2009 AAAS/Subaru Essay Writing Competition for K-12 Educators

Finalist Essay

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7th and 8th Grades

The Vibrational Nature of Sound

Our science program for seventh and eighth graders at Ruffing Montessori School is a two-year cycle. One year involves a study of chemistry, with units on DNA and heredity. The second year involves a physical science year where students investigate sound, light, electromagnetism, and simple machines. I will concentrate on the investigation of sound because the topic lends itself well to inquiry-based learning and to integration with students' work in mathematics and music.

After investigating the concepts of frequency and wavelength by experimenting with Slinkies® and long springs, students develop the sense that the two values are inversely proportional. They perceive that, if the speed of sound in air is a constant, the inverse proportionality makes sense in light of the units involved, multiplying vibrations per second by meters per vibration. The relationships among velocity, frequency, and wavelength relate to topics being covered early in the first-year algebra class (eighth grade) and pre-algebra (seventh grade). When we use the tuning forks, whose frequencies are given, and the velocity of sound, students are able to calculate the wavelength of a given tone. Paper and pencil exercises in finding any one of the three variables (frequency, wavelength, or velocity) follow, along with "thunder and lightning" problems, where students figure out the proximity of a lightning strike by using the given value for the velocity of sound in air and the interval between the lightning and the thunder.

Students investigate the vibrational nature of sound with several simple but effective hands-on activities. They activate tuning forks ranging from our lowest frequency (125 vps) to our highest (4000 vps), and touch the vibrating tines to the surface of water. They analyze the reasons for the different actions of the tuning forks on the water. Students find an interesting, and unintended, consequence within this series of activities. When the very high-frequency tuning forks are touched to the water, the wavelengths are so small that they do not even create a splash. However, students find that if one touches the water's surface carefully with the vibrating 2000 or 4000 vps tuning forks, one can detect a distinct change in pitch before the tuning fork ceases making a sound entirely. For just a second or two, the effect of a slower frequency (i.e., lower pitch) is empirically clear.

In a similar activity, students touch the end of a stationary, vibrating tuning fork to a table tennis ball suspended on a string. When the tuning fork touches the ball at just the right point in its vibration cycle, the ball flies upward. In a manner similar to the water results, the high-frequency tuning forks do not budge the ball because their wavelengths are so short. We use our strobe light to follow the movements of the tines on the larger tuning forks so students can see the considerable distance that the tuning fork moves during a cycle.

We introduce the Doppler Effect for sound waves using a tuning fork on a long string. When the tuning fork is activated, then rotated quickly in a large circle in front of the class, students can clearly distinguish the higher pitch as the tuning fork comes closer to the listener and the lower pitch as it recedes. We develop this topic further through a number of examples on an old record from Bell Labs, "The Science of Sound," in which we hear racing cars, railroad sounds of various kinds, and moving sirens. Discussion ensues regarding the uses of the Doppler Effect in weather forecasting and radar. The treatment of the Doppler Effect in studying sound—where the effects are obvious and the values are more or less within the range of students' ordinary experiences—becomes more significant when we deal with the topic in studying light, where the "Doppler Shift" of stars and galaxies comes under scrutiny in a more abstract setting.

Like our work with the Doppler Effect, we introduce the concept of resonance through experiment and demonstration, using two mounted tuning forks of identical frequencies. If we activate one of them, then stop its vibration, we find that the other is producing a clearly audible tone although it was never struck. This leads to a basic and thorough understanding of resonance and natural frequency. We also use two tuning forks of similar frequencies (880 and 883 vps). Many of us are unable to distinguish between them when they are struck separately, but when they are played together, there is an unmistakable "beat," three per second, as the waves interfere. The importance of professional musicians' ability to tune their instruments precisely becomes clear. Natural frequency is one of several topics covered creatively on the website of The Exploratorium in San Francisco, and we perform several of their interactive experiments in acoustics as a class and as individuals.

I have devised an outdoor experiment in which we use a drum, a tape measure, and a stopwatch to find a good approximation of the velocity of sound. We measure a distance of about 100 meters, although we will vary the distance from 90 to 120 meters from one trial to the next. One student operates a stopwatch with a classmate beside him/her signaling another student 100 meters away. Upon the signal from the student next to the timer, the distant student hits a drum. The timer starts the watch at the visual signal and stops it when he/she hears the sound of the drum. Although this method seems fraught with error, we run the experiment for at least fifty trials, and the results are remarkably accurate. Working in teams back in the classroom, we average the times obtained (generally about 0.3 seconds) after dispensing with the obvious outliers. Students are then asked to come up with a way to work with the data (for example, an average of 0.33 seconds for a 105 meter distance, the result from one of my classes in 2007) to obtain a value for the velocity of sound in air in meters per second. For the example cited, we calculated a value of about 318 meters per second, a reasonably close approximation of the reference value of 343 meters per second.

In studying musical sounds, we work with the music teacher to define harmony and dissonance, both in terms of subjective reactions to music and the ratios of the frequencies of various musical tones. Using a set of mounted tuning forks, we activate constituent notes of a C-major chord, middle C at 256 vps, E at 320 vps, G at 384 vps, also including high C at 512 vps. Students then have the task of making each possible combination into a ratio, which they can reduce to a small, familiar value. For example, middle C and G activated together result in a 256:384 ratio, which reduces to 2:3. Students tried a variety of other combinations, and they found that dissonant tones had frequency ratios which were less reducible, for example, B and high C, whose frequencies are 480 vps and 512 vps, reducing to a ratio of 15:16.

In our classroom, we have a small oscilloscope, and we use it to observe the wave patterns of our voices, output from an RF (radio frequency) signal generator, tuning fork tones, and music. I have arranged our "FlexCam," which we normally use to project microscope images to a computer monitor and our SmartBoard, to focus on the small oscilloscope screen, so that everyone can see the wave patterns on the SmartBoard. The differences between a mechanically produced tone and the rich, overtone-laden vibrato of a note played by a student on his/her violin or flute are dramatic and obvious. We observe the wave patterns in a variety of musical recordings, from solos, to chamber music, to full orchestra. Students can compare not only through listening but also by observing how twentieth-century composers such as Stravinsky and Schoenberg used harmonies and dissonance differently from old masters such as Mozart or Beethoven.

We then use the RF signal generator with the oscilloscope. Students research the characteristics of sounds whose frequencies are too low for us to perceive (such as the vibrations preceding an earthquake) and too high (such as the vibrations produced by a dog whistle or by a bat performing echolocation). By attaching a telephone-style speaker to the generator, we conduct a fairly reliable range of hearing test, always inviting a few adults (the older the better) into the tested population to demonstrate the loss of our ability to perceive high-frequency sound as we age.

I have been satisfied with using sound and acoustics as a first science topic in a physical science course for a number of reasons. Concepts can be developed through experimentation and empirical data gathering. The mathematics required is simple yet fundamental to the topic. Students have the opportunity to employ sophisticated equipment in their work. Finally, we can begin the year relating science appropriately and meaningfully to the arts.