Physics of Music: Making Waves in a Science Classroom

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Overview

This unit is designed to fit in with the School District of Philadelphia Core Curriculum for Physical Science in the Waves unit. In the curriculum, this unit is allotted four weeks, in which students study the nature and properties of waves with specific applications to light and sound waves. This curriculum unit will consist of a 3-week unit focused on sound waves and specific applications to the design of several families of musical instruments used in a number of genres. During this unit, students will be introduced to the basic properties of waves through a variety of inquiry-based and analytical activities, and will then use this solid conceptual understanding to explain the behaviors of sound, particularly in the case of musical instruments.

Depending on the exact nature of the curriculum, elements of this curriculum unit could be used in eighth grade Physical Science or as part of a more advanced physics curriculum in the upper grades. Some of the topics covered may be slightly more advanced than a middle school level or lower level for the later high school grades, but the general structure should be useful. The level of questioning in the inquiry activities or the amount of math used throughout could be tailored to the appropriate student level. Much of the material is also designed to be easily differentiable for learning styles and reading and math levels. The unit could be extended to include other topics such as history and music in order to present a coherent inter-disciplinary study.

Rationale

Motivation for unit

A substantial challenge facing high school science teachers is the task of making general science curricula relevant and accessible to students without making it trivial. Fun demonstrations and activities sometimes replace legitimate objectives and quality science in the interest of temporarily snagging student interest. While this approach no doubt makes science seem “cool”, it fails to portray an accurate view of science or convey useful skills and knowledge. The challenge, therefore, is to maintain student interest without abandoning the high level content. This unit seeks to do this with the topic of waves by centering the unit on a topic of common student interest, music, and using that to guide the study. In this way, the unit will simultaneously achieve the goal of attracting student interest and maintaining rigor in the content studied.

The general theme and structure for this unit will be using what is known and familiar, both in terms of scientific content and the context of the unit, music. Students tend to have much more success and are willing to take greater risks when they feel some level of comfort and independence in the subject area. This comfort is facilitated by grounding the unit in what is known. However, despite the theories that we increasingly need to teach to the “hip-hop generation” and incorporate students’ funds of knowledge (Moll, 1992), framing new knowledge entirely in the context of what is already known prohibits students from opportunities to expand their knowledge and extend the boundaries of their academic comfort. Thus while students may feel comfortable with a specific genre of music, namely hip-hop, many are largely unfamiliar with other genres. In order to facilitate several aspects of music and the application of the principles of waves, students will encounter a number of genres and characteristic musical instruments during the course of the unit.

Student background knowledge

The physical science curriculum begins with an introduction to basic units of measurements, including length and time. Students encounter these units in the context of measuring physical objects, and apply them to the concepts of speed, velocity, and acceleration in the early units of physics in the physical science curriculum. In the context of this unit on waves, which puts so much emphasis on sound and light waves which have visible effects but whose actual physical parameters, such as wavelength and speed, are not visible, it is critical to base a discussion of these properties for waves on a physical understanding. The most important parameters for the study of waves are length, time, and speed. Students will also be introduced to the concept of frequency, which will be a new topic to the students at this point.

Wave basics

Fundamental to the definition of waves as a disturbance that propagates through a medium, transmitting energy, are the concepts of energy and the idea of a disturbance moving rather than the entire medium. The majority of topics encountered in physical science and other early science curricula deal with concrete objects—balls, cars, and such—moving in observable ways, such that the idea of a wave presents a new and different phenomenon. As a result, dealing with student misconceptions about the structure and nature of the waves up front is critical. A wave differs from a classical particle, such as a ball, in that it is not a single "object" moving through space. Rather, it is a change, either transverse or longitudinal, in the arrangement or position of parts of a substance. The exact nature of this change depends on the type of wave and the medium.

One way to bridge the gap between an understanding of the motion of particles and the motion of waves is to consider a slinky or other spring-like tool. Unless you plan to throw the slinky across the room, in which case it will behave like a particle, the slinky can be used to demonstrate wave motion in a medium that is visible to students, with equally visible consequences. A general problem I have encountered when trying to convey abstract concepts is that without some means of visualizing it, the students are not able to manipulate the idea to meet new and different situations and the topic remains abstract and paper based. At the same time, a too-pervasive analogy likewise restricts students' abilities to expand past the suggested example. Therefore, the introduction of the nature of waves must be structured in such a way that students grasp the concept that a wave is a moving disturbance without being restricted to the examples of a slinky or telephone cord. Otherwise, students will not grasp the connection between a graph drawn on a board and light and sound waves. This can be done by taking a two-pronged approach: observing the position of an entire medium at a single point in time, and observing the motion of a single point throughout time.

Once the nature of wave as a disturbance has been established, it is a fairly straightforward jump to explaining how waves transfer energy, particularly how this varies from a particle, and a graphical 2D representation of a wave. By this point in the year, students should be familiar with the ideas of energy and force, with a particularly heavy emphasis on potential and kinetic energy. While "light energy" is previously discussed briefly to the extent that it exists in light sources, there is no mention of how this light energy varies between types of light and why, and therefore up to this point is a simple matter of identification. Understanding that waves transfer energy and then identifying light as a wave would enable students to make better sense of the term "light energy". In order to do this, physical demonstrations and observations of propagating waves serve as a useful tool: students can observe that in a mass oscillating on a spring energy is being transferred from potential to kinetic and back again, and that each kind of energy is being transmitted through the medium, eventually reaching the other "end." The challenge remains to demonstrate that rather than the entire physical object moving through space, a disturbance is propagating within a given medium, but this can be done with the aid of graphs.

The target audience for this curriculum is students who are concurrently taking Algebra I, and are therefore not familiar with periodic functions such as sine and cosine.

As a result, the representation of a periodic event in graphical form will be a new concept. Waves are typically graphed as functions of time, in which the motion of a single point is referenced, and the properties of wavelength and amplitude are defined in reference to this graph. If students have developed a familiarity with physical waves, the transition from looking at many points moving in a physical object to the description of a single point as time continues could be confusing. However, graphs of wave are particularly useful for defining and representing various wave properties, and the ability to interpret and explain graphs is a fundamental skill for students studying science, as it develops analytical skills and reinforces the aspects of science requiring creating models of situations. Such abstract concepts force students to operate on a much higher level than typically expected. One approach for tying the graph to the motion of a single point is to have students exclusively observe a single point, and describe the motion of that point, rather than focusing on the motion of the entire medium, which is particularly tempting when using such items as a slinky or telephone cord. The shape formed by the whole medium very closely resembles the graph of the position of a point in time. Because each can be used to obtain different information (for example, the period of the wave as compared to the wavelength), the two must be distinguished. With both representations, students will be able to describe all of the fundamental features of the wave.

At this level of science, students should be familiar with the concepts of wavelength, frequency, speed, period, and amplitude. An understanding of each of these is necessary for students to describe the way waves interact to generate the sounds heard in music, and how changing each of these factors might change the resulting sound. Wavelength is perhaps best described as the distance between one peak disturbance and the next. This description is useful whether one is talking about water waves, slinky waves, or sound and light waves. It can also be easily located on a diagram of a wave. The frequency, or number of wavelengths to pass a point in a given amount of time, can be a confusing concept if introduced solely mathematically. However, using physical demonstrations (and prior familiarity with other concepts such as current in which the number of *things* to pass a point in a unit of time is used to define the concept), it is fairly straightforward to show that if you stand at a particular place, a series of peaks passes by you. The greater the speed of the wave (another familiar concept), the more often a peak disturbance passes by, and the less time passes between subsequent peaks. With this single demonstration, we can therefore introduce speed, frequency, and period, all interrelated concepts, without relying too heavily on an immediate interpretation of a mathematical description. This will in fact make the mathematical description much more accessible to students.

Sound and Waves

A major feature that is lacking from the Physical Science curriculum as structured in the Philadelphia Core Curriculum is an overall coherence between the units taught. Students are briefly introduced to Chemistry, Physics, Earth Science, Space Science, and

Environmental Science, and the largely factual approach often minimizes the connection between subsequent units. This unit therefore presents an excellent opportunity to incorporate some of the prior topics, such as motion, force, and energy. The motion is easily incorporated into the discussion of wavelength, frequency, and speed, using the concepts of displacement and velocity. Force and energy can be fairly easily incorporated into the discussion of physical and visible waves, such as in a slinky, because students can see and feel the work required to generate the wave. This connection becomes somewhat less easy to grasp with sound and light waves where the source of the wave energy is not as specific, and factors leading to wave dissipation are not as obvious. However, this is another situation in which thorough familiarity with a wave in one context will make extensions to another more complex and abstract context more manageable. Students will thus be able to deal with the concept of wave dissipation as a manifestation of energy transfer and connect the volume of sound to the amount of energy present in a sound wave. While this may seem to be something of a stretch for a basic Physical Science course, tying various topics together as well as explaining observed phenomena is critical to making the course meaningful and worthwhile.

Another challenging but essential concept for students is the difference between a transverse and longitudinal wave. Visualizing the application of wave characteristics such as the crest, trough, and wavelength are fairly simple with a transverse wave. In a compression, or longitudinal, wave, the disturbance in the medium no longer takes the shape of what we typically imagine as a wave. However, the same principals apply: rather than talking about a crest, we talk about a compression which is a region in which the medium has maximum density due to the disturbance. Replacing a trough is a rarefaction, where the medium has a minimum density. In order to tie this concept to the more easily grasped longitudinal wave, students could help to generate another graph demonstrating both the density of the whole medium with position (as in with a slinky), as well as the changes in density at a single point with time. For this type of wave, it is necessary to expand the definition of wavelength from simply the distance between two crests to the distance between any two corresponding points in a wave (two compressions, two rarefactions, etc).

Sound in Musical Instruments

Ideally, the emphasis in my classroom is the application of the topics to an actual situation of interest. In order to do this, students must be able to see how the properties of something govern its behavior. Waves are a particularly suitable topic for this approach as a number of fascinating phenomena with which the students are founded on the properties of waves. While most students do not have a great deal of experience with instrumental music, some participate in the school band, participate in a choir, or have some other meaningful relationship with music. We will therefore use musical instruments as a vehicle to discuss wave properties in general, and later in the unit as the primary means for introducing sound-specific topics.

Among the musical instruments involved in jazz are brass instruments, such as the trumpet and trombone, stringed instruments such as the bass and occasionally violin, and percussion instruments such as the piano and drums. Each of these demonstrates particular features of sound and waves. This serves not only to augment the student understanding of general wave types, both longitudinal and transverse, and wave properties, such as frequency, wavelength, and amplitude, but also to introduce the music-specific concepts of resonance and pitch. First among these phenomena is how the structure of the sound wave relates to what we observe: the pitch of a sound is determined by its frequency: higher pitch leads to higher frequency; the volume of the sound is determined by the amplitude of the wave, and the amplitude does not affect the pitch.

Musical instruments produce various forms of standing waves in order to create the complex sounds we hear. While the complete waveform produce by a musical instrument is very complex, the basic mechanics involve a standing wave, either compressional (in an air column) or transverse (on a string) that vibrates at different frequencies, as determined by the length either of the air column or the string, to produce a specific sound. A standing wave is created when the frequency of the wave in the medium causes reflected waves to interfere with source waves so that parts of the medium (called nodes) appear to be standing still. Different musical instruments produce different types of standing waves, but each instrument has a set of natural frequencies corresponding to its size and shape (length); each of these natural frequencies corresponds to a certain formation of standing waves in the medium. The complexity of sound waves lies in the fact that for a particular length of the medium (air or string), several standing waves can be produced, known as the first harmonic (or fundamental), second harmonic, etc. These are particularly easy to visualize for stringed instruments because the formation of the waves lines up with our basic understanding of waveforms. (The Physics Classroom, 2004)

Stringed instruments, both pianos and the violin family, rely on strings to produce the initial vibrations. In order to produce the actual sound that reaches our ears, both types of instruments require an additional resonator (essentially a shaped box) to produce vibrations with sufficient magnitude that the sound reaches our ear. This is because the size of vibration in the air produced by the string alone is too small to create a discernible sound. While the violin follows the pattern of first, second, and third harmonics in exact whole number multiples of the fundamental frequency fairly well, the piano departs from this increasingly as the frequency increases. However, the approximate understanding is sufficient for this introduction to musical instruments and sound principles. Both types of instruments rely on strings under tension; when these strings are pulled from their rest position, they vibrate at the natural frequencies described above. The strings are attached to the resonating box which in turn produces the vibration that reaches our ear. In a piano, when a key is pressed a hammer covered in felt hits the string of the appropriate length. In a violin, the string can either be plucked or bowed. The shape of the instrument as well as the method of producing the sound change the timbre, or sound quality. A hammer with the wrong felt quality will produce a sound that is either too harsh or too mellow; a violin bow with too much rosin will produce a scratchy sound. While this interferes with the quality of the sound and some of the more enjoyable complexities of the sound, the basic vibrational pattern of standing waves remains the same. These instruments can be artificially simulated in a classroom using strings stretched across a box. (Hutchins, 1948)

Woodwinds and brass employ different systems of creating the sound and therefore have different sound qualities; however, they both rely on changing the length of a vibrating air column to create different sounds. Woodwind instruments use a reed (either single or double) which creates the vibration in the air column by converting a steady stream of air into a series of puffs, creating the compressional wave that is the basis of wind instruments. The exception to this is the flute, which functions like an empty soda bottle in that the vibrations are produced when air is blown across an opening; for the reed based instruments, the puffs come when the reed is opened, and stop when the reed is shut. These two different systems of sound production lead to two different patterns of standing waves, depending on the end condition required. In order to change the wavelength, the wind instruments rely on a set of keys or openings in the bore: if these openings are sufficiently large, the location of the opening essentially determines the wavelength and therefore the natural frequency of the instrument. Most wind instruments rely on a set keys to produce whole tones, and various combinations to produce intermediate tones. Higher pitches of the same "note" (A, B, C, etc) can be produced either with special keys or by blowing harder.

Brass instruments likewise create varying pitches by changing the length of the air column: trombones by changing the position of the bell and trumpets and French horns by changing the path of the air within the column. Although the actual instrument is flared at both ends, which is largely responsible for the quality of the sound produced, a basic cylinder provides a good starting point. For the brass instruments, rather than a vibrating reed producing the vibrations in the air column as with the woodwinds, the player's lips produce the vibrations. The formation of the lips is responsible for some of the changes in sound we hear.

By extending the study of waves to concrete objects, musical instruments, students will be able to grasp both the abstract and concrete features of waves.

Objectives

The specific teaching objectives for this unit are prescribed in the Philadelphia Core Curriculum and stated in the Appendix. The overall objectives for this unit are centered on a basic understanding of the characteristics and properties of waves. While the objectives themselves contain a somewhat eclectic sampling of wave-related phenomena in both sound and waves, they are all tied to the fundamental physical properties of waves, regardless of the specifics addressed. The unit, in addition to the individual objects, therefore seeks to achieve the following objectives related to the content:

- Explain the connection between real-world experiences with music and studied principles.
- Apply an understanding of the physical properties of waves to explain observed phenomena for both sound and light.
- Apply the physical properties of waves to design musical instruments.

The unit will also be structured in such a way as to develop the skills of students in the field of science, specifically:

- Design experiments to test a hypothesis
- Critically evaluate laboratory results and present the data and analysis in the format of a lab report
- Use laboratory equipment to gather information

Through these objectives, students will be able to connect their theoretical understanding of the concepts studied in class to concrete applications and real-world scenarios, and generate curiosity about a broader range of experienced phenomena. Students will also develop analytical skills by using a range of representations to approach and describe waves, and becoming familiar with how to analyze and create each of these.

Strategies

This curriculum unit will focus on the strategies of inquiry-based learning and universal design. According to Trowbridge et al, "Inquiry is the process of defining and investigating problems, formulating hypotheses, designing experiments, gathering data and drawing conclusions about problems" (Trowbridge, 2004). In a science classroom, inquiry represents a pedagogical method that authentically conveys the process of science as well as much of the content. It is often avoided in secondary classrooms due to the perceived difficulty of implementing it, the planning and resources required, and the additional element of classroom management added when students are not primarily sitting in their seats. However, an argument in favor of using inquiry as a strategy is the observation that students generally retain more information and develop a higher-level understanding of the subject at hand. Continued exposure to inquiry methods enables students to think in a more scientifically appropriate way, and eventually to tackle problems independently. It is in direct contrast to method of reading from books, lectures, and worksheets that are so prevalent in urban schools, and is also substantially different from activity-based lessons. While inquiry tends to incorporate hands-on activities, it is not the same as replacing lessons with inquiry. The ultimate teaching goal remains the same. This unit is an ideal vehicle for teaching through inquiry because it involves a subject in which many students are interested and curious to begin with.

Universal design is a principle that originated with architecture: making buildings accessible to all learners. The idea is that one creates a flexible environment that serves learners with diverse needs. This is a particularly applicable and necessary strategy for the community of learners I serve, who represent a broad range of testing levels, learning styles, and needs in my classroom. Many of the tools recommended for universal design, such as computer tools, are not available in my school. However, the principles are still applicable and are particularly useful in a science classroom, where visual, hands-on, and audio tools improve the quality of instruction in any event. The additional motivation for using this in a classroom is that what makes certain content accessible for learners with special needs actually improves the overall quality of the instruction for all the classroom learners. (Hitchcock, 2002)

In order to meet the needs of students coming from a diverse range of backgrounds and interests, this unit will use the KWL (Know-Want to Know-Learned) structure throughout the unit. Students will be asked to write down and discuss what they have learned about waves, sound, and music in previous classes or outside of school. Along these lines, students will also be asked if they have any particular musical talents that they would be willing to share with the class, in order to make the environment as student centered as possible and to encourage students to build on what they know. We will use the "Want to Know" portion to determine what students are curious about, any misconceptions they have, or questions that have been raised previously. This list will be posted in the classroom and we will refer to it throughout the unit and us it to guide the various parts of the unit.

This unit will ask students to use a variety of different skills and learning styles, some of which they may be more comfortable with than others. On some occasions, all students will be required to complete the same activity. However, in order to reach the maximum number of students, some lessons will be differentiated for differences in reading and math levels, and other lessons will give students choice about how they would like to learn and practice the material.

Classroom Activities/Lesson Plans

Lesson 1. Introduction: What is a wave?

Objective: Define a wave as a disturbance propagating through a medium and explain how waves transfer energy.

Background: Students should have seen waves in previous science courses, notably the 7th or 8th grade physical science courses (depending on the school). However, middle school science courses tend to focus more on the form of a wave than a broader definition that can be equally well applied to all types of waves, largely because students lack the supporting knowledge to justify this more in-depth look. The objective of this introductory lesson is to generate a broader definition of wave that students can apply to the many types of waves they will encounter: water waves, slinky waves, sound waves, and light waves. It is particularly important for them to be able to explain how waves transfer energy in order to understand the behavior of musical instruments.

Part 1: Defining a wave

The first part of this lesson will use concept attainment to enable students to see similarities between different types of waves. Concept attainment is an inquiry-based strategy used to help students generate their own knowledge through a process. I will introduce a set of examples and non-examples of waves, using demonstrations and images. These will be organized into two columns. After each example or set of examples, students will brainstorm possible rules that tie the examples together and separate them from the non-examples, first individually, then with a partner, and finally with the whole class. Students will record the examples and non-examples in their notes, as well as the brainstorming process. As more examples are added to the list, students will either suggest more similarities or eliminate previous suggestions that no longer apply to the whole group. The concepts of light and sound as a wave will not be introduced immediately. Instead, once students have a description of waves and wave properties, they will use these to predict behavior they would expect to see in a wave, and use this to make observations about light and sound waves and their wave properties.

This part of the lesson will incorporate visual, aural, and hands-on components in order to enable all students access to the concept. Students will be encouraged to draw pictures in their notes on the examples and non-examples.

Examples	**Non-examples**
Slinky Telephone cord/rope Water wave (in a tub, at the beach) Stadium wave Spring-connected poles (move longitudinal and transverse) Seismic waves Shock wave Vibrating string/rubber band (mechanical, not sound yet) Tacoma Narrows bridge	 Water from the faucet Beauty queen wave Volcanoes

Using the examples of waves, we will then construct a new chart based on this same idea, this time with the goal of distinguishing between a longitudinal and transverse wave. Keeping in mind that all the examples are waves, students will again brainstorm possible characteristics that distinguish between longitudinal and transverse waves.

Students will then be asked to determine whether new examples are longitudinal or transverse and justify their decision.

Part 2: Explaining how waves transfer energy

This lesson will include a number of demonstrations of how waves transfer energy through a medium but ultimately not to the medium. The demonstrations will include both longitudinal and transverse waves. For ease of demonstrating the concept, the demonstrations will be mechanical waves, with the intent of applying the concepts to other waves later. Students will write down observations on a graphic organizer, and describe the transfer of energy taking place on a macroscopic and molecular level. The wave medium will be attached or connected at one end to a physical object with the ability to move (but clearly not part of the medium). Students will be asked to predict what they expect the object to do when the traveling wave reaches it, with the intent of addressing the potential misconception that a transverse wave transfers energy up and down, rather than in the direction of the wave motion. After watching the demonstration, students will write down their observations and compare their predictions to what actually happened. Examples of particles hitting similar objects will be shown as well, to tie the concept to particle behavior and energy transfer, a concept students learned earlier in the year. Specific demonstrations of energy transfer with waves: Two tuning forks mounted on resonating boxes; a speaker and a wine glass; a tuning fork and an air column over water.

After several examples, students will work in groups to describe the energy transfers taking place to complete their graphic organizer.

Lesson 2. Observing wave properties in a variety of waves

Objective: identify the features of the wave and describe the effects of changing one property on the others.

This lesson will introduce students to the specific terminology and mathematics of waves, applicable to all types of waves, specifically wavelength, amplitude, and frequency. Students will already be familiar with the general behavior of a wave, such that this lesson will focus on development and application of skills and knowledge.

Part 1: Describing wave properties

In the first part of this lesson, students will complete an interactive reading activity. The reading includes a description of how to illustrate each particular property, wavelength, frequency, and amplitude, using a slinky. Students will read the passage 3 times. The first time, they will identify all the instructions relating to demonstrating the properties with a slinky. They will then read it again, this time carrying out the instructions for the slinky.

Once they have completed the slinky instructions, they will draw an image of what they see the slinky doing. Students will then identify whether the slinky example best matches with a transverse or longitudinal wave. Students will then read the reading one final time and add the vocabulary to the picture they created from the demonstration with the slinky.

Once students have generated their own description of frequency, wavelength, and amplitude, they will compare their description to a standard labeled drawing. Students will determine which definitions they interpreted correctly and which ones they did not, and edit their own drawing appropriately. Finally, students will take the written definitions from the reading and add them to their illustration. The primary reading will be based loosely on texts drawn from the Holt Physical Science textbook and the Physics of Music reading from Tufts education website. Owing to the range of reading levels within the classroom, students will be assigned one of 3 readings according to reading level. Each reading will incorporate the same concepts and the same instructions involving slinky; thus, each student will be accountable for the same high-level of understanding of the concepts, which is one of the reasons for the physical and visual demonstrations of the concepts using the reading. A sample reading and worksheet are included in the Appendix.

Part 2: Identifying wave properties and the effects of variation

In the second part of this lesson, students will apply their understanding of the concepts of wavelength, frequency, and amplitude to different types of waves and use these examples to develop a mathematical description on top of the conceptual definition. Each group of students will be given a slinky or heavy rope with which to carry out a series of demonstrations. To begin with, students will be instructed to generate a wave of a particular frequency and amplitude, and to determine an approximate wavelength. Students will then determine what happens to each property if they change one; for example, if students increase the frequency, they will describe what happens to the wavelength using their rope. Students will accompany their written descriptions with a drawing of what they see. The purpose of this is not to have students to generate a precise relationship but rather to give them an opportunity to experiment with the meaning and appearance of these properties.

Using the qualitative description, the teacher will introduce the equation expressing the relationship between wavelength and frequency. Students will then complete a two-part activity using a wave tank and wave generator in order to enable them to get specific measurements as well as a qualitative description: in the first part, they will predict the qualitative and quantitative changes in one property caused by changes in one property and then test their prediction. In the second part, students will determine how they must change the other properties in order to obtain a specific value of another property.

As an assessment for this part, students will generate changes in the behavior of a wave in the wave tank and write down their own description of what they changed, and the visible effect on the wave (e.g., the first student will adjust the speed at which the waves are generated, and perhaps note that the frequency is higher or the wavelength is shorter). The partner being tested will then write down his or her own description of what is happening without reading what the first person wrote. Once each partner has complete his writing task, the students will exchange papers and continue a silent debate in which they respond to what each other wrote and address the following questions: (a) do you agree or disagree with what your partner wrote? (b) if you disagree, what evidence supports your point of view? (c) if you agree, how did the two of you describe the scenario differently? Which of these seems more valid now that you have read both? Partners will be paired heterogeneously. This activity could also be completed in slightly larger groups with one person creating the scenario and the remaining group members writing their own observations. In this case, the students would have an opportunity to read and respond to more than one other idea about the scenario. Students should have 1-2 minutes to complete each stage of the writing process, and depending on the productivity of the conversations, this could include anywhere from 1-3 responses from each partner. These will be turned in at the end to determine student misconceptions or difficulties before moving onto sound as a wave.

Lesson 3. Sound as a wave

Part 1: Wave properties of sound

Objective: describe the wave properties of sound

As suggested in the "Rationale" section, one of the most challenging parts of discussing the wave properties of sound is making the connection between what students have observed visually and physically, and what they are only able to observe by listening. In order to apply the wave characteristics introduced previously, students must understand how sound travels as a wave and how the characteristics of the wave are evident in sound.

The demonstration of sound as a wave will reinforce the concept of scientists making predictions based on theories. In previous units, students have seen how to develop a theory based on experimental evidence. Now students will determine what they would expect to hear if sound was a wave or otherwise. Students will work in pairs to generate ideas of how sound would act as a wave, what kind of wave it would be, how it would travel, and where the wave characteristics might appear in sound. Once students have completed this preliminary work, the teacher will present two demonstrations. In the first demonstration, a frequency generator will be attached to a simple speaker. The frequency will start out high, and students will write down what they observe about the sound (students will not know that it is the frequency that is changing; this information will be added once students have concluded that sound does in fact demonstrate wave properties). As the frequency changes, students will continue to write down observations. Eventually, the frequency will be low enough that students will be able to hear the pulses. The teacher will then gradually increase the frequency again until the pulses are no longer audible. Students will write down any additional observations.

The second demonstration will add evidence to the proof that sound is a wave. Sound is just one type of wave. We want to investigate sound and find out more about it. Ask students what the two main types of waves are. Which is sound? Demo with 5 volunteers in a line: 1. be solid solid - particles bonded, transmit both types of waves; 2. be a fluid (liquids + gases), transmit only longitudinal waves. Therefore sound (in air) must be a longitudinal (or pressure) wave. This explains how your eardrum and a loudspeaker work -- something to move in and out creating/ responding to pressure waves -- pressure waves push in and out. Students will create their own image of a sound wave in air, and compare it to a standard diagram of a sound wave in air. We will then address the question, how is sound transmitted in a vacuum? It is not -- there is no medium for the wave to go through. We will probe this using another demonstration with a vacuum jar and electric bell. The bell will start ringing while there is still air in the jar. The air in the jar will gradually be removed; students will record their observations about what happens to the sound, until there is no air left. Students will combine their observations from the two parts of this demonstration to explain how sound is a wave and how sound travels. The two requirements for sound are (I) a vibration (source of sound) – may be wave or pulse like thunder and (ii) a medium. Could demonstrate tuning fork and strobe light. As an end of lesson assessment, students will determine if they think sound could travel through a liquid or a solid based on their observations, and how they would be able to test their hypothesis.

Part 2: Mathematical description of sound properties

As an introduction to the application of the wave equations previously discussed, this lesson will return to the demonstration of the frequency generator and speaker. This time, students will specifically observe the effect of frequency changes and volume changes on pitch. At this point, students should come to the conclusion that higher frequency results in higher pitch, but a higher volume (amplitude) does not change the pitch.

Students will now generate graphs of sound waves at various frequencies, specifically at even multiples of a base number (students will already be familiar with graphing waves in terms of wavelength and amplitude). Each graph will be drawn on the same scale, and students will be able to super-impose their graphs, in order to make observations about how each wavelength lines up. Students will then compare their observations with the graphs to observations they make using a pair of frequency generators set to different frequencies. Although we will not discuss them mathematically, students will identify the “beats” that are audible when two dissimilar frequencies play at the same time, and

Part 3: Musical instruments as sound generators

In this lesson, students will investigate how musical instruments generate sound, how the sound is changed in the musical instrument, and how different wave properties appear in different musical instruments.

This lesson will be an inquiry-based discussion of musical instruments of various kinds, specifically: a piano, brass instruments, woodwind instruments, and stringed instruments. Over the course of the lesson, students will connect whatever prior knowledge they have to concepts of waves and music, and use these to extend their understanding of music as it is produced by musical instruments alone and in concert. As an introduction to this lesson, students will listen to a recording of jazz and attempt to identify different types of sound they hear. For each of these types of sound, students will conduct an inquiry lesson using a recording of the instrument at various frequencies, pictures of the waves created by the instrument and graphs of the waves. The purpose of this activity is to get students to draw connections to the concepts they have learned themselves. This activity follows the “process-oriented guided inquiry learning” structure, in which students are presented with graphs, pictures, and other information, and follow a series of questions to arrive at a more thorough understanding of the topic. The questions are arranged to follow the sequence information, exploration, concepts, and application. The questions and suggested diagrams are included in the appendix.

As an assessment for the unit, students will complete the activity described below: Your task is to design a set of wind chimes to put on your porch. You need to complete several tasks:
1. Determine what and how many sounds you are trying to produce.
2. Determine how the sound will be produced in your wind chimes (compressional waves, transverse waves, or both).
3. Design the wind chimes.

References

Backus, John. (1969) *Acoustical Foundations of Music*. W.W. Norton.

Hitchcock, C.G., Meyer, A., Rose, D. & Jackson, R. (2002) Access, participation and progress in the general curriculum: A universal design for learning. Retrieved January 12, 2007, from the NCAC web sit: http://www.cast.org/ncac/techbrief.

Hutchins, C. M. (1948) *The Physics of Music: Readings from Scientific American.* San Francisco: W.H. Freeman and Company.

Moll, N.C., Amanti, C., Neff, D., & Gonzalez, N. (1992). Funds of knowledge for teaching: Using a qualitative approach to connect homes and classrooms. *Theory into Practice, 31* (2), **132-41**.

The Physics Classroom: A High School Physics Tutorial. www.physicsclassroom.com 2004 The Physics Classroom and Mathsoft Engineering & Education, Inc.

Trowbridge, L.W., Bybee, R.W. & Powell, J.C. (2004) *Teaching Secondary School Science: Strategies for Developing Scientific Literacy*. New Jersey: Pearson Prentice Hall.

Annotated Teacher Reading List

Lapp, David. (2003) *The Physics of Music and Musical Instruments*. Wright Center for Science Education, Tufts University. Extracted from website February 14, 2007. www.tufts.edu/as/wright_center/physics_2003_wkshp/book.htm This online textbook is an excellent resource for information about the physics of music at a high school physics level. Some of the reading and the math are more advanced than is suitable for the context of this particular curriculum unit, but it provides useful background material for teachers, and a reasonable starting point for developing course readings.

Backus, John. (1969) *Acoustical Foundations of Music*. W.W. Norton. This book has a wealth of information about the basics of waves, sound, and acoustics. It is presented in a very readable format and includes a very solid foundation in wave behavior before launching into the specifics of musical instruments and room acoustics. All major families of musical instruments are addressed, as well as a number of other topics of interest. This is an excellent place to start research about the physics of sound and music.

Hitchcock, C.G., Meyer, A., Rose, D. & Jackson, R. (2002) Access, participation and progress in the general curriculum: A universal design for learning. Retrieved January 12, 2007, from the NCAC web sit: http://www.cast.org/ncac/techbrief. This article discusses the principles of universal design: its origins as an architectural concept, its applications to a special education classroom, and its relevance to a regular education classroom with a wide range of learners. It is particularly clear about methods and benefits for all students, regardless of special needs.

Trowbridge, L.W., Bybee, R.W. & Powell, J.C. (2004) *Teaching Secondary School Science: Strategies for Developing Scientific Literacy*. New Jersey: Pearson Prentice Hall.
This book addresses a number of pedagogical strategies aimed at developing scientific literacy, including inquiry-based learning, effective questioning, and student assessment, among other things. It discusses the benefits of being student centered and departing from the lecture-based, direct instruction method of teaching science.

The Physics Classroom: A High School Physics Tutorial. 2004 The Physics Classroom and Mathsoft Engineering & Education, Inc. http://www.physicsclassroom.com/Class/waves/wavestoc.html
This website provides conceptual background information about most topics in mechanics, electricity, and waves. It often provides real-life examples and practice problems, as well as animations for certain topics.

The Science House. (2006) North Carolina State University. Physics Curriculum Resource Guide. http://www.science-house.org/learn/Physics/goal7.html
This site has a large number of online resources for teachers to incorporate into a unit concerning waves. It is not specific to sound waves, but is immensely useful for exploring alternative ways to introduce content, obtaining background information, or providing student practice. Teachers would find this useful both for their own familiarity with sound concepts but also when looking for ways to reach students who are not best served by traditional instructional methods.

Sounds Amazing. The University of Salford. http://www.acoustics.salford.ac.uk/feschools/
This website is designed for students of A-level physics, and therefore goes into greater depth on some topics than is necessary for physical science classes. As a result, it is a great resource for teachers who need to expand their own understanding of topics such as wave types, wave propagation, and waves on a string, as well as a number of other topics that are not addressed in this unit.

"Sound Unit" http://www.physics.uwo.ca/~harwood/sph4a1/u-sound.htm
This is an excellent, high-school level website, that includes full lesson plans that contain lesson openers, description of the basic concepts, demos, activities, and sample problems. The lesson plants are an excellent resource, and can either be used as-is, or tailored to meet the specific needs of a classroom. Some of the units and topics covered may be a little complex or in-depth for high school students, but provides suitable background and teaching support for high school teachers.

Annotated Student Reading List

Holt Physical Science Textbook

Lapp, David. (2003) *The Physics of Music and Musical Instruments*. Wright Center for Science Education, Tufts University. Extracted from website February 14, 2007. www.tufts.edu/as/wright_center/physics_2003_wkshp/book.htm
This is an excellent enrichment resource for students who are advanced in reading and mathematics and are looking for a more in-depth description of the physics involved.

http://www.nationalgeographic.com/volvooceanrace/interactives/waves/index.html
This website, affiliated with National Geographic, provides an excellent simulation of a wave traveling past a boat, and the behavior of the boat. It is one possible demonstration of the disturbance traveling but not the actual medium. Fun for students to explore how changing wave properties changes behavior.

http://www.internet4classrooms.com/eoc_physci.htm
This website is designed for students to practice skills they should learn over the course of a Physical Science Class. Although only parts of it are directly applicable to this unit, it incorporates a number of other skills and concepts that serve as the foundation for this unit. Students with access to the internet and in need of extra review could access this site for additional help and resources.

Appendices

State Standards and Core Curriculum Objectives

The material contained in this unit fits within Unit 7 of the Physical Science Core Curriculum mandated by the School District of Philadelphia. This unit falls specifically under Pennsylvania State Standard for Physical Sciences, 3.4C according to which students should be able to

- Describe sound effects (e.g. Doppler effect, amplitude, frequency, reflection, refraction, absorption, sonar, seismic).
- Describe and measure the motion of sound, light, and other objects.

According to the Core Curriculum, students should specifically be able to

- Explain how waves transfer energy
- Determine the wavelength, frequency, velocity, and amplitude of transverse waves
- Explain how longitudinal waves work
- Describe the Doppler effect and the effect of absorption on sound
- Explain how waves are affected by changes in medium or interaction with one another
- Explain why instruments have resonance frequencies
- Analyze how frequency and amplitude affect sound

- Explain how light, sound, and other wavelengths are related on the electromagnetic spectrum.
- Explain why light and sound weaken with distance and how they can be filtered

In addition, this unit is designed to meet other parts of the science standards, including Unifying Themes (Standard 3.1), Inquiry and Design (Standard 3.2), connecting technology, the scientific method, and scientific techniques to the science classroom. Specific standards to be addressed include:

- Explain the concept of system redesign and apply it to improve technological systems.
- Examine and describe stationary physical patterns.
- Examine and describe physical patterns in motion.
- Know that science uses both direct and indirect observation means to study the world and the universe.
- Integrate new information into existing theories and explain implied results.
- Use process skills to make inferences and predictions using collected information and to communicate, using space/time relationships, defining operationally.

Lesson Plan Supplements

Please see the following pages for sample worksheets associated with this unit.

Lesson 1.2 Demonstration Observation Sheet

Waves and Energy Transfer

For each demonstration you see, you should write down and/or draw:
(a) In what form the wave starts and ends
(b) What is going on in the medium that is visible
(c) What you think is going with the individual particles
You should complete step (a) by yourself during the demonstrations. You will complete parts (b) and (c) with your group once the demonstrations are finished.

<table>
<tr><th colspan="3">Demonstration 1:</th></tr>
<tr><td>Wave starts as. . .</td><td>What the whole substance does:</td><td>What the molecules do:</td></tr>
<tr><td></td><td rowspan="3">↓</td><td rowspan="3">↓</td></tr>
<tr><td>Wave ends as. . .</td></tr>
<tr><td></td></tr>
<tr><th colspan="3">Demonstration 2:</th></tr>
<tr><td>Wave starts as. . .</td><td>What the whole substance does:</td><td>What the molecules do:</td></tr>
<tr><td></td><td rowspan="3">↓</td><td rowspan="3">↓</td></tr>
<tr><td>Wave ends as. . .</td></tr>
<tr><td></td></tr>
<tr><th colspan="3">Demonstration 3:</th></tr>
<tr><td>Wave starts as. . .</td><td>What the whole substance does:</td><td>What the molecules do:</td></tr>
<tr><td></td><td rowspan="3">↓</td><td rowspan="3">↓</td></tr>
<tr><td>Wave ends as. . .</td></tr>
<tr><td></td></tr>
</table>

Lesson 2.1 Reading and Worksheet

Wave Characteristics

Waves come in two basic types, depending on their type of vibration. To show this, lay a long slinky on the ground and shake it back and forth. In this way, you are making what is called a transverse wave. A transverse wave is one in which the direction of vibration is perpendicular to the direction the wave is traveling. Now, with the slinky on the ground again, push the slinky forward and pull backward. In this way, you are making what is called a compressional wave. Compressional waves are also known as longitudinal waves. A compressional wave is one in which the direction of vibration is the same as the direction the wave moves.

Certain terms and ideas related to waves are easier to visualize with transverse waves, so let's start by thinking about the transverse wave you could make with a slinky. Repeat your first demonstration with the slinky (shaking it back and forth). Imagine taking a snapshot (this is the picture you are going to want to draw in your notes). Some wave vocabulary can be taken directly from the diagram. Other vocabulary must be taken from a mental image of the wave in motion (this is the hard part!)

On the drawing you created of your slinky, try to label the following parts of your wave (read the description carefully!)

- **Rest position—**the rest position is what the "medium (your slinky, water, or wherever else your wave is traveling) if the wave were not there. In other words, what does your slinky look like before you shake it back and forth? In order to label this on your drawing, you may have to add another line (dotted) to your drawing)

- **Crest—**the crest is the topmost point of the wave medium or greatest positive (upward) distance from the rest position.

- **Trough—**(pronounced "troff") the trough is the bottommost point of the wave medium or the greatest negative (downward) distance from the rest position.

- **Wavelength (λ)—**the wavelength is the distance from one crest to the next crest or from one trough to the next trough (each of these should give you the same wavelength). Think wavelength = length of wave.

- **Amplitude (A)—**The distance from the rest position to **either** the crest of the trough (each of these should give you the same amplitude).

Slinky Lab

Reading #1
List the instructions for what to do with the slinky below. Keep in mind that this time, you are just identifying the instructions. You are not actually doing them yet.

1. ____

2. ____

3. ____

Reading #2
This time, actually perform the slinky instructions. Draw what you see the slinky doing in the boxes below:

Transverse

Compressional:

Reading #3

List the wave characteristics below, then define them in your **own words**. Once you have done this, label the parts of the wave **on your drawing** of a **transverse wave** (not compressional!)

1. ________________--____
2. ________________--____
3. ________________--____
4. ________________--____
5. ________________--____

Once you have completed the steps above, ask for the "standard picture". This is what we traditionally draw. Fill out the chart below then answer the questions.

Between your picture and the "standard picture"

What's the same?	What's different?

1. Which wave characteristics did you understand correctly (in other words, what did you do right in your drawing)? ____

____

2. Which wave characteristics confused you (were incorrect in your drawing)? ________

____

3. How did you have to modify your drawing? Why do you think this part of your drawing was challenging? ____

____

Lesson 3.3 Inquiry Acitivity

Music POGIL

Instructions: you are going to listen to sounds produced by instruments and compare them to pictures of sound waves to determine how a variety of different instruments (including your voice) produce musical sounds. By the end of this activity, you should be able to suggest explanations for the behavior of a completely new musical instrument.

Part 1: Stringed Instruments

Diagram of Bass, Cello, Viola, and Violin

Diagram of Four Standing Waves on a string; one with twice the frequency

To begin this lesson, listen to the notes being played on the recording. Then answer the questions:

1. How does the sound change throughout the recording? (Use **specific vocabulary**)

2. Using what you know about sound, how do you think you could produce this change?

3. What do you notice about the size of the instruments shown above?

4. In general, how does frequency (*f*) relate to wavelength (λ) if the speed of the wave stays the same?

5. What are the wavelengths of the four standing waves shown above?

6. Which standing wave produces the highest frequency? On which instrument would you find this wave?

7. Which of the instruments shown above do you think would produce the lowest pitch? Which part of the recording does this correspond to?

8. Which of the instruments shown above do you think would produce the highest pitch? Which part of the recording does this correspond to?

Extension activity: Pianos have a particular tone quality known as timbre. In order to make the strings in a piano vibrate, you hit the string with a "hammer". Play around with the xylophone in front of you and explain which materials for the "hammer" produce which kinds of sounds. Which would you recommend for a piano?

Part 2: Wind instruments

Diagram of saxophone family

Diagram of pressure wave in a wind instrument

To begin this lesson, listen to the notes being played on the recording. Then answer the questions:

1. How does the sound change throughout the recording? (Use **specific vocabulary**)

2. Using what you know about sound, how do you think you could produce this change?

3. What do you notice about the size of the instruments shown above?

4. In general, how does frequency (*f*) relate to wavelength (λ) if the speed of the wave stays the same?

5. Which of the instruments shown above do you think would produce the lowest pitch? Which part of the recording does this correspond to?

6. Which of the instruments shown above do you think would produce the highest pitch? Which part of the recording does this correspond to?

7. What kind of wave does a wind instrument produce? How is this different from a stringed instrument?

8. Looking at the pictures shown below, how do you think each of these two instruments, a trumpet and a trombone, is able to produce different pitches?