Luke Jerram & Adam Nieman

School workshop toolkit

Part Two: Vibration and Sound

A resource from Sound Matters, an initiative of the Acoustics Research Centre, University of Salford, the Institute of Sound and Vibration Research, University of Southampton and the Engineering and Physical Science Research Council

http://bit.ly/soundmatters

EPSRC
Engineering and Physical Sciences Research Council

University of Salford
A Greater Manchester University

University of Southampton
Institute of Sound and Vibration Research

Contents

Cover: Sound sculpture (sketch), Luke Jerram

Introduction

This resource contains notes for workshops developed by Luke Jerram with Adam Nieman for Sound Matters. It is the second of a two part series. *Part One: Why? and How?* contains general advice for teachers and practitioners working creatively in schools. In *Part Two: Vibrations and Waves*, the focus is on specific activities. It is also aimed at both teachers and external practitioners.

The notes aim to:

- Describe the activity and how to do it
- Explain the phenomena simply
- Highlight interesting facts and context
- Provide illustrations to use in class

Some of the activities have been developed in the context of a Creative Partnerships project called Momentum, which also resulted in series called Wow Starters, which are short videos that introduce practical science activities at the beginning of a lesson. Wow Starters are presented by children and encourage open-ended exploration of phenomena whilst also instilling the value of scientific experimental methods.

Being prepared, but not too prepared

For workshops on vibration and sound it helps to be prepared to address some fundamental topics such as 'what is sound like?' or 'what are harmonics?' But it is not advisable to over prepare. The workshops with most impact are usually those in which the students feel you are responding to them, rather than the other way around.

Productive preparation can involve no more than asking yourself, 'how many ways could I answer a question like that?'. You may also want to consider collecting media and demonstration equipment to have on hand just in case it turns out to be useful. The sites listed on the right are good sources of media.

How many ways could you answer these questions?

- What is the difference between a vibration and a wave?
- What is the difference between transverse and longitudinal waves?
- If sound is a vibration in the air, how can we hear under water?
- Why do musical instruments sound different even when they play the same note?
- If a tree falls in a forest and there's no one around to hear it, does it make a sound?

The first section, *Some Basics*, covers a few of the fundamental topics that could come up in any of the activities described later on. It is not intended as a last word on these topics, but they may act as a starting point to help you to find an approach that is appropriate for your workshop.

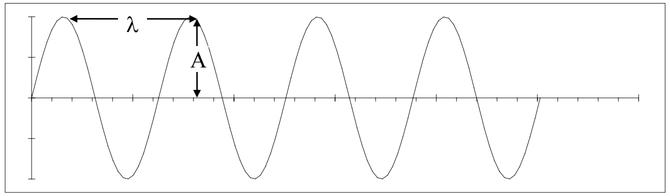
Useful Websites

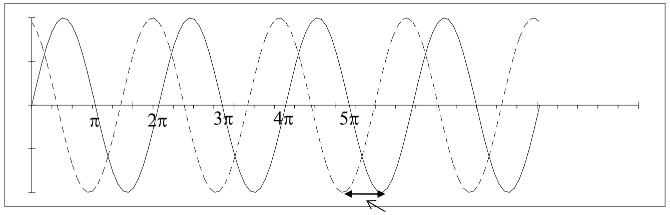
ISVR teaching materials:
http://bit.ly/u1of0

University of Salford list of GCSE/A-Level resources:
http://bit.ly/6bXhb

Acoustics and Vibration Animations – Dan Russell, Kettering University:
http://bit.ly/na4db

Properties of waves (summary)





Amplitude, A

The size of the wave's peak value.

Wavelength, λ (lambda)

The length (distance) of one complete cycle

Frequency, f or ν (nu)

The number of complete cycles per second (unit - cycles per second, also known as hertz, symbol: Hz).

Period, T

The time taken for one complete cycle (=1/f)

Speed, v or c

The speed that the disturbance caused by the waves travels through space. The speed of sound in air at sea-level is 340 m/s

Phase angle / phase difference, ϕ (phi)

The part of the cycle that the wave has reached (measured from an arbitrary starting point). A whole cycle is 360° (or 2π radians). Phase difference is how far behind or in front one wave is in its cycle compared with another.

Harmonics

Stings on a stringed instrument such as a guitar or an aeolian harp can vibrate in a number of different ways. The simplest vibration is when the whole string vibrates up and down (top) but it is also possible to fit shorter waves along the length of the string. Vibrations that consist of a whole number of wavelengths like this (actually, a whole number of half wavelengths) are called 'harmonics'.

In practice, you never get just one vibration in a string. You always get a combination of different vibrations. The strongest vibrations in the mix will usually be the harmonics – those that fit perfectly into the length of the string. The relative strength of different harmonics is what gives stringed instruments their particular quality of sound, and partly explains why guitars sound different from harps and pianos sound different from violins.

If you lightly hold your finger at the correct point on the guitar string you can 'excite' the higher harmonics (that is, you can make the string vibrate at a harmonic frequency) whilst suppressing the simple vibration. (Instead of going BBOOINGG, the string goes TINGG.)

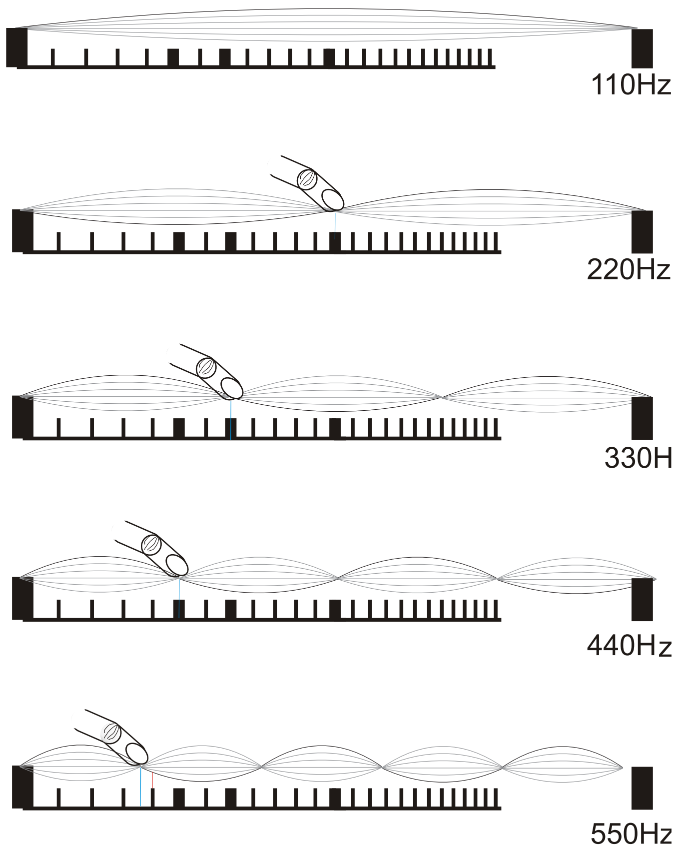
In an aeolian harp, many such vibrations can start up simultaneously and the higher harmonics are often louder than the lower ones.

Harmonics demos on the Web

Piano harmonics and Fourier analysis on You Tube:
http://bit.ly/LQUJO

Guitar harmonics and chords on You Tube:
http://bit.ly/IWHII

Some Basics



Harmonic frequencies a string with a 'fundamental' frequency of 110 Hz.

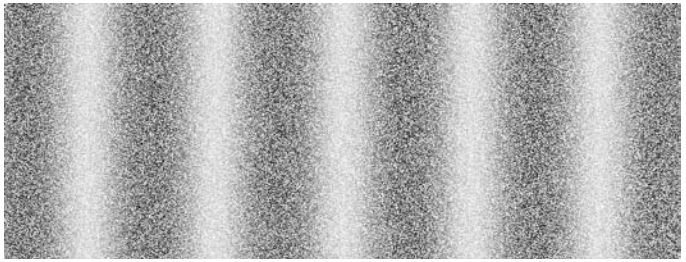
What is sound like?

Sound travels through the air as a pressure wave. If we could see individual air molecules, as a sound wave went past, we would see the molecules bunch up and spread out, bunch up and spread out, bunch up and spread out.

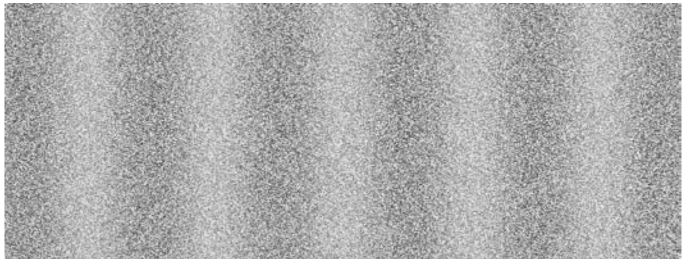
Sound can also travel through solids and liquids. The energy in the sound wave is transferred from one medium to the other as the wave passes. The Tin Can Telephones activity (page 11) shows this particularly well. Energy in the sound wave is transferred from the air to the tin can to the string and back again.

Loud and quiet sounds

If we could see air molecules then if a loud sound went past, we would see the molecules bunch up very densely and then spread out very thinly. If a quiet sound went past, there wouldn't be so much difference between the density of the patches. When a sound wave caused by ordinary speech went past, the air pressure would change by 0.01 Pascals. For comparison, normal air pressure is 100 Pascals. (That is, when sound-waves from ordinary speech go past, the pressure changes by just 0.01%.)



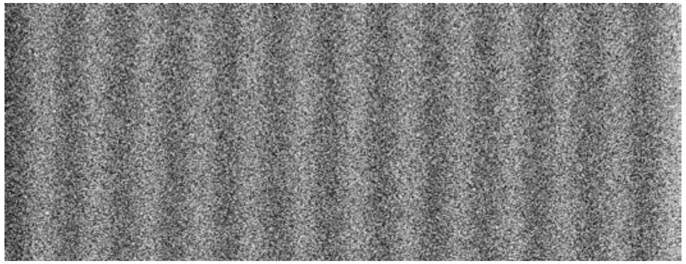
Loud sound



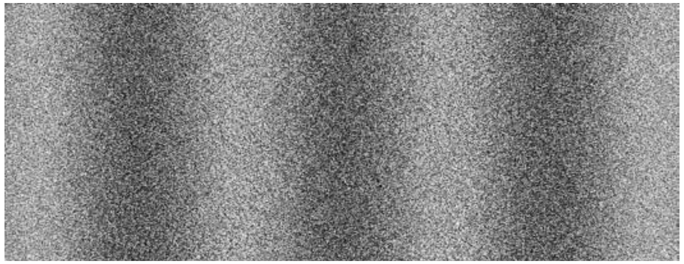
Quiet sound

High and low pitched sounds

If we could see air molecules then if a high-pitched sound went past, the width of the bunched up area and the spread out areas would be very short. If a low-pitched sound went past the width of the bunched up and spread out areas would be very long.



High-pitched sound



Low-pitched sound

Aeolian Harp

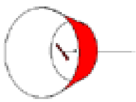
Websites

Aeolian Harp on Wikipedia:
http://bit.ly/aeolian
Luke Jerram's aeolian harp experiments:
http://bit.ly/yvWMo

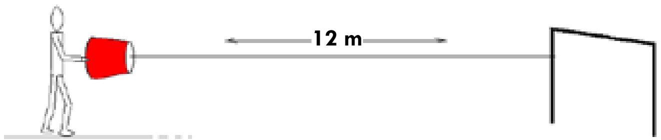
A bucket harp

Make an aeolian harp with a bucket, some strong fishing line and a peg. Use on a very windy day.

1. Tie one end of the fishing line to a fixed object such as a tree, a fence or a goal-post. The line must be exposed to the wind on all sides.
2. Feed the other end of the fishing line through a hole in the base of a bucket or bin and tie it to a peg inside the bucket to hold the line in place.



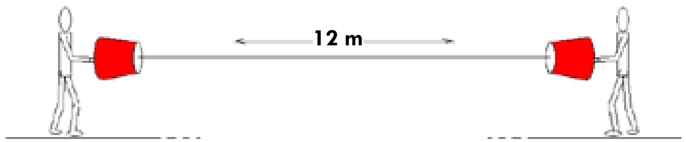
3. Stand so the line is perpendicular to the wind. Pull the line taught, but be careful not to break it.
4. Wait a few seconds for the wind to excite the fishing line. Eventually you should hear strange and haunting sounds emanating from the bucket.



View from above

Wind 90° to fishing line

Alternate method



National Curriculum references:

SC1 Planning: 2a, 2b, 2c, 2d
SC1 Obtaining and presenting evidence: 2e, 2f, 2g, 2h
SC1 Considering evidence and evaluating: 2i, 2j, 2k, 2l, 2m

SC4 3e that sounds are made when objects vibrate but that vibrations are not always directly visible.
SC4 3f how to change the pitch and loudness of sounds produced by some vibrating objects.
SC4 3g that vibrations from sound sources require a medium through which to travel to the ear.

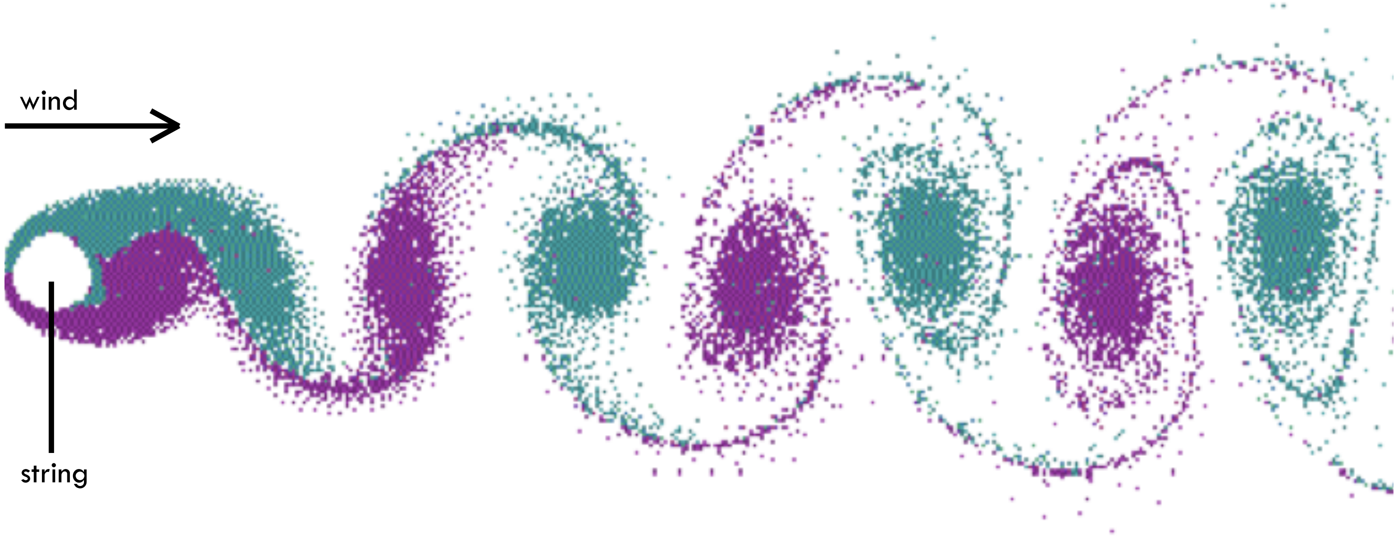
An aeolian harp in the classroom

With a bit of cunning, you can explore the excitation of strings by wind even when it's not windy. If possible, get hold of a purpose built aeolian harp. It will need a smooth (laminar) flow of air across its strings which you can get by funneling the air from a domestic fan.

Aeolian harp experiments are great basis for discussing:

- The transmission of sound in different media
- Sound amplification
- The transfer of energy (from wind to sound)
- How complex sounds can be made by combining many simple vibrations

An aeolian harp in the classroom
Left: Sir Bernard Lovell School, Bristol
Above: St Katherine's School, Pill
A cardboard funnel creates laminar flow from a fan, which excites the strings of the harp.



What's going on?

How does the wind 'play' the string?

The motion of the wind across a string causes vortex (swirl) downstream that flips from one side of the string to the other. The alternating vortex causes the string to vibrate.

Why does the aeolian harp make such weird/beautiful sounds?

A long string can vibrate in many different ways simultaneously. The complex sounds that come from the aeolian harp are made up of a combination of very many simple vibrations. Some waves are particularly easy to set up – these are ones that fit neatly in the space between the two ends of the string. Combinations of waves that fit like this sound harmonious, and that's why the harp makes beautiful sounds. In an aeolian harp, many such vibrations can be set up simultaneously and the higher harmonics are often louder than the lower ones.

The frequency of the vibrations depends on the tension in the string. As the wind blows, the tension changes, and this can also produce some interesting sound effects.

What does the bucket/bin do?

The string itself has a very tiny surface area so it doesn't move much air (indeed, it's the air that's moving the string in this case). By itself, the string makes a tiny sound, but because the string is attached to the bucket, the vibrations pull on the base of the bucket and make it vibrate the same way. The bucket has a large surface area and so it pushes a lot of air and makes a big sound. What makes the effect even stronger is that the volume of air in the bucket 'resonates' (vibrates in tandem with the bucket).

Coat-hanger Sounds

What to do

1. Attach a piece of cotton to a metal coat-hanger
2. Wrap the other end of the cotton around your finger Place your finger loosely in your outer ear
3. Let the coat-hanger swing into objects such as table legs and chairs

You will hear surprising, otherworldly sounds

4. Try other objects too (though coat-hangers are the best)

Coat-hangers in the classroom

Coat-hanger experiments can be great basis for discussing:

- Transmission of sound in different media
- Transfer of sound energy
- How complex sounds can be made by combining many simple vibrations

Coat-hanger experiments also reveal a 'world of wonder' that is right in front of us but usually goes unnoticed. That is, the experiments transform a mundane object into something wonderful.

Coat-hanger sounds can remind us a) that there is a world of beauty and wonder under our very noses; and b) that science is a good way to reveal and explore it.

National Curriculum references:

SC1 Planning: 2a, 2b, 2c,
SC1 Obtaining and presenting evidence: 2e, 2h
SC1 Considering evidence and evaluating: 2i, 2j, 2l, 2m

SC4 3e that sounds are made when objects vibrate but that vibrations are not always directly visible.
SC4 3g that vibrations from sound sources require a medium through which to travel to the ear.

Why are coat-hangers quiet?

Because they do not have a very big surface area, it is not easy for coat-hangers to push air around. This is why the vibrations of a coat-hanger do not sound very loud. Tuning forks are similar in that, because they don't have a large surface area in contact with the air, they are rather quiet. To make a tuning fork loud you have to touch it on a surface, such as a wooden box. The vibrations in the tuning fork can then be transferred to the box, which has a much larger surface in contact with the air.

What does the string do?

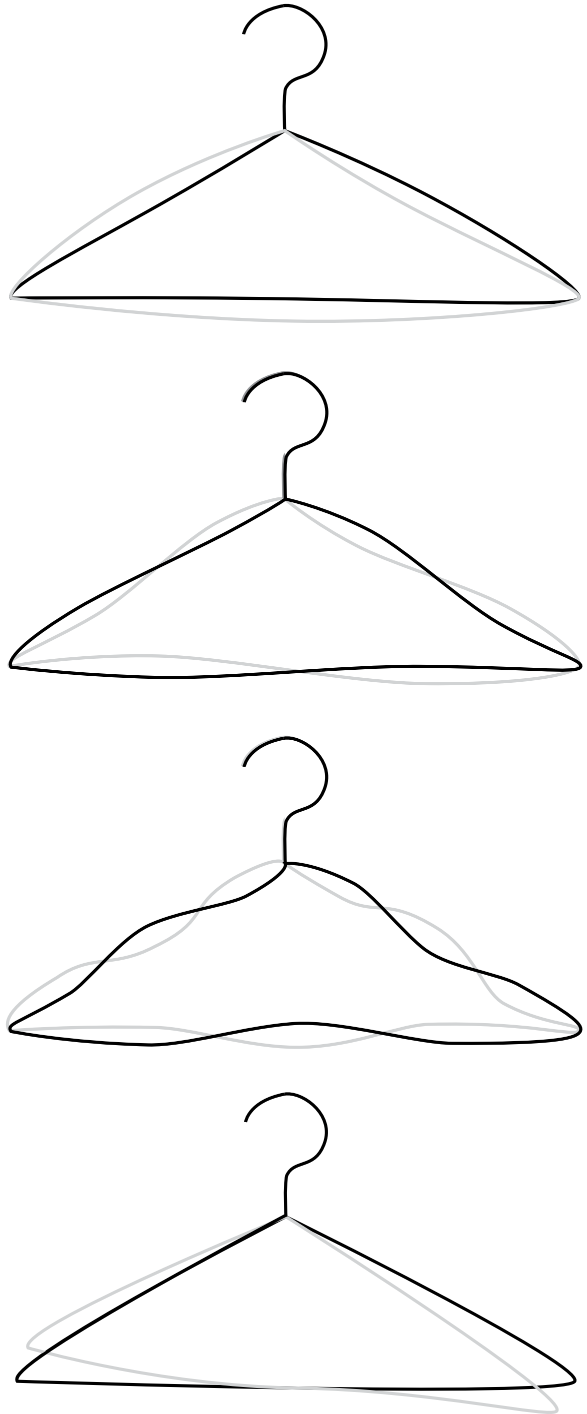
Even though all this interesting vibration is going on in the coat-hanger, we can't hear it because coat-hangers are not good at making air move – so the sound doesn't travel through the air. But, the vibrations in the coat-hanger can make the string vibrate and the so the sound of the coat-hanger is transmitted directly up the string to your finger, which makes your finger vibrate. Because your finger is in your ear, it makes the bones in your face vibrate and the air trapped in your ear vibrate and both these vibrations make your ear-drum vibrate.

Why do coat-hangers make such weird sounds?

Unlike tuning forks, which are designed to vibrate in only one way, coat-hangers can vibrate in a wide range of different ways:

- The metal can twist
- The metal can flex
- Waves can reflect off the corners and the hook and interfere with other waves coming the other way
- Twisting waves can pass their energy to flexing waves, which can pass it back again.

All these different types of vibration can combine to make strange sounds. Different objects will have different ways in which they can vibrate.



Tin-can Telephones

What to do

You will need two empty tin-cans, 5-10 metres of string, a couple of matchsticks, a hammer and nail.

1. Make a small hole in the bottom of each can. A hammer and nail is useful for making the holes.
2. Feed each end of the string through the holes in two cans and tie it to a matchstick to prevent it falling out again.

Students can now communicate with the telephones. They take a can each and pull the string taut (whilst being careful not to break it) then one speaks while the other listens.

3. Try a three-way phone by tieing another phone to the middle of the line.
4. Explore the effect of changing the size of the can.

National Curriculum references:

SC1 Planning: 2a, 2b, 2c, 2d
SC1 Obtaining and presenting evidence: 2e, 2f, 2g, 2h
SC1 Considering evidence and evaluating: 2i, 2j, 2k, 2l, 2m

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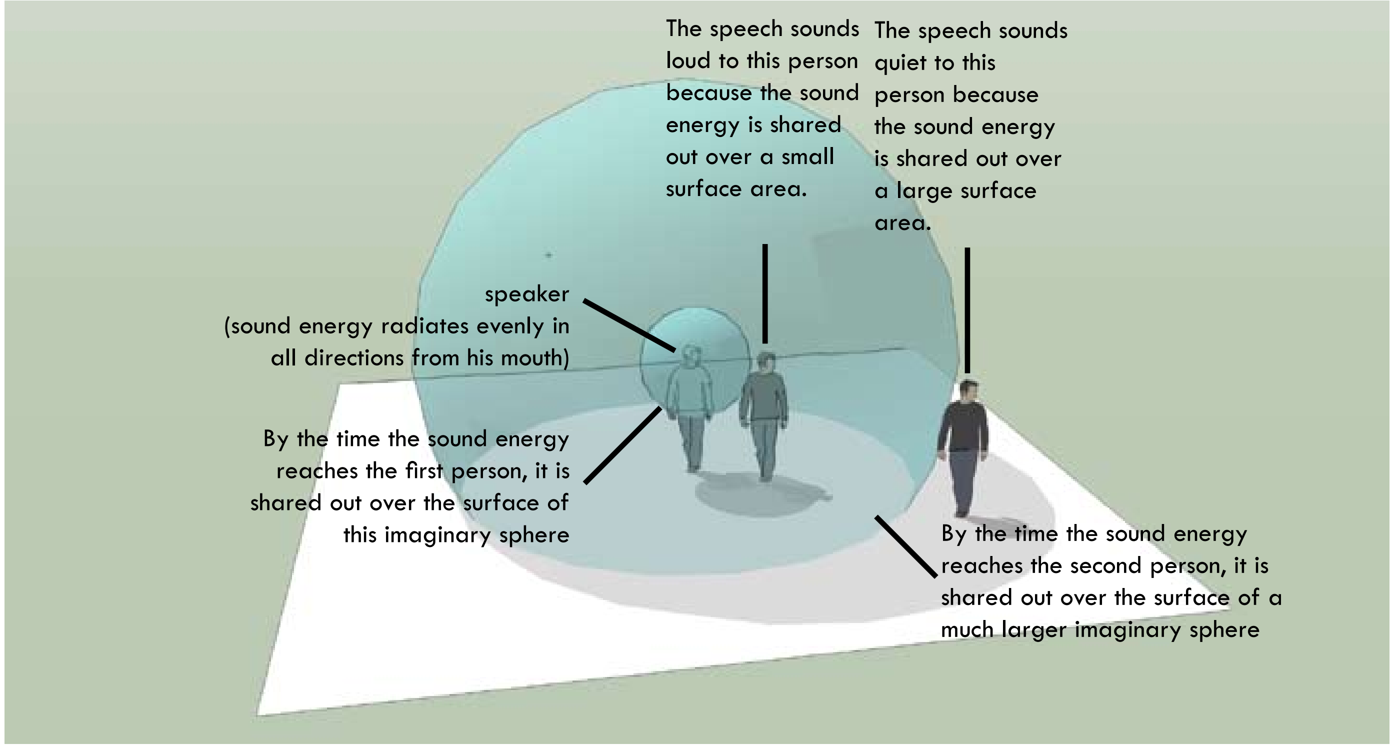


What's going on?

A question at the heart of the tin-can telephone experiment is:

Why can we talk to people normally when they are next to us but we have to shout if they are on the other side of a room?

This is a good opportunity to discuss the transmission of sound energy.

Sound waves radiate out from a sound source and so the sound energy is shared across a larger and larger area the further away we are from the source. If you are close to the source, the sound energy is still fairly concentrated but if you are too far away, the sound energy that you receive is only a tiny fraction of the total sound energy.

If sound waves could be made to travel through the air in only one direction, rather than spreading out, then the sound energy would not be shared over a big area. Cupping your hands around your mouth or using a loud hailer helps sound travel further by concentrating it in one direction. Another way to concentrate the sound energy would be to speak into a tube. In a tube the waves bounce off the sides of the tube and so do not escape and spread out.

Tin-can telephone

Like a loud-hailer or a tube, a tin-can telephone is a way of ensuring that sound energy gets directly from one place to another place without spreading out, but it involves a few steps along the way:

1. **Speaking:** Air is pushed past the speaker's vocal chords, which make it vibrate. This makes sound waves in the air that spread out from the speaker's mouth.
2. **Air/can interaction:** The sound waves travelling through the air hit the tin-can, bumping it and making it vibrate (move backwards and forwards).
3. **Can/string interaction:** The string is pulled tight, but because the tin-can is moving backwards and forwards it changes the strength of the pull on the string (the tension in the string) which makes waves travel down the string.
4. **Sting/can interaction:** When the waves reach the other end of the string, they change the pull on the second tin-can, making it vibrate.
5. **Can/air interaction:** The vibrations of the tin-can push and pull the air in the tin-can, making it vibrate.
6. **Hearing:** The sound waves in the air in the tin-can spread out through the air and reach the ear of the listener.

At each step, energy is transferred: from the waves in the air to the vibration of the can; from the vibration of the can to the waves in the string; etc. The transmission of energy this way is not very efficient. Lots of sound energy is lost along the way. But, the energy is concentrated – it doesn't spread out – and that's why you can hear better with the can than without.

Three or more cans

Adding a third can means that the sound energy is shared, so you might notice a difference. Also, the join is another point at which sound energy can be lost. In the case where two cans are joined by a single string and a third string is tied to the middle, sound energy will be transmitted more efficiently between the first two telephones than the third. That is, reception to and from the third phone may be poor because a) sound energy does not easily get passed to the extra string; b) a lot of the sound energy from the third can is lost when it gets to the join.

Bigger cans

Bigger cans may or may not make a difference. This is an example where there are too many factors involved to be able to predict with certainty what will happen. Nevertheless, it is an ideal opportunity to discuss a) good experimental design (a good experiment isolates a single variable); and b) how ingenious scientists have to be some times to be able to draw conclusions about nature.

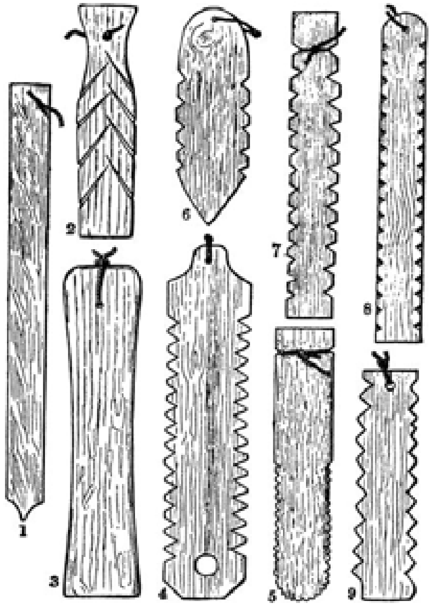
In addition to the size of the can, other factors could make a difference: the material the can is made from; the shape of the can; the welding; the thickness of the walls; etc. By having a bigger surface area, bigger cans may make the interaction between the can and the air more efficient, but the extra area also means that the sound energy is spread more thinly and so it offers another route for the energy to dissipate.

It is probably impossible to come to any conclusions about the importance of size with the cans available to a school but there are many conclusions to be drawn about science and scientific knowledge.

A conference call with tin-can telephones at Summerhill School, Bristol

Bullroarers

African bullroarers in the Pitt Rivers Museum, Oxford



Nineteenth-century British bullroarers

Websites

Bullroarer videos:_
http://bit.ly/Wp0UY (bullroarer busker)
http://bit.ly/1wWrn (good sound)
http://bit.ly/Z0Gt2 (used in irreverent advert)
http://bit.ly/rpUZS (bullroarer variant how-to)
http://bit.ly/1ayN7a (how-to in 34 seconds)

Bullroarer on Wikipedia: http://bit.ly/1bkXOw
Bullroarer for purchase: http://bit.ly/OhgM6
Physics of bullroarers: http://bit.ly/xRjwW

What is a bullroarer?

The bullroarer is an ancient ritual musical instrument and means of communicating over extended distances. It consists of a weighted aerofoil, a rectangular slat of wood about 15 cm to 60 cm long and about 1.25 cm to 5 cm wide, attached to a long cord.

Players swing the bullroarer around their head. The aerodynamics of the roarer keeps it spinning about its own axis. The cord winds fully first in one direction and then the other.

It makes a characteristic roaring vibrato sound with notable modification from both Doppler effect and the changing speed of the roarer at different parts of its circular path. The loudest component of the sound is at low frequency, typically around 80 Hz. The low frequency component of the sound travels extremely long distances, especially on the wind.

The instrument dates back to the Paleolithic period. Examples have been found in the Ukraine dating from 17,000 BCE. It is found all over the world, including Britain. In ancient Greece it was a sacred instrument used in the Dionysian Mysteries and is still used in rituals worldwide. Along with the didgeridoo, it is prominent technology among Australian Aborigines, used in ceremony across the continent.

Variants of the bullroarer work by pulling taut elastic bands in circles through the air.

National Curriculum references:

SC4 3e that sounds are made when objects vibrate but that vibrations are not always directly visible.
SC4 3f how to change the pitch and loudness of sounds produced by some vibrating objects.

What to do

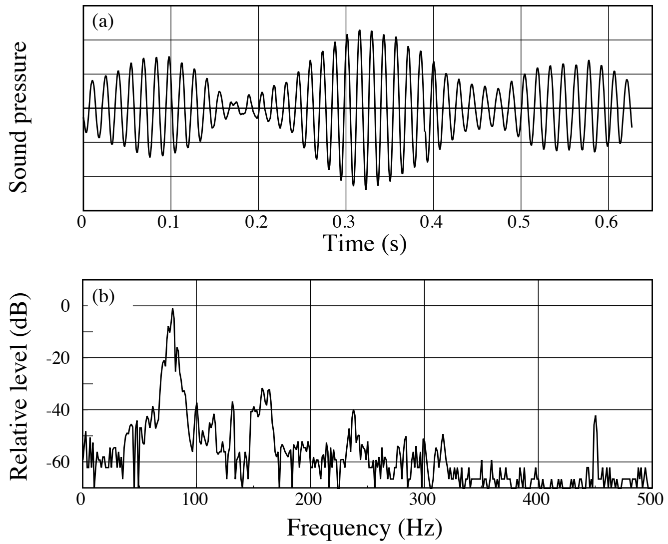
One of the main features of this workshop is the opportunity to combine art, DT and science. Nevertheless, it is usually easier if students work with pre-prepared blank bullroarers. These can be cut fairly roughly with a jigsaw from sheets of ¼" plywood. Alternatively bullroarers can be made by laminating sheets of heavy cardboard (gluing layers with PVA). Students can then sand the rough edges off, drill a hole near the top and attach a cord. In our experience, most students had no experience of using electric drills and many could not tie a knot in a cord. Once sanded, the blank bullroarer is ready to be painted.

Whilst the painted design is unrelated to the science, and the physics of bullroarers can be explored perfectly adequately with blank instruments, we have found that painting the bullroarers is an important part of the process. Perhaps it is because, having invested their time and creativity in the instrument, students are then more motivated to understand it.

Use paint that comes out in the wash and supply plastic aprons. You can either paint a plain undercoat and finish the job another day or paint the design directly. In either case, the paint will need time to dry. Test outside and ensure that accidentally released bullroarers will not cause damage or injuries.

Bullroarer science

The bullroarer makes a complex sound, which is possibly why it has had such an important role in cultures around the world. Nevertheless, the complexity is different from the complexity of other musical instruments in that the harmonics are less important to the sound than the pulsing and Doppler effects. As communication medium, it can be compared to elephant communication with infra-sound. A concise account of the physics of bullroarers can be found here: http://bit.ly/xRjwW.



a) Pressure waveform of sound from a bullroarer shows typical pulsations. b) Frequency analysis of the sound reveals the strength of the fundamental frequency in relation to the harmonics. That is, the sound of a bullroarer has a strong low hum without many high frequency components.

Figures from *Australian Aboriginal musical instruments: the didjeridu, the bullroarer and the gumleaf* N.H. Fletcher Acoustics Australia 31, 51-54 (2003). Reproduced with kind permission of Prof. Neville Fletcher, Australian National University.

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