests, troughs, wavelengths, resting potions and amplitudes. Drawing a picture of it would be another method of practice.

2. Objective: to give a physical and visual example of a longitudinal wave.

   Materials: Slinky

   Two people hold the ends of a Slinky. One pushes the slinky toward the other to create compression waves. Observe the distortion of the Slinky and what it does. Ask the children what they observe. Explain that the dense areas of the Slinky represent compression, and the spaced out or stretched out areas are called rarefactions. I would have the students put this in their science journal and write the definitions and draw a picture. Another important concept is comparison. What is the difference between longitudinal and transverse, and how are they similar? Where is the trough? Where is the crest? What is the amplitude and resting position?
3. Objective: to give a physical and visual example of a transverse wave and how a String on an instrument moves to make sound.

   Materials: Cut Violin shapes from felt and poke some yarn into the end where the violin strings would be. The yarn needs to be about twice as long as the felt violin.

   Using violin shaped felt that has a "string" attached, have the children make the shape of a transverse wave on the violin. Change the size of the wave. Ask the students to make a half of a wave, one and a half? Two waves? This is a very concrete exercise that helps children or any age student grasp the idea of a wave.
4. Objective: to give a physical and visual example of frequency of a wave.

   Materials: Washers, String, tables

   Tie a washer onto the end of a string about a foot long. Lift the washer only two inches in an arch, then swing the washer. Ask will it make any difference if we add more washers to the string? Will it change the velocity of the pendulum swing? What happens if we change the length of the string by half maybe? Is there a difference now? What? Why?
5. Objective: to give a physical and visual example of frequency of a wave and pitch.

   Materials: 12-15 plastic rulers, silly putty.

   Attach a plastic ruler to the top of a desk with only two inches on the table. Pluck It. Have the class observe the sound produced by the ruler. Next, reduce the length of the portion of the ruler that is hanging off the table. (If this is done quickly, then the pitch changes rapidly, too) What happens if we put some silly putty on the ruler, right on the end? What happens? What will happen if we place the putty in the middle of the ruler? What does happen? In this exercise, as in most of them, I am attempting to make questioners out of the children. Predict what will happen. It is important to note that the slower the ruler moves the lower the pitch. The longer the ruler is, the lower the note. The opposite is also true.
6. Objective: understand frequency of a wave, resonance, intensity (loudness).

Materials: Cigar boxes, rubber bands of different thicknesses.

Stretch two of the rubber bands of different thicknesses over the boxes. Strum or pluck the strings. What do you think will happen? What is the result? Why does this sound occur? Which rubber band has the lowest sound? Which is higher? Why? Tighten or stretch the rubber bands tighter. What do you think will happen? What happens? Pluck the "string" harder. What do you think will happen? What actually happens? Why does it get louder?

7. Objective: understand resonance

   Materials: Large coffee can, plastic wrap, and rubber band,

   Tuning fork, salt or sand.

   Using a large coffee can, some plastic wrap and a rubber band make a drum out of the items. Place the salt on the top of the coffee can drum and tap the bottom of the drum. Observe the patterns on the drum. Try tapping it in different locations on the drum. You can also use a tuning fork to make the salt resonate. This illustrates what resonance looks like. Cool!

8. Tin Can Telephone –this is a common trick. It can be used for young children as well as middle school students.

   Objective: Understand that sound will travel well through solid objects.

   Materials: Two tin cans, String.

   Connect two tin cans with a very long string. Stretch the string. One person speaks into the can while the other put his/her can over the ear. What will happen? Stretch the string in between the cans and talk to each other. Why does this work?

9. Swinging Paint Stirrer

   Objective: understand Doppler effect and pitch.

   Materials: Long string and one paint stirrer.

   Drill a hole in the end of the paint stirrer and tie to the string. Holding the string up high, twirl it over your head. This will start to make a humming sound. The motion makes a sound as it moves around your body and displays the Doppler effect. It also changes pitch if you increase or decrease the length of the string.

10. Rubber Band Guitar.

    Objective: music, sound, waves, frequency, etc.

    Materials: Cigar box, rubber bands, wood pieces for the bridges.

    The major culminating project is to get the little rascals to make their own guitars. A cigar box works very nicely, but if children have other ideas, great! It needs to be made out of something strong enough to have a resonating soundboard.

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