Experimental musical instruments are made with objects put to new use. They can be used for producing musical performance, for teaching music or for producing visual art. Experimental musical instruments can also be used as teaching material for illustrating courses of acoustics, wave physics and sound engineering. An educational toolkit, consisting in a collection of minimal experimental musical instruments has been defined in order to present different classes of mechanisms involved in usual acoustic sources. These classes are described by action verbs describing the gestures required for the sound production: plucking, striking, rubbing, whistling, blowing a reed, buzzing. All instruments are chosen to be illustrative of clear and independent physical phenomena. Their design is minimalist in order to be reproduced at very low cost. The educational toolkit is used in three different teaching situations: 1/ Using experimental musical instruments with Young children (5-10 years old) permits to classify the different types of mechanisms and to use the ears to experiment the links between the pitch and some geometrical characteristics. 2/ The same instruments can also be used in undergraduate courses for acoustic experiments, introducing the structure of musical sounds, the representations of the signals, the models of the resonators which give the relation between the pitch and the geometrical characteristics. 3/ In a master (or engineering school) course, these experimental musical instruments can also be used to test basic and advanced physical models of sound production. Such sound synthesis is based on a minimalist description of the excitation, a modal representation of the resonant element of the instrument, and a finite difference scheme describing the time variation of the resonator acceleration and the radiated pressure. The purpose of the communication is to present the instruments of the educational toolkit and their use in the three mentioned contexts in order to examine the induced pedagogical leverage effects.

Keywords: Experimental musical instruments, Acoustics teaching, Illustrative experiments.
1. **Context and pedagogical approach of the MERITE project**

The connections between science and music are numerous and ancient. Using the natural attractiveness generated by these connections is an efficient lever for acoustics teaching. Musical acoustics activities usually comprise the study of musical sounds, the physical modelling of the phenomena involved in the sound production, the links between the sounds characteristics and the instrument’s making, the perception of complex sounds. All these questions can be explored in a particular manner using experimental musical instruments used in the proposed approach.

Experimental musical instruments are made by using objects of recovery. They result from explorations of incongruous associations between misappropriated objects [1], [2],[3]. Such an approach arouses generally a great interest and is an efficient way for experimentally investigating acoustic phenomena, physics and engineering related to sound sources. In this context, the MERITE project is a scientific dissemination project whose goal is to design an educational toolkit for acoustic teaching. This toolkit comprises a collection of elementary experimental musical instruments chosen and organised in order to present in a structured way the functioning of acoustic sources (Fig. 1).

2. **Design of an educational toolkit based on minimal experimental musical instruments**

The toolkit instruments are called pre-instruments. As there is a pre-history before history, there is a pre- instrument before any instrument. A pre-instrument contains the germ of what will become a musical instrument. However, it does not have the ergonomy and the robustness required for the system to be a real playable musical instrument.

The pre-instruments are chosen for their capability to illustrate clear and independant physical phenomena. For each instrument, the correspondence between the pitch and some geometrical characteristics (length, mass, volume of one element playing the role of a resonator) is highlighted. The design is minimal in order to be reproduced at very low cost. It is known that most of sound sources can be analysed by identifying 3 subsystems playing different roles : the excitation mechanism (which is the physical mechanism at the origin of the sound), a resonant subsystem (which controls the produced pitch) and a
radiating subsystem (which defines the sound level). The selected pre-instruments highlight this structure. The collection of minimal experimental musical instruments is organised using a classification following the excitation mechanisms, described by action verbs associated to the gestures required for the sound production: plucking, striking, rubbing, whistling, blowing a reed, buzzing. Each verb is associated to two instruments: one is simple and can be used by the teacher as demonstrator, the other one is very simple and can be reproduced by a group of students, at very low cost and without any particular technological difficulty. The simplicity is a key factor of success. Among the proposed pre-instruments organised with the 6 verbs, we can cite 3 illustrative examples.

- The CD flute (2-a): 3 CD, glued using double-face adhesive tape are used to produce a basic embouchure for a flute. Blowing this embouchure placed on a glass produces very easily a sound whose pitch is governed by the volume of glass, which plays the role of a Helmholtz resonator.
- The nails violin (2-b): nails driven in a wood block are clamped-free beams, which can be used as resonators. A bow made with nylon wire produces a sound whose pitch is defined by the nail characteristic (geometry and boundary conditions).
- An adhesive belting tape (2-c): a belt made with a scotch tape can be put under tension using a wood spacer. Putting the finger on the adhesive side leads to a clear plucked sound whose pitch is controlled by the length and the tension of the membrane.

3. Pedagogical tests

The analysis of a pre-instrument can be performed by different audiences with distinct goals (Fig. 3): young children (5-10 years old), undergraduate students (20 years old), and master students (22 years old).

- With Young children (5-10 years), the objects and the sounds of the Merite Toolkit are observed, described, analyzed, played and modified. The toolkit is presented as a construction game and the ways the sounds are produced are highlighted. The categorization of the pre-instruments is based on the involved physical mechanisms, which are progressively identified and discussed. The characteristics of the sounds (intensity, pitch, duration) are also discovered progressively. The instruments are also intended to be reproduced in order to constitute an instrumentarium for the class, and ultimately to make music. Currently, ten copies of the Merite toolkit has been produced and have been tested by French teachers.
- The same instruments can also be used in undergraduate courses to introduce the representations of signals (waveforms, spectrum and spectrogram) as well as acoustic models of resonators. In such courses, the pre-instruments can be copied by the students, which are invited to drive their own experimental analysis on their instrument to test the capability of the presented models for explaining what they observe.
- Physical modelling of the sound source can also be presented in more advanced courses (in master
Figure 3: Three uses of the experimental musical instruments of the Merite toolkit: (a) Observations can be performed with young children, (b) spectral analysis can be done with undergraduated students, (c) physical modelling is developed with master students.

or engineering school). In such contexts, the experimental musical instruments are as test benches in order to test basic and advanced physical models of the sound production. These models are based on a minimalist description of the excitation, a modal representation of the resonant element of the instrument, and a finite difference scheme describing the time variation of the resonator acceleration and the radiated pressure. Sound synthesis using such physical modelling is a powerful way for identifying the influence of geometrical variations made on the instrument on the resulting sound. This is a way to identify the physics which can be heard and, as a consequence to make a hierarchy in the physical parameters of a model.

4. Conclusion

A collection of elementary acoustic sources called pre-instruments has been gathered in order to develop a pedagogical toolkit for acoustics teaching (MERITE Project). The curiosity generated by the creative activities consisting in exploring unusual associations between some acoustical excitation mechanisms and different kinds of resonators is an efficient lever for catching attention and for developing teaching activities. Such pre-instruments, even if they are elementary can be used with very different audiences. In this context, it is often shown that the simplicity of an illustrative experiment is often a key factor of success.

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