Overview

Tool Kit IV
Amplification – Acoustic

How is the energy of sound waves transferred from one acoustic (nonelectronic) medium to another?

a. Discover how resonance can be used to amplify sounds.
b. Explore how the various design elements of a musical instrument can influence its resonance.
c. Build a working prototype of your own acoustic musical instrument.

Tool Kit V
Amplification – Electric

How is the energy of sound waves transferred from an acoustic (nonelectronic) medium to an electronic one?

a. Investigate how a device called a transducer helps to capture and electrify sound wave energy
b. Electrify your own prototype musical instrument.

Tool Kit VI
Oscillators – Electrical Sound Synthesis

How can electrical circuits be used to generate sound?

a. Engineer a simple electrical circuit that generates sound.
b. Explore the basic concepts of digital music technology.

Tool Kit VII
Science and Technology in Society

What drives innovation in music technology?

a. Discover events, people, and circumstances that have driven past innovations in music technology.
b. Contemplate the driving forces of current technological innovation in music.
c. Project what future innovations might occur in your lifetime.

Extend the Learning
Links to curricular resources supporting project-based learning are provided in each tool kit. Examples include resources to explore electrical engineering, computer programming, material sciences, trigonometry, and advanced physics.

Museum Collection Highlights, Vocabulary, and Concepts

- Amplification
- Resonance
- Electromagnetism
- Compound Waves
- Wave Propagation
- Frequency
- Wavelength
- Speed
- Medium
- Compression
- Rarefaction
- Rock and Roll
- Hip-Hop
- Thumb Piano
- Electric Guitar
- Theremin
- Synthesizer
- Robert Moog
- Les Paul
- C. F. Martin & Co.
- RCA

Discover the inner workings of an electric guitar.

Field Trip
During a field trip to MIM, students explore how the principles of acoustic and electronic amplification are represented in the wide variety of instruments on display, how the principles of electronic sound synthesis have been employed in those instruments, and, finally, how new music technologies have impacted cultures throughout the world, beginning with some of MIM's oldest musical instruments up to the present day.

Book a field trip at MIM.org/field-trips!

Standards Addressed

The following project-based learning activities were designed to introduce concepts and practices of the sciences as they relate to music; however, numerous interdisciplinary connections and extensions to these activities are also possible. Embedded STEM learning facilitates inquiry across numerous disciplines, a few examples of which are listed below:

Arizona Science Standards

- Strand 4
  - Life Sciences
- Strand 6
  - Earth and Space Science

Arizona Social Studies Standards

- Strands 1 and 2
  - American History and World History
- Strand 4
  - Geography

Arizona Mathematics Standards

- Measurement and Data
- Ratios and Proportional Relationships
- Algebra
- Geometry
- Functions

English Language Arts

- Reading Standards
  - Informational Text
  - Foundational Skills
- Writing Standards
- Knowledge
- Language
- Writing: Opinion Pieces

Arizona Academic Standards in Arts

- Creating
- Presenting
- Responding
- Connecting

Tool Kit IV
Amplification – Acoustic

Objective
Investigate how sound waves transfer energy or interact with different mediums, including resonators and dampeners, and how the transfer of sound energy between different mediums affects the characteristics of the sound.

Materials
- Music-box action*, tuning forks*, or other small source of sound (cell phone, etc.)
- Recycled materials: shoeboxes, cookie tins, plastic bins, string, wire, etc.
- Scissors or box cutters
Available at the Museum Store at MIM

Background Information for Educators
Review the basic characteristics of sound waves (**frequency**, **wavelength**, **amplitude**, and **speed**) in MIM's elementary curriculum for "STEM: How Science Brings Music to Life".

The loudness of a sound wave relates to its **amplitude**. Since a musical instrument is meant to be heard, its **vibrations** (or **sound-wave energy**) must disrupt a relatively large number of air molecules. For acoustic instruments, we can **increase the amplitude** by having a soundboard, or resonator, as part of the instrument design. The sound-wave energy of the initial sound source is **transferred** to a larger medium such as a soundboard or resonator, which itself begins to vibrate, transferring that sound-wave energy to an even larger number of air molecules. Conversely, if we wanted to **decrease the amplitude** of a musical instrument, we would direct its sound-wave energy into a medium that would absorb many of those vibrations without passing them on to the surrounding air molecules. In both cases, the vibrations (or energy) of the initial sound source are transferred from one medium to another.

Activity
What effects do different mediums (with which sound waves transfer energy) have on the sounds we ultimately hear?

Investigate
Present students with a sound source (small music-box action, tuning fork, or any electronic device with a small speaker such as a cell phone or MP3 player with earbud speakers).

A. ***How will we experience the amplitude of a sound source when it is played in the air?*** The amplitude is low; the sound is quiet.

B. ***How will we experience the amplitude of the sound source when it is placed against a hard surface, such as a table or desk?*** The amplitude is high; the sound is louder.

C. ***What will happen if the sound source is placed on a soft surface, such as a pillow or foam pad?*** The amplitude is low; the sound is quiet.

Students experiment with different resonating materials.

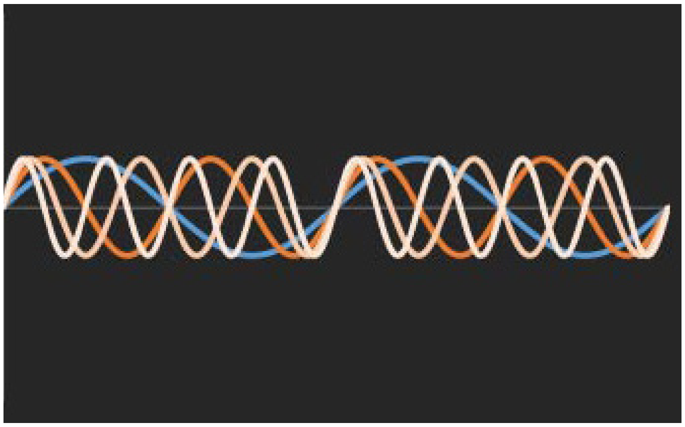
Create
Experiment with different materials and construction techniques to make a resonator—something which will help amplify the vibrations of the small sound source.

D. ***What will happen to amplitude if the sound source is inside a cardboard box? Inside a metal tin?*** Resonance is directly related to both mass and stiffness or tension. Materials that are extremely stiff but of minimal mass, such as a tin can, a thin wooden box, or a hollowed-out gourd, all make highly effective resonators. This is because, due to their minimal mass, it takes a minimal amount of sound-wave energy to get them to vibrate. We sometimes call this "sympathetic vibration."

E. ***Does your instrument sound better if played at certain frequencies more than at others?*** Every material will have a "Helmholtz resonant frequency" at which it will amplify a specific frequency with the most efficiency. Herman von Helmholtz was the German scientist who first discovered how different materials could be used to amplify specific frequencies depending on their mass and density, among other things. Some materials resonate best at very low frequencies, and some resonate best at very high frequencies. This is called the "resonant frequency" of that material. Putting a material under tension (by stretching a drumhead or pulling a string tight) affects resonant frequency because it changes the physical properties of that material at a cellular level.

So-called f-holes on a violin improve its resonance at lower frequencies.

F. ***Will holes make a difference in the amplitude?*** The addition of holes lowers the mass of the resonator and changes the "Helmholtz resonant frequency" of the instrument. Exactly how a hole changes resonance is extremely complex and depends on its location, the source of vibrations, and the frequency of those vibrations. For example, studies have shown that the so-called f-holes on a violin improve its resonance at lower frequencies. It took hundreds of years of experimentation to settle on the placement and size of the f-holes on a violin.



This image is a representation of the type of "compound wave" that makes up sounds you hear. Each color represents a different frequency. The point where multiple waves come together at the same amplitude is called "node."

G. ***Will changing the resonator's structure with bracing or ribs make a difference in the loudness?*** Adding braces or ribs to the inside of the resonator will increase rigidity and mass at certain places on the instrument. Depending on where this rigidity and mass is added, both the resonance and resulting loudness can be affected. Every acoustic instrument resonates at multiple frequencies at once. These simultaneous frequencies are called overtones. Plucking a single string on an instrument creates sound waves at multiple frequencies. You hear the simultaneous frequencies as one note, but what you are in fact hearing is a "compound wave" made up of numerous overtones. Some overtone waves are very slow (low frequency) and some are very fast (high frequency). The point on the instrument where multiple waves come together at the same amplitude is called a node. Stiffening certain parts of your instrument with bracing will affect how these "nodes" behave. Calculating exactly where a node occurs on any given instrument is far too complex for this activity. However, you can experience how your bracing choices interact with these nodes by moving them around and noticing the subtle differences in the resulting sound.

H. ***Which resonator design provides the truest sound reproduction, as opposed to just the loudest?*** Regarding the overtones mentioned above, every instrument will emphasize certain overtones. Large resonators of minimal mass and rigidity can favor low overtones, while highly rigid resonators of added mass can favor higher overtones. Sometimes, a preference for one resonator design over another is a matter of personal taste.

Assessment

Formative

Students will demonstrate their understanding of wave energy exchange and resonance via the choices they make as they create different types of resonators or dampeners for their respective sound sources.

Summative

Students will explain the concept of acoustic resonance as a concept of vibrational (or wave energy) exchange.

Activity on your visit to MIM: Point out the different kinds of acoustic resonators.

Example: Acoustical Amplification – Thumb Pianos of Many Shapes and Sizes

What is a thumb piano?

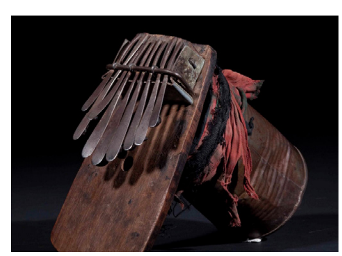
The **thumb piano**, a generic term, is a musical instrument that consists of a wooden board to which staggered metal keys, or tongues, have been added. Another word for thumb piano is **lamellaphone**, which is a subcategory of an idiophone. Thumb pianos have been in use in Africa for thousands of years and are known by many different names, depending on the people who make and play them. There are many types of thumb pianos found within MIM's Africa Gallery, especially in the Zimbabwe exhibit. The mbira is played both in and out of a calabash gourd, which serves as an additional resonator.

First, a wooden soundboard is carved with an adze (like a small ax) and various knives. A hot iron poker is often used to burn/drill holes into it. In contemporary examples, keys/tongues as well as the pressure bars and bridges are manufactured from various recycled metals. The keys are cut to different lengths and shapes, depending on how the instrument is to be tuned. The handheld instrument is played by depressing or plucking the lamellae fixed to the soundboard.

How is a thumb piano's sound amplified?

The resonator can be made of many different materials, such as a solid wooden board, a hollow wooden box, a metal can, or a dried gourd. The shape of the resonator box or instrument body directly affects its sound. On a hollow-bodied resonator, there is often a sound hole to amplify the instrument's sound.

For centuries, the thumb piano has been a preferred instrument of storytellers, historians, and ritual experts throughout Africa. MIM's exhibit has over twenty-five thumb pianos from all over Africa made from diverse materials. Many of the instruments are carved into symbolic shapes or have patterns that carry culturally specific meaning.



Thumb pianos on display at MIM make use of a variety of different types of resonators.

C. F. Martin & Co. is an innovator in acoustic guitar design.

Example: Acoustical Amplification – Guitars

An important characteristic of acoustic guitars is found in the body: an acoustic guitar has a hollow body that acts as a resonator. The hollow body amplifies the vibrations of the strings. In contrast, the solid-wood body of an electric guitar does not have to resonate like an acoustic guitar because the sound waves primarily come from its connected amplifier and speaker, not from the guitar's body.

C. F. Martin & Co. continues to be an innovator and leader in acoustic guitar manufacturing. On display at MIM is a re-created Martin workshop, which prominently features X-bracing, one of the company's most successful innovations. X-bracing enhances the vibrational response of the guitar's resonating chamber (body) as it responds to and acoustically amplifies the vibrations of the guitar strings.

Additional Resources

Stradivarius at MIM: The Science of Stradivarius Violins

The Interconnected Nature of the Laws of Physics (Including Sound, Hearing, and Resonance)

Mathematics and Drumming: Analysis of Vibrating Nodes and Bessel Function Properties

Arizona State University's Consortium for Innovation and Transformation in Music Education (CITME) Curates Numerous STEM/STEAM Music Education Resources

X-bracing improves the resonance of Martin acoustic guitars.

Tool Kit V
Amplification – Electronic

Objective
Investigate the conversion of sound waves into electrical energy via a transducer (i.e., "microphone"). Investigate how, after being converted into electrical energy, those sound waves can be increased or decreased in amplitude. Investigate the reconversion of that electrical energy back into sound waves via another type of transducer (i.e., "speaker").

Materials
- Pre-wired piezoelectric pickup with instrument cable adapter
- Instrument cable and adaptors as required
- Amplifier and speaker [Alternatively, cell phones with headphone inputs may be used.]
- The instrument that you built in "Tool Kit I: Amplification – Acoustic" or an assortment of resonant objects (cups, tin cans, bowls, percussion instruments, or bells)

Piezoelectric pickups are simple transducers that can easily be added to many musical instrument crafts.

Background Information for Educators
A transducer is any object that converts energy from one form into another. In the case of sound, a transducer can convert the mechanical energy of a sound wave (vibrations) into electrical energy (**voltage**). A transducer can covert electrical energy back into sound waves. A **pickup** or a **microphone** can be a transducer that converts sound energy into electrical energy. A **speaker** converts electrical energy back into sound energy. A **biological ear** is a very complex transducer that coverts mechanical sound energy into electrical energy, which a brain then interprets as sound. Transducers are essential tools for the electrical **amplification** of musical instruments as well as for **recording** sounds with electronics. Transducers are also necessary for converting electrically amplified or recorded musical sounds back into something that we can hear via a **speaker**.

Activity
How does a transducer work?

Investigate
Present students with a piezoelectric pickup (i.e., "transducer") connected via cable to an amplifier and speaker.

Create
Experiment with the placement of your piezo transducer to find the best place on your musical instrument for it to pick up its vibrations.

A. ***How do we experience the sound of the instrument if the piezo is held a small distance above the instrument? What if the piezo is placed on the instrument?*** The piezo responds to sound energy by vibrating, and then converts those vibrations into an electrical charge. The more the piezo can vibrate, the better it will work.

B. ***Does the frequency being played affect how well the piezo is able to work?*** Helmholtz resonance demonstrates that a musical instrument will vibrate more efficiently at certain frequencies than at others. If your instrument is vibrating more efficiently, its vibrations will occur at greater amplitude than if it is vibrating less efficiently. Additionally, piezos do not respond well to extremely low or extremely high frequencies.

C. ***Does the piezo work more effectively depending on where you place it on your musical instrument?*** A musical instrument will vibrate in different ways at varied places across its surface because of the way all the various individual frequencies of overtones interact with one another. The sound waves you hear are a compound wave composed of numerous frequencies that all occur simultaneously. Certain places on a musical instrument will vibrate more or less, depending on how these overtones are interacting.

D. ***What does the volume knob on the amplifier do? Can you use the volume knob to compensate for an instrument that does not vibrate very well?*** The piezo will convert the mechanical energy of sound waves into electrical energy (voltage). The amplifier can then increase the amperage of that electrical energy (voltage) before sending it along to a speaker. Imagine waves of electrical energy of low amplitude (soft sounds) being "amplified" into waves of electrical energy of high amplitude (loud sounds).

E. ***What does the speaker attached to the amplifier do?*** The speaker is another kind of transducer that converts electrical energy back into mechanical sound energy (sound waves). If the speaker is given electrical energy of high amplitude, it will vibrate more vigorously than if it is given energy of low amplitude. In other words, to create sound waves of high amplitude (loud sounds), the center of the speaker will actually jump up and down "higher" than it would if it were creating sound waves of low amplitude (soft sounds)

Assessment

Formative

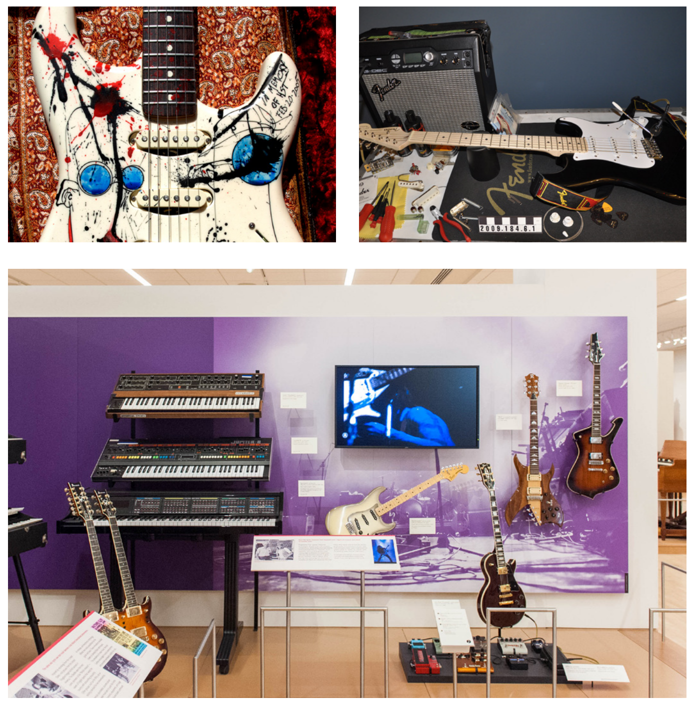
Students will demonstrate their conceptual understanding of transducers by finding the best place to affix the transducer to their musical instrument and turning the volume up or down on the amplifier accordingly.

Summative

Students will explain how transducers work, providing two examples of different types of transducers and their respective uses.

Activity on your visit to MIM: Point out the different kinds of transducers, effects processors, and speakers.

The above activity represents a transducer that converts sound-wave energy (vibrations) into electrical energy. This is the technology inside many microphones and instrument pickups, but it is only one of many different types of transducers. Another very common type of transducer is the electromagnetic transducer, more commonly known as an "electric guitar pickup."



The magnetic pickups on an electric guitar are another form of transducer.

Collection Connection: Electric Guitar

How does the electric guitar work?

The **transducer** (i.e., "pickup") on an electric guitar is a **magnet** wrapped in a wire coil. All electric guitars have at least one such magnetic pickup; some have multiple. In the same way that the placement of a piezo on your musical instrument affected its sound, the placement of a pickup on an electric guitar affects the eventual sound that *that* guitar produces. For this reason, you will often see an electric guitar with more than one pickup. Unlike the piezo pickup you used on your instrument, the pickup on an electric guitar does not respond to sound vibrations. It responds to **magnetism**.

The magnetic pickup on the electric guitar is placed below the steel strings of the guitar. As the steel strings vibrate, the fluctuations in magnetic force caused by their movement above the magnetic pickup is converted into electrical energy. You can experience how this works by waving a piece of metal above a stationary magnet. The magnet will pull toward that piece of metal in the same way the magnetic pickup pulls toward the vibrating steel strings and that pulling motion is what gets converted into electrical energy. From the pickup, the electrical energy can be amplified and sent to a speaker. The electrical energy can also be processed in many ways by adding different sound effects such as distortion. But as the process of creating sounds relies on magnetism, if you were to yell as loudly as you could into the pickup of an electric guitar, nothing would happen (unless you were to yell loud enough to get the metal strings to vibrate too).

Microphones are an additional type of transducer.

Many microphones (but not all) make use of this same principle of magnetism. In the case of a microphone, the sound waves are first picked up by a resonant medium (diaphragm, ribbon, spring, etc.) and then converted to electrical energy. "Dynamic microphones" make use of a delicate metal coil suspended below a magnet. Sound waves make the metal coil move just like the strings on an electric guitar. As the spring moves and the magnet pulls on it, an electric charge is created, which can then be amplified. Other microphones, such as "condenser" or "piezoelectric" microphones, function very similarly to piezoelectric pickup on your musical instrument. These microphones pick up sound vibrations and convert them to an electrical charge via other means.

Additional Resources

The Physics of Piezoelectric Pickups

The Physics of the Electric Guitar Pickup, Amplifiers, and Effects

The Interconnected Nature of the Laws of Physics (Including Sound, Electricity, and Magnetism)

Arizona State University's Consortium for Innovation and Transformation in Music Education (CITME) Curates Numerous STEM/STEAM Music Education Resources

Tool Kit VI
Electrical Oscillation – Making Sound from Electrons

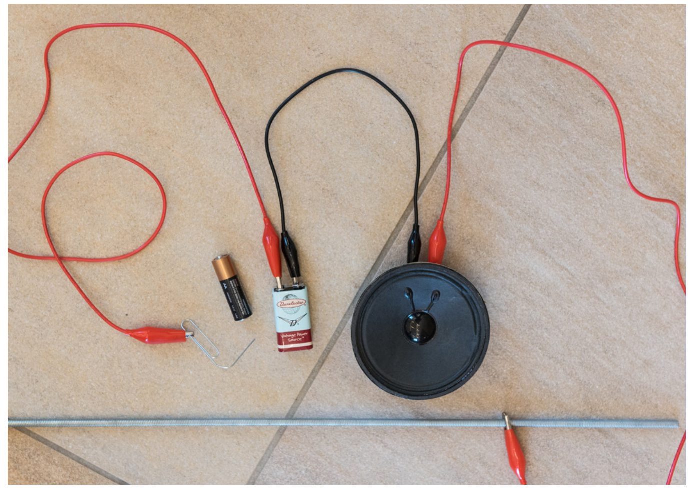
Objective
Investigate how the creation of oscillations in electrical energy can be used to create audible sound via a transducer and how amplitude is related to voltage. Explore the basic principles of square and sine waves as well as the compound waves that are more commonly found in nature. Understand the basic concepts of binary computation and the way in which binary "digital" systems, or bits, are used to create audible sound.

Materials
- Small speaker (such as can be salvaged from old computer monitors, car stereos, or old home entertainment systems)
- 9-volt battery
- 1.5-volt battery (AA, AAA, C, or D)
- 3 wires with alligator clips on each end
- 12-inch threaded rod
- Paper clip

Background Information for Educators

An **oscillator** is anything that creates a regular variance in electrical energy. A light switch is a very simple oscillator. Placed in a **circuit** (e.g., loop) between a light bulb and an energy source, the light switch can create an **oscillation** between a light being "off" or "on." In this case, the light bulb is a **transducer** that converts **electrical energy** to **radiant light energy**. If we wanted to convert these electrical oscillations to **sound energy**, we would need another type of **transducer**: a **speaker**.

The **speaker** responds to the **oscillation** (e.g., variance) in electrical charge by moving up or down. This up-and-down motion creates **sound waves** that our ears can process as sound. The faster the oscillation in the electrical charge, the faster the speaker will move up and down, resulting in a sound wave of higher **frequency**. If the electrical oscillation is slow, the resulting speaker movement will also be slow, resulting in a sound wave of low **frequency**.



Simple circuits including batteries and speakers demonstrate how sound is created from electrical oscillation.

Activity

How does an oscillator work?

Investigate
Present students with the components of a simple circuit composed of the speaker, two wires with alligator clips, and a battery.

A. ***What happens to the speaker when you complete the circuit by using the alligator clips to connect the speaker to the battery?*** The speaker moves either in or out in response to the electrical charge.

> NOTE: Leaving a speaker continuously connected to a continuous electrical charge can result in speaker burnout. Complete the circuit just long enough to see how the speaker moves.

B. ***How does the direction the speaker moves change depending on the direction (+ to -) that the battery is connected to your circuit?*** The direction the speaker moves is in response to the direction (e.g., polarity) of the electrical energy. For example, if the speaker moves outward when it is connected to the battery, you reverse the direction of the battery in your circuit to make it move inward. The polarity of your electrical charge does not matter for the purposes of this experiment.

Speakers vibrate in response to a varying electrical charge.

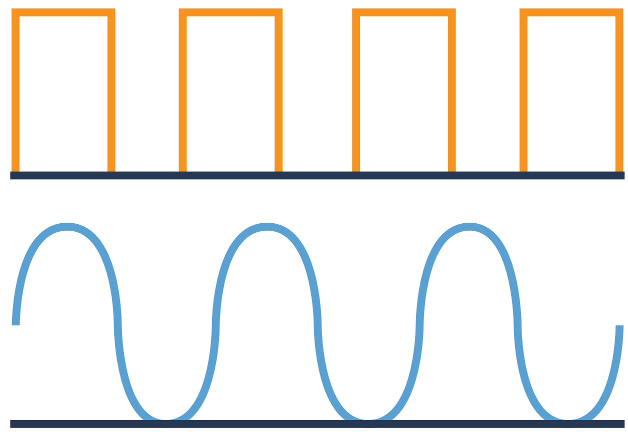
C. ***How does the speaker move differently when connected to the 9-volt battery as compared to the 1.5-volt battery?*** In very simple terms, the higher-voltage battery causes the speaker to deflect/move more than the lower-voltage battery. Speakers being powered by higher voltages can produce sound waves of greater amplitude (loudness) than speakers powered by lower voltages. In simple terms, the volume buttons on your electronic music player increase or limit the available voltage to the speaker, which then directly affects the amplitude of the sound waves it can produce.

Create

Present students with the threaded metal rod and paper clip. Attach the threaded rod to the speaker using one of the cables. Using a second cable, attach the other side of the speaker to the battery. Using the third cable, attach the other side of the battery to the paper clip.

D. ***What happens when you run the paper clip along the length of the threaded metal rod?*** The threading on the rod momentarily "breaks" the circuit created between the battery and the speaker, creating a fast oscillation between the electrical circuit being complete or broken. This is just like flipping a light switch on or off very quickly.

E. ***What happens when you run the paper clip along the metal rod quickly? Slowly?*** The speed at which you run the paper clip along the threaded metal rod will affect the frequency of the wave being created by the speaker. Running the paper clip faster, turns the energy on and off more frequently, which in turn causes the speaker to create a sound wave of higher frequency. Running the paper clip slower turns the energy on and off with less frequency, in turn causing the speaker to create a sound wave of lower frequency. The sound wave being created here is what we call a square wave. A square wave is a wave that is abruptly either "on" or "off" and can be seen illustrated in orange below.

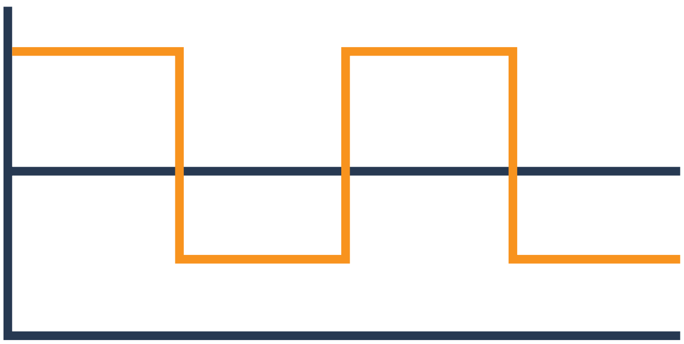


The abrupt angles of the square wave refer to the instantaneous nature of an electrical circuit being connected or disconnected, the power being turned on or off. The greater the amplitude of the wave, the more energy or voltage the wave will carry, and the more it will cause a speaker to move up and down.

Computers can oscillate between the power being on or off extremely quickly. This ability to oscillate only

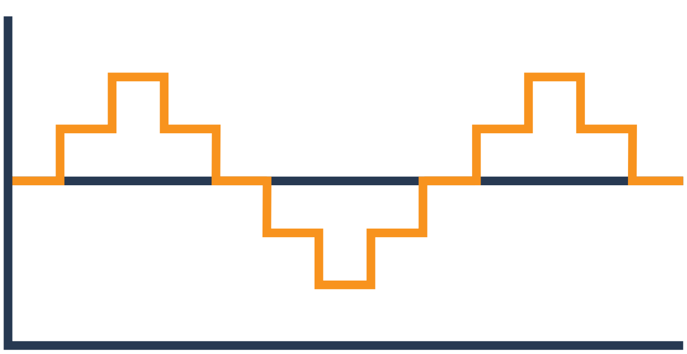
Electronic devices, from phones and computers to theremins and synthesizers, all create sound by sending an oscillating electrical current to a speaker.

between on or off is what we call a binary system, and binary systems are the foundation of modern computers. Computers literally switch between the power being on or off in order to perform all of their functions. The type of oscillation done by computers is known as digital oscillation.

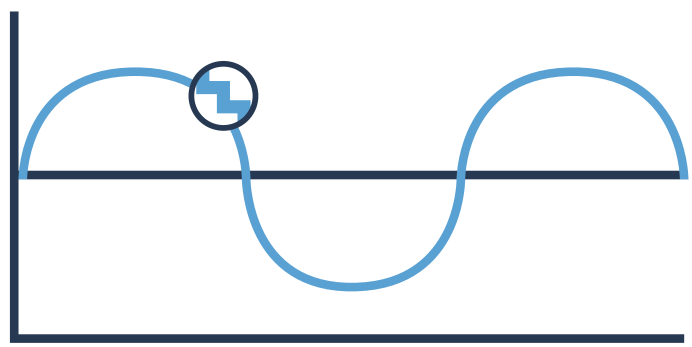


1-bit

Unlike the square waves created by the oscillation of an electrical circuit between on and off, the types of sound waves created by most acoustic or analog instruments are typically not so abrupt in nature. A sine wave oscillates between high and low energy more gradually, as seen in the distinctly curved wave illustrated in blue. In order for a computer to reproduce the sound wave that we might hear as typical of an acoustic instrument, it must not only oscillate between on and off, but also oscillate the amount of electrical energy being delivered to a speaker. Computers do this by breaking down the sound wave into individual variables we call bits. A simple square wave, such as the one we produce with a battery and a speaker, has only one variable, being either “on” or “off.” We call this a bit rate of 1. As we increase the bit rate to include variation in the amount of energy being delivered to a speaker, the bit rate will increase. The closer the binary system comes to mimicking the natural curve of the sine wave, the less computer-like it will sound. We can observe this by looking at graphs of sound waves of differing bit rates. We can also hear the differences. A 1-bit sound, such as that made by our simple battery and speaker, is distinctly electronic-sounding; a 4-bit sound, such as that commonly used in many old video games, is distinctly computer-like. A 16-bit sound (or higher!) is common to compact discs and MP3 players and is comparatively more similar to the sound of an acoustic instrument. You can see how the graphic representation of the wave appears more “smoothed out” than the lower bit rate examples, and yet, if we were to look closely, we would still see the stepwise character of a sound wave being divided into multiple discrete variables. An acoustic instrument oscillates with perfect smoothness naturally. To achieve such oscillations from electronic sources requires complex circuitry. The conversion of electronic bits into audible sound is called digital-to-analog conversion.



2-bit



16-bit

Assessment

Formative

Students will demonstrate their conceptual understanding of electrical oscillators and binary systems by creating a simple circuit and demonstrating how a speaker interacts with a source of electrical energy (battery) to create both low and high frequency sounds. Students will also demonstrate how the amount of electrical energy (voltage) affects this interaction.

Summative

Students will explain how the oscillation of electrical energy creates sound. Students will also explain the basic functions of a binary system, including how the bit rate of such a system affects the resulting sound it can produce.

Activity on your visit to MIM: Try to play the theremin.

The theremin relies completely on electricity to produce sound. It utilizes a loudspeaker connected to an oscillating system and amplifier that are all plugged into an electrical outlet. The oscillators provide a source of repetitive, alternating currents of electrical energy. The theremin creates a small electrical field surrounding each of its antennas just like a small radio broadcaster. The player disrupts these fields due to the electrically capacitive nature of the human body. In essence, you become a part of the electrical circuit of the theremin. The closer your hand is to the straight antenna determines which frequency, or pitch, is heard, while the closer your hand is to the looped antenna controls loudness, or amplitude.

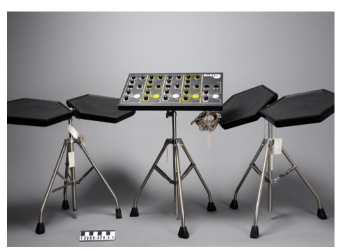
Collection Connection: Clara Rockmore and the Theremin

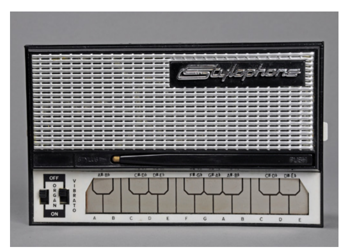
The theremin was invented by Russian scientist Léon Theremin and patented in 1927 in New York. It was there that he met Clara Rockmore, who soon established a successful career as a concert soloist on the theremin. MIM is proud to display the very instrument Léon Theremin built for her.

Collection Connection: Synthesizers

The theremin is not a common instrument today, but it influenced generations of electronic musical instruments. The theremin was one of the first electronic synthesizers (e.g., instruments that make sound using only electronics) that was ever built. MIM has numerous other synthesizers on display, including the Moog, Hammond organ, Elsita drum machine, and Oberheim. Some synthesizers, such as the Hammond organ or the Moog, use what appears to be a normal piano keyboard to control the sounds. Others, such as the theremin, Elsita, or Stylophone, use something different. MIM's collection of synthesizers can be found spread around the United States / Canada Gallery as well as the Artist Gallery. Regardless of how the synthesizer is controlled, it makes its sound using the oscillation of electrons.

The theremin is a historic example of an electronic synthesizer.





MIM displays musical synthesizers of all types.

Additional Resources

Up Close with a Curator: Theremin

Theremin Virtuosa Clara Venice Speaking at TEDxVaughan 2016

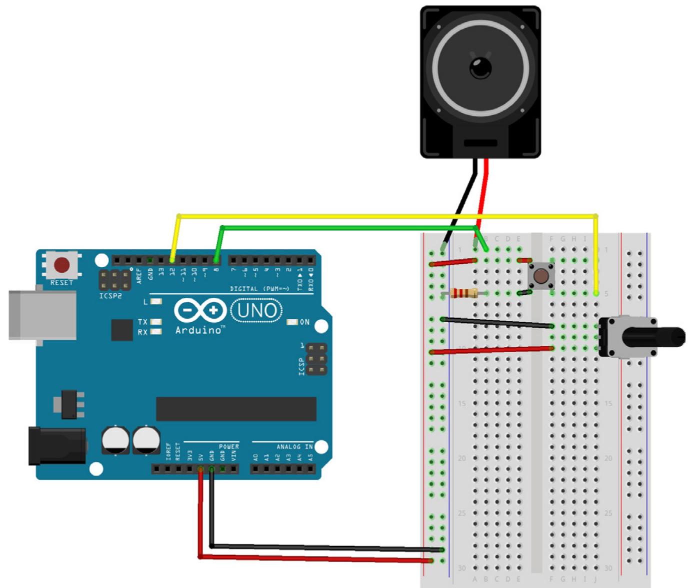
Online Activities Exploring the Intersections of Math, Science, and Music

Arizona State University's Consortium for Innovation and Transformation in Music Education (CITME) Curates Numerous STEM/STEAM Music Education Resources

Extensions

There are numerous resources available online to help educators introduce principles of electronic sound synthesis to students, including principles of electrical engineering and computer programming.

- Fritzing is a free program that facilitates circuit design and computer programming in a fun virtual environment.
- The Arduino microcontroller can facilitate hands-on experimentation with circuit building, computer programming, and design. The "tone" function is a great introduction to digital synthesizer circuits.
- The littleBits Synth Kit is a user-friendly device for creating analog musical synthesizer circuits.



Simple musical synthesizers can be constructed from simple circuits. Software programs such as Fritzing enable users to create such circuits virtually using a computer.

Tool Kit VII
Science and Technology in Society

Objective
Explore how technological innovation and musical taste often go hand in hand. Explore the technological innovations and musical tastes of previous generations and cultures. Consider the technological innovations and musical tastes of the present day. Project what technological innovations might occur in the future.

Materials
- Large whiteboard or butcher paper
- Post-its (or similar pieces of paper)
- Computer with Internet access and speakers

Background Information for Educators

The Chicken-and-Egg Problem: Technological Innovation and Musical Taste
Every instrument in MIM's galleries represents a one-time innovation in music technology that suited the resources and musical tastes of the adopting culture. For example, the early predecessor of the guitar known as the *'ud*, a type of plucked lute, is thought to have been invented in the Middle East (Mesopotamia) from where it traveled throughout the world, changing according to the tastes and resources of the adopting culture. And yet, from the Middle East to Asia, Europe, Africa, and the Americas, the *'ud* has been transformed into musical instruments as disparate as the Chinese pipa and the American banjo. Even the electric guitar can trace its beginnings to the *'ud*. At times, it is possible to examine the impetus for, and social impact of, such innovations in musical technology.

Activity 1: The Technologies of Music Participation

Investigate
Present students with a stack of Post-it notes and request that they respond to the following questions on separate Post-it notes:

Plucked lutes exist throughout the world in forms that have been adapted to suit local tastes.

A. ***What innovations in music technology have affected the way that I listen to or enjoy music? For example, what programs or interfaces did I use to listen to music when I was in elementary school? How do I listen to music now?*** Answers here may vary. Some may have listened to music on technologies such as iPods as children and now use music services such as Spotify. Others may have begun with CDs and now use iPods or Internet radio or any number of other things.

B. ***What innovations in music technology have affected the way adults I know listen to or enjoy music?*** Again, answers may vary from phonographs and 8-track tapes to cassette tapes, laser discs, compact discs, minidiscs, and others.

Create

On a wall or piece of butcher paper, organize the Post-it notes on a spectrum or timeline according to any criteria you choose. For example, you might choose the criterion of "portable music," which includes everything from radios and 8-tracks to CD players and iPhones. Another criterion might be "popular taste," which, depending on the point in history, would provide a different grouping.

C. ***What has technology changed in the ways people enjoy music? What has not changed?*** For example, do people still attend live concerts? Are phonographs still sold? Does anyone know of persons still with cassette players in their car?

D. ***Do I know someone who enjoys music in a completely different way, using a different technology than I do?*** For example, does everyone stream music? Does everyone go to live concerts?

E. ***How have technological innovations affected the way people enjoy music in other places?*** For example, use a music service like Spotify to discover the music that is trending in a foreign country. With Spotify, you can type the name of a country into the search bar and often come up with a "Top 50" music hit list for that specific country. What is similar about the music in this Top 50 list from the music you listen to? What is different? (Have you ever heard Belgian hip-hop?)

F. ***Does everyone in the class use the same technologies to enjoy music?*** For example, does everyone stream music on Spotify? Are there other music services that people stream from? Are there other technologies that people use to listen to music? Does a Top 50 playlist on Spotify represent the taste of all people, or just the people who use Spotify?

Activity 2: The Technologies of Music Creation

Investigate

[Note: Depending on the students, this activity may need to be integrated with an investigation of the names of different musical instruments—keyboards, computers, violins, guitars, trombones, trumpets, drums, etc.]

Present students with a stack of Post-its or similar paper and request that they respond to the following on separate Post-it notes:

A. ***What musical instruments are present in the music that I listen to? Can I identify by name all the instruments that are used?*** List each instrument on a separate Post-it. If applicable, be sure to include instruments such as microphones, guitar-effect pedals, amplifiers/speakers, computers, etc. Anything that produces "sound" for the purposes of recording or performing a song can count here.

B. ***What musical instruments are present in the music that the adults I know listen to?*** List each instrument on a separate Post-it.

C. ***What instruments are present in the music from [pick a country from Activity 1]?***

D. ***What musical instruments are present in [pick any place and time in history that's relevant to your class]?***

Create

Group the musical instruments by genre on the same timeline as was used for Activity 1. Draw lines between the groups of instruments and the technologies that people use to enjoy them. Some groups of instruments may be enjoyed via multiple technologies.

E. *Are there any musical instruments that we have listed as both a musical instrument and a technology?*

F. *Imagine/Compare: What would [X genre] sound like if we were to perform it using the musical instruments of [Y genre]?*

G. *What might this music sound like if specific technologies were not used? For instance, if people played all the parts being played by computers or machines?* For example, a computer can produce "beats" that would otherwise require an entire drum circle to produce. [See Collection Connection "Marking Pianos" and "Hip-Hop" below.]

H. *What might this music sound like if microphones or amplification were not present?* For example, to be able to create sound effects for guitar or vocal sounds, a microphone must be employed along with an amplifier and a speaker. [See Collection Connection "Amplified Guitars" below.]

I. *How have technological innovations affected the music that we listen to?* Do we listen to the same music today as we listened to thirty years ago? Is that because of the technology or because of public taste? Or both?

J. *Chickens, eggs, technologies of creation, technologies of participation: Which came first?*

Recording technology has had an enormous impact on how people participate in listening to music.

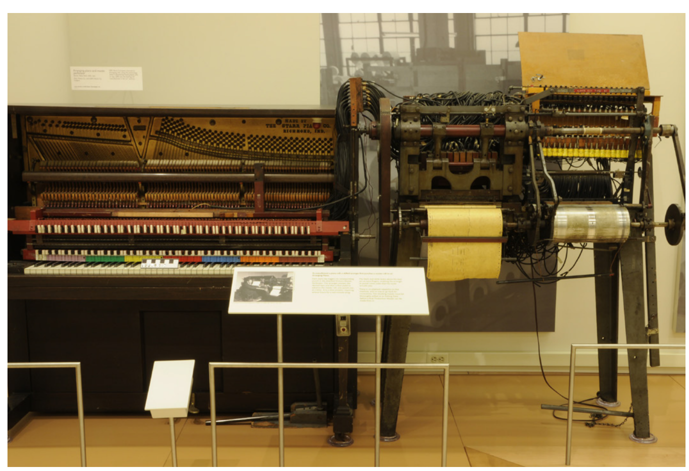
Assessment

Formative
Students will demonstrate their understanding of the interaction between technology and music participation and creation in their own lives as well as those of people they know by their participation in class discussions and activities.

Summative
Students can analyze a specific music technology and its use or impact on the way people listen to or enjoy music. They can also analyze the impact of a technology on the way that music is created (e.g., making beats in a drum circle versus on an iPad).

Activity on your visit to MIM: How do we preserve music for later use? How do we use prerecorded music?

Collection Connection: Arranging Pianos and the Mechanical Music Gallery
The Arranging Piano was invented to preserve "samples" by well-known musicians playing popular music. A player sat down at the piano and played a tune, while an apparatus attached to the piano marked a paper roll with the key strokes of the player. Afterward, a technician put perforations on the paper roll wherever a mark appeared. These technicians could also correct any mistakes that the performer may have originally made. Copies of the roll were endlessly reproduced and sold. Anyone with a player piano could simply insert the roll into their piano, and the self-playing mechanisms would faithfully re-create the tune according to whatever was marked on the piano roll. This is an early example of capturing and reproducing an interpretation of music. If you could not afford to hire a pianist every time you wanted to listen to music, you could invest in a "player piano" and purchase as many piano rolls as you needed. In the same way, if you cannot afford to hire Beyoncé for your next party today, you can still get some of her songs to listen to on your electronic device of choice.


Arranging Pianos copied the mechanics of a musician's piano performance onto a paper scroll for later reproduction in specially designed player pianos.

Electric guitar technologies significantly impacted the development of rock and roll.

The entire Mechanical Music Gallery represents, in certain respects, a desire to create music on demand, whether or not skilled musicians were available to create that music.

Collection Connection: Recording and Hip-Hop
Hip-hop was born in 1973 at a house party in the South Bronx in New York. DJ Kool Herc and Coke La Rock performed break-beat DJing and improvised rap lyrics. Break-beat DJing is just what it sounds like: a DJ plays and repeats small segments of music from vinyl recordings or "records" to create a new piece of music we call a "sample." Turntables, such as the Technics SL-1200MK2, allowed DJs to cut and sample beats from vinyl records. This style of turntable was the most popular model for hip-hop DJs because it had a "direct drive" mechanism that gave DJs more control and the instrument was durable enough to withstand the wear and tear of scratching and beat-cutting.

With the advent of the MP3 file format, computers became the central piece of equipment for creating beats from samples. While turntables are still in wide use, to achieve the scratching sound that is so characteristic of hip-hop, DJs also use drum machines or pads, mixers, controllers, and an array of other implements. The setup of DJs is highly personal and can change throughout their careers, as they seek out new sounds and techniques or as new technologies are invented.

Activity 3: Why do we amplify music with electronics?

Amplifying a guitar does far more than simply enable us to make it louder or softer. It also enables us to alter the sound in an infinite number of ways. MIM's Experience Gallery is full of acoustic instruments, including guitars and various kinds of drums. Investigate how these acoustic instruments sound similarly or differently from the music you listen to on your electronic device (cell phone, iPod, etc.). Are the sounds simply of an amplified acoustic instrument? Or has the sound been processed in some way? Try to create a huge beat with one of MIM's drums. Compare the beat you can make with your friends to the beats you hear in your favorite music. Is there a difference in technology that prevents your beat from sounding like the beats you hear on recordings?

Collection Connection: Amplified Guitars
Beginning in the late 1800s, as tastes in popular music changed and performance spaces became larger, both the musicians and the public sought louder music. Just as vocalists wanted to be heard above the increasingly large and loud dance bands, guitarists wanted instruments that could project a clear sound into huge dance halls, over radio broadcasts and onto phonograph recordings. The public wanted music (and musicians) that they could hear even as they were infatuated with the booming sounds and driving rhythms of certain styles of popular music.

Who invented the electric guitar?
The earliest electric guitars were developed in the 1930s and were intended for Hawaiian music. In

1937, a Texan named George Beauchamp patented the first successful electric guitar design. Around the same time, Les Paul, a musician and inventor, began his own experiments with electric pickups mounted directly onto a solid piece of lumber. Later, in the 1950s, companies such as Fender and Gibson started manufacturing electric guitars on a large scale and making them more accessible and affordable, and in the process inspired a new era of music. As demand continued to grow, innovations occurred in body design, and musicians could express themselves not only through the sound of their guitar but through musical style as well. Not confined to rock-and-roll music, electric guitars have also become standard instruments in blues, surf, punk, heavy metal, country, and more.

Additional Resources

DJ B-Stee Making Music with Turntables and Electronics

Getting Started as a DJ: Mixing, Mashups, and Digital Turntables – Cole Plante

Hip-Hop Turns Forty, *The Atlantic*

Arizona State University's Consortium for Innovation and Transformation in Music Education (CITME) Curates Numerous STEM/STEAM Music Education Resources