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Audio Processors as a Learning Tool for Basic Acoustics

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Abstract

Basing on the audio processor Audacity, this paper presents the use of this kind of programs as a so called “hear-and-see” learning tool for basic acoustics. Some activities designed as laboratory experiments, which can be carried out also remotely in a sort of home laboratory, have been already successfully implemented.

Keywords: audio processors; acoustics; multisensory learning tools, home laboratory; computer-based education.

Introduction

Audio processors such as Audacity can be used as a so called “hear-and-see” learning tool to learn basic acoustics, since they allow to implement activities where the learners see the graphical information and, at the same time, they hear the related acoustic phenomena.

One of the authors has reported in a previous paper [1] that hear-and-see tools are another way of incorporating information technologies into science education in a constructivist approach. This bases on the fact that learning concepts related to sensorial phenomena is more effective, in a constructivist background, when learners are allowed to experiment them with their own senses. In acoustics, most phenomena can be perceived by hearing, although sight is also involved through images and text.

As a result, a learning tool which involves both senses of hearing and seeing should be welcomed, especially if it is easy to implement. As much of the practical work in digital signal processing is now done using computers anyway, it is only natural to apply computer-based education to teaching, as well.

Furthermore, the issue in acoustics is sound, and the best way to teach sound is to use sound [2].

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This paper describes some activities which have been already implemented successfully in our college using Audacity as a hear-and-see tool, in subjects which include oscillatory physics, wave physics and acoustics.

Hear-and-see tools in computer-based education

A hear-and-see tool is a multimedia unit of definite structure basing on the constructivist model of learning. Here, the keyword “multimedia” has to be understood in terms of the 3rd. possible definition given in [3], as a modality of communication or multisensory interaction (in this case, visual and auditory interaction). According to these authors, this modality of communication allows a representation according to a cognitive model based on a combination of visual and auditory information with less cognitive load. Overload on one sense causes tiredness and reduced attention, whereas a balance between visual and auditory information reduces the cognitive load. The efficiency of multisensory interaction in the constructivistic model of learning can be also seen in other examples of involvement of various senses, as in [4].

Computer-based education must be in some way more useful than traditional teaching methods ([2] and [5]). Therefore, the starting point for every computer-based education project is to ask if it can give “something extra” or “a better way” in the means of education compared to traditional teaching. These authors report on several applications in the form of courses, encompassing topics such as perception of pitch, loudness, timbre and duration, masking, and critical band.

Other hear-and-see tools have been implemented in the form of computer-based tools for teaching phonetics ([6] and [7]). These are software tools for analysis and resynthesis of speech sounds. These papers point out the usefulness of hear-and-see tools for teaching acoustics not only to technical students, but also to students majoring in fields such as linguistics, psychology and speech pathology.

Although they are not real experiments, but computer-based learning tools which combine hearing and seeing, there are very interesting interactive simulations on sound in the PhET website (“Sound”, “Fourier: Making Waves” and “Wave Interference”), described in [8], which are of high quality.

Hear-and-see tool based on Audacity

Audacity is an open-source audio processor which allows easy implementation of learning activities on acoustics combining hearing and seeing simultaneously. It can be accessed through the web site <http://audacity.sourceforge.net>. There are similar, commercially available programs such as WaveLab (<http://www.steinberg.net>) or Adobe Audition (former CoolEdit; web site: <http://www.adobe.com/products/audition>), which can also be used and are even more powerful in some aspects. But the fact that Audacity is available on the web, free of charge, makes it an ideal choice in our case, even as a sort of home laboratory, where the student can perform real laboratory experiments as a remote learning activity. In this respect, Audacity has also the features of tailored

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computer-based educational tools for activities in a laboratory or at home, similarly to the tool in [9].

The experiments carried out in such a home laboratory have the advantages of both hands-on laboratories and virtual laboratories as compared in [10] to [12], as well as the advantages of other proven interactive multimedia learning tools based on simulation and discovery learning (e.g. [13] to [17]).

The different aforementioned audio processors share a number of similarities. Therefore, the idea stated in [5] that in computer-based education the emphasis of an application should always be on the subject rather than on the application itself does not apply in this case, as one of the goals of these activities was to familiarise the students with the use of standard audio processors in general.

The environment provided by these audio processors has the advantages of some proven web-based learning environments like that described in [18].

Figure 1 shows the upper, most relevant part of the Audacity environment with a sound sample and the main command buttons. The most important buttons for our purposes are nos. 1 to 6 (playback, stop, etc.) and no. 11 (source selection between microphone and pre-recorded file). Screen elements nos. 16 to 20 are also very useful in ensuring the best display and a better reading of data (amplitude, no. 14, and time, no. 15).

Activities already implemented with the proposed hear-and-see tool

In this section, we describe some learning activities which have already been implemented using Audacity as a hear-and-see tool. Three of them can be seen (so far only in Catalan) in <http://baldufa.upc.edu/arcadi/index.htm>, selecting “Pràctica 1/2/3”. The proposals in [19] and [20] for the design or redesign of educational multimedia software were taken into account.

Timbre, waveform and acoustic spectrum

The aim of this activity was to observe the difference in waveforms and acoustic spectra for different timbres. After installing Audacity, each student had to record his or her own speech (in mono) pronouncing the Catalan word “universitat” (pronounced /ˌuniˌbersiˈtat/) which has different vowels, including a repeated one (“i”). Beforehand, students had seen in the theoretical explanation that timber differentiates also the different vowels.

Figure 2 shows the waveform of the recorded sample in the Audacity screen; the vertical line, moving from left to right, shows the exact place of the waveform being played back at each moment. The white labels with text have been added by the authors, to show what students hear in the playback.

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After identifying the portion of the waveform corresponding to a given pure vowel, for example the Spanish or Catalan “u” [u/], students could enlarge the display in order to observe the waveform in detail and its differences with regard to other vowels (Figure 3).

Students then had to select the proper portion of the waveform, call up the “Plot spectrum” function, and see the acoustic spectrum obtained (Figure 4). Students were encouraged to “play” with the different parameters of the FFT function offered by Audacity (essentially, analysis block size and smoothing window), especially in order to obtain a clear display of harmonics in the spectrum.

Student had to make spreadsheets to compare the frequencies of the overtones (at least the first eight) and their intensity levels. The aim was to quantitatively characterise the spectral differences between two different vowels as well as the similarity between identical vowels (e.g. the two instances of “i” in the example).

Difference between sound and noise

The preceding procedure also allows the differences between sound and noise to be observed. Here, ‘sound’ is understood to be any sound of definite pitch, such as the vowels in our speech, or any typically clear sound of musical instruments of definite pitch (most string, wood and brass instruments, for example), when they are played skillfully. In contrast, ‘noise’ is understood here to be a sound that has no definite pitch, i.e. it has a continuous spectrum or a series of overtones which do not form any series of harmonics. The students themselves could experiment with any typical noise (that of traffic, for example) and observe the lack of pattern repetition in the waveform, as well as the absence of relevant overtones or the lack of a series of harmonics. Figures 5 and 6 show images for the hissing noise that is produced when a long “s” is pronounced; they were obtained in the same way as Figures 3 and 4, respectively.

Pitch and fundamental frequency

The starting point was an MP3 music sample played on a saxophone (Figure 7), including the lowest and highest notes that this instrument can produce and a two-octave ascendant and descendent scale in E_b major, where the musical notes E_b (at octave distances) could easily be recognized by hearing, even by students with no musical training whatsoever. Following the same procedure as before, students had to identify the portion of waveform corresponding to the lowest sound, the highest sound, and the three E_b notes at octave distances. Then they had to calculate the respective periods and fundamental frequencies directly using the time scale of the waveform displayed. Every time, the value for the fundamental frequency had to be checked against the one taken from the spectrum.

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In this way, students could deduce the main relationship between pitch and fundamental frequency, and calculate the relationship between fundamental frequencies for sounds differing by one or more octaves.

The use of music in this activity has the advantages described in [21].

Weber and Fechner's law - Definition of decibel

The audio material consisted of 20 MP3 samples of white noise. Each sample had two phases of maximum amplitude (for reference) alternating with two phases of a given different amplitude for every sample (Figure 8). Each phase was one second long, preceded and followed by one second of silence. In a first stage, students had to hear every sample with headphones in a silent place (preferably at home in a quiet room with as little noise as possible), using Windows Media Player in the compact display mode or any other MP3 "blind" player (i.e. with no waveform display), and to rate the perceived loudness from 0 (silence) to 10 (reference maximum loudness in the same MP3 sample). In a second stage, students opened every sample in Audacity and read the corresponding amplitude A . Finally, they made an Excel spreadsheet with the values for the perceived loudness S and A^2 , to which the intensity is directly proportional, inserting the graphs for S vs. A^2 and S vs. $\log(A^2/A_{\min}^2)$ with the respective correlation coefficient (square). Figure 9 shows a typical result of this activity by a real student. The conclusion to draw was that S is not proportional to intensity, but rather to its logarithm, leading to the definition of decibel, in order to express S quantitatively as "intensity level".

Student response

The activities of the preceding section were implemented within the framework of an elective subject on acoustics, as well as a compulsory subject on general physics which includes oscillatory and wave physics and acoustics. In the latter case, the activities were voluntary and could improve the final mark. In both cases, the subjects are studied in the first author's engineering college.

As the instructions themselves for the activities, also the theory background was provided in the same web site by means of tested web pages [22], tuned to such activities, since it is important that students understand the theoretical foundations of experiments before going to the laboratory [23].

The student response was obtained by means of a questionnaire. The students had to express their degree of agreement with the statements of Table 1, by marking one of a set of five squares which represented a scale of agreement ranging from "absolute disagreement" up to "total agreement". In order to quantify the answers, we gave values ranging from 0 for the first square (absolute disagreement), up to 4 for the fifth square (total agreement). Table 1 gives the results obtained from 42 students, with mean values and standard deviations.

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Summarizing, our students found the activities neither too difficult nor especially easy, but anyway not tedious. In this respect, a few students added as a free comment that our operating instructions for carrying out the activities with the PC were unnecessarily detailed. But other students were grateful for the very detailed instructions.

The highest agreement was reached about the interest because of the contents, i.e. characteristics of sound (pitch, timbre and loudness). Almost the same agreement was found about the interest of the activities for learning to use audio processors in general by means of Audacity.

On the contrary, the students found the use of spreadsheets like Microsoft Excel only of limited interest in order to learn to use them, in spite of having to make a wide use of regression analysis (including graphs), as shown in Figure 9.

Conclusions

The free, open-source sound processor Audacity has proved to be a powerful hear-and-see tool, which allows the relatively easy implementation of a series of activities on acoustics.

We have presented in detail an initial series of successfully implemented activities. They can be extended to other aspects of acoustics, such as the frequency response of the human ear, the formation of beats, the synthesizing of timbres, etc.

Since the activities were carried out by the students in their own homes with considerable interest, this hear-and-see tool can serve as a sort of home laboratory, combining the advantages of both hands-on laboratories and web-based laboratories, with the result of considerable interest on students' part.

Acknowledgements

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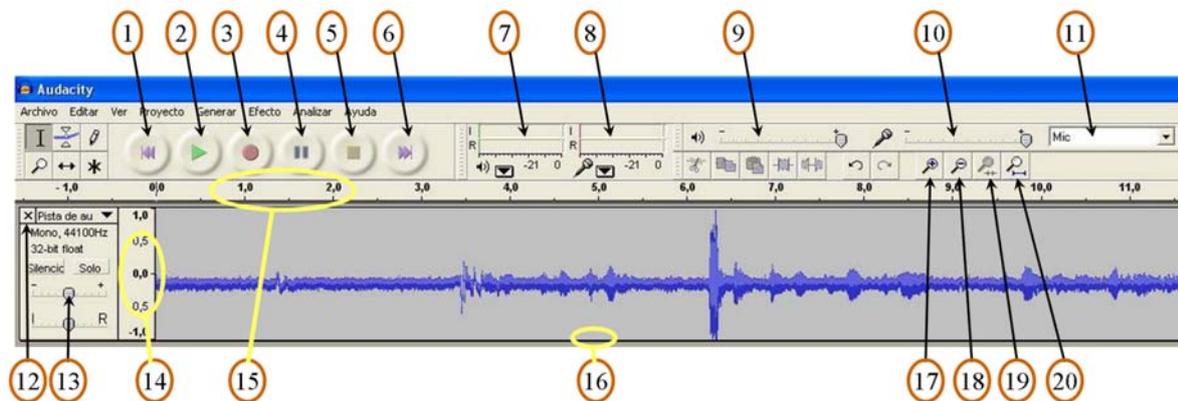


Figure 1: Audacity display, with a sound sample and the main command elements (numbered for reference in the text).

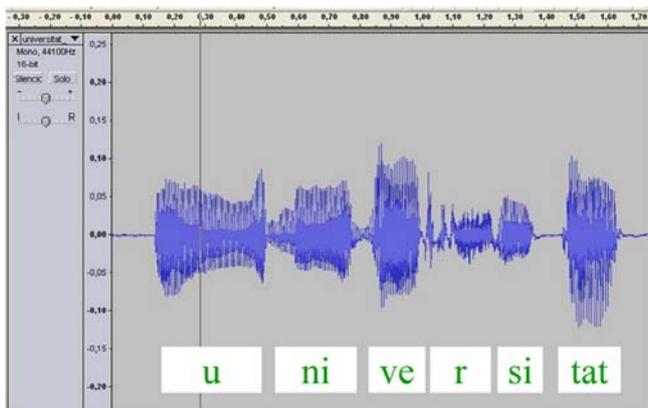


Figure 2: Waveform of a word pronounced and recorded by the student himself or herself (white labels added by the authors).

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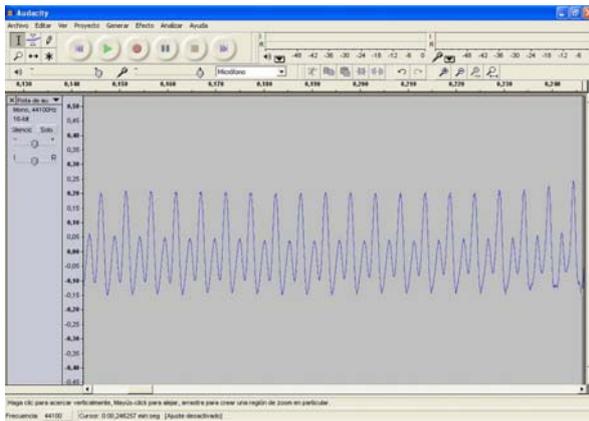


Figure 3: Waveform for the vowel “u” [pronounced /u/] after selection and enlargement from the previous Figure 2.

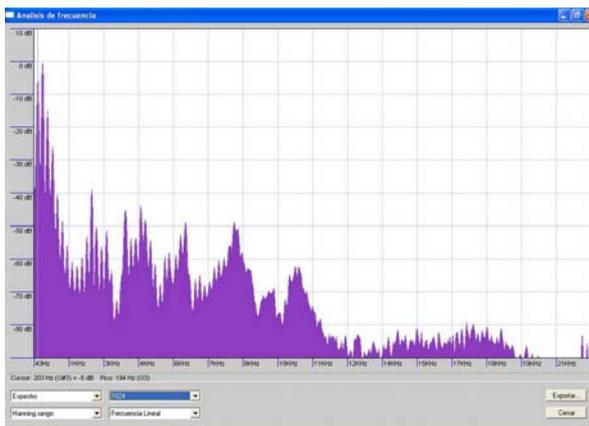


Figure 4: Acoustic spectrum for the waveform of Figure 3, as obtained with Audacity (frequencies up to ca. 11 kHz).

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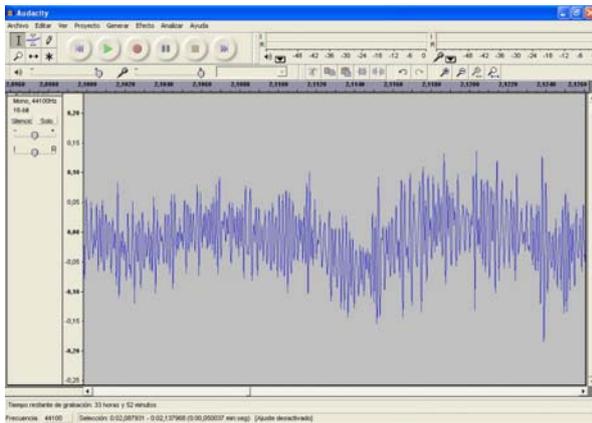


Figure 5: Waveform for a typical noise (hissing noise).

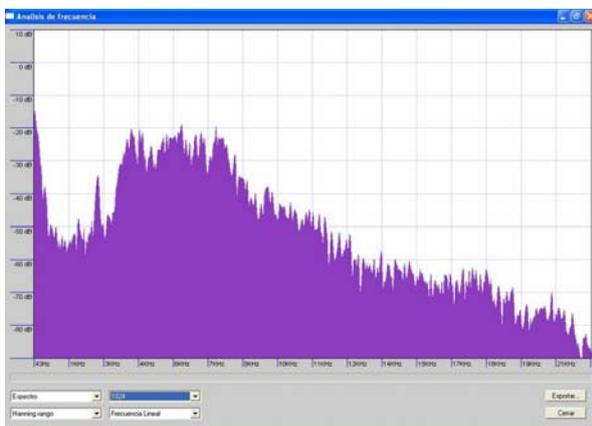


Figure 6: Acoustic spectrum for the waveform of Figure 5.

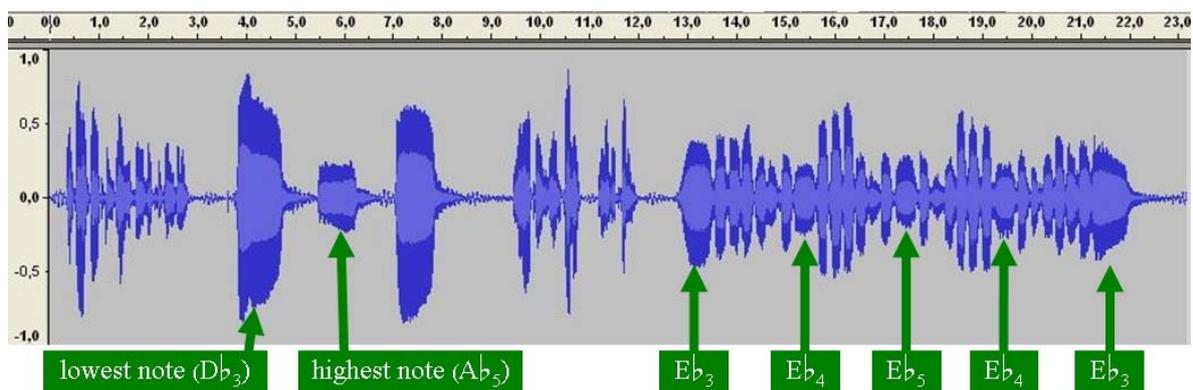


Figure 7: Sound sample with musical notes played on a saxophone, for comparison of the different frequencies involved.

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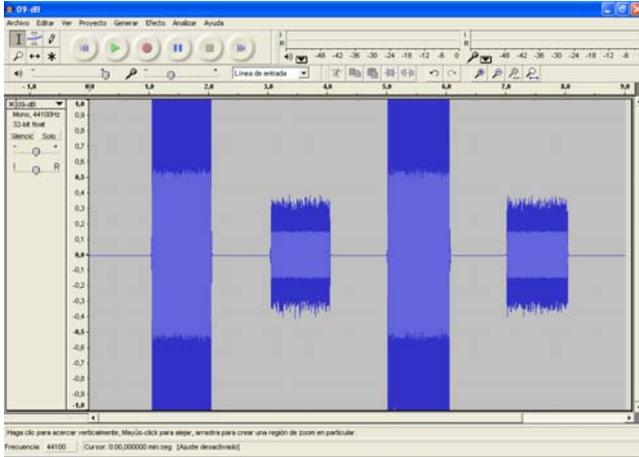


Figure 8: Structure of the sound samples used for verifying the Weber and Fechner's law.

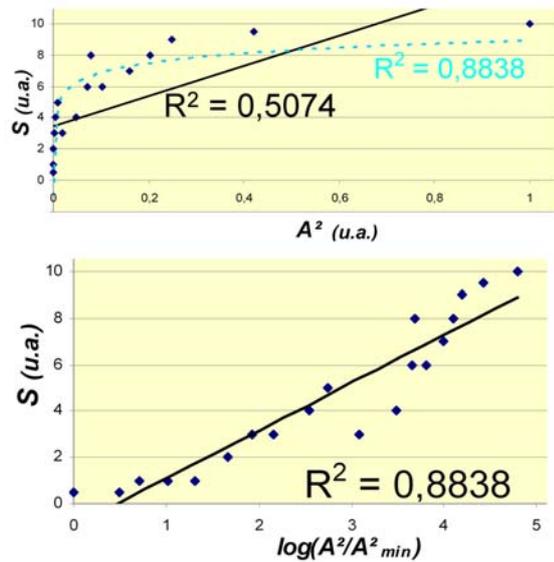


Figure 9: Typical result of the experiment about the Weber and Fechner's law.

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Table 1: Statements of the questionnaire used to study the student response to the implemented activities, and degree of students' agreement with the statements.

Questionnaire statement: "I found the activities with PC...	Agreement (0-4):	
	Mean value	Stand.dev.
1) ... too difficult"	1.8	0.2
2) ... too tedious"	1.3	0.2
3) ... interesting because of their contents (characteristics of sound)"	3.1	0.1
4) ... interesting for learning to use audio processors (like Audacity)"	2.9	0.2
5) ... interesting for learning to better use spreadsheets like Excel"	2.1	0.2