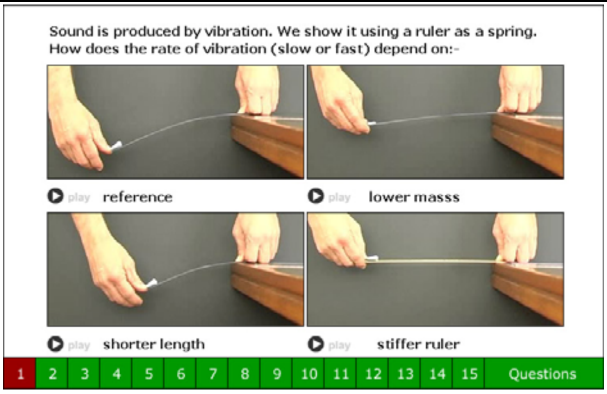
Glimpses of Science
Teachers' notes for Sound and Vibration

Sound is all around us and is the medium of one of our most important means of communication. Yet we can't see it, so how to show it? Even the vibrations that cause sound are hard to study because, if the vibration frequency[1] is high enough to hear, we can't see it.

Although this is about sound, I think that the most important lesson to be learned from it is the **power of experiment**. How do you find things out? Perhaps an encyclopaedia or the net? You can do that for things that are known. But what if *no-one* knows? Then you do an experiment. That's what science is about. That's how we find things out.

In frame 1 (screen shot below), we experiment in the classic style: hold everything constant except for one parameter, then compare the effects of varying that parameter. So we have a reference that gives a clear result (plastic ruler, large mass, large length – we can see the vibrations clearly). Then we compare lower mass, shorter length, stiffer ruler, all the while keeping everything else constant.

At any stage during the lessons, be prepared to return to experiment: if, at some later stage, you ask "Which is faster, long or short?" and someone says "long", you simply say "Let's check, let's do the experiment".



The ruler as a spring.
If you bend a ruler, it springs back to its original shape. (Springs that bend while supported at one end are called cantilever springs.) The reason for using it here is that one can easily produce a very large range of frequencies.

Use a large length of the ruler and add a mass ('blu-tak' or putty) to one end, the frequency can be as low as a few cycles per second. Use several cm with no added mass and the frequency can be hundreds of cycles per second.

What determines the frequency?
The frequency is high if the spring is stiff (a wooden ruler is stiffer than a plastic one).
The frequency is low if the mass is large (add some blu-tak to the ruler).
A ruler is stiffer (bends less easily) if it is short. So a shorter ruler has higher frequency.

Tip: Even if you don't mention frequency, you can draw attention to it by counting vibrations.

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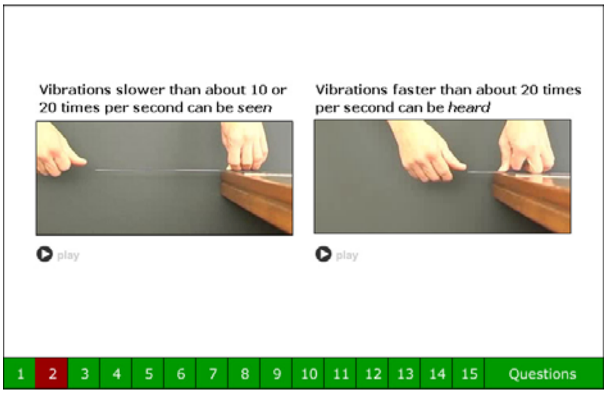
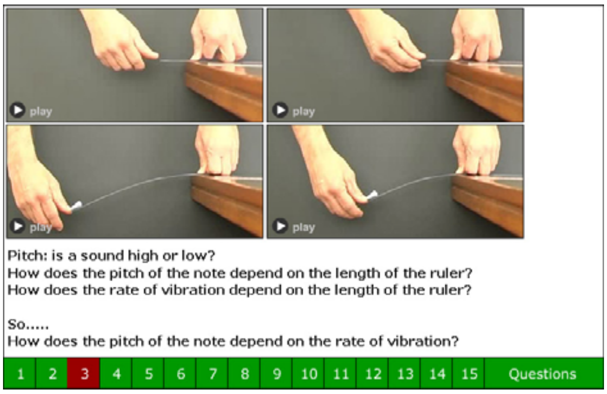
[1] For some reason, some people find the word '**frequency**' frightening (on the other hand 'how frequently', which means the same thing, is not frightening). So the clumsy "rate of vibration" is used in the slides here, but frequency is used in these notes. It might be useful to ask "How frequently does the sun rise?" Once per day. So the frequency of sunrises is 1 per day, or 365 per year. For sound, the vibrations are more frequent, so we measure the number of vibrations or cycles per second. 440 cycles per second is called 440 hertz, or 440 Hz. That is the note A in the middle of the treble clef -- the note to which orchestras tune.

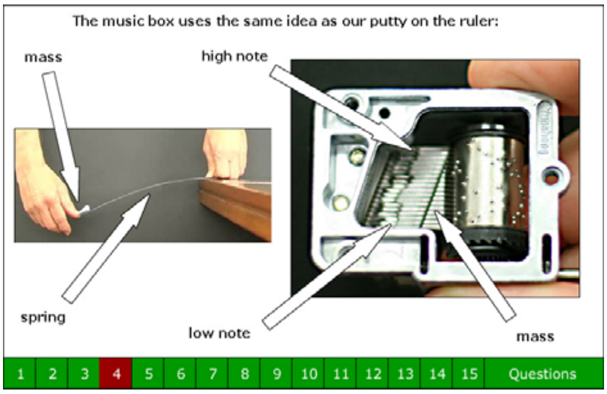


What causes sound?
The aim here is to show the slow vibration and to convince the students that faster vibrations are what causes the sound.

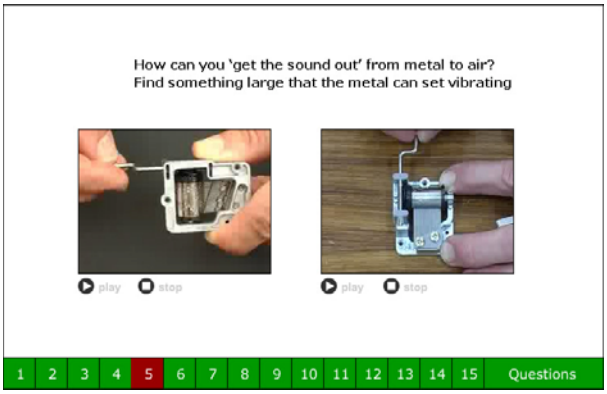
Tip: To make it sound clearly, it needs to be held tightly to the desk.



What determines the pitch?
A shorter ruler has higher frequency (observation with long, loaded rulers)
A shorter ruler has higher pitch (observation with short, unloaded rulers)
So one can conclude that higher frequency gives higher pitch.

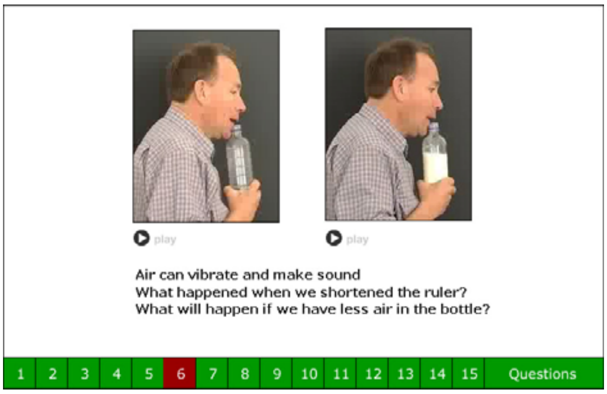


The music box shows several things.
The sound is made by a set of cantilever springs. Their frequencies are determined by the mass on the end of each one (largest mass identifies the lowest note) and some thinning at the other end. Just like our rulers and putty! Because the set of cantilevers looks like a comb, each cantilever is called a tine. See the advanced stuff below.



Getting sound into air
The vibration of a small piece of metal will not make much sound -- think of the strings on an (unplugged) electric guitar. This is because they slip easily through the air, without causing much motion in the air.

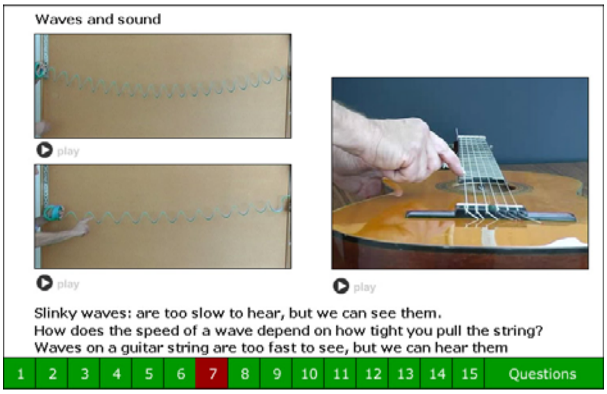
An acoustic guitar, a violin, a harp, a piano.... they all have a large piece of wood called a soundboard or a belly or a front plate. A desk can serve as a soundboard for the music box. Hold it firmly against the desk and the vibrations in the metal are transferred to the piece of wood[2], which has a large surface of air to push against.



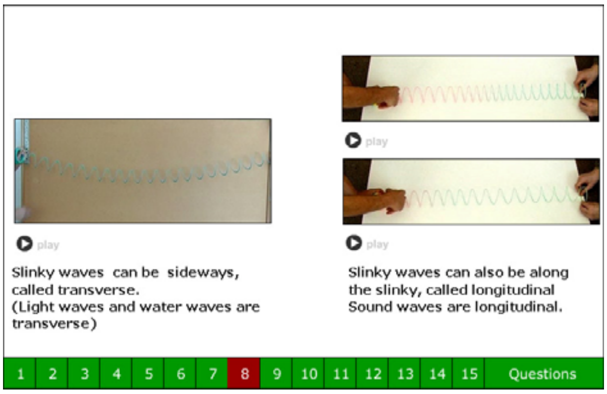
Air is springy and air has mass
So air itself can vibrate. When you blow across the top of a bottle, the air inside the bottle acts as a spring: it can be compressed, but it springs back - like our ruler. The air in the neck of the bottle has mass, like the blu-tak on the ruler. Together, they determine the pitch. If you reduce the volume of air in the bottle (put in some water), the air is a stiffer spring: it's harder to compress it by the same amount. So the pitch goes up. (Technically, it is a Helmholtz resonator.) It might be fun for a group of students to tune a scale of bottles and then playing tunes, perhaps with a conductor to point to the right notes.

Tip: For health reasons, only one student per bottle.

[2] Sound boards are sometimes called resonators. Although they may have resonances, this is often not important to their operation - they work at frequencies where they don't have resonances. So the name resonator is best avoided in this context. Technically, they could be called impedance matchers.

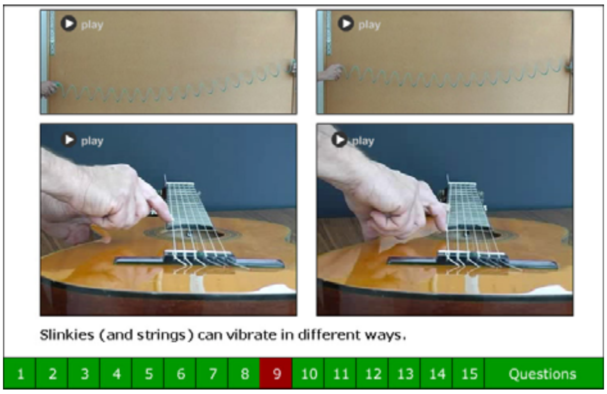


Waves in strings and waves in air
Waves can travel in stretched strings. Again, on a guitar or violin string, the vibrations produced by the wave in the string are too fast for us to see -- if not, we'd not be able to hear them. However, waves in a slinky toy are slow enough to see.



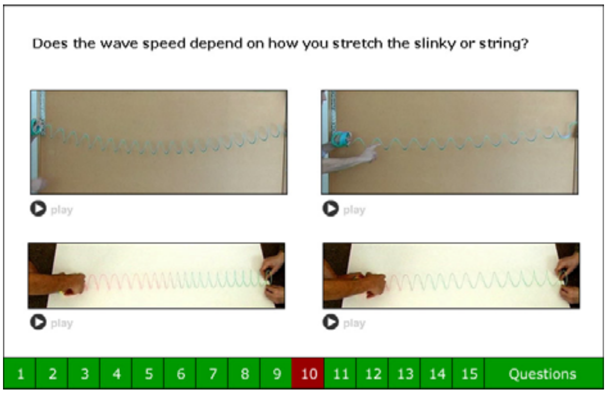
Transverse waves
In transverse waves, the vibrations are at right angles to the motion of the wave itself. A wave in the ocean is a transverse wave: the water goes up and down as the wave goes past, but the wave is travelling in the horizontal direction. A Mexican wave is also a transverse wave. A slinky can support transverse waves: stretch the slinky, then give it a sideways shake.

Longitudinal waves
In longitudinal waves, the vibrations are parallel to the motion of the wave itself. Sound is a longitudinal wave. Again, we can't see it. However, the slinky will support longitudinal waves, though not so easily as transverse. For our clip, we rested the slinky on the ground, with the disadvantage that the friction causes the wave to die away quickly.



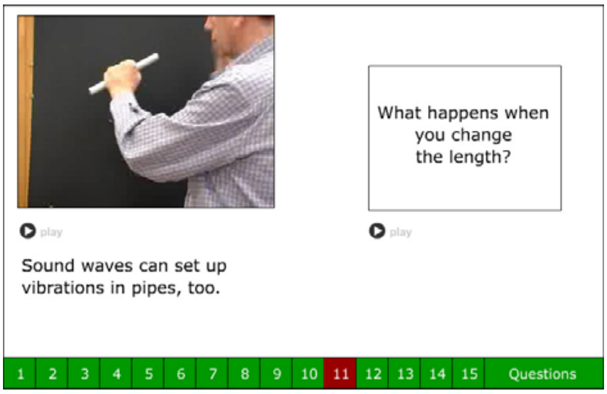
Different modes of vibration
As we show in the clips, it is possible for a string to vibrate with 1, 2, 3.... etc loops along its length. In instruments like flutes, guitars and violins, this can produce the harmonic series, which is fundamental to musical

harmony. There's a slide at the end, just in case you have advanced music students. Also links below.



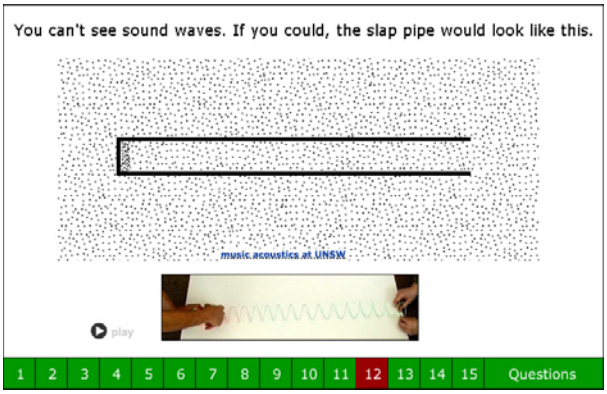
Standing waves
Both transverse and longitudinal waves can set up standing waves. In a string, a wave can reflect at the ends. Waves going backwards and forwards create standing waves, of which the wave in a guitar string or a slinky is a good example.

Here it is interesting to ask how the wave speed (and therefore the frequency) depends on
• the length of the string (how far the wave has to travel)
• how tightly you stretch it
• on the mass of the string.
All of these are important in the operation of guitar, violin, piano etc.

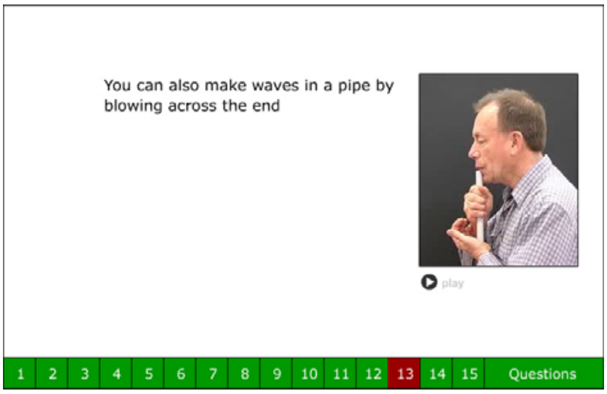


Waves in pipes
Waves going backwards and forwards in pipes also set up standing waves. An easy way to do this is to strike the end of a piece of pipe.

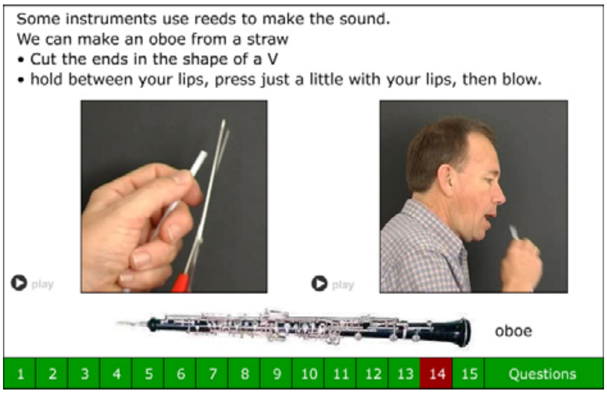
Tip: In the film clips, I strike the end of the pipe and keep my hand in contact. If you bounce your hand off the end of the pipe, it will be open at both ends, and its frequency will be slightly less than twice that of a pipe -- slightly less than an octave higher. These tubes have been tuned for slapping operation with one closed end. They are out of tune when played with a bouncing hand, or when blown at one end.



What is a sound wave like?
You can't see sound waves -- too transparent and too fast. However, if you could, the slap wave in the pipe would look like this animation. (Note that the wave has to travel four lengths of the pipe before the cycle repeats. This allows one to work out the speed of sound.

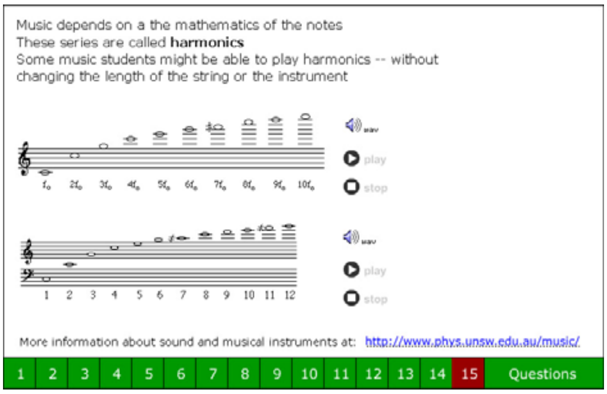


The syrinx
You can also make waves in a pipe by blowing across the end
Tip: I find it easier to play with the far end stopped (like a syrinx or pan pipe) than open (like a shakuhachi or quena)



Some instruments use reeds to make the sound. We can make an oboe from a straw
• Cut the ends in the shape of a V.
• hold between your lips, press just a little with your lips, then blow.
Tip: The V should be a reasonably sharp point, and roughly symmetrical.

More to explore
What do you notice about the pitch and the length of pipes or guitar strings? Is there anything special about the length ratios for notes in chords, such as the octave (doh-doh), the fifth (doh-soh), the third (doh-mi)? This is included just in case there are some musicians with a few years training.



Harmonics
A flutist in the class might be able to play up to 8 notes without moving fingers:
http://www.phys.unsw.edu.au/jw/flutes.v.clarinets.html

A guitarist or violinist might be able to play the harmonics on a guitar string
http://www.phys.unsw.edu.au/jw/strings.html

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Advanced stuff
From the animation, you'll see that for each cycle of the wave in the pipe, the sound wave travels four times the length. So one could use the pitch of the notes to determine the speed of sound. The pipes are tuned for the octave from middle C to the C above (slapping without bouncing). Frequencies at
http://www.phys.unsw.edu.au/jw/notes.html

Science of music
There is lots more interesting science in sound and in music. We have an extensive web site: advanced students can test their hearing, see how instruments work and much else. It has many dozens of pages, including ones about the standing waves on strings and the Helmholtz resonators mentioned above. However, that site is aimed at upper high school level so it is probably better as a resource for teachers than for students.
http://www.phys.unsw.edu.au/music

Voice
Your own voice is capable of a huge range of sounds. We have a number of pages on this.
http://www.phys.unsw.edu.au/speech

Information coding.
The tines of the music box are struck by bumps on the drum. The bumps are binary digital: they are either there or not there. So there is no loudness control: a note is either played or not played. A circumference of the drum corresponds to one tine: it is one channel.
This parallel, binary, digital coding is a simple way of storing information, of recording the song. There are many analogies with other examples of data storage and transmission. (Reference at the end.)
A paper about music boxes and information coding is at
http://www.phys.unsw.edu.au/jw/Info.pdf

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