

Educational ICT Tools to Improve Wave Physics Understanding

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The difficulties connected with the teaching of mechanical waves (and sound in particular) are mainly due to the wide use of complex mathematics, very soon not easily accessible to the majority of non-specialists. To overcome this situation and scaffold the understanding of such phenomena it is important to extend the use of specific learning tools able to take advantage of common representations of phenomena to build correct descriptive as well as interpretative models. In this paper we present experiments and simulations belonging to a Teaching/Learning proposal whose main aim is to help users to better understand the sound propagation process through different media.

Introduction

In these last years many research studies have pointed out relevant student difficulties in understanding the physics of mechanical waves [1]. Investigations [2] have shown that the difficulties met by students in this context mainly involve the mathematical description, which requires the use of two-variables functions, the comprehension and the application of the superposition principle, often mistaken as a mere overlap of waveforms, and of the role played by the properties of the medium through which waves are propagating. It has been shown [3, 4] that university as well as secondary school students show very peculiar difficulties in the representation of mechanical wave propagation. For example, they map object-like properties to mechanical waves and describe a wave pulse travelling through an elastic medium like a ball moving through the air. These researches show that the medium through which waves propagate is usually thought by students as playing a passive role and the propagation properties are wrongly considered as depending on the way the pulse has been generated.

To overcome this situation and scaffold the understanding of wave phenomena we adopted and extended the use of specific learning tools able to take advantage of common representations of phenomena to build correct descriptive as well as interpretative models. The use of information and communication technology tools makes possible to easily link the common ideas about the real world phenomena to specific physical variables relevant for a correct scientific description of the phenomena, without a great mathematical load. In fact, computer assisted data acquisition systems (often known as MBL systems [5, 6]) or modelling environments can greatly enhance students' learning and stimulate their interest, mainly if these are connected to pedagogical methods engaging students in activities addressing their cognitive difficulties, identified by physics education research [7].

The designing, in collaboration with school teachers, of Teaching/Learning Sequences (TLS) in various scientific fields is becoming a field of research worthy to note [8]. It is based on the theoretical developments on teaching and learning as a constructive activity and uses different frameworks. Our approach is based on the assumption that the physics content as well as pupil's knowledge and cognitive approach are relevant in order to affect pupil's

modelling processes of physical world [9]. Consequently, it can be framed in the integrated constructivist approach [10].

In this paper we will discuss some experiments and simulations making part of a TLS regarding the elastic wave propagation. The TLS is built in the framework of a research project aimed at stimulate appropriate knowledge representations improving conceptual understanding through the construction of appropriate mental models [11], by using informatics tools.

Main characteristics of the Teaching Learning Sequence about sound propagation

The first characteristic of our approach is the choice of a "pulse" approach instead of the classic "sinusoidal" one, mainly to have a better representation of a real propagating perturbation. Physicists usually deal with a propagating pulse as a whole and attribute to the pulse some object-like features (shape, width, speed etc.). However, they know that two levels of representation are necessary: the first one involves the analysis of the pulse as a whole and the second one describes the behaviours of the atoms/molecules of the medium. Students find very difficult performing the shift from one level to another one. For this reason we have preferred to carry out in parallel these two levels through a continuous shift between them.

The starting point was the analysis of the sport stadium wave (also known as the "Mexican Wave" or "La Ola") and its description in terms of propagation of an event (standing up or sitting down), then we analysed the propagation of a sound pulse (the signal) in different media (water, solids and air). The T/L sequence is structured on three points: 1) analysis of the behaviour of signal sources; 2) influences on the signal due to the propagation medium; 3) analysis of the behaviour of signal receivers. We here analyse the point 2) which is, in our opinion, mainly responsible of the wrong representations, described above. This part involves the analysis of experiments essentially focused on the measurement of the sound speed in different media (air and metals) and two simulations (performed using the Interactive Physics [12] and NetLogo [13] environment).

Measuring the sound speed

The measure of sound speed in air is a routine task [14], but measurement of sound speed in solids, especially in metals, can be more difficult due to the much higher values with respect to air. A demonstration of the propagation of mechanical wave pulses in a metallic rod can be obtained by producing a shock wave at one end of a fixed rod (by means of a body colliding with it) and observing a small pendulum bob, initially in contact with the rod's other end, displacing after a definite time interval.

The experimental set-up is shown in Fig. 1. A metallic rod of length L is secured to a heavy desk by means of a single vice placed near one of the rod's ends. A d.c. power supply is connected to a metallic pendulum bob, initially in contact of one end of the rod and, through MBL voltage sensors, to another metallic body, that can be made hitting the other end of the rod. The electric circuit is closed when both the colliding metallic body and the metallic pendulum bob are in contact with the rod. The idea is to hit the rod with the body when the pendulum bob is at rest, in contact with the rod; the action closes the circuit, so that a d.c. voltage, due to an external power supply, is detected by the voltage sensors. .

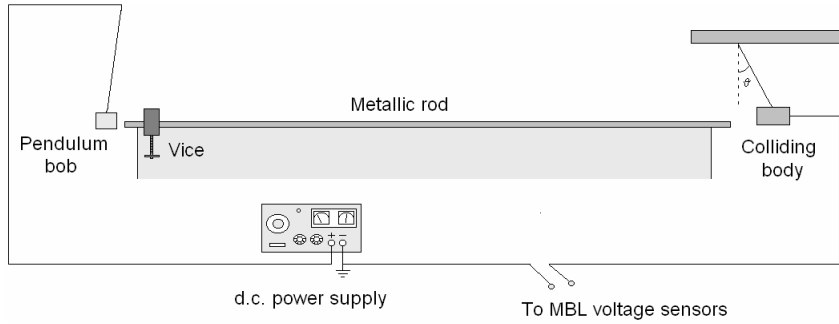


Figure 1: Sketch of the experimental apparatus. A metallic pendulum bob, initially in contact with one of the rod's ends displaces when the perturbation generated by a body colliding with the other end of the rod arrives to it. The pendulum bob is a light, polished metallic cube.

The detected signal only lasts until the circuit is closed, i.e. from the moment the wave is generated by the body colliding with the rod to the moment the bob displaces, actually opening the electric circuit. If we are able to measure the actual time the wave pulse takes to go through the two ends of the rod, the speed of the acoustic wave can be obtained from the known rod's length.

Measurements were performed by using several aluminium and brass rods, of different length and cross-section. Figure 2a reports a typical signal detected by the MBL system with the 2.995 meters long, 1.00 cm cross-section diameter aluminium rod. An enlargement of the detected voltage peak is reported in figure 2b.

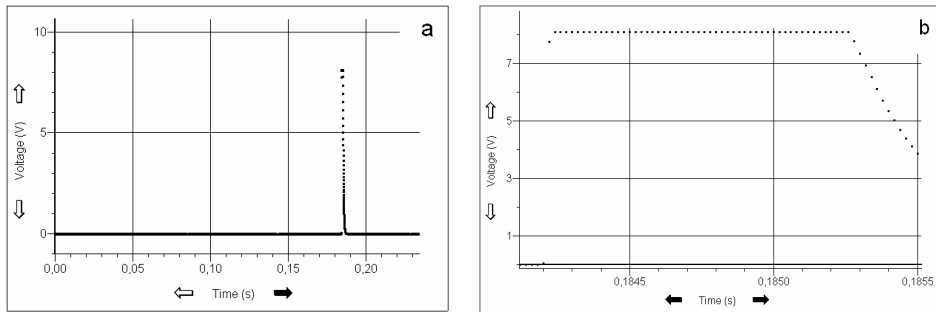


Figure 2: (a) A typical signal detected by the voltage sensors when the electric circuit described in figure 1 is closed by a body (mass = 398.0 ± 0.1 grams) colliding an end of a 2.995 ± 0.001 m long aluminium rod, of mean cross-section diameter equal to 1.00 ± 0.01 cm. The MBL sampling rate is set to 50000 samples per second.; (b) An enlargement of the peak of the voltage signal reported in (a).

When performing measurements of sound speed with this method, one has to consider that the measured times include the time needed by the wave pulse to travel along the rod plus a delay time, δt , that can be considered as the time needed by the bob to actually lose contact with the rod [15]. This involves that such a delay time depends only from the nature of the contact between the rod and the pendulum bob (i.e. from their material and the contact surface) and from the impulse the colliding body applies to the rod during the stroke. As a

consequence, by using two rods of different lengths but equal cross-sections, the influence of δt on the calculation of the speed of the wave pulse in the rod could be eliminated.

If we denote the lengths of the two rods by L_1 and L_2 (with $L_1 > L_2$) and the corresponding time intervals measured by our experimental apparatus by T_1 and T_2 respectively, we have

$$T_1 = \frac{L_1}{c} + \delta t \quad (1)$$

$$T_2 = \frac{L_2}{c} + \delta t \quad (2)$$

where c is the sound speed in the rod.

From (1) and (2) we obtain an expression for the sound speed in the rods:

$$c = \frac{L_1 - L_2}{T_1 - T_2} \quad (3)$$

Measurements were performed by using brass ($L_1 = 1.995 \pm 0.001$ m and $L_2 = 3.010 \pm 0.001$ m) and aluminium ($L_1 = 2.014 \pm 0.001$ m and $L_2 = 2.995 \pm 0.001$ m) rods, all with mean cross section diameter $D = 1,00 \pm 0.01$ cm. The mean values for T_1 and T_2 in the brass and aluminium rods are reported in Table 1, as well as the best estimate for the sound speed values.

Table I

Mean values of T_1 and T_2 in aluminium and brass rods, calculated on a 10 measurements base, and the relative values of sound speed. Errors in T_1 and T_2 are the standard deviations of the means for each set of data.

Metal	$T_1 (\cdot 10^{-3} \text{ s})$	$T_2 (\cdot 10^{-3} \text{ s})$	Speed value (m/s)
Aluminium	1.05 ± 0.02	0.84 ± 0.02	4700 ± 200
Brass	1.19 ± 0.02	0.92 ± 0.02	3610 ± 140

The obtained values are in good accordance with the accepted values of the speed of longitudinal waves in aluminium and brass rods, that are 5000 m/s and 3480 m/s, respectively [16].

Another way to measure the sound speed in solids is the well known method of vibrating rods [17, 18]. A thin rod is clamped at its midpoint and an acoustic wave is generated at one end of the rod by a sound generator or by rubbing one of the rod's end by the thumb and the forefinger fingertips. In this way stationary longitudinal waves can be established. The rod oscillations are detected by means of a MBL sound sensor and analysed in their frequency components. An estimate for the speed of longitudinal waves in the rod is then found by using the well known resonance relation between the fundamental frequency in the rod and the length of the rod itself:

$$f_1 = \frac{v}{2L} \quad (4)$$

where v is the velocity of sound in the material.

Figure 3 reports the graph of resonance frequency as a function of the reciprocal of length for three different sets of aluminium, copper and brass rods. Data show a clear linear relation between the resonance frequency and the reciprocal of rods' length, in accordance with (4).

Lines were fitted to data, by means of the least squares method and the slope of each fitted line was used to find estimates for the value of speed of sound in each specific material.

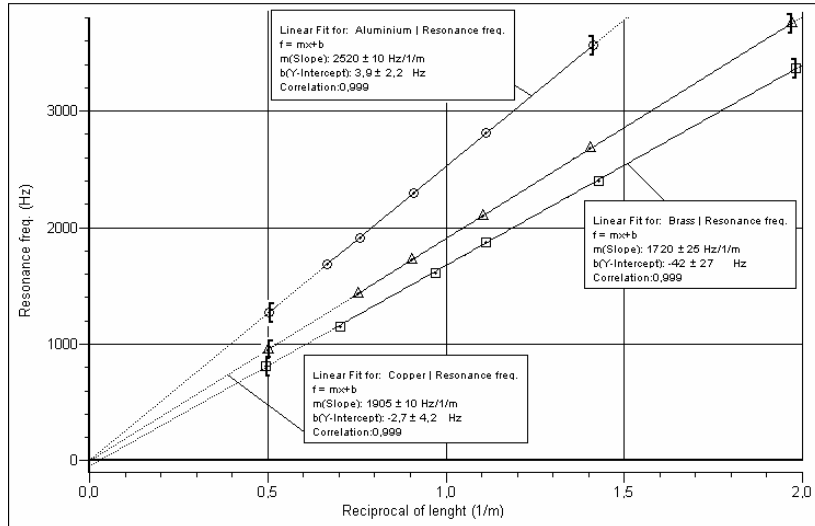


Figure 3: graph of mean values of resonance frequency as a function of the reciprocal of length for each set of different material rods and the correspondent best fit lines and parameters.

Table II reports the calculated values of the speed of sound in the different materials. Values are taken as double slopes of the fitted lines to experimental data of resonance frequency vs. reciprocal of rods' length. Again, they are in good accordance with the accepted values of the speed of longitudinal waves in aluminium, brass and copper rods.

Table II

Values of the acoustic wave speed in aluminium, brass and copper rods measured with the standing waves method described above.

Metal	Speed Value (m/s)
Aluminium	5040 ± 20
Brass	3440 ± 50
Copper	3810 ± 20

Simulations

Simulations reproduce the behaviour of a linear chain of identical masses interacting through a linear nearest-neighbourhood coupling (to simulate propagation in a solid, see fig. 4a) and a bi-dimensional array of small masses interacting through elastic collisions confined into a rectangular container delimited by two moveable pistons (to simulate propagation in a gas, see fig.4b) . A transversal or longitudinal pulse may be produced by forcing the first mass in the chain or the first piston to move back and forth. In this way, it is possible to visualize the pulse propagation along the chain and inside the container (screen-shots are reported in Figs. 4a and 4b respectively). By acting on sliders the user is also allowed to change:

1. the time duration of pulse
2. the elastic constant of springs or the average speed of particles (for pulse propagation in air)

3. the mass of spheres

Students are guided in using the tool by means of work-sheets. They are usually asked to measure the pulse propagation speed by reading on the position-time graph, drawn for two different particles, the time distance between two peaks of the pulse curves. In particular they are requested to collect speed values as function of involved simulation parameters in order to evidence that pulse propagation speed is independent from pulse properties associated to the motion of first sphere in the chain and dependent only from elastic and inertial properties of the chain.

Regarding the pulse propagation through the array of randomly moving particles, students are asked to measure the pulse propagation speed and to compare it with the average random speed of particles.

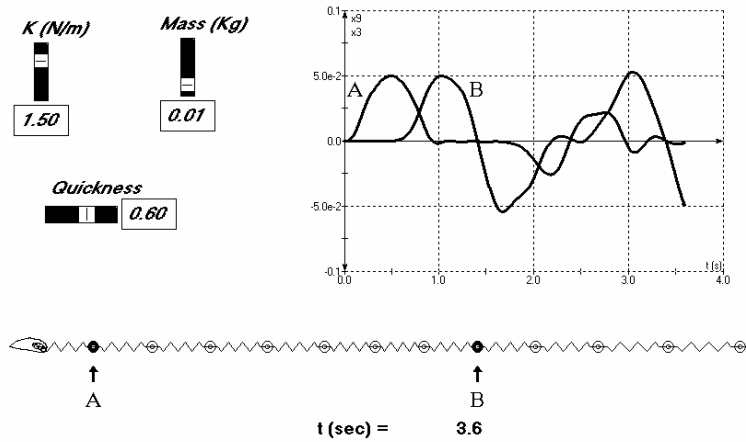


Figure.4a: Pulse, propagating in a linear chain of masses connected by springs

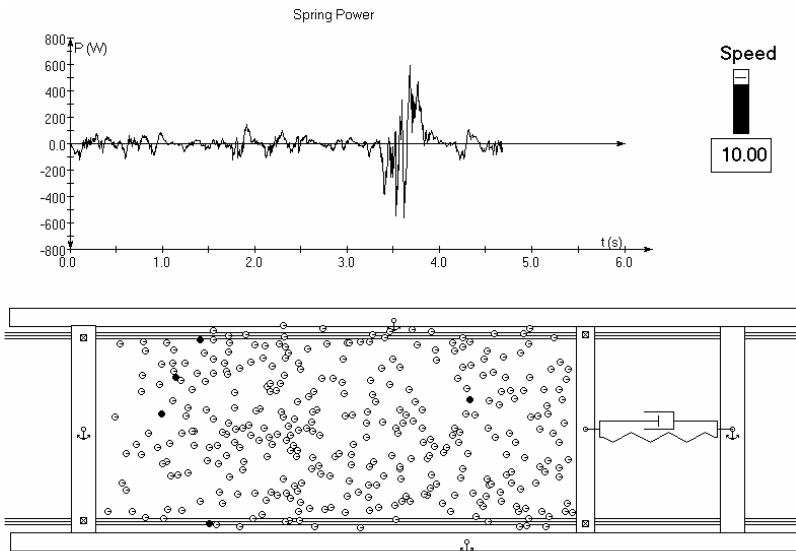


Figure.4b: Pulse, propagating in a gas of particles, registered by the spring on the right

Conclusion

The developed pedagogical materials focus on helping pupils to apply a set of reasoning resources they were not effectively using in describing sound waves. The hypothesis underlying the design of our TLS stays in the ascertainment that students show to have the conceptual resources [19] necessary to understand propagation of perturbations in many fields of everyday life (for example the sport stadium wave). In terms of conceptual resources, we find that the appropriate resources for the description of wave phenomena are mostly stimulated by an approach based on individual agents representation. On the other hand, the approach to waves based on the properties of sinusoidal and/or other periodic waves focus mainly on the periodicity of a wave and not on its propagation. For this reason we find that, in order to explain the role of medium in the propagation process, a pulse approach can be more effective. Moreover, we have found that appropriate tools, able to help pupils in visualizing behaviours at micro-level and able to stimulate them to think of experiments involving mechanisms and cause-effect relationships, play an important role in understanding.

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