Institution: University College London

Unit of Assessment: 17A – Geography, Environmental Studies & Archaeology: Archaeology

Title of case study: Voicebox: Research on the physics and evolution of speech facilitating science teaching in secondary schools

1. Summary of the impact (indicative maximum 100 words)

As part of an EU-funded project on human evolution, a multi-disciplinary team led by a UCL archaeologist reconstructed the vocal tracts and potential speech sounds of Neanderthals (our most closely related extinct relatives). This experience was used to develop *Voicebox: The Physics and Evolution of Speech*, a pre-GCSE science teaching resource, with a booklet, DVD and physical apparatus. The booklet and DVD were distributed to about 6,500 UK science teachers. A follow-up evaluation in London schools confirmed that the *Voicebox* is seen as a valuable extension activity that has the potential to interest and engage pupils, including those with a low general level of interest in science subjects.

2. Underpinning research (indicative maximum 500 words)

As part of a wider study of the evolution of the human brain, language, and tool use [c], a multidisciplinary team led by Dr James Steele (UCL Institute of Archaeology since 2006) reconstructed the Neanderthal vocal tract and its potential to articulate speech sounds. The anatomical reconstruction used 3D scans of Neanderthal skulls, and 3D scans of the soft tissue of human and chimpanzee vocal tracts (from which a predictive model of the position of the tongue root in the Neanderthal vocal tract was obtained by 3D morphometric analysis). The software modelling of the vocal tract's speech potential was done using purpose-built software (Simus_Neanderthal) based on a pre-existing software articulatory model of the human vocal tract and its acoustic properties. Our objective was to contribute to the development of methods that can be used to make further incremental advances in understanding the evolution of speech based on fossil and archaeological evidence.

We focused on Neanderthals because they are our closest extinct relatives and because indirect evidence from other aspects of their anatomy – from tool use and from ancient DNA – is consistent with an adaptation to complex vocal-auditory communication (see [a, e] in section 3). Pre-existing arguments going back to work by Philip Lieberman suggested that the articulatory apparatus for speech had not yet come under intense positive selection pressure in Neanderthals. We provided new anatomical reconstructions of Neanderthal vocal tract morphology, and simulated the acoustic and articulatory properties of this reconstructed Neanderthal vocal tract. Our main result was that the morphology of the Neanderthal skull gives us no reason to believe that they lacked a human-like 'descended larynx' and that the main contrast between the two species was the greater facial flattening found in modern humans. Our published results included supplementary files of simulated human and Neanderthal vowel articulations for the vowels [*a*], [*i*] and [*u*]; see references [b, d] in section 3.

The work was conducted by a team in the UK, with the anatomical reconstruction done in the Institute of Archaeology, UCL by Dr Sandra Martelli (post-doctoral researcher) and Dr James Steele (PI), and the software articulatory modelling done at the Institute of Sound and Vibration Research, University of Southampton by Dr Antoine Serrurier (post-doctoral researcher) and Dr Anna Barney (PI).

3. References to the research (indicative maximum of six references)

The names of UCL researchers are underlined.

[a] Steele, J., Uomini, N. (2009). Can the archaeology of manual specialization tell us anything about language evolution? A survey of the state of play. *Cambridge Archaeological Journal* 19, 97–110. http://dx.doi.org/10.1017/S0959774309000067.

[b] Martelli, S., Serrurier, A., Barney, A. and Steele, J. (2010). 3-D morphometric and acoustic analysis of chimpanzee and human vocal tracts, and their use in the reconstruction of Neanderthal vocal tracts and their acoustic potential. In Smith, A. D. M., Schouwstra, M., de Boer, B. and Smith, K. (eds.) *Proceedings of the 8th International Conference on the Evolution of Language.* London,

GB, World Scientific, pp. 449–450. Available on request.

[c] Steele, J., Ferrari, P. & Fogassi, L. (eds.) (2012) From action to language: comparative perspectives on primate tool use, gesture, and the evolution of human language. Special Issue of *Phil. Trans . Roy. Soc. Series B* 367: 4–160. Submitted to REF2.

[d] Barney, A., Martelli, S., Serrurier, A. & Steele, J. (2012) Articulatory capacity of Neanderthals, a very recent and human-like fossil hominin. *Phil. Trans. Roy. Soc. Series B* 367: 88–102. Submitted to REF2.

[e] Steele, J., Clegg, M., & Martelli, S. (2013). Comparative morphology of the hominin and African ape hyoid bone, a possible marker of the evolution of speech. *Human Biology*, in press. http://digitalcommons.wayne.edu/humbiol_preprints/30.

Key peer reviewed funding:

€1,127,745 from the European Commission (under the FP6 NEST Pathfinder scheme 'What it means to be human'). Project title: *HANDTOMOUTH*. Duration: 2006–2010. PI: James Steele. The project examined common elements in human cognitive systems for language and for tool-use, and the timeline for their evolution using fossil and archaeological data. The EC assessing officer who reviewed the project's final report classified HANDTOMOUTH as an 'excellent project regarding the achievement of their initial objectives'.

4. Details of the impact (indicative maximum 750 words)

The Voicebox: an educational resource for secondary school science teaching. There is a need in the UK to engage school pupils with science at an age where they are still forming their subject preferences. The phenomena of speech and the voice are familiar to pupils and have intrinsic interest because they convey so much social and individuating information. It was therefore expected that an extension activity that uses speech as a vehicle to introduce some key concepts in physics and biology might engage pupils, including those who otherwise show little interest in science subjects.

As an additional outcome of our research, therefore, we decided to produce materials to enable school science teachers to introduce the evolution of speech and language in the classroom. School science teaching has its own priorities and constraints, which require specialist expertise. We therefore formed a separate team specifically for this purpose, involving academics in UCL Archaeology (Sandra Martelli, James Steele) and in UCL Speech, Hearing & Phonetic Sciences (Mark Huckvale), along with curriculum developers at the Institute of Physics (Charles Tracy, Education Manager) and the Nuffield Foundation Curriculum Programme (Peter Campbell, co-Director, Nuffield Twenty-First Century Science project).

The result of this collaboration was *Voicebox: The Physics and Evolution of Speech*, a school science teaching resource for pre-GCSE teaching, which included a 52-page booklet, DVD with additional learning resources, and an innovative physical apparatus [1]. It was published in 2010 as part of the Science Enhancement Programme (SEP; http://www.nationalstemcentre.org.uk/sep) run by the Gatsby Foundation.

The *Voicebox* booklet contains an illustrated overview of the topic with suggestions for teachers on how to introduce the ideas in the classroom, plus student activity sheets and notes for teachers and technicians. The electronic files (now downloadable from the National STEM Centre website [1]) include the activity sheets in PDF and editable Word formats; PowerPoint presentations containing a complete set of the images used in the booklet and activity sheets; and further resources including video clips and drag-and-drop interactives that accompany the student activities. The further resources also include software packages written by UCL's Mark Huckvale to illustrate graphically the different properties of sound (amplitude, pitch and timbre) as pupils speak into a microphone in real time ('Faroson'), and to simulate the sound emitted by vocal tracts of different sizes and articulated into different shapes ('VTDemo'), as well as a video of the larynx showing footage from a camera introduced into the oropharynx to show one of the team's (Steele) vocal folds in motion [1, see online resources]. In addition to this, a physical apparatus (the vowel resonator kit) was specially designed to enable the sound properties of the human vocal tract to be reproduced for three different basic vowels ([*a*], [*i*] and [*u*]), using inexpensive everyday materials

that the pupils can assemble [2].

The *Voicebox* resource was favourably reviewed in the trade press. A reviewer for *School Science Review* commented that "*many of the SEP resources give me a new insight into teaching traditional topics, and this publication is no different. A useful resource that contextualises some of the science behind evolution and sound*" [3], while a reviewer of the vowel resonator kit for *Physics Education* gave it four stars out of a possible five, commenting that "*The apparatus is easy to use and with younger students would make an ideal practical investigation into the human voice. […] the apparatus is simple but excellent and can, with a little ingenuity, be extended into a more diverse investigation into the structure of the sounds produced. […] an interesting extension to the usual sound experiments*" [4]. The whole resource currently (October 2013) has a five star user rating out of five on the National STEM Centre website [1].

When the booklet (with DVD) was published in 2010, it was sent free of charge to the c. 4,000 SEP Associates (school science teachers) who requested a copy. It was also sent by SEP to another c.150 targeted individuals (e.g. Science Learning Centres, Association for Science Education regional officers, and so on). The Institute of Physics meanwhile distributed the booklet to all 1700 of its affiliated schools and has since distributed copies to teachers at events and/or on request (another 847 copies) [5]. The e-resources were hosted on the SEP website from its publication in Summer 2010 until the website closed at the end of 2011, at which time they were transferred to the National STEM Centre. Statistics for individual resources on the SEP website are not available, but there have been 763 downloads from the National STEM Centre website since 2012 (all figures for period to September 2013) [5].

To reinforce and evaluate the *Voicebox* resource, we offered one-hour workshops to up to 10 London secondary schools during Third Term of 2013 (May–June), taught jointly by Steele from UCL and by an experienced teacher from the Institute of Physics curriculum development network, with the science teachers of the host schools. The offer was oversubscribed and nine were delivered, with one postponed to a later date. A freelance educational consultant formerly employed by the SEP programme undertook the evaluation. The workshops were assessed by feedback questionnaires completed anonymously by the pupils, and by follow-up telephone interviews with the teachers at the host schools, and a report was written synthesising these results [6]. The report summary concludes:

> "It was found that the workshops were rated highly by the teachers, and a very large majority of the students were interested in the workshop activities and in doing further similar activities. The workshop appealed to a wide range of students, including those who were in general less interested in science. The teachers reported that they would value taking part in further workshops, and they found ideas in the sessions that they would like to incorporate into their curriculum teaching."

This is based on a sample of 157 pupil feedback questionnaires, and six telephone interviews with teachers (all those teachers who were contactable in the follow-up period at or shortly after the end of term).

Particularly noteworthy, in relation to our aim of engaging a wide range of pupils with science subjects, is the fact that, of the pupils who said they were only 'fairly interested' or 'not very interested' in science generally, 70–80% were either 'interested' or 'very interested' in the workshop activities and in doing more activities on this topic. The report also states that:

> "The teachers were asked whether they thought that students who were not especially interested in science might become more engaged through these kinds of activities on the human voice. All of the teachers were very positive on this point. Although the students attending the after-school workshops tended to be those already interested in science, the teachers felt that the materials would work well with less interested students. They commented on the value of the approaches that were relevant to students and which appealed to their broader interests. In fact, one teacher had already tried some of the resources on the CD-ROM with less motivated lower ability girls and found this to be successful."

In conclusion, a multidisciplinary research project on the evolution of speech led to the formation of

a specialist team to develop a resource on this and related topics for enhancing secondary school (pre-GCSE) science teaching, which was then widely distributed within the UK science teaching network. A follow-up evaluation confirmed that the resource successfully uses the voice and speech, and its relationship to human and hominid anatomy, as a vehicle to introduce some key concepts in physics and biology, engaging even pupils who otherwise show little interest in science subjects. The *Voicebox* is currently part of the Institute of Physics' offer for teacher training workshops on the broader topic of sound, and support for further London schools workshops will be offered by Steele from UCL. It is intended that future initiatives led by UCL Archaeology will follow, taking the *Voicebox* as a model.

Expanding reach and engaging new audiences with research. While *Voicebox* facilitated an in-depth engagement with our research for a specific and defined group, wider media engagements allowed us to broaden the reach of this engagement. Our work reconstructing Neanderthal vocal tracts and speech potential was featured in the media, most notably in a contribution on the vocal tract by Barney and Martelli to the first episode of BBC 2's 'Prehistoric Autopsy' series (aired 22 October 2012; 1.6 million viewers), in which Neanderthals were studied and their bodies and appearance reconstructed [7]. Barney also described our work as part of a podcast on Neanderthals, which is available online on the (London) Natural History Museum's website, where it enhances the presentation of the Gibraltar skull, the first adult Neanderthal skull ever discovered (one of 22 'Treasures' of the Museum, all of which have been on permanent display in a new gallery space since November 2012) [8].

5. Sources to corroborate the impact (indicative maximum of 10 references)

[1] Availability of Voicebox resource and associated materials: Campbell, P., Huckvale, M., Martelli, S., Steele, J. & Tracy, C. (2010) *Voicebox: The Physics and Evolution of Speech* [SEP128] London: The Gatsby Science Enhancement Programme/ Midddlesex University. Available from: http://bit.ly/1dBSgKa (includes 5* review). Online resources and DVD mirror at UCL: http://bit.ly/1jb30Af. Apparatus order page: http://bit.ly/1jb3dDz and http://bit.ly/1qT4brl.

[2] Description of vowel resonator kit: http://bit.ly/1dBTcOz.

[3] Natalie Timoney (2011) 'Voicebox: The Physics and Evolution of Speech [review].' *School Science Review* December 2011, 93(343), p. 134. Available on request.

[4] John Kinchin (2011) 'Voicebox kit discovers the physics and evolution of speech [Review].' *Physics Education* November 2011, p. 721. http://bit.ly/1bBI6tx.

[5] Institute of Physics: 'Distribution of the Voicebox Publication and Resources'. Document and accompanying email, received 17/09/2013, available on request.

[6] Richard Boohan (freelance educational consultant), 'Voicebox Workshop: Evaluation Report. A report commissioned by the Institute of Physics and University College London to evaluate the series of Voicebox workshops held in London secondary schools in the Summer Term 2013.' 18 pp. Document available on request, received August 2013.

[7] Media coverage: BB2 Prehistoric Autopsy, Ep. 1: http://bbc.in/179AvRk. First aired 22/10/2012. Viewer numbers reported in the *Guardian*, 23/10/2013 http://bit.ly/1gT4W3P.

[8] Podcast from the Natural History Museum at: http://bit.ly/1bMKY51.