The Science Enhancement Programme is a part of Gatsby Technical Education Projects. It is developing curriculum resources to support effective learning in science, and providing courses and professional development opportunities for science teachers. This booklet is part of the series ‘Innovations in practical work’, exploring ways in which low-cost and novel resources can be used in secondary science. The Gatsby Science Enhancement Programme has worked in partnership with University College London and the Institute of Physics in the production of this publication and the accompanying resources.

The ‘Voicebox’ project is a collaboration between University College London (UCL) and the Institute of Physics. UCL participation was supported by the Arts and Humanities Research Council-funded Centre for the Evolution of Cultural Diversity, and by the European Commission. The Institute of Physics is a scientific charity devoted to increasing the practice, understanding and application of physics; this includes securing its future through support for physics and physics teachers in schools and colleges.
ACKNOWLEDGEMENTS

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HEALTH AND SAFETY

For practical activities, the Science Enhancement Programme has tried to ensure that the experiments are healthy and safe to use in schools and colleges, and that any recognised hazards have been indicated together with appropriate control measures (safety precautions). It is assumed that these experiments will be undertaken in suitable laboratories or work areas and that good laboratory practices will be observed. Teachers should consult their employers’ risk assessments for each practical before use, and consider whether any modification is necessary for the particular circumstances of their own class/school. If necessary, CLEAPSS members can obtain further advice by contacting the Helpline on 01895 251496 or e-mail science@cleapss.org.uk.
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DOWNLOADING DIGITAL RESOURCES FROM THE SEP WEBSITE

www.sep.org.uk

ORDERING PRACTICAL RESOURCES FROM MUTR

www.mutr.co.uk

See pages 50 - 51 for further details
## CURRICULUM LINKS

The following tables show the main relevant sections for each of the key stages, plus opportunities for cross-curricular collaboration.

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<td></td>
<td>The exemplar scheme of work (QCA) has a Unit titled Sound and hearing. This suggests that children should be able to identify how they can make sounds and recognise that when they do so parts of their bodies move. Suggested activities for children include:</td>
</tr>
<tr>
<td></td>
<td>• identifying sounds they like and sounds they dislike and describing them</td>
</tr>
<tr>
<td></td>
<td>• feeling their faces and throats while they are talking/singing and while they are not</td>
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<tr>
<td></td>
<td>a Using scientific ideas and models to explain phenomena and developing them creatively to generate and test theories.</td>
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<td>Key processes</td>
<td>2.1 Practical and enquiry skills</td>
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<tr>
<td></td>
<td>Pupils should be able to:</td>
</tr>
<tr>
<td></td>
<td>a use a range of scientific methods and techniques to develop and test ideas and explanations.</td>
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<tr>
<td>Range and content</td>
<td>3.1 Energy, electricity and forces</td>
</tr>
<tr>
<td></td>
<td>a energy can be transferred usefully, stored, or dissipated, but cannot be created or destroyed (includes properties and behaviour of sound).</td>
</tr>
<tr>
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<td>3.3 Organisms, behaviour and health</td>
</tr>
<tr>
<td></td>
<td>d all living things show variation, can be classified and are interdependent, interacting with each other and their environment</td>
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<tr>
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<td>e behaviour is influenced by internal and external factors and can be investigated and measured.</td>
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<td>Curriculum opportunities</td>
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<td>c use real-life examples as a basis for finding out about science</td>
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<td>h explore contemporary and historical scientific developments and how they have been communicated.</td>
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## GCSE specification for 2011

<table>
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<td>Physics 1  General properties of waves</td>
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</table>
| Edexcel Sciences| B1 Topic 1  Variation  
Describe the process of evolution by means of Darwin's theory of natural selection.  
B3 Topic 2  Behaviour  
Explain that sexual reproduction requires the finding and selection of a suitable mate, and can involve courtship behaviours that advertise an individual's quality.  
Describe the evidence for human evolution, based on fossils.  
B1 Topic 4  Waves and the Earth  
Use the terms of frequency, wavelength, amplitude and speed to describe waves.  
Differentiate between longitudinal and transverse waves by referring to sound, electromagnetic and seismic waves. |
| OCR Twenty First Century Science | B3  Life on Earth  
How did life on Earth begin and evolve?  
P1 Transverse and longitudinal waves; wave frequency, wavelength, amplitude  
P2 The wave model of radiation |
| OCR Gateway     | B2f  Natural selection  
P5f  Nature of waves [interference] |
| WJEC Sciences  | B1.5  Evolution  
P1.5  Waves: characterise waves in terms of their wavelength, frequency, speed and amplitude.  
P3.2  The properties of waves: distinguish between transverse and longitudinal waves. |

## Modern foreign languages

A significant challenge in learning to speak another language is the fact that it employs a different set of sounds. This becomes obvious, for example, when you listen to non-native speakers of English. Foreign language teachers can help students to use their mouths differently and so make new sounds.

## Voice training for singers and actors

Amateurs need to learn how to sing so that they do not strain their larynx. Singing styles tend to emphasise vowels though some consonants are exaggerated, enabling an audience to distinguish the lyrics. Crisp consonants are an essential part of choral singing. Actors too must understand how to vocalise new sounds, perhaps with the aid of diagrams, so they can speak with different accents.
INTRODUCTION

Human vocalisation is unique in the animal world. Speech enables people to live in complex groups, communicating subtle information of many kinds: hopes, desires, plans, problems, solutions and history.

Scientists study the anatomy and physiology of human speech, as well as acoustics and ways of analysing sounds in general. They are interested in the normal range of voice quality and development from child to adult, as well as pathologies that adversely affect speech. This knowledge is used by professions such as speech therapy, voice training for singers, and foreign language teaching. Scientists also try and understand how human speech historically evolved, making humans so different from all other animals.

‘Voicebox’ is a set of practical activities that encourage students to understand human speech at a basic level. It also explores animal sounds and the evolution of human speech, with a clear link to the ‘How Science Works’ part of the curriculum.

The practical activities and interactive software can be used flexibly, as a circus, or a mix of student practical activities and teacher demonstrations. These resources can enrich the science curriculum by addressing questions which students naturally ask about the human voice.

The activities are designed for Key Stage 3, but they could be adapted to support the requirements of GCSE science specifications, particularly those related to evolution by natural selection. Low-cost practical resources to support the activities are available for purchase from Middlesex University Teaching Resources (MUTR).
**VOICEBOX IN THE CLASSROOM: SOME IDEAS AND SUGGESTIONS**

The human voice is truly remarkable for the variety of sounds it can make. Along with gestures and facial expressions, oral communication is an essential aspect of human life. Although it is not always easy to define the difference between a language and a dialect, it is estimated that there are over 6000 languages spoken in the world. Language sets humans apart from all other animals.

This section gives an ‘illustrated overview’ of how interactive software and practical work can be used in the classroom to develop an understanding of the human voicebox. In the margin, references are given to student activities – these resources and the accompanying teachers’ notes can be found later in the booklet.

All social animals communicate, and many make use of sounds to do so. All members of the biological order Primates, which includes humans, apes and monkeys, use sound to communicate.

Non-human primates use calls to establish their territories and to warn of approaching dangers. They also use calls to ask for help, advertise their strengths and build social bonds. One of the major uses to which many animals put their voices is to advertise their size. For many animal species – and especially for the males – body size is an indicator of fighting ability, and also a measure of desirability as a mate. The size of an animal generally affects the size of its vocal tract, and this in turn affects the sounds that come out. Larger animals will tend to make lower-pitched calls that resonate at lower frequencies, and to be able to make them more loudly.

Humans use their voices for the same reasons as other primates, but many additional reasons too. The amount and range of information that humans can share by talking, and the speed at which that information can be exchanged, are quite extraordinary. This is a result of physical differences that increase the number of distinct sounds that humans can make and differences in the brain that allow humans to control and understand language.
Learning to talk starts at birth. Babies quickly learn to understand speech and they may be talking at about twelve months. The language in which a baby is immersed becomes so deeply imprinted within the first two years that no additional language will sound like a native tongue.

Although human language is elaborate by comparison with the limited range of calls made by other primates, the basic apparatus, the voicebox, is similar.

**Classroom activities**

A PowerPoint presentation can be used to introduce the class to key ideas and questions related to Voicebox. This presentation ends with an activity where students try and list 17 vowel sounds used in one-syllable English words beginning with ‘b’ and ending with ‘d’.

Students may be interested to know that the term for human in Arabic is ‘insang natiq’, which means speaking animal.

The relationship between animal size and vocalisation pitch can be explored with two interactive ICT drag-and-drop exercises and a short video (on the CD-ROM). In *Which dog is growling?* students try and match each growling sound to the correct size and breed of dog. In *Which person is talking?* they try and match synthesised human speech sounds to figures representing people of very different sizes, whose vocal tracts have been proportionately rescaled.

The video shows how a male red deer, when making its distinctive breeding season call, moves its larynx to sound bigger than it is. Its roars serve to attract hinds and scare off competition. Red deer generally defend female ‘harems’, rather than territories. Mating season calls also herd hinds that have already joined the individual male’s breeding group.
Some students will be interested to find out about exceptions to the general pattern relating body size to vocal pitch. They could study and discuss relevant graphs and data provided in a resource sheet, including infrasound signals used by whales and ultrasound signals used by rat pups (see Resource R1 Body size and vocal pitch on page 36).

All sounds originate with a vibration. They are carried from place to place as longitudinal (pressure) waves through any physical material (solid, liquid or gas). Ears detect sounds and, with the brain, interpret their meaning.

Taken together, three concepts are sufficient to describe any particular sound.

- **Pitch** is a commonly used term which describes the frequency of a vibration. Frequency is measured in Hertz, where 1 Hz = one vibration per second.

- **Loudness** is not a simple objective quantity but instead describes how sounds are perceived. Commonly people refer to this as sound volume. Three factors affect loudness for human hearing: how much energy reaches the ears each second, the frequency of the sound and its duration. The rate of energy transferred by a sound (its intensity) depends on the amplitude of the sound wave and is measured in decibels (dB). The frequency range of human hearing is 20 Hz – 20 kHz and the ear is most sensitive to sounds of about 2 kHz. In other words, if the amplitude of a sound wave stays the same while its frequency changes, it will sound loudest at about 2 kHz.

- **Timbre** describes sound quality. A source of sound, such as a voice or musical instrument, typically produces a mix of frequencies related to some fundamental frequency, called harmonics. This is why it is possible to identify two different vowels spoken with the same pitch and loudness, or to distinguish the sound of a trumpet from the sound of a violin. Various software packages can reveal the multiple frequencies present in a sound, and their relative intensities, a process called spectral analysis.
**Classroom activities**
In school science, an oscilloscope is generally used to introduce quantities describing sounds. Sounds that have simple waveforms are displayed and students are taught to interpret them. With signal source volume and oscilloscope time-base settings fixed, more waves across the screen indicate a higher frequency. With signal source frequency and oscilloscope sensitivity settings fixed, vertically larger waves indicate a larger amplitude, which sound louder. The shape of the waveform represents sound quality or timbre; for example, a sinusoidal shape indicates a pure frequency.

*FaroSon* is a Windows PC program (on the CD-ROM) developed by Mark Huckvale, University College London, which converts any sound into a coloured pattern in real-time. The horizontal axis of the pattern represents time and other attributes of the picture are related to our subjective senses of loudness, pitch and timbre. By contrast with an oscilloscope, you cannot make measurements of the sound with this software. However, being a rather pretty way to look at the complexities of real speech, *FaroSon* is likely to make a better introduction for students to the language associated with sound sensations.

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**See Extension X2**
Using *FaroSon* software (page 34)

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**How the Human Voicebox Works**

The human voice is produced by the larynx and vocal tract. Vocal folds in the larynx vibrate as air from the lungs is forced through them, creating buzzing sounds. When the vocal folds are stretched slightly, their tension increases, resulting in a high pitched sound. Likewise, sounds of lower pitch are produced when the folds are slightly shorter and so less tense.

The vocal tract, comprising throat and mouth, shapes these sounds into the vowels and consonants that make up speech. The vocal tract is a very flexible resonating system: the jaw, lips, tongue and soft palate dynamically shape it into a wide variety of tubes, each with variable cross-section, so changing the sounds from the larynx in a language-specific way which is recognisable as speech.
Buzzing sounds are produced by vocal folds in the larynx. The vocal tract dynamically changes sounds from the larynx into recognisable speech.

The length and shape of the vocal tract affects timbre. For a mental model of this, think of the vocal folds as creating a repeating train of pulses and the vocal tract as an airspace which likes to vibrate. When a sound pulse hits the vocal tract, its air resonates at a preferred frequency of vibration. The sound emerging from the mouth has the same pitch but a different timbre to the sound produced by the vocal folds.

The voice changes as a human grows. A baby’s small larynx makes its calls high-pitched. Changes in the shape of the face create more space for sounds to resonate. During adolescence a boy’s voice significantly changes its pitch and resonance. The vocal folds thicken and lengthen, causing them to vibrate at slower rates. More information about this is given in the Background science section of this booklet on page 45.

Classroom activities
You can introduce students to vocal folds by having them touch their throat and compare what happens as they talk and whisper. A balloon can be used to show what makes vocal folds vibrate, and if a model of the larynx is available, you can use it to help students understand the location and structure of the larynx.

A simple way to demonstrate what makes vocal folds vibrate is to release air from a balloon.
See Activity A3
The larynx (page 26)

See Activity A4
Making different speech sounds (page 27)

On the CD-ROM there is a video, *The vibrating larynx*, which shows an endoscope being introduced through the nose, and the movement of the vocal folds as the person speaks. After watching this video, students can answer questions about it, and can investigate the vibrations in their own larynx.

Also available on the CD-ROM is a very short video, *Vocal tract in motion*, with a lateral X-ray view showing the remarkable motion of tongue, jaw and lips as a person speaks. Students could watch this and do a related activity about hissy speech sounds called ‘fricatives’. Example fricatives are the sounds at the beginning of the words ‘shin’ and ‘sin’.

We create fricative sounds by making a partial obstruction in the mouth, then blowing air through it. As the air rushes through the small gap, it makes the hissy sound. Different fricatives are made by changing the place where the obstruction is made. In this exercise, students look at schematic diagrams of the vocal tract, and identify which fricative sound is being produced.
### See Extension X1
More about fricatives (page 32)

Some fricatives used by Scots and Welsh speakers can be explored as an extension activity. Example fricatives used in German and in Arabic are also mentioned and, if there are native speakers of a language other than English in your class, they could be invited to give additional examples of fricatives.

Students can make physical models of the larynx and vocal tract which, used together, produce the vowel sounds “ah”, “ih” and “oo”. Although it makes for a slightly noisy classroom, students in the trial schools really enjoyed doing this. The results are surprisingly effective. The transformation from buzzing to vowel sounds is almost magical.

First they need to assemble a ‘buzzing reed’, which models vocal folds in the larynx. If they do this, you will need a disinfectant solution on hand so that more than one student can use the same buzzing reed. You may also want to experiment with thinner and thicker reeds. Thin reeds are easy to blow but produce quiet sounds. Thicker reeds can be quite hard to blow and resemble loud duck calls.

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### See Activity A5
A buzzing reed (page 28)

Students assemble a buzzing reed, which models vocal folds in the larynx.

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### See Activity A6
Vowel resonators (page 29)

Models typically exhibit similarities and differences with the phenomenon they explain. A simple reed and vocal folds are similar in that both vibrate when there is an air-flow across them. They differ in that a reed vibrates at a single pitch whereas the vocal folds can be stretched or relaxed to alter their pitch.

Different ‘vowel resonators’ can be assembled from simple tubular components to model the vocal tract shaped for different vowel sounds. Using the buzzing reed with the resonator tubes, students can make the vowel sounds “ah”, “ih” and “oo”.

The activity sheet gives cross-sectional images of the vocal tract shaped for each vowel sound, so that students can relate these to the shapes of each of the models. They can also be encouraged to associate each cross-sectional image with their own vocalisation of the vowel.
FOSSILS AND THE EVOLUTION OF SPEECH

Over millions of years, humans evolved several unique abilities that make us very different from other animals. One of the defining characteristics of the human species is the ability to communicate using language – that is, the ability to talk. This ability arises from a combination of physical changes and developments in the brain.

Throughout history people have speculated about when and how language emerged among our ancestors. The CD-ROM contains an annotated timeline showing this in detail. Darwin, for example, observed that language is learned behaviour and yet baby babbling suggests an innate human tendency to speak.

The ability to communicate effectively was a critical development which improved humans’ chances of survival. Yet working out when and how language evolved is still a major unsolved problem. In fact for a long time scientists more or less gave up trying, because the fossil evidence was so sparse as to make any speculations untestable.
It is currently estimated that six to nine million years ago, human ancestors split from the ancestors of the modern chimpanzee, our closest living primate relative. Since that split, new features of anatomy and behaviour have evolved that now define humans as a unique species, *Homo sapiens*. These distinctive features include walking upright, large brains, and a specialised diet. The evolution of each of these features can be timed from their appearance in the fossil record.
Many scientists believe that even if chimpanzees had sufficient mental ability, their vocal tracts are not configured to enable them to produce speech-like sounds. Their tongues lie flat in front of a high larynx, which means they cannot control the tongue muscles to constrict different segments of their vocal tracts independently (as is needed to produce vowel resonances).

Humans have a rounded tongue profile and a lowered larynx. We can move the inner part of our tongues forward and back to constrict or expand the pharynx, or back cavity, of our vocal tract independently of what is going on in the oral cavity itself. This enables us to produce the full range of speech sounds. A major challenge for scientists is to work out when this change evolved in the hominin line, using fossil evidence.

Scientists are still trying to work out if Neanderthals, our nearest extinct relatives, had language abilities similar to humans. Neanderthals only disappeared about 30 000 years ago, in evolutionary terms very recently indeed. If Neanderthals did not have an ability to talk, then neither did earlier hominins.

**Classroom activities**

The human voice is an intriguing context to use when introducing evolution by natural selection and the big story of human evolution. Trying to find out how human language emerged provides an excellent illustration of how science works. What can scientists learn from fossilised skeletons? What limits are there to scientific understanding of the evolution of human speech? Is the question ‘could Neanderthals talk?’ answerable?

Two interactive ICT drag-and-drop exercises are available on the CD-ROM:

- **Comparing chimp and human skulls** – involves labelling in more detail the key features of related living species.
- **Chimpanzees, humans and human ancestors** – involves attaching three descriptive labels which draw attention to key features of the three different hominins.

Students can find further information to help them answer the questions in these drag-and-drop exercises by reading Resource R2 Studying human ancestors (page 40).
Scientists now use the term ‘hominins’ to refer exclusively to humans and to those of our extinct ancestors who lived after the split from the ancestral line leading to chimpanzees. In the days before genetics had shown how closely related we are to chimpanzees, we used to call that human group the ‘hominids’ (the ‘id’ ending indicating that the taxonomic unit is the ‘family’ – which is why we used to speak of ‘the family of man’). The great apes were all grouped into a sister taxon, the ‘pongids’ (named after Pongo, the orangutan), because it was thought that they were all much more similar to each other than any of them is to us – and that they must have had a common ancestor dating from after the split of their line from ours.

We now know from genetic evidence that this categorisation was wrong, and that it is therefore misleading to represent humans as a family-level branch separate from those containing the other great apes. The ‘hominin’ ending of ‘in’ denotes a much lower-level classification of our own distinctive evolutionary branch.
Having introduced Voicebox through activities that focus on making sounds, many schools will wish to return to Voicebox during Key Stage 4, to bring alive discussion of evolution by natural selection.

Alternatively, at Key Stage 3 you could restrict discussion of evolution to the selective breeding of dogs, which has resulted in very obvious differences in dog features, including size. Students may already have explored the relationship between size and growling sound (see the section Animal sounds on page 5).
STUDENT ACTIVITIES

VOICEBOX
Teachers’ notes

The student materials consist of a series of practical activities related to the human larynx and vocal tract, intended for use at KS3 and KS4. The key ideas are concerned with:

- how the human voicebox works
- ways of analysing sounds
- human evolution and what we can know about the evolution of human speech (how science works).

Trials show that young people find the human voice intrinsically interesting and are generally keen to understand it better. The human voice therefore provides a very motivating context for learning some science and learning about how science works. To help teachers, the Background science section of this booklet (see page 45) contains answers to a wide range of questions that students might ask.

Two packs of practical resources have been produced to support the work in this publication and are available from Middlesex University Teaching Resources (MUTR). The ‘Buzzing reed kit’ contains parts from which students assemble a working model of the larynx. The ‘Vowel resonator kit’ contains parts from which students can assemble working models of the vocal tract, shaped to produce three vowel sounds.

An overview of the activities

The activities are:

- Activity A1 Animal sounds
- Activity A2 Making your voice
- Activity A3 The larynx
- Activity A4 Making different speech sounds
- Activity A5 A buzzing reed
- Activity A6 Vowel resonators
- Activity A7 Interpreting skulls

There are three extension activities:

- Extension X1 More about fricatives
- Extension X2 Using FaroSon software
- Extension X3 Using the Vocal tract simulator

In addition, there are two resource sheets that provide additional information:

- Resource R1 Body size and vocal pitch
- Resource R2 Studying human ancestors

Ways of using the resources

The resources can be used in many different ways. Possibilities include whole class activities and circus activities for students in small groups. Trial schools tended to prefer whole class activities.

The subject matter is truly cross-curricular: though understanding the human voicebox chiefly involves biology and physics, it is directly relevant to language teaching and voice coaching. Staffroom discussion with colleagues in other departments could lead to complementary teaching and learning activities that really motivate learning.
Notes on the activities

Activity A1: Animal sounds

Students describe the general relationship between animal size and vocalisation pitch, completing two computer drag-and-drop interactive exercises and viewing a short video.

LEARNING OBJECTIVES

Students will:

• generalise from two examples to state that bigger animals produce lower pitched vocalisations (calls), or smaller animals produce higher pitched vocalisations (calls)
• explain the relationship by relating an animal’s size to the size of its vocal tract.

NOTES

You might begin (or end) by having students listen to a range of animal calls – there are some good libraries of sound clips on the Internet. Search for them using ‘animal sounds’ as key words.

See the related Resource R1 Body size and vocal pitch (page 36), which discusses exceptions to the general relationship between body size and vocal pitch. This resource sheet is designed for use with very able, possibly older students. Students reading it need to understand concepts of pitch, data trends and outliers.

Useful websites are listed in the References and further reading section on page 49.

ANSWERS TO KEY QUESTIONS

2. Growling is typically a warning and a threat – and a means of establishing dominance (who is ‘top dog’). So it pays for a dog to be able to sound big when it growls.

9. The size of an animal is reflected in the size of its vocal tract, and this affects the sounds that come out. Larger animals tend to make lower-pitched and louder calls.

10. During mating calls, the male red deer lowers its larynx down its neck to make the vocal tract longer, to make a deeper or more ‘bassy’ sound. You can read more about this in Voicebox in the classroom (page 5).

11. For many animal species – and especially for the males - body size is an indicator of fighting ability, and also a measure of desirability as a mate.

RESOURCES NEEDED

Each group will need:

• Access to a computer running two drag-and-drop interactives, Which dog is growling? and Which person is speaking?, plus the video Sounding big – the red deer way. (They can be found on the CD-ROM included with this booklet, or can be viewed at www.ucl.ac.uk/voicebox.)

Activity A2: Making your voice

Students are introduced to vocal folds in the larynx.

LEARNING OBJECTIVES

Students will:

• feel their throat while speaking and then think about how their voice works
• find out about vocal folds, what they look like and how they vibrate.

NOTES

Follow this activity with the video The vibrating larynx. This film is quite medical; some students may even comment that it is gynecological. Do preview the video and consider in advance how you might deal with student comments.

Voicebox in the classroom (page 8) contains useful diagrams and explains how the larynx and vocal tract together can produce such a variety of speech sounds.

If the school has a model of the larynx, showing it after they have completed this Activity will help students to understand the anatomy of the larynx. Suppliers of anatomical models are listed on page 49.

A possible demonstration to illustrate how a fold (like the vocal fold) will vibrate when air is blown over it: Blow up a balloon, then make its opening vibrate by letting the air out whilst flattening the hole by stretching it sideways.

Useful websites are listed in the References and further reading section on page 49.

RESOURCES NEEDED

• Access to a computer with the video The vibrating larynx. (It can be found on the CD-ROM included with this booklet, or can be viewed at www.ucl.ac.uk/voicebox.)
Activity A3: The larynx

Students find out more about the larynx by watching a video and investigating the vibrations in their own larynx.

LEARNING OBJECTIVES

Students will:
• find out how the larynx relates to breathing
• distinguish sounds made by the larynx from sounds made elsewhere in the vocal tract.

NOTES

This activity is designed to follow the video The vibrating larynx, which shows how an endoscope is introduced through the nose, and then films the movement of the vocal folds when speaking. It also leads nicely into Activity A4 Making different speech sounds.

Voicebox in the classroom (page 8) contains useful diagrams and explains how the larynx and vocal tract together can produce such a variety of speech sounds.

ANSWERS TO QUESTIONS

2. Vocal folds.
4. The vocal folds are held apart when not speaking.
5. “ar” as in “farm” YES
   “n” as in “noon” YES
   “sh” as in “ship” NO
   “z” as in “zoo” YES
   “r” as in “red” YES
   “t” as in “tea” NO
   “ch” as in “chin” NO
6. Vocal folds are in greater tension for higher pitch sounds.
7. Larynx.
8. Pitch depends on size of larynx and vocal tract (see Activity A1 Animal sounds).

RESOURCES NEEDED

• Access to a computer with the video The vibrating larynx.
  (It can be found on the CD-ROM included with this booklet, or can be viewed at www.ucl.ac.uk/voicebox.)

Activity A4: Making different speech sounds

Students explore hissy speech sounds called ‘fricatives’, made by blowing air through a partial obstruction in the mouth.

LEARNING OBJECTIVES

Students will:
• find out about ‘fricative’ sounds and how humans produce consonants
• use schematic diagrams of the vocal tract to identify lip and tongue positions for particular fricatives.

NOTES

The activity may take 10 – 20 minutes, depending on how you use it. There is also a related extension activity (Extension X1 More about fricatives).

Useful websites are listed in the References and further reading section on page 49.

ANSWERS TO QUESTIONS

3.  A  “sin”
    B  “him”
    C  “thin”
    D  “shin”

RESOURCES NEEDED

Each group will need:
• Access to a computer with the video Vocal tract in motion. (It can be found on the CD-ROM included with this booklet, or can be viewed at www.ucl.ac.uk/voicebox.) This runs for just 13 seconds. (It may be useful if students are able to view this more than once.) This cross-sectional X-ray view shows how much the back of the tongue moves when a person speaks.
• OPTIONAL: plane mirror (so students can observe the positions of their tongue and lips when making each sound).
### Activity A5: A buzzing reed

Students assemble a buzzing reed which can be used with Activity A6 Vowel resonators.

**LEARNING OBJECTIVE**

Students will:
- appreciate how a vibrating reed physically models vocal folds in the larynx.

**NOTES**

**CAUTION:** If students are sharing the use of buzzing reeds, ensure good hygiene. Dip the mouthpiece in disinfectant solution between each use.

Sets of parts for the buzzing reed are obtainable from MUTR (see page 51). Decide in advance how many sets you need. Advantages of having each student make their own buzzing reed are that:
- students quite like to keep the reed once they have assembled it
- there is no sharing so you don’t have to provide a disinfectant solution
- you don’t have to dismantle the reeds between sessions.

Most students are able to make a reed that produces a satisfying buzzing sound. In trials, we found about three out four succeeded. If you are recycling the tube channels and reeds, you will need to dismantle and soak them in disinfectant solution between each use.

The activity works well when the teacher (or a helper) supervises a small group of students. The adult can both respond to students’ ideas and give practical help as they construct their reeds.

The activity could also be one station in a circus of activities, especially if students go on to Activity A6 Vowel resonators. They can take their buzzing reed with them and use it with resonator tubes to make a number of vowel sounds.

If students are already familiar with Faroson software, they could use it to see what picture their reed vibrator makes.

**RESOURCES NEEDED**

- Each student, or student group, will need:
  - Buzzing reed kit (set of pre-cut plastic channels and ‘tongue’)
  - Masking tape
  - Small lump of Plasticine (or Blutak)
  - Access to:
    - disinfectant solution
    - pre-prepared buzzing reed that works (for comparison).

### Activity A6: Vowel resonators

Using a vowel resonator kit with a buzzing reed, students make three vowel sounds.

**LEARNING OBJECTIVES**

Students will:
- appreciate how a set of tubes with different cross-sectional areas physically models the human vocal tract
- understand that changes in the shape of the vocal tract produces different vowel sounds.

**NOTES**

**CAUTION:** If students are sharing the use of buzzing reeds, ensure good hygiene. Dip the mouthpiece in disinfectant solution between each use.

Most students can construct the vowel resonators without help. We suggest that they work in pairs. Ensure that you have a sufficient number of vowel resonator kits for the class. These are obtainable from MUTR (see page 51). Alternatively the school could make its own kits, using DIY plastic tubing (diameter 40 cm) and foam insulation tube (see ‘Make your own vowel resonator’ at www.phon.ucl.ac.uk/home/mark/vowels/).

Students will need encouragement to associate each cross-sectional image with their own vocalisation of the vowel and with the resonator. You may want to go over one or two examples of this with the whole class before they start making their resonators. Extension X3 Using the Vocal tract simulator can also help them to understand how the shape of the vocal tract corresponds to different vowel sounds.

If students are already familiar with Faroson software, they could use it to see what picture each vowel resonator makes.

Brass (wind) instruments are the nearest equivalent to the human vocal tract, with the larynx behaving in a similar way to a musician’s lips. In this activity, students assemble what is equivalent to a woodwind instrument, with a vibrating reed.

**RESOURCES NEEDED**

Each group will need:
- Vowel resonator kit
- Buzzing reed (from Activity A5)
- Roll of masking tape
- Ruler.
**Activity A7: Interpreting skulls**

After an initial briefing, students use interactive drag-and-drop programs to compare chimpanzee and human skulls. They then complete a table with information about extinct hominins, chimps and humans.

<table>
<thead>
<tr>
<th>LEARNING OBJECTIVES</th>
<th>RESOURCES NEEDED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Students will:</td>
<td>Access to a computer running two drag-and-drop interactives, Comparing chimp and human skulls and Chimpanzees, humans and human ancestors. (They can be found on the CD-ROM included with this booklet, or can be viewed at <a href="http://www.ucl.ac.uk/voicebox">www.ucl.ac.uk/voicebox</a>.)</td>
</tr>
<tr>
<td>• be introduced to the concept of human evolution, with a focus on the evolution of language</td>
<td>Resource R2 Studying human ancestors.</td>
</tr>
<tr>
<td>• gain insight into how scientists study fossil remains for evidence of evolution</td>
<td></td>
</tr>
<tr>
<td>• appreciate that there are unanswered questions about the evolution of language.</td>
<td></td>
</tr>
</tbody>
</table>

**NOTES**

Human evolution is a big topic which can be controversial in some classrooms. At KS3 this activity will need careful preparation. It may be better used at KS4 after the concept of evolution by natural selection has already been introduced. It is essential that you read the reference sheet and assess whether your students could comprehend it. If not, give them an oral summary, at an appropriate level, to enable them to access the ICT activities.

Note that some of the information used in the table for the drag-and drop interactive Chimpanzees, humans and human ancestors is not explicitly included in Resource R2. You may need to help students understand that the vocal tract, apart from the hyoid bone, is made of soft tissue which is not fossilised, making direct evidence of the evolution of the human vocal tract impossible. Useful websites are listed in the References and further reading section on page 49.

**RESOURCES NEEDED**

Each group will need:

- Resource R2 Studying human ancestors.

**Notes on the extension activities**

**Extension X1: More about fricatives**

This activity introduces one fricative used by speakers of Scottish English and another used by Welsh speakers. Example fricatives used in German and in Arabic are also mentioned.

<table>
<thead>
<tr>
<th>LEARNING OBJECTIVE</th>
<th>RESOURCES NEEDED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Students will:</td>
<td>Plane mirror.</td>
</tr>
<tr>
<td>• learn to use fricatives from languages and/or accents other than standard English.</td>
<td></td>
</tr>
</tbody>
</table>

**NOTES**

The extension text is suitable only for able students with a good command of written English. If you have a native speaker of a language other than English in your class, invite him or her to give one or two other examples of fricatives. This could stimulate class discussion to conclude the activity.
**Extension X2: Using FaroSon software**

Students use software which converts sounds that they make into a coloured pattern on screen representing loudness, pitch and timbre.

<table>
<thead>
<tr>
<th>LEARNING OBJECTIVE</th>
<th>NOTES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Students will:</td>
<td>FaroSon software tries to give a psychological picture of voice sounds, in real time as sounds are being made. You cannot make measurements with this software, but it does give an impression of the content and variety of different real sounds. Students can see what their own vocalisations look like on screen, and see how the sound produced by a buzzing reed is changed by vowel resonators. You may decide to do this as a participative demonstration, in which case the Activity sheet will not be needed. As well as sounds mentioned on the Activity sheet, students could be invited to make a variety of other (classroom acceptable) vocalisations which interest them, or to play a musical instrument. The horizontal axis represents time, while the other attributes of the picture are related to subjective senses of loudness, pitch and timbre. These, incidentally, are terms which musicians use to describe sounds.</td>
</tr>
<tr>
<td>• develop an understanding of key concepts describing sounds: loudness, pitch and timbre.</td>
<td>• Timbre of a sound is indicated by the colours themselves: sounds with predominantly bass character have a red colour, while sounds with a predominantly treble character have a blue colour. The picture is most effective when the display is adjusted to full screen width but only about ¼ of screen height. FaroSon software was developed by Mark Huckvale, University College London. Further information is available at <a href="http://www.phon.ucl.ac.uk/resource/faroson/">www.phon.ucl.ac.uk/resource/faroson/</a></td>
</tr>
</tbody>
</table>

**NOTES**

FaroSon software tries to give a psychological picture of voice sounds, in real time as sounds are being made. You cannot make measurements with this software, but it does give an impression of the content and variety of different real sounds. Students can see what their own vocalisations look like on screen, and see how the sound produced by a buzzing reed is changed by vowel resonators. You may decide to do this as a participative demonstration, in which case the Activity sheet will not be needed. As well as sounds mentioned on the Activity sheet, students could be invited to make a variety of other (classroom acceptable) vocalisations which interest them, or to play a musical instrument. The horizontal axis represents time, while the other attributes of the picture are related to subjective senses of loudness, pitch and timbre. These, incidentally, are terms which musicians use to describe sounds.

- **Loudness** of a sound is indicated by the brightness and saturation of the colours you see on screen.
- **Pitch** of a sound is indicated by the horizontal banding patterns: when the pitch of the sound is low, then the bands are large and far apart, and when it is high, the bands are narrow and close together. If the pitch of the sound is falling you see the bands diverge; when it is rising, you see the bands converge.

**RESOURCES NEEDED**

- Access to a computer with FaroSon software installed, plus microphone input
- Data projector and screen (optional).

**Extension X3: Using the Vocal tract simulator**

Using software, students can select from six vowel sounds and see how the shape of the vocal tract changes (for a male, female or child) when making each sound.

<table>
<thead>
<tr>
<th>LEARNING OBJECTIVE</th>
<th>ANSWERS TO QUESTIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Students will:</td>
<td>5. Students may notice the following:</td>
</tr>
<tr>
<td>• relate speech to changes in the shape of the vocal tract.</td>
<td>• each vowel sound is associated with a particular shape of the vocal tract, involving movements of the tongue, jaw and lips</td>
</tr>
</tbody>
</table>

**NOTES**

The Vocal tract simulator (VTDemo) is an interactive Windows PC program for demonstrating how the quality of different speech sounds can be explained by changes in the shape of the vocal tract. You can move the articulators in a 2D simulation of the vocal tract cavity and hear in real-time the consequences on the sound produced. You may decide to do this as a participative demonstration, in which case the activity sheet will not be needed.

You may also want to try other displays e.g. the spectral analysis for each vowel. Further information is available at www.phon.ucl.ac.uk/resource/vtdemo/resources.

**RESOURCES NEEDED**

- Access to a computer with Vocal tract simulator software installed, with audible output
- Data projector and screen (optional).
In this activity you will look for a general relationship between the size of an animal and the pitch of sounds which the animal makes.

**Task A  Growling dogs**
1. Open the drag-and-drop interactive called *Which dog is growling?*
2. What message is a dog sending when it growls?
3. Listen to each of the growling sounds. Drag and drop the correct picture of a dog breed to match each growling sound.
4. Check your answers by clicking on the ✅ icon.

**Task B  People speaking**
5. Open the drag-and-drop interactive called *Which person is speaking?* Listen to each of the sound recordings.
6. Drag and drop the correct picture of a person to match each recording.
7. Check your answers by clicking on the ✅ icon.

**Task C  Describing the pattern**
8. In general, how does body size affect the pitch of sounds that an animal makes?
9. Explain this relationship in terms of the size of an animal’s vocal tract.

**Task D  Competing for mates**
10. Watch the video *Sounding big – the red deer way*. What happens to the position of the male red deer’s larynx as it makes its mating call?
11. In general, what advantages might loud, and more ‘bassy’, low pitched sounds give an animal?
When you say something out loud, the sound is different from when you whisper exactly the same words. In this activity, you will find out how you make your own voice.

Task A  What do you feel?
1. Place one hand lightly on your throat and count to five. What do you feel?
2. Try whispering. Again count to five. Do you feel anything now? When you talk and whisper, the sound is different. But you can still count to five.
3. Think about your throat, tongue and lips when you talk and whisper. Describe what is:
   a) the same?
   b) different?

Task B  Trying to explain
4. Talk to another student and discuss the following three questions before answering them. Write down any other questions that come up during the discussion.
   a) How do you think you make a sound?
   b) What is happening in your throat?
   c) People often talk about ‘vocal cords’. Scientists say ‘vocal folds’. Make a rough sketch of what you think your vocal folds look like.
In this activity, you will watch a video to find out about vibrations in the larynx, and see how these vibrations are related to the different sounds you can make with your own voice.

**Task A  Watching the video**

1. Watch the video *The vibrating larynx*.
2. What is vibrating in the larynx when we speak?
3. Normally, do we speak when breathing in or breathing out?
4. Why doesn’t the larynx make a noise all the time we are breathing?

**Task B  Try this**

5. Find your Adam’s apple, and make a humming noise; “mmmmmmmm”. You should be able to feel something vibrating in your neck.

   Now with your fingers on your Adam’s apple try a hissing sound: “sssssssss”. You should feel that there is no vibration for this sound.

6. For each of the sounds shown in the table, indicate whether there is vibration in the larynx.

7. Make an “ar” sound on the lowest pitch you can. Now make it on the highest pitch you can. What do you do to your vocal folds to change the pitch of the sound?

8. When people get a bad cold they sometimes ‘lose their voice’. What do you think is not working properly for these people?

9. Do you think other animals such as a cat or a dog or a cow or a horse have a larynx? Why do you think that these animals make sounds which are lower, higher or similar in pitch to people?

<table>
<thead>
<tr>
<th>Sound</th>
<th>Is there vibration in the larynx? (Yes / No)</th>
</tr>
</thead>
<tbody>
<tr>
<td>“ar” as in “farm”</td>
<td></td>
</tr>
<tr>
<td>“n” as in “noon”</td>
<td></td>
</tr>
<tr>
<td>“sh” as in “ship”</td>
<td></td>
</tr>
<tr>
<td>“z” as in “zoo”</td>
<td></td>
</tr>
<tr>
<td>“r” as in “red”</td>
<td></td>
</tr>
<tr>
<td>“t” as in “tea”</td>
<td></td>
</tr>
<tr>
<td>“ch” as in “chin”</td>
<td></td>
</tr>
</tbody>
</table>
You are going to closely observe where you place your tongue and lips to make some hissy speech sounds, called ‘fricatives’.

Task A  Observing a vocal tract in motion

1. Watch the video *Vocal tract in motion* showing what happens as a person speaks. Notice how the tongue and lips move to make all the different sounds.

Task B  Making fricative sounds

2. Look at the diagram on the right. It shows how you make the “f” sound in “fin”. Say the word “fin”. Notice how you draw your lower lip back and close your mouth so that the lip gently touches the underside of the upper teeth; then blow gently.

3. Try each of the other sounds below. Draw a line to match the fricative sound at the start of each word to the diagram which shows how it is made.

“him” “shin” “sin” “thin”
In this activity you will assemble a simple reed that vibrates when you blow across it. It behaves just like vocal folds in the larynx, making a buzzing sound.

**Task A Assembling the reed**

1. Collect two pieces of pre-cut channel, some masking tape and a piece of flat plastic (a ‘reed’) to fit between the two channels.

2. Place a small lump of Plasticine in the square end of one of the channels, ensuring that it will block off air-flow through this channel.

3. Sandwich the plastic reed between the two channels, as shown in the diagram, ensuring that the last 2 cm is free to move within the curved end.

4. Use masking tape to hold the three pieces together as shown.

**Task B Testing the reed**

5. Blow into the curved end, where the reed is visible. You should be able to get a buzzing sound. (How hard you need to blow will depend on the thickness of the reed. With a thin reed, blow softly. With a thick reed, blow hard.)

It is perfectly safe for someone else to try blowing the same buzzing reed, provided you first rinse it thoroughly in a disinfectant solution.
Task A  An “ah” resonator
This resonator produces a sound like the long “ah” vowel that you find in words like “palm”.

1. Select a 9 cm length of foam sleeve and an 8 cm length of plastic pipe. Fix them together as shown in the diagram, using masking tape. Notice how the internal shape of the vowel resonator resembles the shape of the vocal tract in the MRI image of a person saying “ah”.

2. Place a buzzing reed in the larynx end of the resonator and blow the reed. This should make an “ah” sound.

3. Make an “ah” sound yourself. While doing this, try and compare the shape of your vocal tract with the “ah” diagram and MRI image.

The foam sleeve (A) models the narrow shape of the vocal tract from the larynx to the back of the mouth.

The plastic pipe (B) models the open mouth.

It is perfectly safe for someone else to try blowing the same buzzing reed, provided you first rinse it thoroughly in a disinfectant solution.
Task B  An “ih” resonator
This resonator produces a sound like the short “ih” sound that you find in words like “bit”.

4. Select 3 cm and 7 cm lengths of foam sleeve, and a 6 cm length of pipe. Fix them together as shown in the diagram, using masking tape.

5. Place a buzzing reed in the larynx end of the resonator and blow the reed. This should make an “ih” sound.

6. Make an “ih” sound yourself. While doing this, try and compare the shape of your vocal tract with the diagram of the resonator and the MRI image.

Task C  An “oo” resonator

7. Select a 2 cm length and two 3 cm of lengths of sleeve, and two 5 cm lengths of pipe. Fix them together as shown in the diagram, using masking tape.

8. Place a buzzing reed in the larynx end of the resonator and blow the reed. This should make an “oo” sound.

9. Make an “oo” sound yourself. While doing this, try and compare the shape of your vocal tract with the diagram of the resonator and the MRI image.

The vowel resonator models the shape of the mouth as shown in the diagram:
A - the narrow shape of the vocal tract above the larynx.
B - the wide cavity behind the tongue.
C - the cavity above the front of the tongue.

The vowel resonator models the shape of the mouth as shown in the diagram:
A - the narrow part of the vocal tract above the larynx.
B - the cavity behind the tongue.
C - the narrowing above the tongue hump at the back of the mouth.
D - the larger cavity above the front of the tongue.
E - the narrowing at the lips.
Humans are unique among all animals for the ability to communicate by talking. Understanding how the human capacity for language evolved is a major scientific challenge.

This activity will help you understand what scientists can find out by studying the fossil remains of living and ancestor species.

Task A  Read all about it
1. Read Resource R2 Studying human ancestors.

Task B  Compare chimp and human skulls
2. Open the drag-and-drop interactive Comparing chimp and human skulls.
3. Drag and drop labels to describe key features of the two skulls.
4. Check your results by clicking on the ✓ icon below the table.

Task C  Compare hominins with living species
5. Open the drag-and-drop interactive Chimpanzees, humans and human ancestors.
6. Use information from the resource sheet to help you complete the table. Drag and drop information from the right-hand side into the correct places in the table.
7. Check your results by clicking on the ✓ icon below the table.
VOICEBOX: MORE ABOUT FRICATIVES

Speakers of languages and accents other than standard English use additional fricatives. In this activity you will learn to use some new fricatives.

Task A  The Scottish word “loch”
The Scottish word “loch” is not the same as “lock”. In fact it ends with a fricative that is made at the same place where you make the “k” sound.

1. Say “lock” and feel where the tongue touches the roof of the mouth. Then weaken the strength of the “k” so it isn’t pressed so hard against the roof of the mouth – it will leave a small gap that masks the new fricative sound.

2. Practise “lock” and “loch” until your neighbour recognises them as different.

Task B  Welsh place names
Speakers of Welsh use yet another fricative – one that does not appear in English at all. It’s the fricative that you find in Welsh place names starting with a “ll”, like “Llangollen”. Here’s how to make it.

3. Start with the English /l/ sound where you put the tip of your tongue on the ridge behind the upper teeth, as if you were going to say “la”.

4. Look in a mirror and you will see that the tip of the tongue is touching, but that the sides of the tongue are down.

Contrast this with how you position your tongue for “da”. You should feel that for “d”, both the tip of the tongue and the sides of the tongue are up and closed.

Alternate “la” and “da” until you can feel the difference in the position of the sides of your tongue.
5. To make the Welsh sound, now position the sides of the tongue half way between the two. Make a narrow gap between the sides of the tongue and your upper teeth, so that when you blow air through it you get a hissy sound. If you do it right and say “lla”, then it will sound like a cross between “tha” and “la”.

Practise with the place names “Llanberis” and “Llangollen”. There are two of these fricatives in the second name.

Task C  Other languages

That’s not the end of the story about fricatives: other languages use other varieties not present in English.

6. Try the fricative found in the German word “ich” meaning ‘I’.

7. Try the fricative found in the Arabic word “wahid” (“wahid”) meaning ‘one’.

8. If you speak a language other than English, give an example of a fricative from that language. Carefully try and explain to the class how to make the sound.
The FaroSon software enables you to see what sounds look like on screen, and to compare different sounds. In this activity you will learn how to describe sounds using the terms loudness, pitch and timbre.

Task A  Your own voice
1. Say your name into the microphone, while watching the pattern it produces on screen. Repeat your name, more than once if necessary, to be sure that the pattern is the same each time.
2. See how the pattern changes if you speak
   • more loudly or more quietly
   • with a higher pitch or lower pitch
3. Get a neighbour to say your name. Is the pattern the same as when you say it?
4. Describe in general how the pattern on the screen relates to the sound of your name.

Task B  Buzzing reed
5. Blow through a buzzing reed to see the pattern produced by its sound.

Task C  Vowel resonators
6. Look at the pattern produced by different vowel resonators (making sounds “ah”, “ih” and “oo”).
**VOICEBOX:**
**USING THE VOCAL TRACT SIMULATOR**

This activity uses the Vocal tract simulator computer program, which shows how the quality of different speech sounds relates to the shape of the vocal tract.

**Task A Exploring vowels**
1. Open the program. From the ‘Articulate’ menu, select one of the six vowels listed. It will show the shape of the vocal tract while making the sound.
2. Repeat step 1 with each of the other vowels.

**Task B Changing gender and age**
3. The default setting of the program gives the voice of an adult male. Use the ‘Synth’ menu on the toolbar to change the setting to ‘Female’. Notice that the vocal tract immediately gets a little smaller. Repeat the vowels.
4. Again use the ‘Synth’ menu, this time to change the setting to ‘Child’. Notice that the vocal tract gets much smaller. Repeat the vowels once more.

**Task C Summing up**
5. Describe what you have learned about the vocal tract from these activities.
A general relationship between body size and vocal pitch

The length, mass and tension of the vocal folds determine the frequency at which they vibrate. Larger vocal folds can vibrate at lower frequencies, and thus produce lower-pitched calls.

This means that the biggest animals tend to be the ones that produce the lowest-pitched calls. All species of elephants can produce (and hear) infrasound signals such as ‘rumbles’ (5-30 Hertz), which may propagate over distances of 10 kilometres or more (infrasound is beyond human hearing; humans cannot hear sounds at frequencies below about 20 Hertz). Large baleen whales (fin and blue) can also produce infrasound vocalizations (10-40 Hertz) that can propagate across an ocean, and although the mechanism is poorly understood it may involve vocal fold emissions similar to those in terrestrial mammals.

The smallest animals tend also to be those producing the highest-pitched calls. Most mammals can hear sounds in the higher part of the frequency range audible to humans (i.e. above 10 kHz) and these sounds are inaudible to the larger birds and reptiles. When small mammals were first evolving, and birds and reptiles were their main predators, this may have given them the advantage of a ‘private’ communication channel. Figure 1 shows the relationship between the dominant frequencies used in vocalizations by a large range of land-based mammals, and their body sizes.

![Figure 1: The frequency ranges of the emphasized frequencies of vocalization in a large range of land-dwelling animals, plotted as a function of the mass of the animal. Note that both axes are logarithmic. From N.H. Fletcher (2005) ‘Acoustic systems in biology: from insects to elephants’, Acoustics Australia 33[3]:83-88.](image-url)
Figure 2 shows the relationship between pitch and body size across 19 kinds (genera) of monkeys and apes (the raw data are given in Table 1 - see the appendix of this resource). The graph plots the mean pitch or dominant frequency of calls against the typical adult body mass for that species. It is clear from both graphs that the larger-bodied animals tend to produce the lower-pitched calls, reflecting the greater size of their voiceboxes.

Humans can hear sounds at frequencies up to about 20,000 Hertz (20 kHz), and frequencies above that are classed as ultrasound. A number of small mammals have evolved the ability to emit calls in the ultrasound range. For instance rat pups, which can also vocalize in the upper part of the human-audible range using normal vibrations of their vocal folds, can emit ultrasound calls (30 – 50 kHz) by expiring a high-pressure air stream over constricted vocal folds – this produces a kind of ‘whistle’ sound, although the vocal folds are not vibrating in the normal fashion. Bats use ultrasonic vocal emissions (25 – 100+ kHz) in a much more specialised way to echo-locate, with a specialised vocal membrane that extends above the vocal folds.
Exceptions to the general relationship
Body size is not the only factor that determines the size of the larynx and vocal tract. Many animals have evolved the ability to communicate at frequencies that are in some way optimal for the environment in which they live (one instance, just noted, is the ability of most mammals to communicate in a frequency range inaudible to the modern descendants of what would have been their main predators at an earlier stage of mammalian evolution).

Additionally, many animals have evolved the ability to sound bigger than they really are, by emitting calls that are either lower pitched or have a deeper timbre (the latter reflecting the size of their vocal tracts above the vocal folds). This sends a warning message to potential competitors, since body size would be expected to correlate with fighting ability.

Howler monkeys, for instance, have a greatly enlarged larynx which makes their vocalizations much louder and more resonant, and their long calls are also low-pitched for their body size (dominant frequency typically 300 – 400 Hertz). This is low compared with the spider monkey, a similarly-sized New World monkey with a more representative call pattern for its body size, and whose long calls typically have a dominant frequency of about 700 Hertz. The howler monkey is capable of making extremely loud long calls, which can be heard from as much as three miles away.

A lower resonant frequency seems to be a particularly effective way of signalling body size. In competitive interactions among members of the same species of mammal this seems to be taken as a pretty good cue to fighting ability. This fact is also exploited by some animals which can dynamically extend their vocal tracts by dropping their larynx far down into the neck (it is attached by elastic ligaments) to make their loud calls resonate at lower frequencies (and thus make them sound more intimidating!). Male red deer are a good example of this.

By contrast, horses use relatively high frequency sounds: they advertise dominance visually by making themselves look big (ears up, prancing gait, tail up and out), but vocalize using high-pitched squeals and whinnies even when competing. Perhaps this is an adaptation to avoid attracting predators (since high frequency calls travel less far in open environments).
Appendix: call pitch and body size in a range of monkeys and apes

<table>
<thead>
<tr>
<th>Primate genus name</th>
<th>Common name</th>
<th>Group</th>
<th>Low (Hz)</th>
<th>High (Hz)</th>
<th>Midpoint (Hz)</th>
<th>Weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aotus</td>
<td>Night or Owl monkey</td>
<td>New World monkey</td>
<td>190</td>
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Over millions of years, humans have evolved several unique abilities that make us different from other animals. One of these is the ability to communicate using language - that is, the ability to talk. One question scientists would like to solve is, ‘when did our ancestors first learn to speak?’

Scientists try to answer these kinds of questions by looking at fossilised skeletons. Fossils are bones that have been preserved in the ground, often hardened by exchanging minerals with the surrounding rock and soil. To understand how scientists can reconstruct behaviour from the skeleton, consider locomotion. Humans walk upright, and this frees our hands for using tools. Other living primates are adapted for life in trees, or for moving across the ground on all fours.

**Chimpanzees and humans compared**

Chimpanzees have excellent climbing ability and typically move around on the ground on all fours, bearing the weight of their upper body on the knuckles of their hands. This is called ‘knuckle-walking’. Their arms are a similar size to their legs, their hips are quite narrow, and the bones at the lower end of their spines are quite light. The spinal cord enters their skulls quite far back in the skull base, because they need to look around while moving on all fours.
Humans are bipedal, which means we walk upright. Our legs are much longer and heavier than our arms, giving us a longer stride and keeping our centre of gravity low. Our hips are wider, allowing more efficient walking. Vertebrae of the lower spine are broad and thick and so can support heavy loads in an upright posture. The spinal cord enters our skulls at a point further forward on the skull base, because we need to look ahead while we walk.

Locomotion is only one part of the human story. Human brains have also evolved to be unusually large, about three times the size of a chimpanzee's brain, for instance. This must be one of the reasons why we are so much more versatile in our behaviour and our social communication. Our brain enables us to plan what we want to say, and understand what others say to us. But size alone isn't everything. Humans also have brains that are wired up in slightly different ways to other animals. This may affect how we process information, store it in our memory, and make plans for the future.
Looking at fossils

Now let’s look at the fossils of some of our ancestors, all called hominins. Three of the most important species known from fossils are Australopithecus afarensis, Homo ergaster, and Homo neanderthalensis (Neanderthals).

The name Australopithecus afarensis means ‘southern ape from Afar’. Afar is the region of modern Ethiopia where this species was first recognized, although it belongs to a larger set or ‘genus’ the first skeleton of which was discovered in South Africa. This species, our ancestor from about 3 million years ago, could already walk much as we do today. We can tell this from the shapes of the bones. But they don’t seem to have made stone tools. Their brain was about the same size as a chimpanzee’s brain. Scientists can tell the size of our ancestors’ brains by measuring the volume of their skulls. They think that A. afarensis probably used its voice to communicate in a similar way to modern chimpanzees.
Scientists named *Homo ergaster* because this ancestor species made and used large stone tools of a distinctive type. ‘Ergaster’ means ‘workman’. The species lived about one and a half million years ago, long before humans had evolved. *Homo ergaster* were also able to walk upright like us, and they had long legs like ours – something which had not yet evolved in *A. afarensis*. In many other ways they were similar to humans, but their brains were only two-thirds of the size of a typical human. Scientists do not know whether this species communicated with some very basic form of spoken language.

Neanderthals are named after the Neander valley in Germany, where the first fossils were found in 1856. Neanderthals lived in Europe and central Asia between 230,000 and 30,000 years ago. They lived mostly in the cold climates of the Ice Ages, and their body proportions were good for conserving body heat – they were short and stocky. Of all our extinct ancestors, this species was the most like us. They walked like us and had a slightly larger brain. Their faces looked a bit different, though. They had a more protruding jaw and no chin.

Scientists are still trying to work out if Neanderthals were able to speak like humans. Neanderthals only disappeared about 30,000 years ago, very recently indeed in evolutionary terms. If they couldn’t talk like us, then neither could earlier hominins.
We need to know more about Neanderthals’ voice boxes and their tongues – were their vocal tracts the same shapes as ours? For instance, the main vowels require the tongue to move to produce a narrowing or constriction of parts of the vocal tract. Is there something unique about the shape of the human tongue and the way it sits in the oral cavity that helps us to do this? Could Neanderthals move their tongues as quickly as we can and in the same ways, to make all the different sounds we make when talking?

The tongue is made from soft tissue which does not survive in the fossil record, but it has a small and fragile bone at its root, called the hyoid bone, which does fossilise. *Australopithecus afarensis* had a hyoid bone shaped like a chimpanzee’s. The Neanderthals had hyoid bones similar to ours, and very different to chimpanzees. This suggests that their tongues were also just like ours. But Neanderthals had longer mouth cavities than humans. Scientists are still not sure whether that would have affected their ability to produce speech sounds.
BACKGROUND SCIENCE

This section, which takes the form of answers to questions that students might ask, gives further information about a wide range of matters related to the human voice.

**What happens when you ‘lose your voice’?**
The source of sound for vowels and some consonants is generated in the larynx. The larynx is a kind of valve that sits at the top of the trachea (windpipe) and at the bottom of the pharynx. (The pharynx is the part of the throat behind the mouth and nasal cavity). For the larynx to make a sound, we close the vocal folds in the larynx across the windpipe and, by increasing air pressure from the lungs, force air through them. This makes them vibrate, like blowing between your lips to ‘blow a raspberry’.

If you have an infection, this can cause the vocal folds to become inflamed and swollen. Also the mucus that covers and protects the folds can become thick and sticky. The heavier, stickier folds do not vibrate as well as normal folds, and on occasion do not vibrate at all.

**What happens when boys’ voices break?**
Between 12 and 16 years of age, boys’ bodies change in a number of ways: they grow in size, increase in musculature, develop bodily hair and their voices deepen in pitch. These developments are due to changes in the levels of chemicals called hormones in the body.

The change in voice pitch is caused by a growth in size of the larynx – in some boys this development can be seen as an increase in visibility of the ‘Adam’s apple’ – this is just the projection of the front of the larynx through the skin of the neck.

Since the larynx is changing size at puberty, it becomes harder to control. The muscle settings which the boy learned as a child, to achieve a particular pitch, no longer work. While the boy is learning to control the larger larynx, he makes mistakes in choosing the muscle settings. This can lead to inappropriate jumps in pitch as he works to correct errors.

**Why are girls’ voices different from boys’ voices?**
Actually boys’ and girls’ voices are very similar before puberty. It is hard to identify the sex of a child from their voice alone until around 8-10 years of age. At puberty, developmental changes in the bodies of boys and girls affect the size of the larynx and the length and thickness of the vocal folds. Although these changes are more pronounced in boys, girls’ voices change too. However, in addition to these biological changes to their bodies, boys and girls also develop socially. Boys and girls behave differently in different social situations and this inevitably affects how they use language to achieve desired goals. This in turn can impact on how they speak.

**Why do some people have husky voices?**
There are predominantly two dimensions of voice quality: one relating to the amount of ‘breathiness’ in the voice, and one relating to the amount of ‘creakiness’ in the voice.

Breathiness is predominantly affected by how much air leaks through the vocal folds while they are vibrating and producing voice. Creakiness is predominantly affected by muscle tension in and around the larynx, particularly within the vocal folds themselves. Lack of tension can lead to a low-pitched rough voice that makes someone sound as though they are very relaxed.

A husky voice is probably a voice that is both breathy and creaky, i.e. it has poor muscular tension in combination with poor vocal fold contact leading to the escape of a lot of air. A husky voice can be caused by damaged vocal folds, for example if you have been shouting a lot, although it does not always signify a pathology.
Is everyone’s voice different? Can voice recognition be used in security systems?
Aspects of our individuality are present everywhere in speech: in our voice pitch and voice quality, in our accent, our preferences for words or phrases, and in our preferences for topics of conversation. At the biological level we all have similar vocal tracts and larynxes, so the differences here are mostly related to physical size. People with smaller larynxes tend to have higher-pitched voices, while those with larger larynxes tend to have low-pitched voices. In addition, tall people have ‘darker’ sounding speech, while short people tend to have ‘brighter’ sounding speech.
Automatic systems for identifying you from your voice ought to operate on these attributes of your voice because they do not change much. If, however you try to recognise someone from measurements of their voice quality, or vowel quality or rate of speech then the system will fail to recognise the person if they deliberately change the way they speak. Normally though, in a security application, you are wanting to be recognised, so it would not make sense to ‘put on a funny voice’!

How do infants learn to speak?
There is still much debate about how children learn how to use language to communicate through speech. It appears that newborn infants have an intrinsic interest in faces and speech-like sounds, so it is likely that straight away they are observing their mothers and fathers and how sounds are used to communicate. An ability to speak provides an infant with enormous power over its environment. Since human infants are incapable of looking after themselves, they must learn how to persuade adults to do things for them.
In the first few months of life, the infant begins to recognise the meaning of certain phrases spoken by adults. It also experiments with control of its vocal tract, to see what noises it can make. Through experimentation with its own speech, through observation of the effect of that speech on adults, and in combination with the recognition that sounds have meanings, the child learns its first few words for objects and events in its immediate environment. Significant changes occur in the language abilities of the child between 12 months and 36 months. The child learns a huge vocabulary of words and starts to be able to construct sentences of several words. This means that the child has learned how words can be combined to create a greater range of meanings than single words alone ever could. This process is still not well understood.

What produces regional and class accents in England?
Since each of us learn to speak through interactions with our family and friends, it is not surprising that we adopt some of their mannerisms. Not to do so, to model our voices on someone on the television say, would make us sound odd and as if we were trying to be different. There are social pressures on you to conform to the particular pronunciation preferences of your peers. In addition, you might deliberately avoid some pronunciations which make you sound ‘apart’ from your friends.
However people’s accents do change over time, particularly if they change where they live or if they work with people with different accents. However, some people are very proud of their accent, and work against the normal processes of adaptation.

Can you permanently change your voice/accent with practice/training? Is there an age at which this ability cuts off? Do people keep the accent they had at age 18?
You certainly can change characteristics of your voice or your accent with training. An ability to do so is probably more affected by motivation rather than age. When we are young we are probably more compliant to the pressures on us to fit in. The situation is different with foreign accents: that is when you are speaking in a language other than the first language you learned.
It appears that the first language you learn has a significant impact on how you speak second and subsequent languages, and that only children who change language before the age of about 10 can really be said to lose all the influence of their first language. Immigrants of 40 years are still recognised by the accent influence of their first language.
How do skilled language teachers help their students to speak a new language correctly?

There is no short answer to this question, but one key idea is to get the student to ‘think’ in the new language, that is to stop them using a conscious process of translation from their native language. This may be possible by immersing the student in an environment in which all communication, including the simplest aspects of greeting and having conversations are performed in the new language. Another important aspect is to make the student aware of the grammatical structure of his or her first language, so parallels can be drawn at the level of sentences rather than just words.

How do Kalahari bushmen make the clicking sounds when speaking?

A number of African languages include click sounds as part of their repertoire of consonants. Click sounds may seem exotic because their use is rare, but they function in language in the same way as ‘p’, ‘t’ or ‘k’ sounds function in English: to differentiate words.

As consonantal sounds, all clicks have a similar means of production. They key is to create a region of the vocal tract which is sealed at two places: for example the tongue blade might seal against the teeth ridge, while the back of the tongue might seal against the upper teeth and soft palate. Once two closures are made, the volume of the sealed cavity is then increased by moving the tongue. This creates a region of low pressure in the mouth. The front closure is then quickly removed, and the air flowing into the sealed region creates an impulsive sound.

Even English speakers use clicks for communication in some circumstances, though they are not part of the English language sound system. You may use the “tut-tut” sound of disapproval – that is a ‘dental click’, or the “giddy-up” sound to a horse – that is the ‘lateral click’. Blowing a kiss without pursing the lips produces a bilabial click.

Are there any languages that don’t use the larynx?

There are many ‘dead’ languages which aren’t spoken anymore, like Latin or Ancient Greek, so these don’t use a larynx! But the question is probably referring to ‘whistled languages’. These aren’t really languages at all, but a way of speaking using an ordinary spoken language known to both speaker and hearer. Instead of producing the vowels and consonants that make up recognisable words, a speaker can communicate some ideas by simply whistling the rhythm and melody of the utterances.

You can get the idea of this from a number of children’s television programmes that use puppets or characters that make noises having different tones but which are not recognisable as words. Simple distinctions of meaning are possible by whistling, particularly those related to tone.

How do people who have had their larynx removed speak?

There are three basic approaches. Since the larynx is the sound source for the majority of speech sounds, a person without a larynx can only produce a limited range of sounds (like “f”, or “s”) inadequate for producing a sufficient number of words.

One way to generate sounds is to use an ‘artificial larynx’ which is a buzzer that is applied to the outside of the neck. The sound of this buzzer passes up the throat and out the mouth in a similar way to the sound of a normal larynx. Unfortunately, it is hard to learn to control the buzzing in a natural way.

A second way is to ‘burp’ and speak over the burp sound. This is called ‘oesophageal speech and involves deliberately swallowing air and making a long burp over which you can form vowels and consonants in the mouth as normal.

A third way is to install a one-way valve from the trachea to the oesophagus (from the windpipe to the food tube) such that the person can blow air into the neck of the oesophagus. This reproduces the sound of a burp but without the need to swallow air.

One final point: removal of the larynx is disadvantageous regardless of its impact on speaking. We need the larynx to help us cough up mucus from the lungs and to stop food going down into the lungs.
What do speech therapists do?
Being able to speak is an extremely important aspect of being human. If you have problems speaking, then that can seriously impact your self-confidence, your ability to hold down a job, your ability to socialise, or your ability to get help from other people. Speech therapists work with different groups of people who may have very different types of problems. A young child might not be learning to speak correctly, a person who has gone deaf may have problems speaking clearly, a person who has had a stroke may have problems remembering words, or someone with cancer of the throat may have to learn to speak without having a larynx. By knowing about the typical problems, the speech therapist can assess an individual in terms of the nature and scale of the problem and whether they would benefit from therapy or communication aids. Speech therapists can sometimes design programmes of therapy which will improve the speech or ameliorate the problems of people with a communication disorder.

What does voice training involve, for actors and singers?
Part of voice training is about protecting the structures in the larynx used to make voice. In the theatre and in singing, it is often required to ‘project’ your voice, in other words, to create a loud sound which carries to the back of the auditorium. If you do this incorrectly, then you can damage your vocal folds, just as if you spent many hours shouting. Some training to control breathing and the larynx muscle settings can reduce the impact of producing a loud voice.

Another aspect of voice training, particularly for singers, is to create the right kind of ‘tone’ to the singing voice. Different musical singing styles expect different qualities of voice: two examples are the ‘bel canto’ voice used in opera, and the ‘belting’ voice used in popular musicals.

What are the highest and lowest notes possible for singers?
The pitch range of a Bass singer is approximately 65 Hz to 260 Hz, that is, two octaves below ‘middle C’ up to ‘middle C’. The pitch range for a soprano singer is approximately 260 Hz to 1040 Hz, that is, from ‘middle C’ to two octaves above ‘middle C’.

It is interesting to realise that the pitch of a sung note depends on the vocal folds (their frequency of vibration) whereas the timbre and quality is determined by the shape of the vocal tract; (there are analogies with strings on guitars or violins – where the pitch is determined by the string but the tonal quality by the structure, material and holes in the body).

This is most strikingly demonstrated by inhaling a gas other than air. For example, breathing helium makes speech sound very strange, but this is due to changes in the frequencies of the resonances in the vocal tract tube affecting the timbre, while larynx vibration and hence pitch is relatively unaffected.

How is the vocal tract used in ‘the human beatbox’?
People who produce this rhythmical music using only their vocal tracts employ a mixture of speech-like and other percussive sound sources. Component sounds which have a clear pitch are produced using vocal fold vibration, just as in singing. Percussive sounds can be generated by blocking off and releasing the air stream from the lungs, either with the tongue or the lips. This effect can be enhanced by placing the microphone close to the lips so that the air-flow from the mouth becomes turbulent when it hits the microphone. Hissy sounds like a snare drum can be made by blowing air through narrow constrictions made with the tongue against the walls of the mouth. The challenge is to make a variety of such sounds quickly and sequentially so as to appear as though they are being made concurrently by multiple instruments.

How do ventriloquists ‘throw’ their voice?
The key to ventriloquism is misdirection – the ventriloquist must make it appear that the sounds they are making in their own throat could have come from the puppet. They can do this by moving the mouth of the puppet while keeping their own mouth relatively still, or by looking towards the puppet while ‘it’ speaks. They can also produce a quality of voice unlike their own, which fits the size and mannerisms of the puppet. If there is an art to ventriloquism, then it is related to how to produce clear speech without moving the jaw and lips very much. For example, producing a “t” sound using the tongue tip on the upper teeth can produce a sound that is similar to “p” which is normally produced using the lips.
REFERENCES AND FURTHER READING

Websites
Additional resources can be found on the SEP website (see page 50). Links to other particularly relevant websites are also listed on the SEP website. Some examples are given below:

Voicebox (www.ucl.ac.uk/voicebox)
All of the files on the CD-ROM are downloadable from this web page, and the videos and drag-and-drop interactives can also be viewed directly online.

Mark Huckvale’s webpage (www.phon.ucl.ac.uk/home/mark/)
Mark Huckvale, one of the authors of this booklet, is a Lecturer and Researcher at University College London. His homepage has links to learning materials and software related to the science of speaking and listening. It also gives useful background information: how humans make vowel sounds and a physics explanation of the acoustics of vowel production (source-filter model).

The Internet Institute for Speech and Hearing (www.speechandhearing.net)
Designed for the lay person as well as the professional, this website has answers to some frequently asked questions about the science and technology of normal speech and hearing. It also has interactive web tutorials and practical experiments in sound, speech and hearing.

Sounds familiar? (www.bl.uk/learning/langlit/sounds/)
This British Library website offers a fascinating collection of 42 different sound recordings to illustrate the diversity of spoken English in the second half of the twentieth century. Notes and a transcript accompany each recording.

Human beginnings (www.bbc.co.uk/srv/prehistoric_life/human/)
This BBC website describes what is known about human evolution. It contains fact pages about hominins, images of fossils and artists impressions of what some human ancestors may have looked like.

Sounds amazing (www.acoustics.salford.ac.uk/schools/)
This website for Key Stage 3 and 4 students, developed by the University of Salford, is a learning resource about sound and waves.

Practical Physics (www.practicalphysics.org)
This very useful website for teachers describes hundreds of classic experiments in physics. For relevant experiments, search on its homepage using the word ‘sound’.

Anatomical models
Anatomical models showing the larynx and features of the human vocal tract are useful but not at all essential when using Voicebox in the classroom. At the time of printing this booklet, relevant anatomical models cost upwards of £200. They are available from several sources:

• Adam, Rouilly Ltd (www.adam-rouilly.co.uk)
• Bones Clones (www.boneclones.com)
• Educational and Scientific Products Ltd (www.espmodels.co.uk).

SOURCES
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SEP produces a range of digital resources to accompany each of its publications. These are available from the ‘SEP Associates’ area of the website (www.sep.org.uk).

Membership of SEP Associates is free to all science teachers and technicians in UK schools. To join, fill in the online form on the website. SEP is wholly funded by the Gatsby Charitable Foundation, and joining SEP Associates entitles its members to additional benefits, including offers of free publications and other resources.

www.sep.org.uk

PDF files of student sheets
In addition to the whole booklet, the student activities are available as separate PDF files.

Voicebox CD-Rom files
The drag-and-drop interactive exercises, videos, software and other resources on the CD-ROM can also be downloaded from the website.

Links to other sites
The SEP website provides links to other useful websites on this topic.

PDF file of booklet
On the SEP website there is a downloadable PDF file of the whole booklet that can be printed or viewed on screen.

PowerPoint presentations
These contain the photographs and drawings shown in this booklet. They can be used to create custom-made presentations.

Word files of student sheets
Each student sheet also exists as a Word file. These files can be edited in order to adapt the activities to suit individual circumstances.
SEP works in close partnership with Middlesex University Teaching Resources (MUTR) in identifying and developing low-cost practical resources to accompany its publications. Many other resources for school science and technology can also be purchased from MUTR.

The latest prices of the products shown below and further information can be obtained from www.mutr.co.uk, or by requesting their latest catalogue. Orders can be made by post, telephone, fax or email by providing an official school order number or by credit card.

Buzzing reed kit
SEP 265
Contains parts from which to assemble a buzzing reed, for use with the vowel resonator tubes.

Vowel resonator kit
SEP 266
Contains a set of tubes that can be assembled in different ways to produce three vowel sounds.
You can download the written materials in this booklet, and find further information from: Science Enhancement Programme www.sep.org.uk

The Science Enhancement Programme (SEP) is part of Gatsby Technical Education Projects. It undertakes a range of activities concerned with the development of curriculum resources and with teacher education.

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Web: www.sep.org.uk

The Gatsby Charitable Foundation

You can order the Voicebox kits and a range of other practical resources from Middlesex University Teaching Resources.

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Fax: 01992 719474
Email: sales@muventures.co.uk
Web: www.mutr.co.uk

www.sep.org.uk