Using birdsong to support the teaching of sound and graphs

James de Winter

ABSTRACT The teaching of sound and associated concepts such as pitch, frequency and amplitude is often done with demonstrations using a signal generator, a loudspeaker and an oscilloscope. While these provide control over the sounds themselves and provide a way to visualise the sounds, the complexity of the equipment often causes confusion. Common birdsongs that students may be familiar with can provide an alternative way to introduce these concepts. Here, an approach to teaching sound using birdsong is explored using the sonogram as a tool to support students' understanding of these ideas.

In primary school, children are often introduced to sound and the scientific ideas and language around the topic by the use of musical instruments, some of which they may make themselves. This provides a real-life context and concrete examples to relate the ideas and descriptions of the sounds to the things that they see and hear making them. When sound is taught at secondary level, it is often introduced with a demonstration using a microphone, a loudspeaker, an oscilloscope and a signal generator. While this approach can have some benefits to help the visualisation, it also has several drawbacks. Students can become confused as the oscilloscope displays a longitudinal wave as a transverse one. Also, the sounds generated are abstract and unfamiliar, creating a detachment between the sound heard and its source. It is hoped that some of the tools used in professional analysis of birdsong and other animal sounds can be applied in a simpler form to provide a new context and approach for teaching sound.

This article is in three sections. The first introduces sonograms as a sound analysis tool and cites recent use of them in ornithology. The second, and main, section suggests a classroom teaching approach primarily aimed at, but not limited to, students aged 11–14. It could be developed into an introductory lesson or used to change how some sound topics are taught. The final section makes some suggestions for those interested in developing the study of sound further. All the images, as well as the bird and animal sounds mentioned in this article, are available free for educational use as part of a more comprehensive teaching pack available from www.physicsandbirdsong.co.uk.

Birds, songs and sonograms

For as long as humans have looked at birds, their identification has proved a challenging but rewarding endeavour, although this has primarily been focused on their colour, size and behaviour. While bird guides often make reference to songs and calls, these can be rather vague; they vary from guide to guide and are difficult to imagine. Most people would struggle to identify with confidence the difference between the *tsee-tsee-tsu* of the blue tit and the *tui-tui* of the great tit; being told one of these calls is more 'urgent' is of little help. Nevertheless, the voice of a bird does have a characteristic fingerprint and this can be seen much more clearly with a sonogram.

In its simplest form, a sonogram, sometimes called a spectrogram, is an image that shows how a sound varies with time. In most cases, this is shown as a graph with frequency on the vertical axis and time on the horizontal. Examples are provided in Figures 1 and 2.

One of the most widely used software programs for creating sonograms is called *Raven*; it is available in free (Lite) and paid-for (Pro) versions from www.birds.cornell.edu/brp/raven. I have found the Lite version to be more than sufficient for use up to and including A-level classes.

Animal songs and calls have a complex spectrum of frequencies and so their sonograms can be initially confusing. It is also common for any recording to have a certain amount of background noise. The software has the ability to manipulate the colour contrast and brightness on the sonogram to help to highlight the main

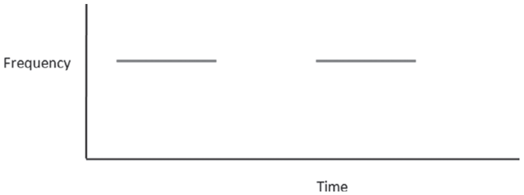

Figure 1 A sonogram of two notes of equal frequency and length with a pause between them

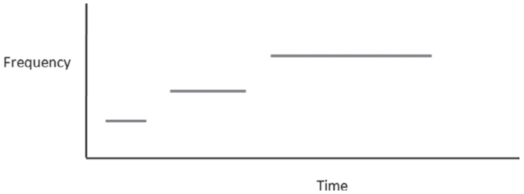

Figure 2 A sonogram of three notes of increasing duration; the frequency of each note is constant but higher than that of the preceding note

characteristics and reduce the visual impact of background noise. The two images in Figure 3 show a sonogram of the same recording of a song thrush before and after colour adjustment. The characteristic shape is present in both cases but the second image more clearly shows the four calls with rapidly descending and then slowly increasing frequency. However, the colour manipulation has also removed the three harmonics shown in the first image, providing a warning that not all apparent noise is unwanted or insignificant. Clearly, these tools need to be used with caution.

Here, and with most sonogram software, the relative brightness of the colour (or darkness on a black and white sonogram) provides an indication of the amplitude (loudness) of the sound.

Sonograms can be used to identify birds as well as to illustrate differences between them. In a recent piece of research, the Sound Approach team located fish owls in Turkey and, by combining sonogram data with DNA analysis, they were able to distinguish them from fish owl populations that exist further east (Van den Berg *et al*., 2010). In October 2013, what seems to be a completely new species of owl (the Omani owl) was identified with the aid of sonograms (Robb, van den Berg and Constantine, 2013). Sonograms can help make a lesson more engaging and interesting, but it is also hoped that students will appreciate that sonograms are valuable tools for professional scientific researchers.

The birding approach to teaching sound in the classroom

The use of sonograms, birdsong and animal noises could be incorporated into any sound-related topic. The details below suggest one approach that has been developed, trialled and refined after work with Postgraduate Certificate in Education (PGCE) trainees, teachers and students.

Introduction of the sonogram as a concept

The use of graphs to ‘tell a story’ is a common way in which many teachers introduce some of the graphs that they require students to learn. Motion graphs are perhaps the most common examples but there are many other opportunities. The website Graphing Stories (graphingstories.com) provides many examples. Graphing in class can become rather abstract and is sometimes seen by students as a chore that is carried out after experiments without them being fully clear about its function

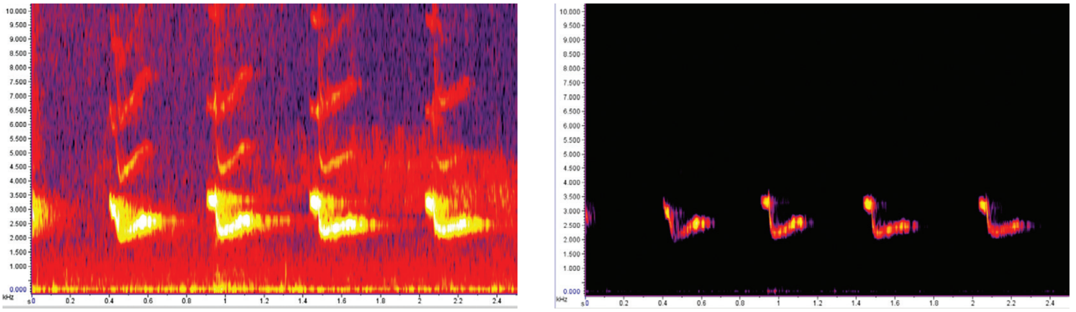

Figure 3 Two sonograms of the same songthrush song, before and after colour manipulation aiming to improve visualisation

and purpose. Even if the contexts slip outside the prescribed curriculum, opportunities to develop students' skills in this area can be worthwhile.

It is a relatively quick process to introduce students to sonograms showing frequency varying with time with nothing more complex than a voice and a set of mini-whiteboards. One can develop this to include simple notes of fixed frequency, notes of differing length and then on to those that change frequency. While this may all seem rather trivial, as well as developing students' understanding of the words pitch and frequency, this provides a way to support their learning about graphs and how they can represent changing variables. I would suggest not concerning the class too much with numerical values on the axes at this point although they could add approximate time values if so wished.

Using sonograms as identification tools

Sonograms are used as field identification tools professionally and this can be replicated in class. Some bird calls can be quite complex and so it is important to try to select calls that are simple enough to be remembered and recognised, or they could be provided with sets of sounds and sonograms for them to try to match up.

Two examples of common British birds (Figure 4) that are suitable are:

- the repeating 'see-saw' call of a great tit (sometimes said to sound like *teee-cher*);
- the yellowhammer, whose call is made up of lots of short notes ending with a long one (sometimes said to be like someone saying *a-lit-tle-bit-of-bread-and-no cheeeeeeese*).

Having fun with sonograms (and learning at the same time)

Once the students are confident with the use of sonograms, they can be encouraged to draw sonograms of familiar sounds for others to recognise or to make sounds for the other members of the class to draw, or one student can draw a sonogram and the others can then try to sing it back to them. The sounds do not have to be restricted to birdsongs and, in many cases, more appropriate and familiar sounds will already exist in the classroom. It is worth stressing to the class that, while there are not any numbers on the vertical axis which represents frequency (although some musicians with perfect pitch may be able to add them), they could add some data to the horizontal, time axis. One possible way to consolidate this work is to play a game called *Singalongasonagram* where students are shown various graphs and asked to sing along, sometimes in mixed groups where one part of the class sings back to another. This activity mimics the *twit-twoo* (or more correctly *kewick kewick-koo*) of the tawny owl call. This is often thought to be the call of one bird but is usually two different birds – the female calling and the male responding.

Other sonograms

While the most common sonogram drawn show the variation of frequency against time, an alternative shows changes of loudness or amplitude over time. Together with the frequency sonogram, this pair can provide richer detail and show different aspects of the same phenomenon, albeit ones that students can easily muddle. There are parallels that could be drawn with the

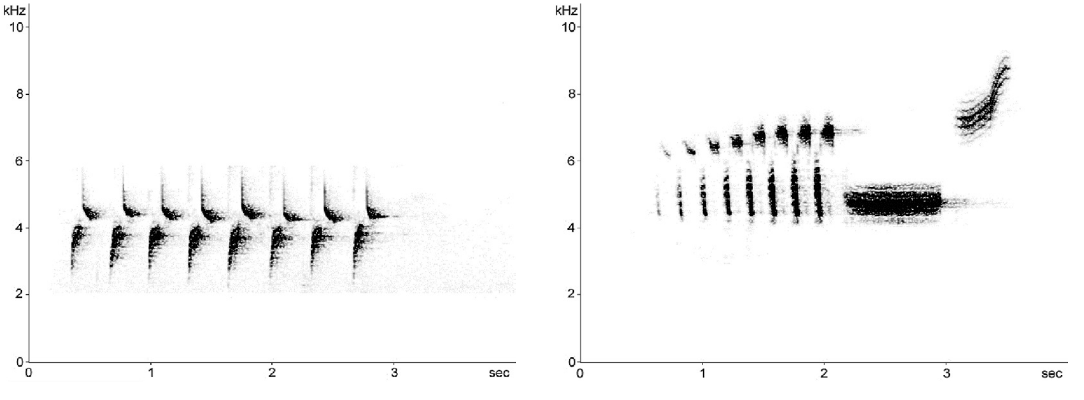

Figure 4 Sonograms of a great tit (left) and a yellowhammer (right); with thanks to Fraser Simpson (www.fssbirding.org.uk)

challenges some students have with distance/time and speed/time graphs.

Once someone has become familiar with the concept of loudness sonograms, where an upward slope indicates increasing loudness, it becomes relatively easy to see the difference between what one would hear when comparing the drumming sounds made by the lesser spotted and greater spotted woodpecker by looking at the relevant sonograms. Look at the images in Figure 5 and try to hear them in your head.

These two diagrams provide a simplified representation of the loudness of the drumming of these woodpeckers. Simply put, the loudness of the drumming from a lesser spotted woodpecker is pretty consistent throughout but the loudness of the drumming from a greater spotted woodpecker tails off towards the end of each set of drumming. This is quite a strong argument for the power of a graph and, to add to that, you can now identify your British woodpeckers at a distance. The horizontal scales have been compressed for this article although it is worth noting that the drumming separation for the greater spotted woodpecker can often be over 15 seconds whereas for the lesser spotted they are closer together, often of the order of 5 seconds or so. The green woodpecker is the only other British woodpecker and this is the one that makes that screeching, cackling call and tends to poke into the ground rather than trees and so you do not hear it making a drumming noise.

The terms loudness and amplitude are sometimes used interchangeably and, while related, they are different. We often talk of the ‘loudness’ or ‘volume’ of a sound, this describes what we hear and so is dependent on human perception. Amplitude is a more precise and measurable term that describes the periodic motion over time of the vibrating objects that are creating the sound. When amplitude sonograms are generated, they represent the high and low pressure regions caused by the vibrations that created the sound. These are recorded by the motion of the microphone in response to these pressure changes. This means that, while the graphs in Figure 5 offer a visual representation of the loudness of the sound changing over time, they are not true amplitude graphs as they do not show all of this periodic motion. Amplitude graphs for the two woodpecker sounds, adapted from professional sonogram software, are shown in Figure 6. The consistent or changing amplitude over time is still shown but there is now a fuller representation of what is happening and the positive and negative values of the amplitude can be seen.

To provide a full picture, most professional sonogram software packages provide separate amplitude and frequency sonograms together. The intensity of the colours on the frequency sonogram are also used to represent amplitude. Figure 7 shows the amplitude (top) and frequency (bottom) sonograms of what is perhaps one of

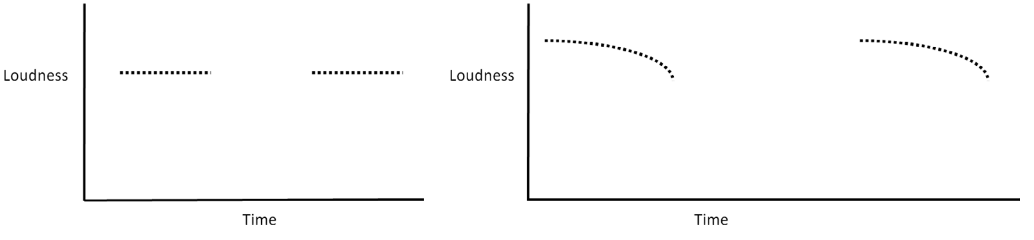

Figure 5 Representations of loudness against time for the drumming of a lesser spotted (left) and a greater spotted woodpecker (right)

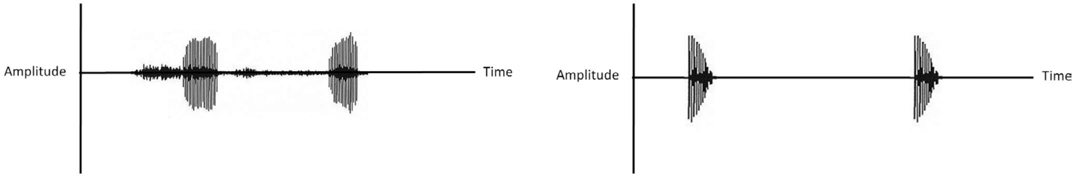

Figure 6 Amplitude sonograms of a lesser spotted (left) and greater spotted woodpecker (right)

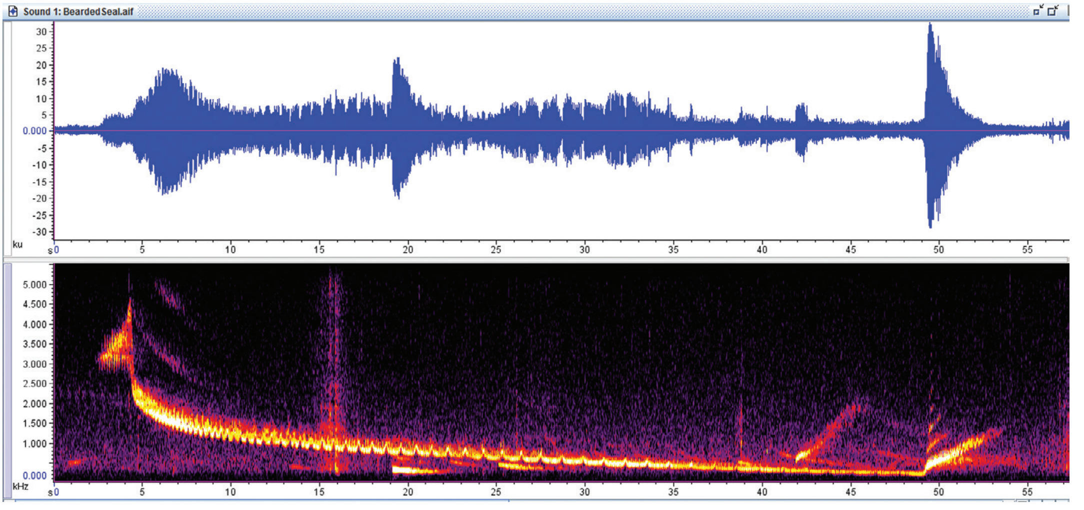

Figure 7 Amplitude and frequency sonograms of a bearded seal

the most remarkable animal sounds, that of the bearded seal. In this case, it can be seen that, as well as the main descending call, something loud and of roughly constant low frequency happens at around 19 seconds (a passing whale?) and something louder but with increasing frequency happens at about 50 seconds.

You could try to sing this based on the sonogram but when you hear the actual recording you will be astounded that any animal can make this noise: www.birds.cornell.edu/brp/listen-to-project-sounds/bearded-seal or in the free download teaching pack.

Birds in every physics lesson

There are a number of other aspects of birdsong that can be used to teach ideas that are on many physics curricula and so these can be included in the lesson ideas as outlined above or drawn into the lesson as appropriate when teaching them.

Human hearing range

The range of human hearing is often taught and it is possible to find a range of (mainly) British bird songs that are across the human hearing range. The ones I use are the great bittern (167 Hz), Ural owl (370 Hz), common cuckoo (570 Hz, 520 Hz), little owl (1.2 kHz), common redshank (2.33 kHz), common sandpiper (4.8 kHz), goldcrest (7 kHz) and lesser whitethroat (11.7–12.3 kHz). The first few notes of the lesser whitethroat call are often beyond the hearing range of some adults, something noted as a sad fact for some more mature birdwatchers.

Doppler shift

You may be familiar with the *wou-wou* sounds that you sometimes hear when a mute swan flies over. From a physics perspective, there are two interesting aspects worthy of note here. Firstly, that *wou-wou* sound is not the call of the swan at all but a sound caused by the wings. These birds will hiss and call but usually only when they or their family are threatened. Secondly, it is common to be able to hear a Doppler shift in the sound as it flies over, where the frequency of the sound heard increases as the swan flies towards you and deceases as it flies away. An audio recording of this phenomenon is included in the download pack or can be heard at sounds.bl.uk/Environment/British-wildlife-recordings/022M-W1CDR0001383-0300V0.

Taking sonograms and sound analysis further

The ideas above provide a starting point for the teaching and analysis of sound using *Raven* mainly from a descriptive position. There is scope for teachers to look into areas of interest to students such as voice recognition, which in its simplest sense is a spectrogram pattern-matching activity. Raven has a record feature and so it is relatively simple to record a few students speaking the same phrase and then to compare the sonograms. As an alternative, there are a number of smartphone apps that produce a sonogram of the microphone input and so it is possible to show the relationship between the sound and the sonogram quickly and easily in real time. Many of these are free (with advertisements), or the professional versions are available for minimal cost. Two user-friendly ones are *Spectrogram Pro* (around £2) for iOS and *Spectral Audio Analyzer Pro* for Android (around £4).

Another free sound software package that some teachers may be familiar with is *Audacity* and in recent years there have been a number of articles written on its potential use (Keeports, 2010; Groppe, 2011). One particular feature that has been less widely written about is the ability of *Audacity* to provide a frequency analysis of a particular sound. This can be of value when teaching students about digital and analogue signals and sampling rates, with particular reference to MP3 files and the corresponding sound quality difference between them and compact discs or even the higher quality downloads that some sites now offer with greater data than is held on a CD. The generation of an MP3 file is a complex algorithm that aims to reduce file size with as little reduction in quality as possible. In part, this is done by the filtering of certain frequencies that are considered to be beyond the auditory response of most people, and the lower the sampling rate the more significant and noticeable the filtering. As a consequence of this, it is common for many lower quality MP3 files to simply cut off sounds above a certain frequency and so analysis of the frequencies present can help an audiophile tell whether a sound is from an MP3 file or CD and also indicate the likely sampling rate.

Figure 8 shows the frequency analysis of the same sound sampled at two different MP3 bitrates. The image on the left is of a sound sampled at 256 kbit s^{-1} and shows a sharp drop-off or 'shelf' at around 19 kHz, which is towards the top of the human hearing range. The image on the right is of the same audio track sampled at 16 kbit s^{-1} and you see this reduction happening for frequencies above 4 kHz. The file size of the second file is significantly smaller and helps to illustrate the trade-off between file size and the amount of information that it contains. This example could be used to broaden any discussions about analogue and digital signals and sampling rates.

Many MP3 files bought from online retailers currently are sampled at or above 256 kbit s^{-1} although lower sampling rates, and thus lower quality, are not uncommon. Some streaming audio services use files at a lower sampling rate to reduce interruptions during playback; however, this reduces the quality and is partly the cause of them sounding a bit bass-heavy as some of the higher frequencies have been filtered or reduced. It is worth noting that the sampling rates (256 and 16 kbit s^{-1} here) and the sound cut-off frequencies (19 and 4 kHz) may look similar to students but they refer to different things. The first provides information about the amount of information processed per second and the second the frequency of the sound itself. Full details of this activity, how to generate your own samples and other *Audacity*-based physics teaching ideas are all freely available at audacityphysics.pbworks.com.

Some final thoughts

I fully acknowledge that trying to convince teenage students of the pleasure that bird watching and listening can bring may be a challenge beyond

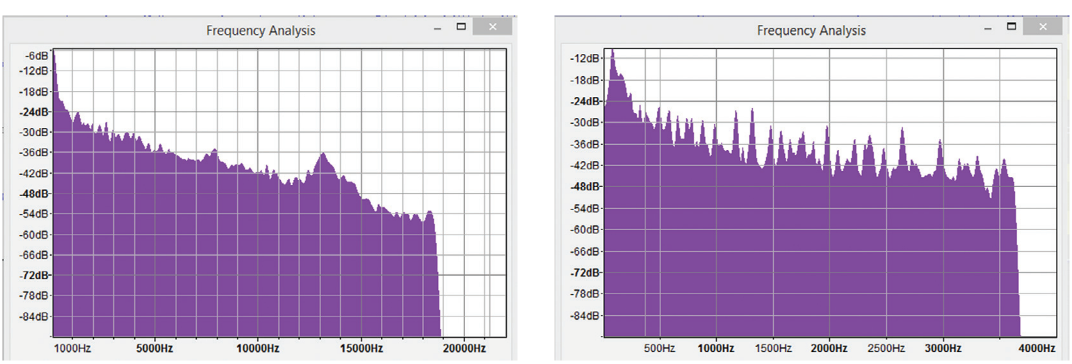

Figure 8 Frequency analysis of MP3 sound files at different sampling rates: 256 kbit s^{-1} (left) and 16 kbit s^{-1} (right)

most of us. However, I hope that there is room for this to filter down into some real and relevant physics lessons that can support the learning of sound as well as the development of students' graph drawing skills. And, if all else fails, at least you will be able to identify your woodpeckers.

Acknowledgements

I am most is grateful to the Sound Approach team (soundapproach.co.uk) for their support as well as for providing the images and sound files for the download pack freely and without restrictions if used in a non-commercial education context.

References

Groppe, J. (2011) The hope of Audacity® (to teach acoustics). *Physics Teacher*, **49**, 99–102.

Keeports, D. (2010) Demonstrating sound with music production software. *Physics Education*, **45**(3), 243–248.

Robb, M., van den Berg, A. B. and Constantine, M. (2013) A new species of *Strix* owl from Oman. *Dutch Birding*, **35**(5), 275–310.

Van den Berg, A. B., Bekir, S., de Knijff, P. and The Sound Approach (2010) Rediscovery, biology, vocalisations and taxonomy of fish owls in Turkey. *Dutch Birding*, **32**(5), 287–298.

Websites

Audacity Physics Homepage: audacityphysics.pbworks.com.
Graphing Stories: graphingstories.com.
Physics & Birdsong: www.physicsandbirdsong.co.uk.
Raven software: www.birds.cornell.edu/brp/raven.
The Sound Approach: soundapproach.co.uk.

Further reading

Constantine, M. and The Sound Approach (2006) *The Sound Approach to Birding: A Guide to Understanding Bird Sound*. Poole: The Sound Approach.

Kroodsma, D. (2007) *The Singing Life of Birds: The Art and Science of Listening to Birdsong*. New York: Houghton Mifflin Harcourt.

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