# TEACHING PHYSICS VIA THE WEB USING MUSIC ACOUSTICS

**Joe Wolfe** **George Hatsidimitris** **John Smith** **John Tann**
School of Physics, The University of New South Wales, Sydney
J.Wolfe@unsw.edu.au georgeh@unsw.edu.au John.Smith@unsw.edu.au
John.Tann@austmus.gov.au

## ABSTRACT

The UNSW Music Acoustics site provides a learning experience for its users, but it has also provided one for its makers. This paper describes how it was made and some of what we learned in making it. It also describes a new, larger project, called Physclips, which is being made with a consistent philosophy, in the light of our experience. We describe these ideas as well as some of the principles from the educational literature.

## 1. INTRODUCTION

Any branch of science introduces its practitioners and students to principles with broader application. For music acoustics, the list is long and there are many favourites: wave-particle duality, Weber-Fechner response, evanescent waves, heterodyne production, coherence etc. Beyond that, it can be used to teach the practice of science: experimental design and observation, analysis, hypothesis formation and testing, modeling and more.

For teaching science, music acoustics has several advantages: first, many of its important phenomena (*e.g.* sound, vibration, harmony) are familiar and regarded as pleasant. Some (*e.g.* pressure waves) can be sensed and produced with no additional hardware, and sometimes (*e.g.* frequency ratios) with precision high enough to allow relatively subtle evaluation of models. This makes it easy and inexpensive to create excellent lab exercises. High quality audio interfaces for computers allow for higher precision and a range of analyses.

For these reasons, many university physics teachers, including the present authors, have developed a Science of Music course for the institution's general education program: a 'physics for poets' course.

Our experience with the UNSW course prompted us to consider writing a book. Up to the late twentieth century, texts on acoustics were often published without an accompanying record, CD or web site. In the 1990s the web offered a way of integrating text, sound and movies, as well as a new way of navigating among learning elements: this seemed like a more suitable medium.

Another pathway independently led us to use the web for education. In the mid 1990s, JS and JW made a career switch and set up a research lab in music acoustics. In this field, research results are interesting not only to scientists in the area, but also to musicians especially and to the public generally. Further, music acoustics can be an effective way of introducing students to physics.

The Music Acoustics web site at UNSW [1] was launched in 1996 with both of these objectives: to explain the research of our lab to non-technical readers and to introduce interested users, perhaps especially school students, to aspects of physics.

Feedback from users told us that the site was valued, but also gave us guidance for improvements. Many of these came too late to be retrofitted to what was then already a large site.

More recently, we have used our experience to develop a new learning and teaching site, called Physclips [2]. In the future we intend this to grow so as to cover most of the topics of introductory physics, but the volumes completed to date are the areas most fundamental to acoustics: Mechanics, Sound and Waves. Unlike the Music Acoustics website, Physclips was planned and so has a coherent structure and a consistent philosophy.

The first part of this paper gives examples from the Music Acoustics site and discusses its structure and purpose. The second part explains some of what we learned from making the site and from library research in multimedia presentation, as well as the ideas and principles that inform Physclips.

## 2. THE MUSIC ACOUSTICS SITE

The Music Acoustics Lab for which the site was developed began with three research projects. Two took advantage of new techniques to measure acoustic impedance over a wide dynamic range. The first involved measuring the acoustic response of the vocal tract at the lips, in parallel with the radiation impedance, which is a low impedance inertive shunt [3]. A second concerned flutes, which operate at impedance minima [4]. A third was an industrial project aimed at improving music perception by users of cochlear implants [5].

In each of these areas, we made web sites explaining our research progress for a non-specialist reader [1,6]. All three, however, involved subtleties and so led users naturally to further questions, which they sometimes sent to us. On the web, such further questions are usually answered by following links to further pages. In the twentieth century, before Wikipedia, we often saw it as our role to make these.

Auditory perception in particular was a source of questions, so we made further web pages to answer these. One, 'What is a decibel?', is still one of the most popular. It combines sound files and animated versions of their sound tracks, as suggested in Figure 1.

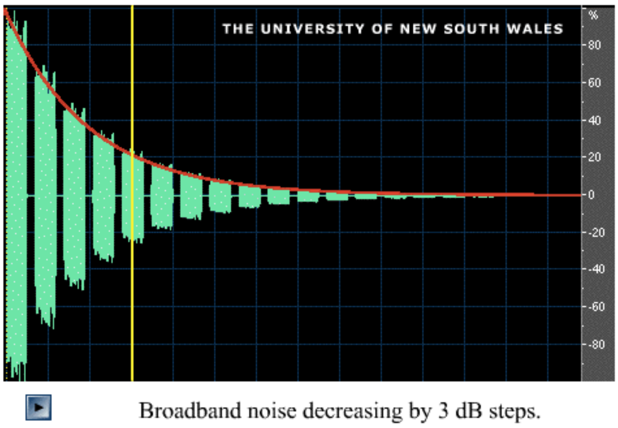


**Figure 1**. An early multimedia feature from Music Acoustics. This is one of several illustrations of the decibel scale: broad band noise pulses are reduced in amplitude by 3 dB each step. A cursor keeps pace with the plot of the sound track, illustrating the exponential decay.

The 'do-it-yourself' hearing test (Figure 2) also responded to these questions. On this page, an interactive table produces a large range of sound levels over most of the audible range, two to the octave. The user, who is advised to use headphones, can quickly make a set of equal loudness curves for each ear.


**Figure 2**. Also from Music Acoustics: an interactive table that allows users to determine their own equal loudness curves.

For each of the musical instruments we studied, as well as for the voice, we made web essays that introduced the acoustics of that instrument, linked to further pages on the questions raised. For the woodwind instruments, we made sites that included compendia containing sound files and impedance spectra for each of several dozen fingerings. For the flute this expanded into the 'Virtual Flute' [7], a web service that provides many thousands of machine-predicted alternative fingerings.

We made the FAQ in Music Acoustics, which is now rather large. Since then, new questions and issues have regularly required new pages. The result of this accumulation is a large and growing site whose overall structure was never planned. Mostly, it comprises essays, which were illustrated with graphics, sound files and occasionally movies, interactive elements and animations.

## 3. PHYSCLIPS: A SITE WITH A PLAN

Mechanics, sound and waves are the physics topics upon which acoustics is based. They are also among the topics that students first meet in physics. We decided that we could contribute to learning and teaching introductory physics, at the level of senior high school or first year university, via the web.

Physclips is a large, integrated set of learning and teaching resources. It is funded by the Australian government's Office for Learning and Teaching and the UNSW School of Physics. Because of this, it has no advertising and is freely available to students, world-wide. It is also regularly used by teachers: all of its film clips and animations are available in compressed form so that they can be downloaded and included in teaching materials.

We started Physclips with the experience of the Music Acoustics site and the feedback we had received. We were joined by GH, a multimedia designer, who knew the literature on multimedia learning and teaching. We were starting from scratch, so we could plan ahead. In this section, we describe how we made it and the ideas behind it, in the hope that some of these ideas may be useful to others.

### 3.1 Experiments and theory

Physics is an experimental science: observation and experiment are paramount. Too often, students and sometimes even teachers miss this central point: the student may think that the lab exercises are to illustrate the theory, whereas the reality is completely the opposite: the entire structure of theoretical physics exists to explain the observations from the laboratory.

Ideally, one might hope to teach much of physics in a laboratory, but this is impractical for reasons of time and expense. In many cases, a movie of an experiment is a good substitute: this is what happened. Movies can be replayed, in real time or slow motion as necessary. Occasionally, we also use cartoons ('this shows qualitatively what we thought would happen') or animations ('this is what the simplified equations predict would happen').

Sometimes, the experiments we show require sophisticated equipment, and this is one of the common uses of Physclips: teachers, especially in schools, can use it to show experiments that they cannot perform in class. In many cases, however, we use familiar objects so that students can repeat or extend the experiments at home. In some cases, we give explicit advice on acquiring and setting up experimental gear.

Combinations of animations and movie clips can have advantages: an animation can show, superimposed on or alongside a movie, time-varying vectors or histograms and graphs. This can allow the student to share the point of view of the expert, whose 'mind's eye' 'sees' these quantities. And of course sounds can be accompanied by spectrograms and oscillograms.

### 3.2 The structure and navigation

Why do so many students find physics difficult? One of the problems comes from the 'vertical' structure: higher levels depend on several levels below, and one needs to understand all levels. A typical chapter is long, and contains a number of complications and subtleties. Many students lose the view of the metaphorical forest while dealing with many individual trees. A desire to help students overcome this difficulty inspired the structure of Physclips.

Each chapter of Physclips covers about the same material as a chapter in a typical introductory physics text. It begins, however, with a narrated multimedia tutorial, of typically five two-minute sections. These tutorials show movie clips of key experiments. Using these, plus graphics and animations as necessary, they develop the key ideas and derive the important results.

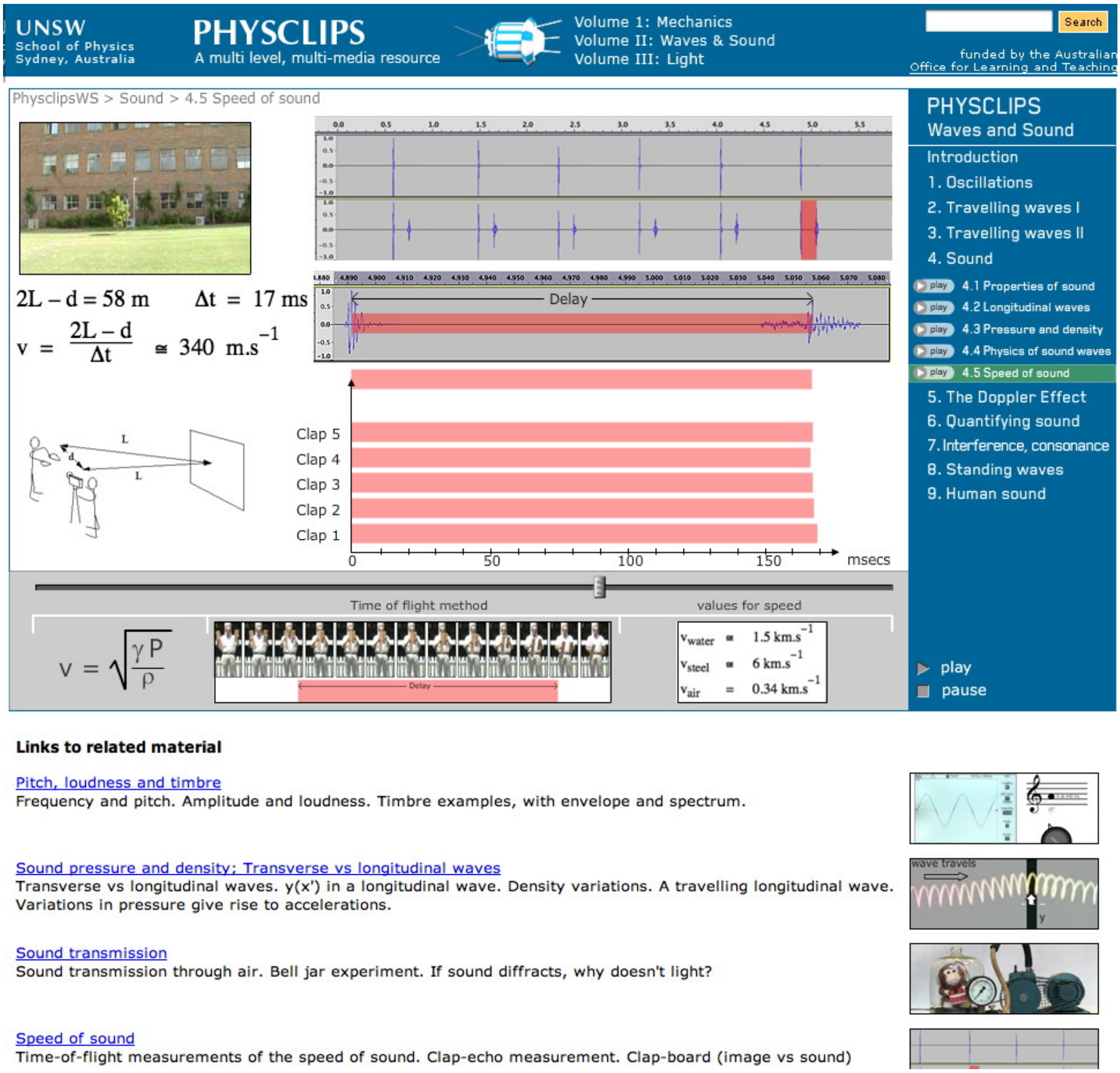


**Figure 3**. From Physclips. At the end of the chapter about the physics of sound, we include a simple time-of-flight method for measuring the speed of sound using a recording of the direct sound of a hand-clap and its echo from a building. A portable computer or smart-phone is the only hardware needed. Below the scroll bar, a series of images shows another method using a video camera. Below the scroll bar are seen the logos and links to the first four of the support pages for this chapter. At right is the chapter outline for the volume Waves and Sound.

A ten-minute overview necessarily omits some subtleties and some of the longer mathematical derivations. To maintain rigour and to allow for interesting digressions, these overviews contain links that appear during and at the end of each section, as well as in the chapter splash page: these link to broader and deeper discussion. Often the presentation pauses when the information content of the screen is high, and recommences with a 'click to continue' button. Support pages are also provided for necessary mathematical tools: calculus, vectors, graphing and error analysis.

The Web makes it easy for users to navigate their own learning pathways, so we provide cross-links, site maps at different levels, and a search function.

Many of the users of the Music Acoustics and Physclips sites use them as a reference, searching for a particular topic or combination of key words. We sought therefore to facilitate searching on the multimedia overviews as well as on the support pages. Easy searching is also important for those using the multimedia overviews as lessons, and who wish to repeat sections. The Physclips scroll bar was designed for this purpose: when clicked, a set of key images and/or text and equations appears in order to simplify navigation to the desired section. Research suggests, however, that users often require instruction to take full advantage of this form of learner control [8].

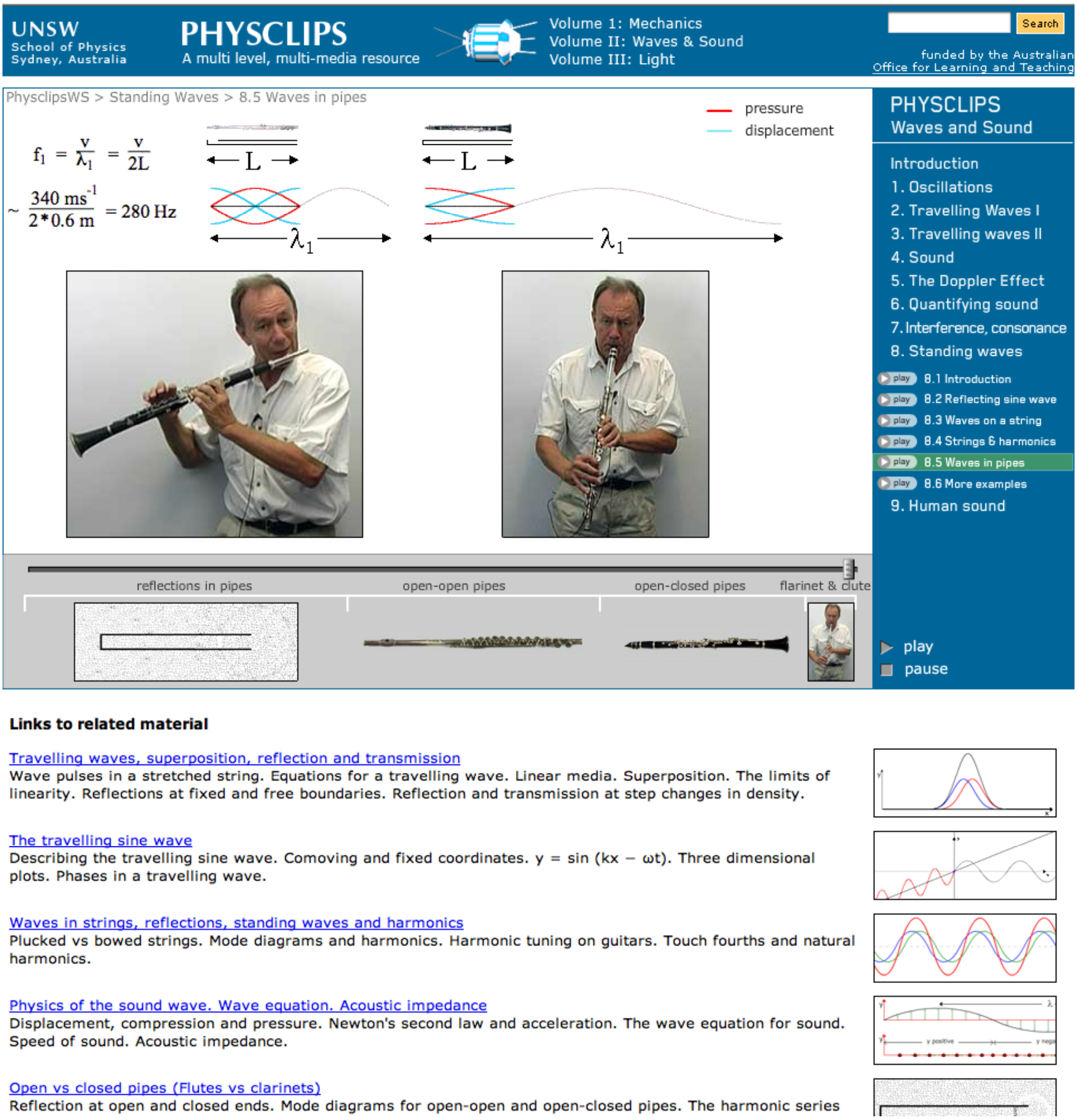


**Figure 4**. Standing waves in an open-open pipe and a closed-open pipe. To emphasise the importance of the boundary condition, the open-open pipe is a clarinet fitted with a flute head joint, while the closed-open pipe is a flute played with a clarinet mouthpiece. Below the main window are the scroll bar and the first of the support pages for this chapter.

## 4. EVIDENCE-BASED GUIDELINES

Education researchers have identified some potential problems in the use of animations and movies in teaching, and have suggested guidelines for their use in multimedia learning. [9,10]. Usually, Physclips is consistent with these. For example, one study recommends minimising the use of text in combination with moving visual material [9]: the narration reduces this problem.

Some of these guidelines would be regarded by experienced teachers as common sense. For instance, one recommended tactic is called segmentation [10], *i.e.* breaking the material up into digestible sections. Another tactic is signaling, *i.e.* drawing attention to important information. We do this in several different ways in Physclips, such as highlighting with colour, or by temporarily reducing other, competing information to grey or pale colours. Another recommendation is spatial contiguity, locating labels close to the objects labeled, rather than using a legend. We give examples of these evidence-based guidelines on the site [11].

## 5. USE AND THE FUTURE

The UNSW Music Acoustics site is typically accessed by a few thousand computers each day, each one downloading a dozen or more files, giving high hit rates. The usage statistics are somewhat higher for Physclips. The sites have won a number of national and international awards.

Since finishing the volume Waves and Sound, we have embarked on Light, and have posted several chapters. If funding continues, we intend to add additional volumes and to continue making this broad introduction to physics freely available on the web.

## 6. CONCLUSIONS

Hindsight makes for useful foresight: a planned educational website is better than one that accretes. Sometimes education research seems obvious in retrospect, but it is still worth consulting.

**Acknowledgments**

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