Raising public awareness of acoustic principles using voice and speech production

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Public engagement with science, technology, and engineering is seen as being increasingly important as the numbers of school leavers choosing to read for degrees in these areas is typically dropping. Engagement with pupils during their school years is seen as being a key element in influencing their choices of career for which seeds are sown from the primary years. Acoustics is an excellent vehicle for public engagement since the demonstrations can be appreciated directly by the sense of hearing and the underlying principles also apply in many branches of physics and engineering. This paper describes a number of demonstrations that have been employed during science engagement events for schools and the general public in the context of the principles of acoustics and human speech production. The apparatus used, which in some cases has been purpose-built, is described along with the activities themselves. In addition, a way to quantify the success of the process is proposed that involves a single button press on entry to and exit from an event.

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I. INTRODUCTION

The inspiration of the young to the field of science, technology, engineering and mathematics is very important for the future. Acoustics is a rich field in which to inspire people because you can hear the results of whatever experiment or activity you are carrying out. During my three years (2005–2008) as a Senior Media Fellow of the UK Engineering and Physical Sciences Research Council (EPSRC) I was involved in running activities such as workshops, lectures, and activity sessions for schools, colleges, and the general public as well as looking for opportunities for exposure in the media, whether written, radio or television. During the course of this Fellowship the following three words served to sum up the overall aim of the various activities: “awe,” “wonder,” and “amazement”; if a sense of these could be instilled in the minds of members of the audience then they have been hooked and they themselves will fill in later any underlying mathematics or other technical details.

Acoustics is at the heart of teaching and research activities in the Audio Laboratory at the University of York, UK and formed the basis of the activities, discussions and demonstrations designed and implemented during the Fellowship. This paper described a number of these activities under seven separate headings (Secs. II A to II G below) and it is offered as a resource for others offering acoustics education for the public. In each case, the key features of the demonstration, the apparatus used and the experimental procedures employed are described along with the underlying acoustic principles. All the demonstrations have been used with the general public and/or primary and secondary school pupils in the UK. Evaluation of the effectiveness of such activities is an important part of such work and a novel quantitative assessment technique based on a single button press on entry and another on exit is described that was developed as part of the Fellowship.

II. APPARATUS AND EXPERIMENTAL PROCEDURES

This section describes the apparatus used for each acoustic demonstration along with the experimental procedures employed. Some of the apparatus is very simple and makes use of readily available items, while some is rather more specialized and makes use of purpose-built or specially purchased equipment. In every case, the information provided should be sufficient to enable the demonstration to be repeated either as a direct replication or by taking the basic idea and making appropriate variations to the basic apparatus and experimental technique. The author is always happy to be contacted for further details.

A. Sound communication over distance

Sound transmission over some distance in a situation with poor signal-to-noise ratio due to the presence of competing acoustic noise can be demonstrated using cheap plastic drinking cups and string. Participants work in pairs, each having a cup and a piece of string long enough to ensure that the pair are sufficiently far apart from each other so they cannot readily hear each other at normal conversational speech levels (a large hall is ideal for this demonstration). One participant is the speaker (the cup is placed over her/his lips) and the other is the listener (the cup over an ear) and each cup is attached securely to one end of the string (passing it through a hole and tying a paperclip on the end works well). The best result is achieved when least physical contact is made with the sides of the cups to reduce damping on the acoustic vibrations and when the string is taut to enable transverse wave sound transmission.

A written sentence is given to each speaker that is to be transmitted to the appropriate listener. If this is done as a
group activity in a reverberant environment, the speakers will tend to raise their voices possibly to the point of shouting to be heard over the other speakers. There comes a point where the cup and string communicator is redundant if the overall sound level that is reaching each listener’s ear is dominated by high sound levels in the room itself. This provides an opportunity to discuss the potential for message or data disruption over a communication channel due to competing noise and to introduce the notion of signal-to-noise ratio. In addition, the acoustics of the room could be explored using an acoustic impulse (hand clap) while listening to the result. This impulse could be enhanced in amplitude by organizing the whole group to clap in unison together, perhaps after a count of three. It would be worth noting that many singers, speakers, and musicians, use a hand clap acoustic impulse to test the acoustics of spaces to determine optimum performance positions and these are not always centre stage or behind a speaker’s lectern.\footnote{”Salve nauta!” agricola dicit. (”Hello sailor!” said the farmer.)}

For a group studying a foreign language, the effects of a poor signal-to-noise ratio due to competing sounds can be made even more pronounced if the exercise is carried out using message in a foreign language. If in addition the listeners are not primed to expect a foreign language, the importance of having a robust method for verification becomes apparent along with the overall quality of the spoken message itself in terms of good diction and steady pace.

Use has been made of French and Latin phrases in this way in a local school where short sentences were composed by one of their teachers to ensure that they only made use of vocabulary and grammar that would be familiar to the pupils. Compared with using English, the background noise rose much more rapidly and multiple attempts were required before the listeners received even a meaningful message. After swapping the speakers and listeners, the group was brought together with the teacher who wrote the sentences and each participant was asked to read out the message they received as a listener and to offer a translation. Confirmation of the sentence was sought from the speaker and the teacher often intervened during the translation! Typically, the heard versions were incomplete sentences; indeed on one occasion, a transmitted Latin sentence was received as a French one! Here are some example sentences and their translations in brackets.

1. “Salve nauta!” agricola dicit. (“Hello sailor!” said the farmer.)
2. Mon grandpère a un nez énorme. (My grandfather has an enormous nose.)
3. Iuppiter est rex deorum. (Jupiter is king of the gods.)
4. Mon chien est plus grand que ton hamster. (My dog is bigger than your hamster.)
5. Elephantus maximus in atrio sedebat. (The most enormous elephant was sitting in the hall.)
6. Mon chat préfère les gateaux au chocolat. (My cat prefers chocolate cakes.)

**B. Wave shape transmission and integrity of data**

The integrity of data during transmission can be explored using visually clear wave shapes and a large group of participants standing or sitting in lines of any length, one behind the other. All that is required in terms of apparatus is a supply of paper and pencils. This exercise explores wave shape degradation, where a given single cycle of a wave form such as those shown in Fig. 1 are transmitted using physical gestures down a line of participants.

The explanation to the group as a whole is that some point, the person behind you will place their hands on your shoulders and move your shoulders backwards and forwards to represent the wave shape. They will take their hands away to indicate the end and then you will be expected to repeat this action on the shoulders of the person in front of you. A demonstration should be given initially in front of everyone to show how the movement relates to one of the original drawn wave shapes; a push forward represents a positive change (upwards on Fig. 1) and a pull back represents a negative change (downwards on Fig. 1). The person at the front of each line is given a blank sheet of paper and a pen or pencil with which to sketch the received wave shape from their line. The exercise begins by giving the participants at the back of each line a wave shape picture (see Fig. 1) and they start its transmission down the line.

When all the lines have finished and the person at the front of each line has a drawn version of the transmitted wave shape, the first and last person from each line is invited in turn to show the whole group the starting and ending wave shape. Typically there will be significant differences between these shapes and comparisons can be highly entertaining. When the results from all the rows have been exhibited a discussion can follow that describes sound transmission through air as longitudinal waves and how each person in a line was in effect a molecule passing on the wave shape to the next molecule. In addition, the types of differences found during the exercise between the wave shape that was sent and the one that was received can be explored in terms of the ways in which errors in data transmission can occur such as missed data, clipping, gain variation, and filtering.

**C. Sound levels**

An appreciation of sound levels and the decibel can be provided if one or more sound pressure level (SPL) meters are available (it is worth noting that SPL meter App is available for mobile devices). The SPL meters should be used with A weighting, approximating to the frequency domain.

FIG. 1. Example wave shapes that can be used in the data transmission demonstration.
response of the human ear. Some means of measuring distance is also required as well as a large open space such as a school hall. SPL meter calibration should be demonstrated if a calibrator is available as this makes and reinforces the point that a dBSPL measurement is made relative to a reference pressure value (in this case 20 μPa).

Two practical aspects relating to sound pressure level can be demonstrated as follows: (1) The change in dB when the sound pressure level of a source is doubled and (2) the dynamic range and comfortable playing level of musical instruments.

1. Change in dB for doubling sound source level

This experiment involves the use of an SPL meter and a sound source that can be doubled in pressure, consisting of spoken output from 1, 2, 4, 8, 16, and, if available, 32 members of the group. Some thought needs to go into the distance because the distance between the sound source and the SPL meter should be less than the critical distance (the distance from the source at which the direct sound and the reverberant sound are equal) but not too low because the source itself will become considerably larger as more members are added to it. The critical distance can be estimated using Eq. (1) which requires the volume of the room and the reverberation time. Whilst both can be calculated, the reverberation time calculation requires information about the acoustic absorption properties of the various surfaces in the room, so in practice a value of 0.75 s could be used to allow a very approximate working estimate of critical distance to be calculated from the purpose of these demonstrations:

\[ D = 0.057 \times \sqrt{\frac{V}{RT_{60}}} \]  

(1)

where \( D \) = critical distance (m), \( V \) = room volume (m\(^3\)), \( RT_{60} \) = reverberation time (s).

If two or more SPL meters are available then they could be placed at different distances; indeed, one could be placed beyond the critical distance to demonstrate the constancy in the level of the reverberant sound. Averaged multiple readings for each individual SPL meter could be taken for each sound source.

The sound source consists of the speakers each saying a different word repeatedly, such as “rhubarb, rhubarb, rhubarb,...” and the SPL level is measured. To double the sound pressure level a second person is added and two of them each speak a different word each at about the same level while another SPL measurement is taken. Then the process is repeated for 4, 8, 16, and, if the group is large enough, 32 speakers. One issue with this experiment is that the sound source should ideally be a point source so the mouths of the speakers need to be close together. Clearly this is not really very easy for a group size above about four, but in practice, the demonstration works well if the speaker group are very close together.

Following the measurements, the group can be given the values from one of the SPL meters that is within the critical distance for each sound source group (1, 2, 4, 8, 16,...) from which they should work out the average change in dB for a doubling in sound pressure level. At a previously run session, the overall average change in dB per doubling was 5.7 dB. Theoretically it should be ~6 dB or 20 log\(_{10}\)(2).

If SPL measurements were made beyond the critical distance, then these should be seen not to vary particularly, providing a basis for describing the nature of reverberation, the importance of the direct sound and why being within the critical distance improves speech intelligibility and perceived clarity particularly of rapid music.

2. Dynamic range and comfortable playing level of acoustic musical instruments

This demonstration requires at least one SPL meter and that at least some members of the group have their acoustic musical instruments with them. The object of the exercise is to find which player and instrument has the largest dynamic range measured in dB between the softest and loudest note they can play. An SPL meter (A weighting, set to an appropriate range, maximum capture if available) is used to measure the levels and it is placed at a fixed distance (1 m has been used but any distance within the critical distance that is not too close to the instrument is appropriate, providing it remains constant for all the measurements on a given instrument). If additional SPL meters are available these could be used at different distances as discussed in Eq. (1) above. The player is instructed to sustain any note at the softest and loudest level they can achieve and also at a comfortable playing level. In each case, an SPL measurement is made. Average measurements could be taken for multiple attempts as desired.

The measured comfortable playing levels enable the relative levels of the instruments to be compared, and this will provide a basis for a discussion as to why, for example, there are many more stringed as opposed to wind instruments in an orchestra. The dynamic range for each player and instrument is found in dB by subtracting the dB reading for the softest note from that for the loudest note. The results might be discussed in terms of the number of dynamic steps that are typically found in musical scores (e.g., pp, p, mp, mf, f, ff) and the fact that 1 dB is approximately the minimum change in level that humans can hear.

D. Vocal fold vibrations challenge

The use of computers in singing training to provide real-time visual feedback of acoustic and voice source parameters has proved to be successful and is on-going. During speech and singing related UK National Science and Engineering Weeks events for the public, the winsingad software was adapted to enable a display of the total number of vocal fold closures to be displayed in a large font on the screen of a laptop PC. The most accurate approach is to carry out the fundamental frequency (f0) analysis in the time domain as each cycle can be accounted for directly. However, for the purposes of this challenge a good estimate can be made based on any microphone-based f0 analysis technique.

A vocal challenge that has been employed is to produce as many vocal fold closures as possible in one breath. While the f0 data is being gathered, the total number of cycles is
shown on screen using a large font. To achieve a large number of vocal fold closures in one breath, two strategies will help: (1) singing on a high pitch and (2) reducing breath usage by singing quietly. Table I shows the top three results for each of three days at the National Science and Engineering Week in York, UK in 2007. For this event the first two days were devoted to local schools and the Saturday was for members of the public, hence the entries for adults and children on the Saturday. It turned out that Colin, who gained the overall maximum of 20612 cycles in one breath, achieved this due to his background as a trained diver!

### E. Efficient acoustic transmission

The main topic for this exercise is amplification and it is first introduced acoustically leading on to work on electronic amplification and the use of a potentiometer. The acoustic demonstration requires “talking tapes” (internet search for “talking tapes” will find them) which have pre-recorded messages on them in the form of a series of a number of ridges across the tape which are the sound pressure variations from the originally recorded sound source. The tape is played by holding it at one end securely with one hand securely while running the thumbnail of the other hand along the ridged side of the tape. A supply of plastic cups and/or inflated balloons is also required.

When the tape is used on its own, the sound produced is usually inaudible and some means of enhancing the energy transmission from the tape to air is required. This can be achieved by placing an object with a large surface area, such as a plastic cup or an inflated balloon, against the held end of the tape to enable the vibrations to be transmitted into the room at a large enough amplitude to be heard by a small group.

Talking tapes enable other aspects of sound to be demonstrated. Playing the tape in the other direction time reverses the message. Changing the playing speed varies the pitch and overall timing. It is worth noting the effect of playing the tape very slowly and very fast. These differences could lead on to some thoughts about recorded sounds and how they might be processed to make such effects. Analog tape could be described (and possibly demonstrated if equipment is available) as working in much the same manner when it is reversed or played at different speeds. These effects can be readily demonstrated digitally with shareware audio wave editing software such as GoldWave.8

### F. Speech and singing production

This demonstration aims to provide an increased understanding of human speech and singing production and it can be used via a hard rubber coupler. Arai10 also proposes the use of a horn loudspeaker driver unit and he provides a description of a suitable design for a hard rubber coupler, so that it can be used as an electrical driver to enable any signal to be used as excitation such as a pulse train, white noise or the LF source model11 that is commonly found in practical electronic synthesis systems such as the Klatt synthesizer.12 Three oral tract tubes and the sound sources from the VTM-10 kit are shown in the upper left panel of Fig. 2.

The lower left panel of Fig. 2 shows a simple but effective power source and sound source model can be fashioned out of the top section of a two liter plastic drinks bottle, three plastic sandwich bags (marked “B” in the figure), plastic insulating tape, plastic tubing with a “T” piece and a whistle-type artificial larynx from the VTM-10 kit (marked with a “W” in the figure). The T piece is fitted to one end of the plastic tube and a plastic sandwich bag (B) is taped on each of the two branches of the T as the “lungs.” The other end of the plastic tube is taken through a hole in the screw-top lid of the bottle, the lungs are emptied and the whistle-type artificial larynx (W) is attached. The third plastic bag (B) is taped around the bottom of the bottle as the “diaphragm.” The demonstration is set up by unscrewing the top a little and pushing the diaphragm into the bottom of the bottle tightening the top to set the “raised diaphragm” position (to go with the “empty lungs”). Breathing in is achieved by gently grasping the

<table>
<thead>
<tr>
<th>Thursday</th>
<th>Friday</th>
<th>Saturday (adults)</th>
<th>Saturday (children)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Holly 7757</td>
<td>James 9920</td>
<td>Colin 20612</td>
<td>Joey 9030</td>
</tr>
<tr>
<td>Jack 7732</td>
<td>Alex 8397</td>
<td>Martin 18516</td>
<td>Ellery 8638</td>
</tr>
<tr>
<td>Eleonora 7169</td>
<td>Paul 8299</td>
<td>Jane 14896</td>
<td>Carieann 8472</td>
</tr>
</tbody>
</table>

A lung model has been used in acoustics education but it is not available commercially8 and would not be easy to reproduce. An excellent resource that is available for demonstrating the acoustics of speech production is the VTM-10 kit,10 which comprises practical demonstrations of both the sound source and sound modifiers during speech production. There are two sound sources provided: (1) a battery-powered electro-larynx that provides a falling f0 over about 3 s and (2) a whistle-type artificial larynx consisting of a small rubber membrane that vibrates over a tiny hole when one blows into its mouthpiece. Arai10 notes that the use of prosthetic artificial larynxes has the following advantages: (1) their outputs are designed as a practical speech sound source, (2) they are portable, and (3) sound source acoustic leakage is low as their output signals are appropriately coupled to the sound modifier tubes.

The VTM-10 kit sound modifiers are provided in two forms. There are five acrylic tubes representing in cylindrical cross-section the oral tract for the vowels /i/, /e/, /a/, /o/, and /u/. In addition, there is a set of acrylic squares with central holes of various diameters and these can be placed together on a special frame to enable other vocal tract shapes to be made up. In both cases, either of the two sound sources can be used via a hard rubber coupler. Arai10 also proposes the use of a horn loudspeaker driver unit and he provides a description of a suitable design for a hard rubber coupler, so that it can be used as an electrical driver to enable any signal to be used as excitation such as a pulse train, white noise or the LF source model11 that is commonly found in practical electronic synthesis systems such as the Klatt synthesizer.12 Three oral tract tubes and the sound sources from the VTM-10 kit are shown in the upper left panel of Fig. 2.
centre of the diaphragm and pulling it gently away from the bottle. The lungs should inflate. On breathing out by pushing the diaphragm into the bottom of the bottle, a sound is heard from the whistle-type artificial larynx.

An on-line design for a tilting paper larynx has been modified to create an aluminium larynx that is around 25 cm tall onto which rubber bands can be fixed to show how the vocal folds are stretched as the larynx is tilted as illustrated in the right hand panel of Fig. 2. It is fashioned from two parts as illustrated in the figure that are bent appropriately and joined at the points marked with “o” and “O.” The ends of the rubber band are attached to the points marked “X.” It should, however, be made clear to audiences that the laryngeal voice source consists of two folds of muscle tissue rather than two cord- or string-like structures and this can be clearly illustrated if medical models of the larynx are available. Medical models of the lungs, bronchi, vocal tract, and cut-away details of the head can also be used to enhance understanding of human speech and singing production in a graphical and hands-on manner.

A very visual demonstration of human speech production can be made with a von Kempelen speaking machine of 1793, and for this a replica was commissioned from a local pipe organ builder: Principal Pipe Organs of York, UK which is shown in Fig. 3. The von Kempelen machine is useful for demonstrating the basis of speech production because it makes very visual and practical a model of the power source, sound source and sound modifiers whilst having considerable historical interest.

Since it is such an unusual object in itself, it provides an excellent starting point for any workshop or presentation.

The physiology and acoustics of speech production can be readily demonstrated in terms of the power source, sound source, and sound modifiers.

1. **Power source**

The power source for speech and singing production is the breathing mechanism for which two main muscle groups are employed: (1) the diaphragm and abdominal muscles and (2) the intercostal muscles of the lower ribs. To breathe in the thoracic cavity is enlarged which enlarges the lungs thereby lowering lung pressure, and if the airway is open, air will enter the lungs. To breathe out the thoracic cavity is shrunk, the lung volume becomes smaller, lung pressure is raised and air is expelled if the airway is open. The plastic bottle lung model enables diaphragmatic breathing to be demonstrated.

The importance of controlled breath control can be discussed in the context of singing, where the key is to keep the upper chest, shoulders and neck relaxed and free from tension through the use of the two main muscle groups. The first of these breathing mechanisms can be demonstrated by placing a hand over the navel and breathing in trying to push that hand outwards. The second can be demonstrated by placing hands on the lower rib and breathing in while trying to push outwards against the hands. During both demonstrations, breathing in should be carried out without raising the shoulders.

2. **Sound source**

The key aspect of the sound source is that it is a buzz-like sound that changes in pitch but it remains buzz-like no matter what sound is being articulated. An electrolarynx or whistle-type artificial larynx allows this to be clearly demonstrated since the buzz-like quality can be readily heard from...
the device alone. When it is placed to one side of the Adam’s Apple against the thyroid cartilage with a closed glottis (by holding one’s breath) and activated, speech sounds are heard as they are articulated. The tilting aluminium larynx model enables the pitch changing mechanism to be demonstrated in terms of how the vocal folds can be stretched.

3. Sound modifiers

The size of the sound modifiers is usefully shown with a rubber tube, particularly if it has an appropriate bend in it (a quest for something suitable was successful in finding a tube from a Toyota 4 × 4 gearbox oil heat exchanger). Magnetic resonance images of the vocal tract when articulating different vowels show the differences in shape along the length of the oral tract length and their shapes can be compared with what is experienced during vowel production. The acrylic tubes enable the shapes to be explored and the resulting sound can be heard when an electrolarynx input is activated. The (ex-Toyota) rubber tube can be placed over a suitably sized loudspeaker that is driven by an electronic oscillator and squeezed in different places to demonstrate vowel-like sound modification.

4. Overall

For all demonstrations that involve a sound output it might be appropriate to view the differences between the sounds either as a waveform or a spectrum or a spectrogram depending on the audience and purpose of the demonstration. If speech or singing formant synthesis is an appropriate demonstration, then the MADDE freeware formant synthesizer is an excellent demonstrator and it can be used in conjunction with RTSECT to show its acoustic output. Whenever a waveform and a spectrum or spectrogram are being displayed it is useful to indicate that the waveform is the signal reaching the ear and the spectral representation is to a reasonable approximation what is sent to the brain by each ear. It is appropriate, though, to acknowledge that the linear frequency axis should really be closer to logarithmic and the filter bandwidths should vary with center frequency for audiences who can readily appreciate these distinctions.

An example of the application of knowledge of speech and singing production is in the creation of the singing of a castrato by electronic morphing which was carried out for a BBC4 television program. Additional material written for boys relating to their voice change in adolescence is available as a web resource set up to encourage boys to sing.

G. Acoustic harmonic synthesis and organs

Harmonic synthesis can be readily demonstrated on a computer using a freeware resource such as Pure Data (PD), or with a purpose-implemented iPad Application such as “Harmonic Synthesis.” However, the use of organ pipes makes for a much more physical and tangible acoustic demonstration. The stops on an organ enable the player to create different sounds through acoustic harmonic synthesis. Most organ stops have a footage associated with them that indicates the length of the open pipe that produces the lowest note on the organ keyboard (two octaves below middle C). A stop with an 8 on it indicates that the pipe for the lowest note is approximately 8 ft long. Such a stop sounds at concert pitch; in other words, the notes sound at the same pitch as the piano.

Figure 4 shows a pipe organ demonstrator for a single note that has 16 stops with one pipe for each stop built by Principal Pipe Organs of York, UK, but a visit to a local pipe organ will facilitate similar demonstrations. The demonstrator organ is designed to show different types of organ pipes as well as acoustic synthesis using harmonics 1 to 8. There are two main types of organs pipe: flues and reeds. Figure 4 shows that the demonstrator has 13 flue pipes numbered 1 to 13 in the figure (harmonics 1–8 based essentially on principal pipes, harmonics 1–3 based on stopped flue pipes, and two pipes that are slightly de-tuned to create a string sound—salicional and voix celeste) and three reed pipes numbered 14 to 16 in the figure (oboe, trumpet, and cornopean). The principal and string pipes are open and the flute pipes are closed (the stoppers in their ends are visible in the figure). Each pipe can be played separately or in any combination by means of small brass buttons and the unit has a small electric blower to supply its wind.

The organ demonstrator enables acoustic harmonic synthesis to be demonstrated through acoustic reinforcement of individual harmonics as a practical demonstration of Fourier synthesis. Harmonics are sine waves whose frequencies are integer multiples of the fundamental frequency (f0) (1f0, 2f0, 3f0, 4f0, 5f0,…), and acoustically, they can be produced using organ pipes of appropriate relative integer ratio lengths. A pipe will have its f0 at the second harmonic of an 8 ft (concert pitch) pipe if it is half its length, or 4 ft (8/2). A pipe with its f0 at the third harmonic of an 8 ft pipe will be a...
third of its length, or 2 2/3 ft (8/3) and it will sound one octave and a fifth above concert pitch. Table II lists harmonic numbers, musical intervals and pipe lengths for the first eight members of the 8 ft harmonic series for manuals. A complete set of organ stop footages is provided in Ref. 3, p. 255, and on the “organ stops” iPhone application. Discussion of pipe organs offers an excellent opportunity for working with fractions.

Harmonic synthesis for eight harmonics can be demonstrated acoustically and visually in terms of the lengths of the pipes themselves with the demonstrator. With a suitable spectrum or spectrographic display it can be shown how each of the harmonics added to the 8 ft has its own fundamental aligned with the appropriate harmonic of the 8 ft pipe.

The use of an organ demonstrator or a visit to a local pipe organ can provoke thinking and discussion as to how a pipe organ works, the number of pipes and their pitch range. This thinking could be supplemented by indicating that a large pipe organ can span an overall frequency range that is greater than that of human hearing and an overall dynamic range that is greater than any other musical instrument. In addition, a pipe organ is a complex and large feat of engineering, which is highlighted through a visit to a local organ to meet the organist and explore the instrument itself, perhaps using a laptop with a real-time spectrum or spectrogram display.

### III. ASSESSING THE SESSIONS

It is always important to know how successful or otherwise learning activities are in order to inform, for example, sponsors, parents and teachers, but effectiveness of such sessions is something that is not easily quantified, particularly with younger groups. There was an expectation that the effectiveness of sessions would be quantified during the Senior Media Fellowship, for which the following technique was developed.

The original thinking was based on the fact that some sessions would be run with young children and that time was always at a premium, and on this basis the use of questionnaires was ruled out. Awareness of the fascination that many of us and especially the young have for pressing buttons led to a multiple set of five stock-taking tally counters being purchased of a type that is used to enable different types of stock to be counted separately. Originally the idea was to ask questions with a choice of answers, but further thought provided the idea of associating the five tally counters with five smiley faces from happy to sad (see Fig. 5) which could be used to gain responses to “I feel confident about…” style statements.

The procedure adopted was to invite participants to respond to such a question by pressing the button next to the appropriate smiley face on entry to and again on exit from a session (Fig 5). The statements might be as follows but would vary depending on the audience and the activity itself:

1. “I feel confident describing how science works.”
2. “I could describe harmonic synthesis to others.”
3. “I know all about my voice.”
4. “I have learned something about my voice.”

#### FIG. 5. Set of five tally counters with smiley faces.

#### FIG. 6. Example data from the tally counters for participants (school pupils aged 9–16 years) on entry and exit to a voice production session at a Schools’ Day during National Science and Engineering Week 2007 in York UK in response to the statement “I know all about my voice.”

<table>
<thead>
<tr>
<th>Harmonic number (n)</th>
<th>Stop name (principal)</th>
<th>Pipe length (8/n)</th>
<th>Notes from f₀</th>
<th>Musical interval</th>
<th>f₀ for C₂ (bottom C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Open diapason</td>
<td>8</td>
<td>0</td>
<td>unison</td>
<td>65.41 Hz</td>
</tr>
<tr>
<td>2</td>
<td>Principal</td>
<td>4</td>
<td>8</td>
<td>octave</td>
<td>130.8 Hz</td>
</tr>
<tr>
<td>3</td>
<td>Twelfth</td>
<td>2 2/3</td>
<td>12</td>
<td>octave and a fifth</td>
<td>196.2 Hz</td>
</tr>
<tr>
<td>4</td>
<td>Fifteenth</td>
<td>2</td>
<td>15</td>
<td>two octaves</td>
<td>261.6 Hz</td>
</tr>
<tr>
<td>5</td>
<td>Tierce</td>
<td>1 3/5</td>
<td>17</td>
<td>two octaves and a major third</td>
<td>327.0 Hz</td>
</tr>
<tr>
<td>6</td>
<td>Larigot</td>
<td>1 1/3</td>
<td>19</td>
<td>two octaves and a fifth</td>
<td>392.5 Hz</td>
</tr>
<tr>
<td>7</td>
<td>Septième</td>
<td>1 7/8</td>
<td>21</td>
<td>two octaves and a flattened minor seventh</td>
<td>457.9 Hz</td>
</tr>
<tr>
<td>8</td>
<td>Octavin</td>
<td>1</td>
<td>22</td>
<td>three octaves</td>
<td>523.3 Hz</td>
</tr>
</tbody>
</table>

*2 octaves below middle C, 8 ft value in equal temperament relative to A₄ (440 Hz).
The results for entry are noted at some point during the session by copying down the five numbers, the tally counters have been used effectively with all age groups. The results for entry are noted at some point during the

Figure 6 shows tally counter data for a National Science and Engineering Week event in 2007 at which human voice production was explored with 184 nine to sixteen year olds in which the differences between the two results are statistically significant at the 0.1% level (Chi-sq, 4 degrees of freedom: 64.48, p < 0.001).

IV. CONCLUSIONS

Acoustic science is something of a mystery to many people possibly because it cannot be seen or easily interacted with. This paper has described a number of acoustic demonstrations that can be readily implemented, in some cases with everyday objects, and used both in schools and with the general public. Increasing public understanding of science is important in today’s society where scientific and technical advances play increasingly important roles in human existence. Scientific engagement at an appropriate level can play a vital role in increasing public understanding and awareness of scientific principles and to make progress with such engagement, it does not matter what topic is used. In addition, it can encourage young people to think about careers in related professions, such as engineering, information technology, physics, chemistry, or mathematics. Assessing the effect of scientific engagement is not easy particularly with people possibly because it cannot be seen or easily interacted with everyday objects, and used both in schools and with the general public. Increasing public understanding of science is important in today’s society where scientific and technical advances play increasingly important roles in human existence. Scientific engagement at an appropriate level can play a vital role in increasing public understanding and awareness of scientific principles and to make progress with such engagement, it does not matter what topic is used. In addition, it can encourage young people to think about careers in related professions, such as engineering, information technology, physics, chemistry, or mathematics. Assessing the effect of scientific engagement is not easy particularly with children, and an assessment technique based on single button presses on entry and exit from an event is described that has been used effectively with all age groups.

Acoustics offers a special vehicle for this process since the demonstrations can be heard and there is a heightened degree of fascination with topics that engage directly with the human senses. The principles behind acoustic harmonic synthesis, whether by organ pipes or electronic means, underpin major topics in physics and engineering. Young minds that are opened to these and other phenomena may well become tomorrow’s generation of scientists, technologists, and engineers that society needs.

In seeking to engender a sense of awe, wonder, and amazement, acoustic demonstrations that engage with music, sound synthesis, speech and singing appeal powerfully to audiences; anyone can join in and hear the effects being considered. Knowledge of how the body works, in this case the speech and singing production system with some reference to hearing, is of interest to most people since they all have something to gain directly out of increased knowledge in these areas. In addition, reference to healthy speech and singing production and hence healthy breathing and posture as well as timely advice on noise induced hearing loss and looking after the hearing system as appropriate offers potentially long-lasting general health benefits.

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