MATERIALS™ EXPLORERS

SCIENCE OF SOUND

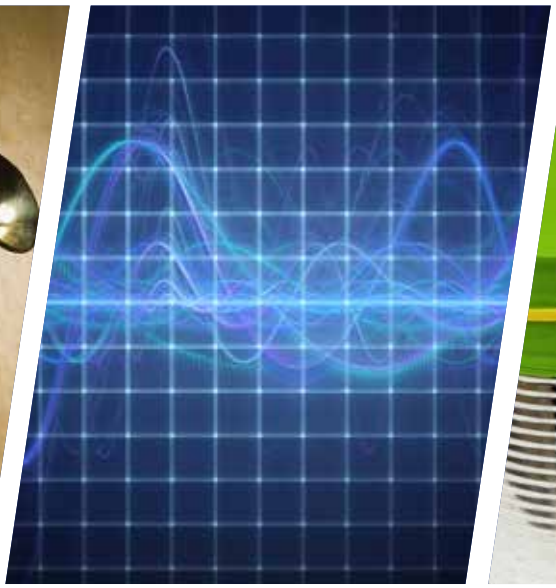
Ever wonder how music is made? In this chapter, you'll learn about the connection between waves and music by exploring how musical instruments produce sound. You'll also learn more about how musical instruments can be affected by the materials they are made from.

In this module students will be able to:

- Explain how pitch and amplitude can be adjusted for string and wind instruments
- Construct a prototype of an instrument which can be adjusted for pitch and amplitude
- Demonstrate the prototype and discuss challenges encountered
- Explore how various materials are used in the manufacturing of musical instruments
- Interpret graphs displaying sound waves, comparing pitch and loudness

Class Activity

ACOUSTIC AUDITION


Background:
When you hear your favorite song play on the radio or listen to a band play at a concert, what you're really experiencing are a series of waves, causing vibrations within your ear. These vibrations cause signals to be sent to your brain which, in turn, translates those signals into the amazing variety of noises you hear every day.

Sound is simply energy that moves through a medium, usually air, in a wave pattern. The **frequency** of a sound is directly related to its **pitch**. The more waves per second that hit your ear, the higher in pitch the tone is and the smaller the wavelength. Instruments can have high or low frequencies and some instruments sound louder than others. Louder sounding instruments have higher **amplitudes,** meaning they can compress air to a greater extent.

When a musical instrument produces a note, what it's really doing is creating a sound wave with a unique frequency, pitch, and amplitude. However, not all musical instruments do this in the same way. One of the most common ways to organize musical instruments is by classifying them into families based on the materials used in their construction and the method by which they produce sounds. The most common families are percussion, string, brass, and woodwind. In percussion instruments, sound generating vibrations are caused by a striking action, such as when drums are hit or when piano strings are struck by the piano's hammer. String instruments, such as guitars, cause vibrations in a slightly different way. The string of the instrument is pulled or plucked and the sound occurs as the string returns to its original position. Finally, the sound produced by brass and woodwind instruments is created by forced air interacting with the instrument. Think of how air is pushed through a recorder or trumpet.

Class Activity

Problem

An award-winning school marching band has decided to audition for a televised talent competition. The band members are very excited about this opportunity and know they need to deliver a unique performance in order to qualify. The students have decided to design, create, and play their own musical instruments instead of traditional instruments to make them stand out. Since you have exceptional knowledge of waves, pitch, and amplitude, they have enlisted your help to make the endeavor a success.

Task:
You are tasked with applying what you have learned about the properties of sound and acoustics as you design and create a musical instrument to present to your class.

Requirements:

1. The instrument must be a string, percussion or wind instrument.
2. The instrument cannot contain parts taken from other musical instruments.
3. The instrument must be capable of playing the following eight notes in order of increasing pitch: C, D, E, F, G, A, B, C.
4. The song you play for the class must consist of at least six different musical notes.
5. The class presentation you deliver must include a discussion of the following:
   a. How pitch and amplitude can be adjusted on your instrument.
   b. Problems you encountered while building and tuning the instrument.
   c. The inspiration behind the design of your instrument.

Definitions

Frequency
Frequency refers to the rate at which a wave is repeated over a specific period of time. It is typically measured in Hertz (which is calculated as the number of cycles per second).

Pitch
Pitch is related to frequency. The more waves per second hitting your ear, the higher in pitch the tone seems.

Amplitude
Amplitude is a measure of how “loud” a sound is. The greater the amplitude of the wave, the louder you perceive the sound.

Class Activity

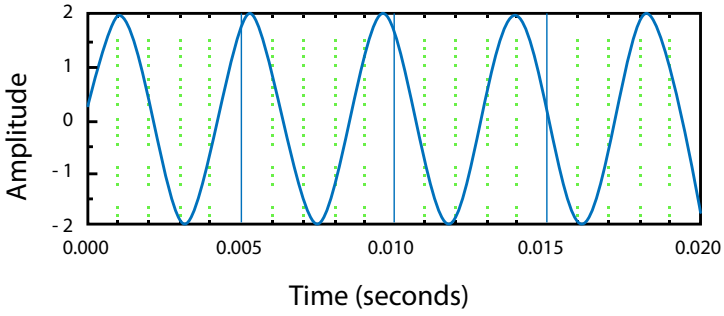
Questions

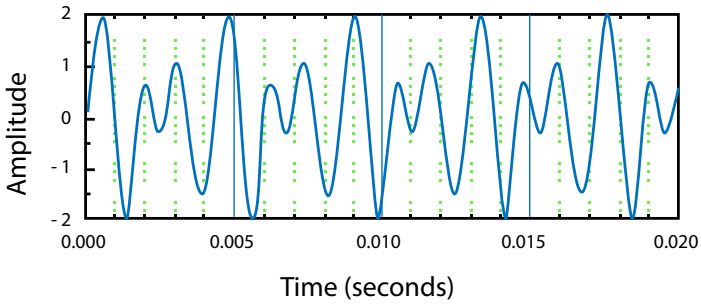
1. **Does frequency change based on the material used to create the instrument?**

2. **Do higher pitched sounds have a higher or lower frequency? Do they have a greater or shorter wavelength?**

3. **How can pitch and amplitude be adjusted for the following:**
   - **i.** A string instrument?
   - **ii.** A wind instrument?

4. **If the two waves below represent sound waves, how do the pitch and loudness compare?**





5. **What kind of work might an acoustical engineer do?**

Teacher Resources & Answer Key

Standards:	NGSS	HS-PS4-1

Notes:
N.B. This activity can be modified to take less time by having students work in groups to create different instruments.

1. Students should be encouraged to research ideas for their instruments.
2. Set deadlines throughout the project, including a deadline for a design draft, a prototype, and the final product.
3. PVC pipe is cost efficient and can be used to create a wind instrument. Bamboo also works well.
4. Fishing line can be used for string instruments, but students should be cautioned that fishing line can stretch so they may need to adjust tuning periodically.
5. Rubber sheeting, metal pipe, PVC pipe, and copper tubing can be used to create a percussion instrument.
6. Remind students that while they may be concerned with appearance, they are graded on functionality and their ability to discuss the scientific concepts at work.
7. The timeline for this project is at the teacher's discretion. Note: If students are not permitted to work on the project at home, it may take up to a week longer to complete.

1. **Does frequency change based on the material used to create the instrument?**

   Yes. All objects have a natural frequency or set of frequencies at which they vibrate. For example, steel, brass, and wood all have different natural frequencies. However, some instruments may be more affected by material choice than others.

2. **Do higher pitched sounds have a higher or lower frequency? Do they have a greater or shorter wavelength?**

   Higher pitched sounds have a higher frequency and shorter wavelength.

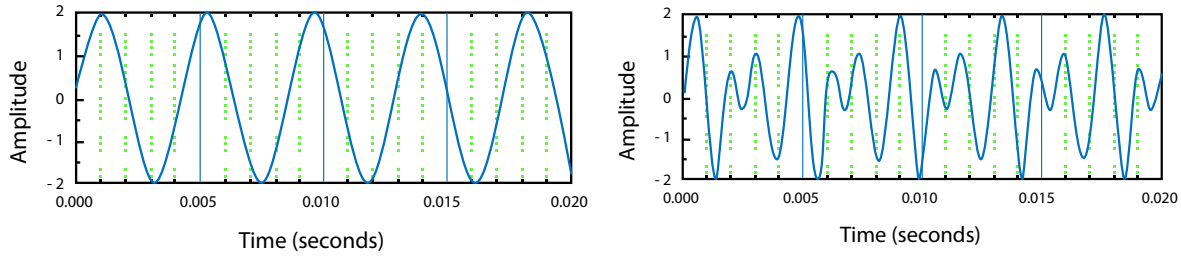
3. **How can pitch and amplitude be adjusted for the following:**
   - **i.** A string instrument?
   - **ii.** A wind instrument?

   i. String instrument: Pitch depends on the size of the string and the tension on the string. Amplitude depends on how hard the strings are plucked.

   ii. Wind instrument: Pitch depends on the size of the air column. Amplitude depends on how much air is forced through the column.

Teacher Resources & Answer Key

4. If the two waves below represent sound waves, how do the pitch and loudness compare?



The pitch and loudness are the same because the period and frequency as well as the amplitude are the same.

5. What kind of work might an acoustical engineer do?

Student answers will vary. Some examples include: Work on the design and sound of performance spaces; ensure buildings comply with local noise ordinances and standards; work to minimize noise on the highway or in air traffic; design sound systems; or work with bioengineers to develop medical technology like hearing aids.

Activity Grading Rubric

Points	Design	Pitch	Explanation
4	Instrument and design is well thought out and supports the solution to the problem. Song can be played fluently.	Seven or eight distinct pitches were played.	Information is clearly focused in an organized and thoughtful manner. Information clearly addresses how pitch and loudness can be adjusted as well as construction challenges.
3	Instrument and design is well thought out and supports the solution to the problem. Song could be played with 1 or 2 difficulties.	Five or six distinct pitches were played.	Information supports the solution to the challenge or question. Information addresses how pitch and loudness can be adjusted as well as construction challenges.
2	Instrument and design supports the solution. Song is a struggle to play.	Four or fewer distinct pitches were played.	Information loosely supports the solution. Information does not clearly address how pitch and loudness can be adjusted. Construction challenges are mentioned.
1	Instrument and design does not support solution.	No distinct pitches were played.	Information does not support the solution. Information does not clearly address how pitch and loudness can.

Extension Activity

DO MATERIALS MATTER TO MUSIC?

When it comes to creating a musical instrument, one thing is certain. Materials matter. Instrument makers may use a signature material to differentiate their works from others, a rare material to add to the prestige of an instrument, or a pliable material to make production of the instrument easier. The choice of materials can also affect the sound an instrument creates and even traditional craftspeople have been known to tinker with advanced materials for better sound quality.

However, the influence of material choice on sound quality can vary vastly from one musical instrument to another. Take, for instance, the debate around brass instruments.

The prices of brass instruments can vary widely based on the type of material used to produce them, but players and manufacturers alike are divided on whether this makes any difference at all to the final sound. Researchers have set out to find an answer.

At the Institute für Wiener Klangstil (IWK) in Austria, researchers tested seven identical flutes made out of silver, various degrees of gold, and platinum, as well as coated instruments, to determine if the sound quality from the different flutes was affected by the choice of material. (Photo courtesy of the IWK)

Testing Precious-Metal Flutes

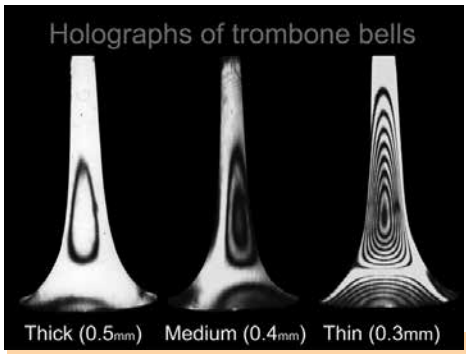
Gregor Widholm, who established the Institut für Wiener Klangstil (IWK) at the University of Music and Performing Arts in Vienna in 1980, conducts applied research in the field of musical acoustics. The institute credits Widholm with founding the scientific research field of musical acoustics in Austria by adapting scientific physical measuring methods to the investigation of the functionality of musical instruments.

Widholm and his colleagues set out to learn the effect of different metals on the sound of flutes. They chose seven identical flutes made by a single manufacturer, Muramatsu, in seven different materials: silver coated, full silver, 9 kt gold, 14 kt gold, 24 kt gold, platinum coated, and all-platinum. Seven professional flute players from Viennese orchestras were recruited to test the flutes by playing short solo pieces and individual notes on each of the seven flutes. These results were recorded and analyzed by IWK researchers, and the professionals listened to the results. What they found was that the instrument being played had little effect on the sound being produced.

“Silver, 24 kt gold, and platinum all have different vibrating properties,

Extension Activity

of course, but the musician can mask all these properties by generating the sound," said Widholm. "That's the reason why there's really no difference between the $3,500 flute and the $150,000 flute. We conducted these tests with professional flute players, and when they heard the samples recorded, they heard no difference." These tests also measured the dynamic range of the instrument—that is, how loud or soft the musician can play. The platinum flute provided a slightly higher dynamic range, but, while measurable, it was not significant. The difference between musicians varied more than between instruments.



This image shows holographic measurements of vibrations in trombone bells of various thicknesses. Though there is a measurable difference in vibration, instrument players were able to detect little difference in sound quality among the three.
(Photo courtesy of Richard Smith)

An Experiment in Brass

Unlike many instrument makers, who start out as musicians, Richard Smith began as a scientist, receiving master's and Ph.D. degrees in acoustics. His doctoral research dealt with the application of quantum physics to musical instruments.

Now, Smith uses his scientific background to manufacture brass instruments with high sound quality at his own company, SmithWatkins, where he designs instruments with trumpet player Derek Watkins.

Like Widholm, Smith has also put instruments to scientific tests–this time, to determine if varying the material of a trombone will change its sound. Smith conducted an experiment using several trombone bells of various materials and thicknesses. Although holographic measurements show differences in the vibration for the various thicknesses of material, Smith found that not one of the professional trombone players in his study was able to tell the difference either between different types of material or different thicknesses of material in the bell of the trombone.

Internal shape is important to the sound, bell shape is important, and the lead pipes are important, according to Smith. "Materials are

Instrument manufacturers are always experimenting with alternative materials. Ted Brewer's Vivo² electric violins deviate from traditional violins in both material and shape. (Photo courtesy of Ted Brewer Violins)

really just the icing on top," he said.

However, sound quality isn't the only factor determining material choices and, for Smith, brass is still best. "It's all about what material is easiest to work with," said Smith. "Brass is ideal because it's malleable."

While the body material will likely stay the same, there is room for materials innovations in some of the instrument's smaller pieces. For example, Smith would like to see a materials redesign of trumpet valves to make them faster. Using lighter weight materials in the valves, such as magnesium or titanium, could be the solution, he suggested.

Extension Activity

Instruments are Like Golf Clubs...

If specific metals have not proven to make much difference in the sound of metallic instruments, why select one material over another? Some manufacturers use materials as a marketing device to differentiate themselves from competitors. For others, it is simply a way to offer musicians more choice.

Elizabeth Holm, a materials scientist and amateur musician, notes that another factor driving material choice is likely psychological. She compares it to the golf club industry, where new clubs made of "better materials" are introduced every year, claiming to improve your game. "There's a strong placebo effect. If you have more confidence in your clubs, doesn't it make you play a little better, at least for a while?" she said. "I don't know; I've never measured it. But it's the same with music."

Elizabeth Holm (right), a materials scientist, plays violin with her friend Jude Rowe, as members of a band that performs primarily for Celtic dance groups and festivals. (JOM: December 2013)

This article is excerpted from "The Science of Sound: Examining the Role of Materials in Musical Instruments" by Kelly Roncone Zappas, published in JOM, August 2007, Volume 59, Issue 8, pp 13-17.

Questions

Whether the choice of material affects the sound, appearance or cost of an instrument, craftspeople give serious thought to the types of materials they use. While Widholm and Smith found that the choice of material did not affect the sound quality for their flutes or trombones, it has a major influence on the sound produced by a violin.

1. **How is sound produced in a traditional violin and why might the choice of materials be important to this?**

2. **What materials are violin bows traditionally made of and what challenges to this material have caused violin makers to explore new materials?**

3. **What alternative material is currently in use for bows? What are the pros and cons of using this material?**

4. **Kevlar, a material often used in bullet-proof vests, is also used in violins. What part of the violin is composed of Kevlar and what is the advantage of using this material?**

5. **While there are no restrictions on materials that can be used to make electric violins, what are some factors manufacturers should consider when selecting materials?**

Extension Activity Answer Key

1. **How is sound produced in a traditional violin and why might the choice of materials be important to this?**

   A string which is attached to a soundboard can be vibrated by plucking or tapping it. The vibrations create compression waves in air. The compression waves result in sound according to the frequency of the waves. Materials are important to violins because the frequency or pitch is dependent upon the material the strings are composed of.

   The three types of strings available to use for violins are gut core, steel core, and synthetic core. Gut core strings are made from a natural fiber, making them pliable and sensitive to temperature and humidity. Steel core strings—consisting of thin fibers of roped or spiraled steel coated in metals such as aluminum, chrome, steel, tungsten, silver or titanium — are sturdy and create a stable pitch. Synthetic core strings are composed of nylon and sound similar to gut strings, but are more stable in pitch.

2. **What materials are violin bows traditionally made of and what challenges to this material have caused violin makers to explore new materials?**

   Violin bows are traditionally made from Pernambuco wood, however Pernambuco trees in Brazil are now considered endangered. This makes it both challenging and expensive to purchase the wood.

3. **What alternative material is currently in use for bows? What are the pros and cons of using this material?**

   Carbon fiber composite has been an alternative material used to make bows. Carbon fiber allows bows to be sturdier, lighter in weight, and less prone to warping. Carbon fiber is also less expensive and more uniform, which allows consumers to expect consistent quality from a manufacturer.

4. **Kevlar, a material often use in bullet-proof vests, is also used in violins. What part of the violin is composed of Kevlar and what is the advantage of using this material?**

   Kevlar string is used on the tailpiece in place of a traditionally stiff metal wire coated with plastic. Kevlar string improves the sound from the tailpiece.

5. **While there are no restrictions on materials that can be used to make electric violins, what are some factors manufacturers should consider when selecting materials?**

   Student answers will vary but should relate to important qualities such as durability, aesthetic appeal, ease of manufacturing or cost effectiveness. For example, a student may respond that the weight of the material should be taken into consideration so that the instrument is not cumbersome.

Materials Explorers™ is a STEM educational outreach initiative of The Minerals, Metals & Materials Society (TMS). TMS is non-profit, international professional society with a mission to promote the global science and engineering professions concerned with minerals, metals, and materials.

TMS
The Minerals, Metals & Materials Society