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Bruno Gazengel, Christophe Ayrault

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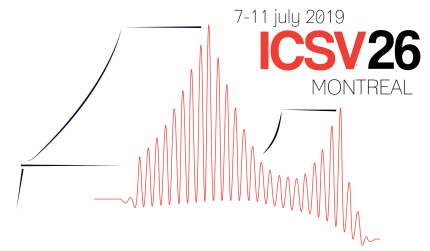
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## SCIENTIFIC CONCERTS OR LEARNING ACOUSTICS WITH ARTS

Gazengel Bruno

*Laboratoire d'Acoustique de l'Université du Mans LAUM - UMR CNRS 6613, Avenue Olivier Messiaen, 72085 Le Mans Cedex 9, France*

*email: bruno.gazengel@univ-lemans.fr*

Ayrault Christophe

*Laboratoire d'Acoustique de l'Université du Mans LAUM - UMR CNRS 6613, Avenue Olivier Messiaen, 72085 Le Mans Cedex 9, France*

*Mans Cedex 9, France*

*email: christophe.ayrault@univ-lemans.fr*

This paper presents the concept of "scientific concerts" developed at Le Mans University by two acoustics teachers-researchers and professional musicians, with the collaboration of three professional musicians.

This project was born in 2009 and aims to introduce the basic concepts of acoustics by mixing science and arts. The originality and core principle of a scientific concert is to combine projected animations and spoken explanations with real-time experiments and demonstrations that are being given and played by both physicists and musicians. Learning is also eased by alternating musical themes and scientific content. Two different shows have been developed and given either in high schools, in popular science events or in concerts halls welcoming teenagers or general audience. The first show deals with the three main characteristics of a sound (intensity, pitch, timbre), while the second introduces the physics of musical instruments using the principles of elemental resonators like ducts and strings.

The presentation will describe the science-to-music back-and-forth process that has been followed so as to achieve this project, including examples of experiments and auditory demonstrations. A quantitative and qualitative assessment of the concerts given in France and Canada will be finally provided.

Keywords: acoustic teaching, concerts, real time demonstration

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### 1. Introduction

Today, many projects mixing arts and science are proposed in different areas [1, 2]. Particularly, acoustics is a very good candidate for mixing science and arts, since music is very near from many physical problems such as room acoustics and musical acoustics. Some examples of project using art for presenting science exist, such as the "scientific concert" organized at EPFL (Switzerland) [3] presenting research projects by alternating music and scientific presentations. Another project mixing acoustics and music is also presented in France for preventing young people from ear damage. This project, untitled "Peace and Love" [4] presents the history of amplified music and the danger of high levels.

The "scientific concerts" presented in this paper differ from this approach by presenting the physical aspects of acoustics which includes intensity, pitch and timbre and physics of musical instruments. They were created by acousticians and musicians working together at Le Mans Université (France). The aim of this project is to present acoustics fundamentals during a concert for young students or non scientist people. For this, the mix between scientific presentation, real time demonstration and musical interlude enables the public to alternate between focus and entertainment. The music is played by a quintet composed of three saxophones, a double bass (or electric bass) and a drum. Moreover, many sound accessories are used in order to make real time auditory and visual demonstrations.

## 2. Scenario contents

This section presents the two scenarios built for the "scientific concerts". The first scenario was designed to present the three usual characteristics of a sound (intensity, pitch, timbre) and the second one to present the physical principles of musical instruments.

### 2.1 Intensity, pitch, timbre

The scenario designed to present the three characteristics of a sound is presented in this section.

#### 2.1.1 *Sound loudness*

Scenario of the first part (sound loudness) is presented in figure 1 and show how oral presentation, sound demonstration and musical excerpt alternate to make the concept clear for listeners. This scenario is built in three major parts. First part aims at discovering the phenomenon with perception, second part presents physical aspects of sound loudness, then last part is dedicated to decibels and danger of high levels.

The most important aspect of this part is to understand that acoustic pressure is a very low variation of atmospheric pressure and that these very low pressure variations lead to high acoustic levels which can damage strongly the ear. For this, we use a analogy between atmospheric and acoustic pressure as shown in figure 2.

Real time measurements of acoustic levels while musicians playing are performed in the middle of room and at the drummer ears. The effect of the listening duration is also presented in order to prevent young people to listen music at high level during a long time. A original tool, called "acoustical head" developed by the Engineering School in Electronics ESEO (Angers, France) is used in order that young people measure the level of their own music player (mp3).

#### 2.1.2 *Pitch*

The aim of this part is to show the relation between pitch perception and frequency. Pitch is illustrated by listening to different musical instruments and simpler sounds, such as a tuning fork or a glass excited by friction. Drum brushes which produce a random noise which pitch can not be identified are also singed. Specific phenomena such as the missing fundamental are not presented. The signals produced by the pure tone sources are observed on a real time oscilloscope presented to the public. Real time signals enable to introduce the period and the fundamental frequency of a simple signal (sinusoid). The comparisons of two different sounds (tuning fork at 440 Hz and singing glass at 600 Hz) enable the public to link between the perception of pitch and the fundamental frequency represented by the number of oscillations per second shown by the real time oscilloscope. An example of Flash animation explaining the sinusoidal signal is given in figure 4.

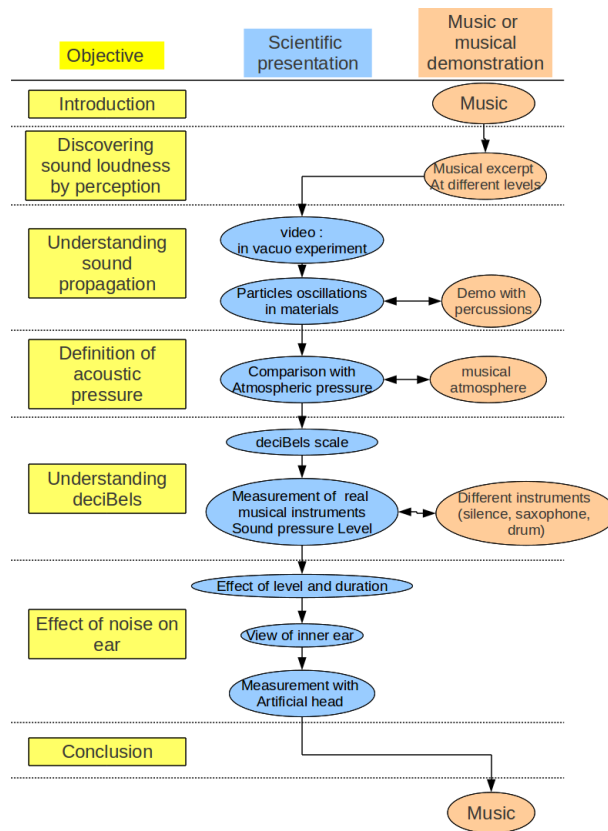


Figure 1: Sound loudness scenario.



Figure 2: Analogy between atmospheric pressure and acoustic pressure. (a) View of the atmospheric effects. (b) schematic view of the acoustic effect.

### 2.1.3 Timbre

The timbre is illustrated by musical examples generated by two different instruments (flute, and soprano saxophone) playing the same tune at the same loudness. Then differences in the sounds emitted by different instruments (tuning fork, flute, saxophone) are analysed in real time using the RTSPEC software [5] or AudioXplorer for Mac OS X. The analysis of the real time spectra of periodic sound (tuning fork, flute, saxophone) gives to the listeners the understanding of the fundamental frequency and harmonics. Differences in the spectra enables to show the differences in timbre. Finally, the signal produced by drum brushes and applause are analysed in real time, which permits to show the concept of non tonal sources like random or pseudo-random noise.



Figure 3: Acoustic head used for measuring acoustic level of music players. Initial green light becomes orange above 85 dBA, for one ear, and red above 100 dBA

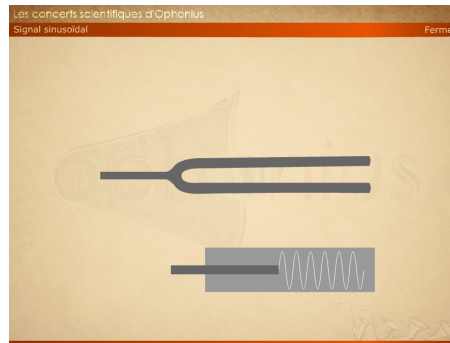


Figure 4: Presentation of the sinusoidal signal drawn by the tuning tip while vibrating, in order to explain the role of the fundamental frequency in the pitch perception.

## 2.2 Physics of musical instruments

This section presents the general principle of the scientific concert dedicated to the physics of musical instruments.

### 2.2.1 General principle of musical instruments

The general organization of musical instruments, splitted into three parts (exciter (called transmitter), resonator and emitter) is first presented with different instruments (double bass, cajon and transverse flute). For each part we show the different elements described in Table 1. Music is played by the three instruments in the background allowing to focus on each element described by the speaker.

Instrument	Exciter	Resonator	Emitter
Double bass	finger	String	soundboard
Cajon	hand	wood plate	wood plate + Helmholtz resonator
Transverse flute	Air jet	cylindrical air column	mouthpiece + first opened hole

Table 1: Examples used for describing the classification of musical instruments



Figure 5: View of the experiment made for measuring the fundamental frequency of a spring mass system, the spring being the horizontal string.

### 2.2.2 Principle of string resonance

First, the sound provided by a string vibration of a double bass is observed in the time domain (oscilloscope). The periodic effect is highlighted. Then, in order to observe the cause of this periodicity, a long string (8 meters) of elastic trap type is plucked. This allows to see the wave travelling along the string. The experiment is repeated twice for two different values of the string tension, which enables to observe a difference in the wave speed.

This periodic phenomenon leads to talk about resonance. The Single Degree of Freedom (SDOF) resonator is then observed and explained, first, with a mechanical system. Experiment is realized with a mass-spring system using the string as a vertical spring (figure 5). Measurement of the period for two different tensions of the string are realized. Explanation of the role of mass and spring for calculating the resonance frequency are provided. Then, an analogous acoustical system, the Helmholtz resonator, is presented with bottles. Demonstration of the effect of different bottle size on the fundamental frequency when blowing into the bottle is presented. Three musicians are playing a musical sequence with three bottle as a musical background and illustration.

The first resonance frequency is then explained in a string by viewing a wave traveling in a string with a video at low speed [6]. Explanation of relation between distance, period and speed and relation with resonance frequency are given. Influence of different parameters (length  $L$ , tension  $T$ , mass per unit length  $m$ ) on pitch is illustrated with the double bass.

Finally, the explanation of harmonics is made using the long string with a weak tension, providing a fundamental frequency weaker than 1 Hz. Two operators are showing the 6 first modes of a string (figure 6). In parallel musicians are playing a rhythm with percussion at the same tempo (we assume that the quarter note corresponds to the fundamental period). This experiment can be criticized because the harmonics of the string (expressed in frequency domain) are illustrated by percussive musical excerpt (in time domain). Musical illustration of the harmonics (which has of course another meaning) is played by the double bass, introducing a new tune.

### 2.2.3 Principle of ducts resonance

After the string instruments, wind instruments are presented only for cylindrical ducts.



Figure 6: View of the experiment made in order to show higher modes of the string in forced excitation.

First, duct is opened at both ends, like for the flute. An animation shows a pressure wave travelling in the duct and radiating at both ends (see figure 7). The relation between distance, period and speed and resonance frequency is explained. The influence of length  $L$  on pitch is illustrated with two musical ducts from boomwhackers [7]. Sound speed is assumed to be constant. In particular, for a lengths ratio of 2, octave is introduced using physical and musical approaches (frequency doubling, singing the octave) The equation  $f = \frac{c}{2L}$  is used to design an instruments with many ducts and to explain briefly the role of side holes in a resonator. It also shown, like in the string, that harmonics can be emitted with an homemade harmonic flute

Secondly, cylindrical duct opened at one end and closed at the other one, like for the clarinet, is exhibited. Clarinet and transverse flute, playing a melody separately and then together, show that the clarinet plays lower than the flute with a different timbre. Simplifying the experience with a cylindrical tube (boomwhaker), the effect of the end closing, leading an octave below, is shown. Real time analysis of clarinet and flute spectra, with the same tube length, shows that the fundamental of the clarinet is indeed an octave lower than the flute fundamental. Physical explanation of this phenomenon is made with a theatrical demonstration of the wave propagation in an opened-closed duct. The duct is mimicked by a string hold by two persons and the presenter mimics the positive and negative pressure traveling into the duct. This shows that the wave needs to travel along  $4L$  (and not only  $2L$  for the flute) at speed  $c$  so that the period is twice greater and the fundamental frequency twice lower than in the flute.

Last aspect concerns the building of strange instruments using demonstration made by Joe Wolfe [8]. Mouthpieces of flute and clarinet are inverted with suitable plastic pieces and played. It has to be said that it is difficult to build quickly (without any simulation) instruments with good intonation.

### 3. Design process

The development of the different shows have followed the following steps. Scientists first listed all items that could be concerned by the topic of the show with some demonstrations ideas (animations, videos or real time experiments ...). A selection of the most relevant and easiest elements to understand and to illustrate was made and a first scenario, with slides, was presented to musicians. Musicians asked a lot of questions to understand the physical concepts and obliged scientists to simplify the scenario. Musical illustrations that can explain the main concepts were thought together. A try error process to



Figure 7: View of the animation made to illustrate the propagation of a pressure wave in an open-open cylindrical duct. The green color represents the negative acoustic pressure while the red color represents the positive acoustic pressure (Animation made by André Almeida).

create sequences with explanations, demonstration, musical illustrations and music was used. Then, a complete and precise scenario with speech, and suitable music, was written. Finally, a work with an artistic coach was realized in order to simplify and transform the conference into a real show (work on motions, attitudes, expressions, intentions in the music, voice ...) with sound and lights creations.

The first show on intensity - pitch - timber was developed in one year (2009) but modified during several years with the experience of the concerts, particularly in high schools, with the pupils' evaluation. The second show on instruments, more complex, was developed during 2 years (2013-2014) and modified in 2018 with the professional stage direction and sound and lights creations.

#### 4. Project assessment

These shows were presented 75 times (in total), for around 10 000 listeners, mainly in high schools (around 70 % of the public), in France but also in Canada (2018). The satisfaction of the public was measured after each concert from 2014 to 2016, with a satisfaction inquiry filled by teachers and pupils. A few points on the complexity of the scientific speech and the show were highlighted. However, this assessment was not systematically provided and can not enable to bring out strong tendencies expressed by this young public. However, one can cite for instance a 14 years-old pupil saying after the concerts: "I usually don't like science, but it was really interesting".

Assessment was also achieved with informal discussions with public in real concert rooms for instance. It appears that the professional stage direction with sound and lights creations has improved greatly the perception of the show. Particularly, the smoothing between music and science is appreciated. It is considered now as a real show that could be distributed in professional cultural network. The initial idea to avoid a musical conference (dichotomous separation between music and scientific speech) seems to be achieved. Therefore, it is easy to interest the public to a science (here acoustics), which is the main goal (the idea is not to understand everything, like in a lesson). However, this point could be even more developed by removing all slides (and so the few equations included) with only real-time experiences, speech and music, leading to a real live show.



## 5. Conclusion

Two shows, mixing science (dealing here with acoustics) and music, were developed from 2009 to 2019 by a group of teachers - researchers - musicians and professional musicians. It is based on different media, mainly real time demonstrations, supported by music and staged. The collegiate work between scientists and non scientists made scientists adapt the scientific presentation and speech to a general non experienced public. Thereby, this educational approach has influenced our own lectures at the university. The professional stage direction has been essential to make easier the perception of the show and so to go easily into the science, even for uninterested people. The show can be given today in high schools but also in show rooms with general public. Prospects of these scientific concerts can concern the realization of MOOC [9], educational booklets for teachers wishing to work on acoustics before the concerts, transmission of this experience to musicians or scientists acting in scientific mediation ...

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