MUSIC AND PHYSICS

Flawed slide whistles are put to good use in frequency studies

Always looking for bargain laboratory supplies, I recently purchased 30 slide whistles online [1] for only $1 (51 pence) each. However, when they arrived, I realized that the reason they were so inexpensive was that they didn't work – at least not very well.

I used a small saw to cut the bottom off one of the plastic whistles to see what the end of the slide looked like. It was immediately clear why the quality of sound was so mediocre. The part of the slide that was meant to define the length of the whistle was made from flimsy plastic. The tip of the end had a slot through which air could escape, thereby producing only a partially closed pipe (figure 1).

Without the slide the closed-pipe slide whistle had become an open-pipe whistle with fair sound quality. Fortunately I was able to use a modified whistle in a classroom activity investigating the physics of open- and closed-pipe wind instruments.

The equipment for this activity includes the modified slide whistle (with the slide removed) and a container of water that is at least as deep as the whistle is long. An ideal container is a clear plastic water bottle that can be capped when not in use.

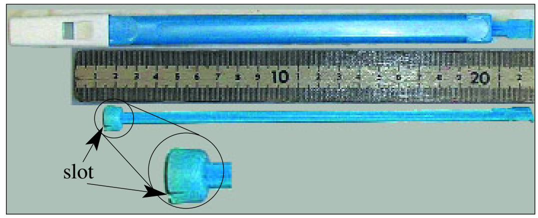

Figure 1. *The slide in the whistle has a small slot that allows air to escape. This seriously degrades the quality of the sound produced when the whistle is played.*

Figure 2. *With the slide removed from the slide whistle, it can act as either a closed pipe with a variable length (when submerged in the water) or an open pipe (when out of the water).*

Qualitative investigation

Students are directed to place the end of their whistle into the water container and listen to the pitch produced (see figure 2). The activity begins with pairs of students making a qualitative investigation into the different ways in which the pitch (sound frequency) of the whistle can be changed.

Typically, they will all observe that the frequency of the whistle increases when the whistle is deeper in the water. Most students will realize that this means that there is an inverse relationship between the length of a whistle and its pitch. If given enough time for the activity and encouraged to make careful observations, many will blow the whistle while removing the end from the water and notice the instant and dramatic increase in frequency. Some students will also note that the frequency can be changed dramatically by blowing a bit harder on the whistle (in or out of the water).

There are three ways to change the frequency of the whistle:

- lengthening the whistle (so it is shallower in the water) gradually decreases its frequency;
- raising the whistle above the surface of the water dramatically raises its frequency;
- and blowing harder on the whistle dramatically raises its frequency.

To help students to give a more accurate description of a 'dramatic rise in frequency', the concept of the octave can be introduced. The octave separates two frequencies by a factor of two. In the song *Somewhere Over the Rainbow*, the two syllables in 'somewhere' differ in frequency by one octave.

Frequency equations

closed pipe

$$f_n = \frac{nv}{4L} \qquad \text{(only odd } n\text{)}$$

open pipe

$$f_n = \frac{nv}{2L}$$

f = frequency
n = mode of vibration of the standing wave within the pipe (always an integer and increased by overblowing)
v = velocity of sound in air
L = length of pipe

Figure 3. *The change from a '4' to a '2' in the denominator of the equations causes the octave change when going from a closed to an open pipe.*

Students can then go back and listen to the change in frequency when the whistle emerges from the water, noting a change of exactly one octave.

They can also try blowing harder into the whistle when it is either in or out of the water. When it is out of the water, a slight overblowing will cause an octave change, but they should notice that slight overblowing on the submerged whistle gives a change in frequency of more than an octave (student musicians may detect that it is an octave plus a fifth – which is three times the lowest frequency).

At this point, the distinction between closed-pipe and open-pipe musical instruments can be made and students should see that when the whistle is submerged, it is a closed pipe and when out of the water it becomes an open pipe. The equations describing the frequency of wind instruments can now be introduced (see figure 3).

Making connections

So far, all of the observations in the activity are designed so that the students can make a connection between the causes for change in frequency and the more abstract variables used in the equations for frequencies of closed and open pipes.

Students are now asked to use their observations to qualitatively demonstrate the relationship between the change in variables/constants in the equations and the change in frequencies that they have observed.

While the velocity of sound in air cannot be changed, students should easily be able to see how their observations are predicted by these equations. The only variable in either equation that can be changed by the student is the length of the pipe, which is why this is the only change that can cause a gradual alteration in frequency. It should be clear that the change from a '4' to a '2' in the denominator of the equations is the reason for the octave change when going from a closed to an open pipe.

Mode change

The connection between overblowing and the value for n is a bit trickier for students to understand. Two things work together to produce a change in mode. First, increasing the pressure of your breath through the slit of the mouthpiece increases the airflow past the edge of the hole on the mouthpiece. If the mouthpiece were not coupled to the body of the slide whistle, the resulting frequency would be proportional to the airflow speed [2].

However, with the body of the slide whistle coupled to the mouthpiece, a strong feedback results, allowing only certain frequencies to exist for a particular length of pipe. Therefore, as the player overblows, increasing the airflow speed, discrete jumps in frequency occur when the airflow speed is fast enough to cause the next higher allowed frequency mode in the pipe. Since the closed pipe can only produce odd modes, the next highest frequency produced when overblowing the closed pipe in its lowest mode is the third mode, giving a frequency that is three times that of the first mode.

This activity provides the student with an engaging and meaningful way to investigate the physics of both open and closed pipes. Additionally, it provides a means of intuitively understanding the equations for frequencies produced by wind instruments.

References

[1] 66.96.141.180/cgi-local/shop.pl/page=hezzie slidewhistle.html
[2] hyperphysics.phy-astr.gsu.edu/hbase/music/edge.html#c4

David R Lapp, *Tamalpais High School, 700 Miller Avenue, Mill Valley, CA 94941. E-mail: drlapp1@aol.com*