Specially Designed Sound-Boxes Used by Students to Perform School-Lab Sensor-Based Experiments, to Understand Sound Phenomena

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Ch. Tsihouridis[1], D. Vavougios[1], G. S. Ioannidis2, and S. Paraskeuopoulos[1]
[1] University of Thessaly, Volos, Greece, [2] University of Patras, Patras, Greece

Abstract—**The research presented herein investigates and records students' perceptions relating to sound phenomena and their improvement during a specialised laboratory practice utilizing ICT and a simple experimental apparatus, especially designed for teaching. This school-lab apparatus and its operation are also described herein. A number of 71 first and second grade Vocational-school students, aged 16 to 20, participated in the research. These were divided into groups of 4-5 students, each of which worked for 6 hours in order to complete all activities assigned. Data collection was carried out through personal interviews as well as questionnaires which were distributed before and after the instructive intervention. The results shows that students' active involvement with the simple teaching apparatus, through which the effects of sound waves are visible, helps them comprehend sound phenomena. It also altered considerably their initial misconceptions about sound propagation. The results are presented diagrammatically herein, while some important observations are made, relating to the teaching and learning of scientific concepts concerning sound.**

Index Terms—**ICT in education, sensors, MBL, Microprocessor Based Laboratory, physics education, physics teaching, school-lab experiments, sound, sound wave propagation, sound waves reflection, hands-on experiments, data logger, computerised experiment, evaluation and outcomes assessment, new learning models and applications, real world experiences**

I. INTRODUCTION

During the past thirty years a large number of studies [1] have examined students' and teachers' understanding of numerous scientific concepts. These studies indicate that students initially fail to understand natural world phenomena while, as they try to grasp an understanding of their own, they do develop some personal ideas, theories and models to explain their observations. These students' ideas are in many cases in conflict/contradiction with currently accepted scientific theories, while their formation is a constant and evolving process (distinct for every individual).

Students' and teachers understanding of Sound is a good example for the pervasive nature of the dichotomy between alternative ideas from the one hand and scientifically accepted concepts from the other. Although Sound is a science topic not far from the students' everyday experience, many researchers report [2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21] that this area exhibits many pitfalls in understanding for a lot of the principles involved. In a number of studies concerning students' ideas about Sound it was found the occurrence of a great number of misconceptions [5, 22]. For example, students may not understand how sound generation and propagation occur, while investigations about students' models on sound propagation indicate [6, 7, 8, 9, 14, 15, 20, 21, 23, 24, 25] that two alternatives are used in preference to the scientifically accepted (and correct) wave model, these two being the "entity" and the "hybrid" models. Hrepic et al.[6] believe that ".....in the "entity" alternative model sound is a self-standing "entity" different from the medium and propagating through it.... all other observed alternative models are composed of "entity" and "wave" components, but at the same time they are distinct from each of the constituent models...". Hrepic et al. [6] called these models "hybrid models". According to Bisesi and Michelini [24] "….. arising of such a conflict between wave and particle-like models of sound does directly link to one of the most troublesome problems underlying knowledge structure in modern physics: coupling between sources and medium in effective field theories ……". Houle and Barnett [22] indicate that according to the literature [4, 11, 13, 20, 21] students tend to hold a materialistic view of sound. They suggest that "... students view the Sound as a substance with the physical properties of matter rather than a process of energy transmission through a substance... ".

One of the uses of ICT in large Physics experiments is to allow the direct data-taking, in other words the accurate real-time recording, storage, processing of experimental data. At the same time, all processed information is graphically depicted in suitable easy-to-understand diagrams allowing the control of the experiment; high energy physics is one such example.

The abundance of cheap processing power, nowadays, allows the use of such techniques in the school laboratory, thereby helping students focus their efforts towards the interpretation and (ultimately) the easier comprehension of the observed phenomena, as these develop in real time. Such a setup, using sensors as primary data-taking devices, can be used to teach the concepts of sound generation and propagation and also to easily guide students to the scientifically accepted model.

II. RATIONALE OF THE PRESENT STUDY AS TO THE METHOD AND THE TOPIC CHOSEN

During the laboratory exercise, students usually spend most of their effort to ensure correct operation of measuring devices, and flawless data-taking (and recording) of these data. Little attention is paid in observing the phenomena as they develop, the educational value of the whole process being only partly successful in most occasions. Students can hardly be blamed for this, as they have far too many tasks to complete while the experiment unfolds. Clearly, some help would be beneficial here, and this could take the form of automated data collection and some rudimentary data analysis.

The use of sensors, automated data loggers and suitable software, allows the design of experimental setups that promote student concentration on the overall appreciation of the physical process in its entirety, potentially improving students understanding. Main benefits from such a change would include allowing more time for students to reflect and discuss the phenomena observed amongst themselves, the teacher intervening to answer to student's queries and (at a more advanced level) perhaps discuss what students initially expected that the measurements would show, and whether or not their expectations were fulfilled, and if not why. Side benefits would include (at times of limited space and/or budget) the possibility of a larger number of students using the same experimental apparatus (i.e. while the previous group discussed with the teacher).

Sound generation and propagation phenomena represent an ideal trial for the use of data-logger methods in school-lab environment. Despite the simplicity of the sensors, the all-important device calibration and the necessity of rapid data-taking and recording present far too high a workload to the students, when done conventionally. It is no wonder, therefore, that most educators choose not to offer such "sound generation and propagation" lab experiment at school, despite the fact that this forms a considerable part of the syllabus for many Vocational Schools: they know by experience that students only marginally gain by it - when done conventionally, that is.

III. EDUCATIONAL HYPOTHESIS

The hypothesis of the present educational research was as follows: *The use of simple but carefully designed experimental setups, through which the effects of sound waves are visible to students, utilising microphone sensors, coupled with the use of suitable data collection and data processing software, promotes the overall comprehension of sound phenomena by students attending Vocational School classes.*

IV. DESIGN AND CONSTRUCTION OF THE EXPERIMENTAL APPARATUS

The experiment was designed and set-up for the purpose of the present study and was composed of the following components:

1. One personal computer (PC).
2. Test tone generator (in the form of application software and used as an audio-frequency generator).
3. An audio signal amplifier, to amplify the PC audio-output signal.
4. Two audio-frequency electrostatic microphones type DT 008 made by Fourier. These have output of ±2.5 Volts, sensitivity 57-117 dBA, and frequency response from 35Hz to 5.8 KHz.
5. Data Logger, type: MultiLog DB 526.
6. DB-Lab application software, suitable for the above.

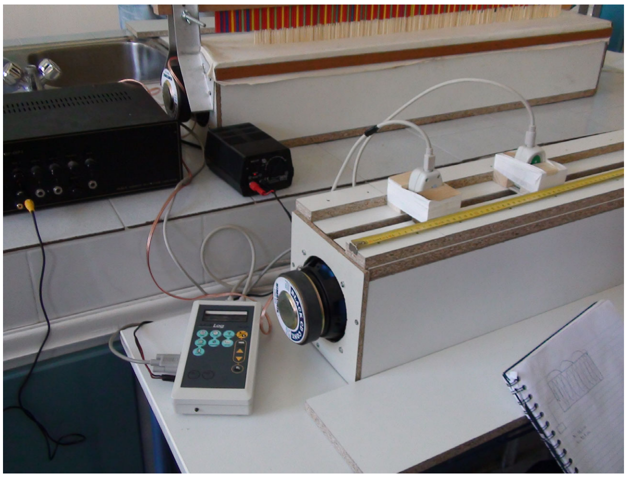

Figure 1. Audio boxes, loudspeakers, data-loggers, amplifiers

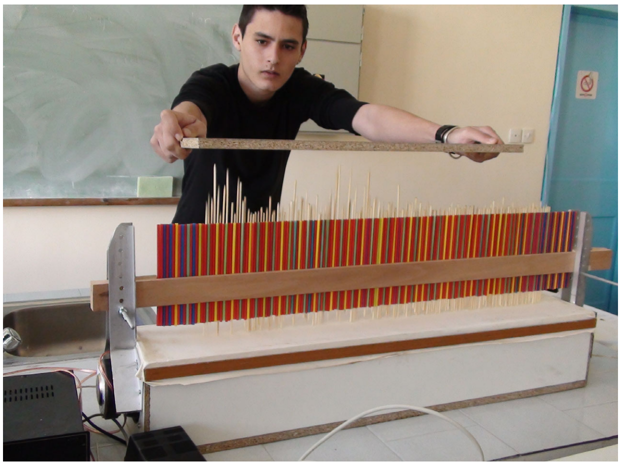

Figure 2. Membrane and wooden rods vibrating in their liners

7. Two inexpensive SimSonic CWD 520 audio-woofers, of 15 cm cone-diameter, 8 Ohm nominal impedance, 120 W RMS max.
8. Two enclosures designed and constructed in the laboratory especially for this school experiment.
   a. The first of these enclosures is a squared section rectangular box internally sized 15cm x 15cm x 90cm. Three of the long (i.e. 15cm x 90cm) sides are made from loudspeaker-grade high density chipboard, and are considered acoustically inert for the purpose of the present study. On the fourth of the 15cm x 90cm sides the box closes using an elastic membrane. This was inexpensively made by stretching a balloon, and was held in position by an appropriate frame (Figure 2). While the one of the small squared-section (i.e. 15cm x 15cm) sides is also made of chipboard, the opposite one is occupied by one of the aforementioned woofers – suitably mounted.
   b. The second box is similar in dimensions to the first, the major change being that instead of having one side being effected by the flexible membrane, this (upper) side is also made by high density chipboard, with the provision of having a long slit of 1 cm width, suitable for the insertion of acoustic sensors (the aforementioned microphones) at various positions along the whole length (fig. 1 & 3). Furthermore, this box was constructed so as to

have variable effective length – for experimenting with acoustic standing waves at various frequencies. To do this, the small (i.e. 15cm x 15cm) side opposite to the one with the loudspeaker could slide inside the squared section, piston-like, and could be secured internally at any point. Some additional experiments could, thus, be implemented.

V. THE EXPERIMENTAL SETUP

The software-based audio-frequency generator is used to produce any single frequency. The analogue audio signal is thus created at the computer's audio-output jack. This is subsequently amplified (by the external amp) at a level appropriate for the two woofers attached to the audio-boxes of the experiment. The speaker cones vibrate, thereby creating sound waves, whose frequency and volume depend on the signal received. As these are transmitted within the enclosed space of the audio-boxes, static sound waves are created, which force the membrane (of the first box) to vibrate in such way that the membrane surface can be seen undulating with maximum and minimum amplitude. To emphasize the phenomenon and generate additional educational impact amongst the students, an additional over-structure has been built.

A large number of low-mass wooden rods have been placed inside plastic drinking straws acting as liners for their low-friction movement. These were placed in series along the length of the audio-box and were held in place by the separate over-structure positioning the straws in straight line (see figure 2) and perpendicular to the membrane. The wood-rods were free to slide in their plastic liners and, as they were in contact with the membrane beneath them, they vibrated giving to all students a most impressive overview of the energy transfer via sound waves (fig 4 & 6).

Simultaneously, the same signal was fed in parallel to the woofer of the second audio-box, in which similar standing waves were produced. There, the audio sensors were installed at the top of the box, the signal from which was collected by the aforementioned data logger, and transferred to the computer that analysed the data in real time allowing the students to observe the signal on the screen. By observing the shape of the signal on the screen, and by measuring distance between the sensors, the students were able to better comprehend the various characteristics of static sound waves. This was done by encouraging them to solve the relevant physics equations on standing waves, and to compute the results expected to be observed.

All students were thrilled by the experiment, and especially so by the visual impact of the sound that could be seen by the wooden rods. To make these "dance to the sound", after the end of the measuring process, students were allowed to replace the single frequency audio generator by a music-playing iPod, much to their delight (Fig. 6).

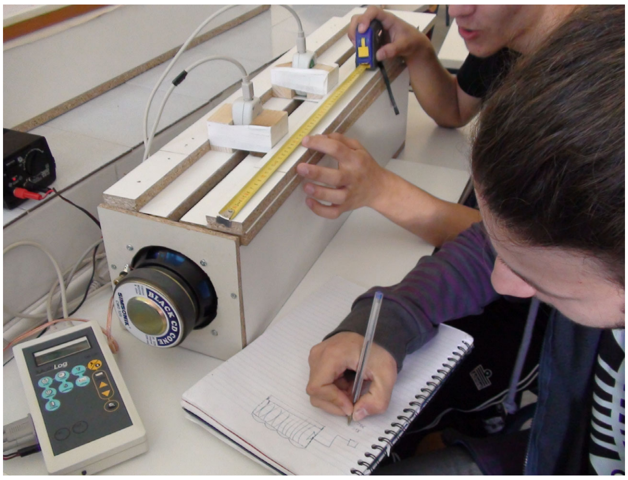

Figure 3. Second audio box with audio sensors in place

Figure 5. Measuring the position of audio sensors

Figure 4. Altering the amplitude of audio signal sent to woofer

Figure 6. Fruitfully exchanging educational ideas in class

VI. THE RESEARCH

During the present research effort, **71** Vocational School students of first and second grade, aged from **16** to **20**, studied phenomena, which concerned sound: sound definition, sound production, sound wave propagation, and sound characteristics. For their experimental practice, they used the simple purpose-designed teaching apparatus, described above.

The research was carried out in four successive phases of instructional intervention, and lasted for a total of **five hours** of instruction for each student. An additional hour was devoted to the detection of possible changes in students' initial ideas on sound phenomena (this being the fifth phase). More specifically:

A. 1st Phase of intervention (1 hour)

All students of both grades who participated in the experiment were given a questionnaire, through which their initial ideas relating to phenomena concerning sound and sound wave properties were detected. An open discussion along with personal interviews followed, to clarify their views, concerning the procedure, which was about to follow.

B. 2nd Phase of intervention (1 hour)

An explanation of the function of the various components of the experiment was carried out by the teacher, in addition to analysing the method of operation of the sensors, the measurement, the data processing, and finally the interpretation of the information taken as experimental output.

C. 3rd Phase of intervention (2 hours)

It was carried out by groups of four or five students, each of which was given different distances of the sound sensors from the sound source (loudspeaker) to study. Moreover, the students experimented (in their own will) with different frequencies, changing the volume of the sound source as well, observing the effects of these changes in the apparatus, processed their measurements, and presented their results.

D. 4th Phase of intervention (1 hour)

The students gave individual oral interviews to the researcher. An open discussion followed, during which students' ideas, as regards the complete experimental process and its assessment were detected and recorded.

E. 5th Phase of intervention (1 hour)

Later, the same students took the initial questionnaire again, in order to detect any changes to their ideas as regards the sound phenomena.

VII. DATA ANALYSIS

An overall analysis of the data collected followed, concentrating in minimising systematic errors. Any remaining systematic errors were subsequently evaluated, and were determined to be at the level of 2.0%. The statistical variance was computed and the Bessel-corrected standard deviation was calculated for each and every data point presented herein. The total experimental error was then calculated by adding in quadrature the systematic with the statistical errors, these two errors being by definition independent.

VIII. THE RESULTS

The analysis of students' answers, before the experimental-instructive intervention, showed that a large percentage of them did not generally have clear ideas on the issues that were subsequently taught, although they did possess some rather confused ideas about the concept of sound itself, as well as the one about sound-wave propagation. The researchers found that students approached the phenomena verbally and superficially, this in itself preventing them from any deeper scientific understanding.

The questionnaire contained 15 questions. More specifically, the first question dealt with the definition of sound. A significant percentage of students could not define the concept of sound either correctly or partially correctly, before the instructive intervention. The percentage of students that gave correct or partially correct answers was 19.7±5.2% (see figure 7). After the instructive intervention this percentage increased considerably to 46.5±6.3%. Nevertheless, 1 out of 2 students was unable, once again, to correctly define the concept of sound

Questions 2 and 13 (of the test) concerned the production and propagation of sound waves from the sound source. A small percentage of students answered correctly these questions. For question 2 (see figure 8), where sound is produced by the blow of hands, the percentage of students that answered correctly/partially correctly initially was 7.0±3.6% while after the intervention it reached the 26.8±5.7%. Furthermore, in question 13, which deals with how the sound of the bell is produced, the percentage of students who answered correctly and/or partially correctly before the instructive intervention was 11.3±4.3% (see figure 9) while after the intervention this increased to 29.6±5.8%. That is to say, almost 1 in 3 students could not, even after the intervention, give a correct interpretation of the sound waves production and propagation phenomena.

Questions 8 and 15 concerned with whether sound waves transfer energy or matter. The percentage of students that answered correctly and/or partially correctly these questions was 40.9±6.2% and 36.6±6.1% respectively before the intervention (see figures 10 and 11), whereas after the intervention this percentage increased to 54.9±6.3% and 50.7%±6.3%. Nevertheless, once more, nearly 1 out of 2 students was unable to answer questions correctly.

Questions 3 and 14 concerned with the propagation of sound waves in the void. In question 3, which concerns the propagation of sound on the surface of the moon, the percentage of students that answered correctly/partially correctly before the intervention was 63.4±6.1% and increased to 77.5±5.4% after the intervention (see figure 12). In question 14 that dealt with the propagation of sound from the explosion in space, the percentage of students that answered correctly and/or partially corrected was 32.4±5.9% before the intervention (see figure 13), while this increased to 56.3±6.3% after the intervention. This differentiation in students' answers in questions 3 and 14 can be attributed to the misconception originating from cinema-film explosions, where any sound can be heard by the audience no matter where the camera is, thus forming the misconception that sound is propagating even through empty space.

In Questions 4 and 12 we deal with the propagation of sound waves through an elastic medium. The percentage of students that answered these questions correctly and/or partially correctly was 57.7±6.2% and 53.5±6.3% respectively before the intervention (see figures 14 and 15), while these improved, respectively, to 76.1±5.5% and 76.0±5.5% after the intervention.

For questions 5, 6, 9 and 10, (see figures 16 to 19), which concerned the reflection of sound waves on various types of surface, the percentage of students that answered them correctly/partially correctly before the intervention was 76.6±5.6%, 63.3±6.1%, 56.4±6.3% and 56.3±6.3%, respectively. These percentages increased afterwards to 80.3±5.2%, 84.5±4.8%, 76.1±5.5% and 71.8±5.7%, respectively, thereby showing a consistent improvement throughout.

In Questions 7 and 11 we deal with the issues of attenuation and the absorption of sound within materials. Question 7 concerns the attenuation of sound by the heavy curtains inside closed rooms like cinemas or theatres, while question 11 examines what happens in such rooms when their surfaces are covered by a sponge-like material stuck on them. The percentage of students that answered question 7 correctly and/or partially correctly was 53.5±6.3% before the intervention (see figure 20), while this increased to 80.3±5.2% after the intervention. The percentages for question 11 were 71.8±5.7% and 80.3±5.2%, respectively (see figure 21).

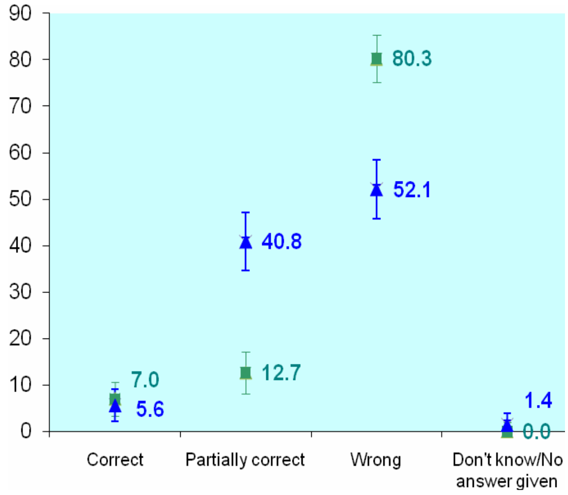

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Figure 7. Q1. Definition of sound

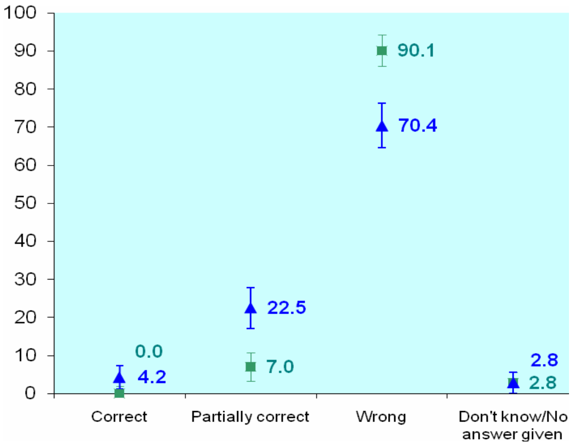

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Figure 8. Q2. Production and propagation of sound by applause

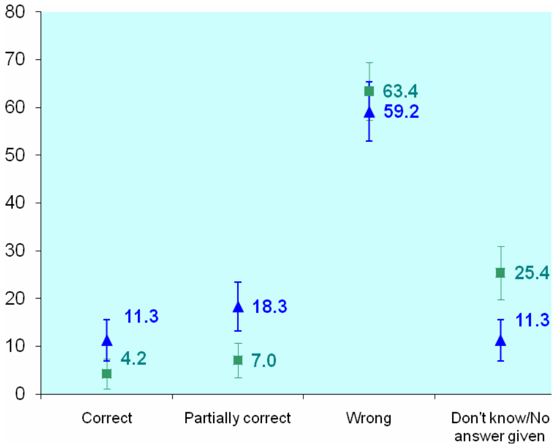

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Figure 9. Q13.Production and propagation of sound created by the ringing of a bell

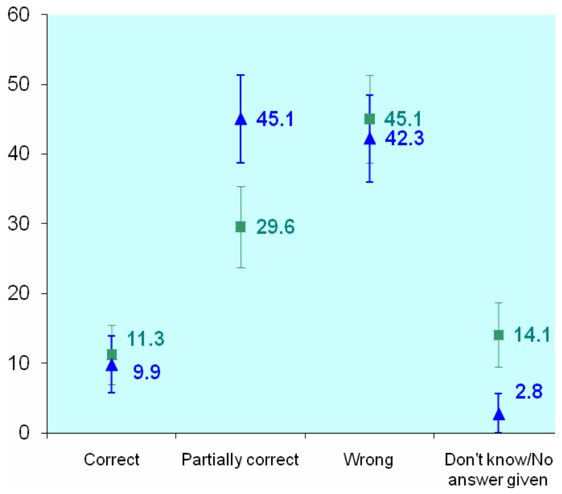

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Figure 10. Q8. Transfer of matter or energy through sound waves?

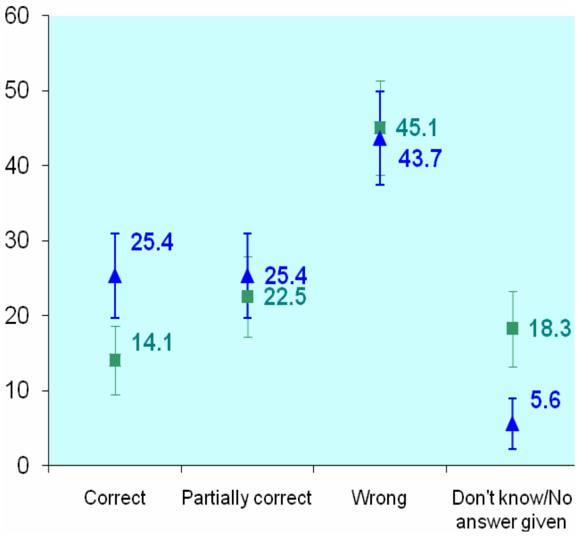

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Figure 11. Q15. Is it possible for an earless animal to feel sound-waves?

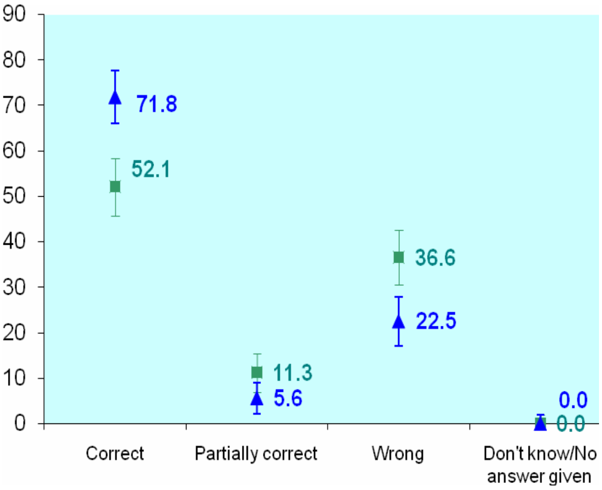

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Figure 12. Q3. Propagation of sound waves on the surface of the Moon

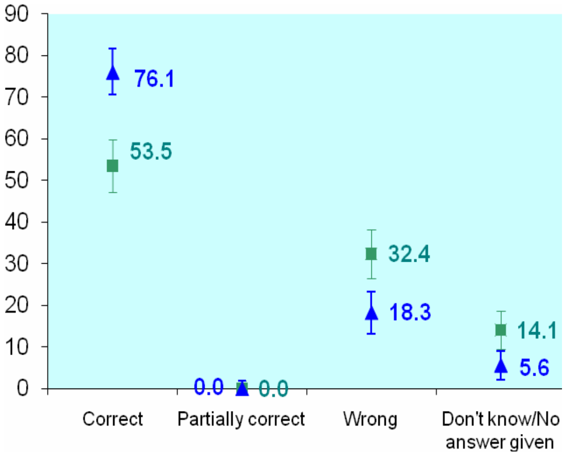

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Figure 15. Q12. Propagation of sound velocity in elastic mediums (comparing sound velocity vs. light velocity)

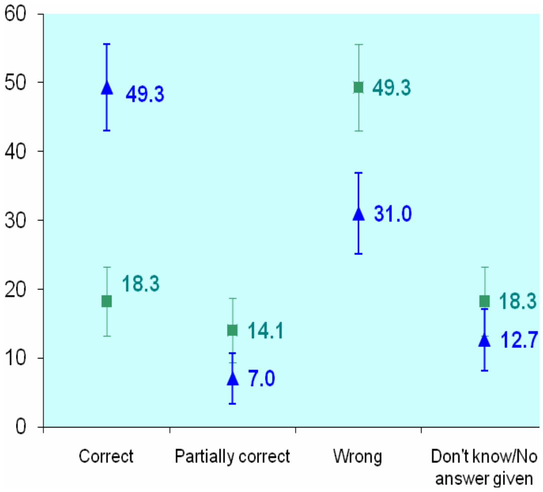

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Figure 13. Q14. Propagation of sound waves in (empty) space

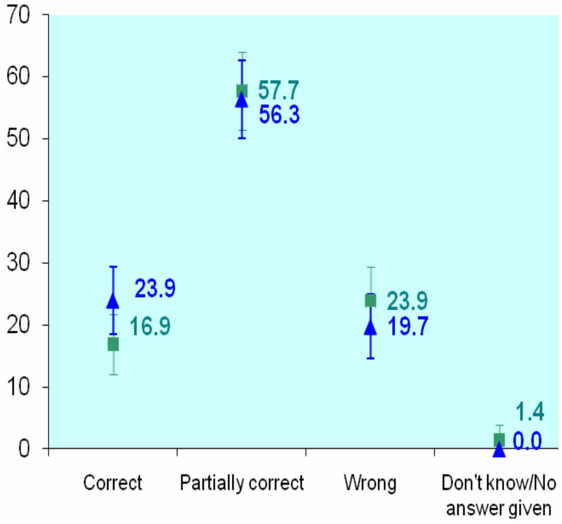

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Figure 16. Q5. Reflection of sound waves in a classroom

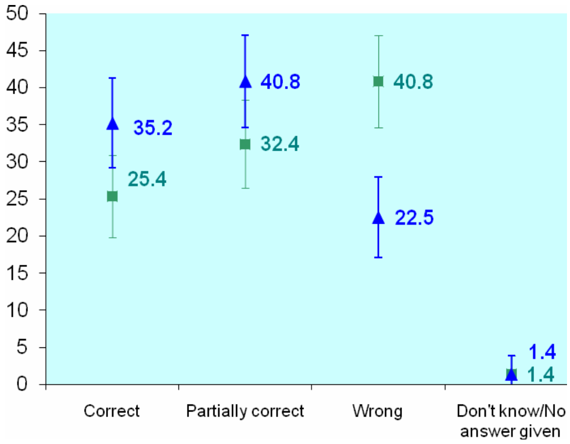

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Figure 14. Q4. Propagation of sound velocity in elastic mediums (propagation in railway tracks vs. propagation in the air)

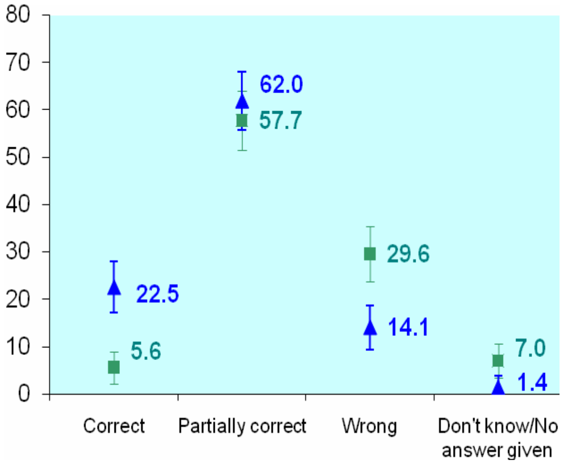

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Figure 17. Q6. Reflection of sound waves in a canyon

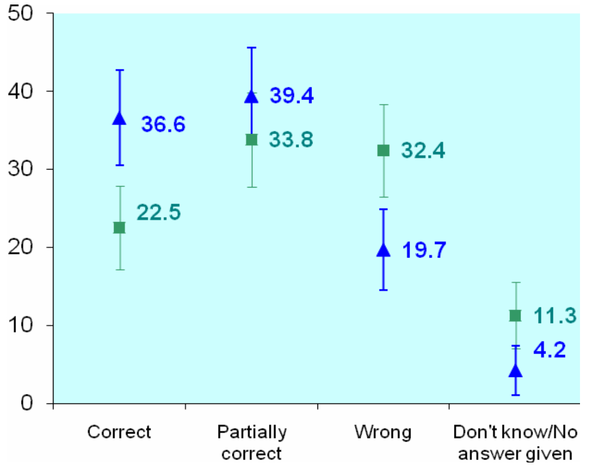

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Figure 18. Q9. Reflection of sound waves on a hard flat surface.

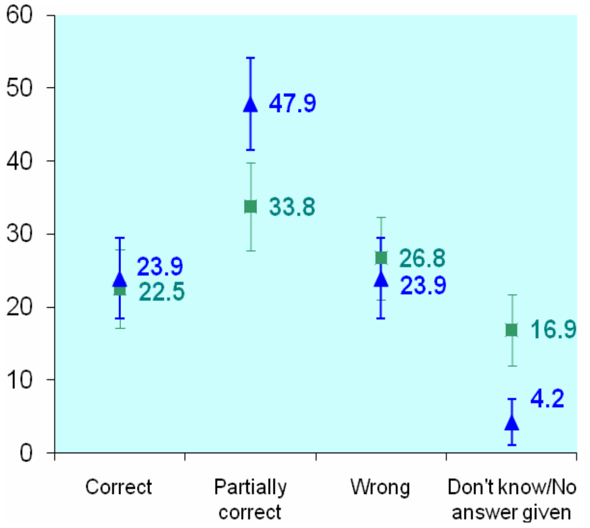

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Figure 19. Q10. Is it possible to have sound reflection without the flat surface?

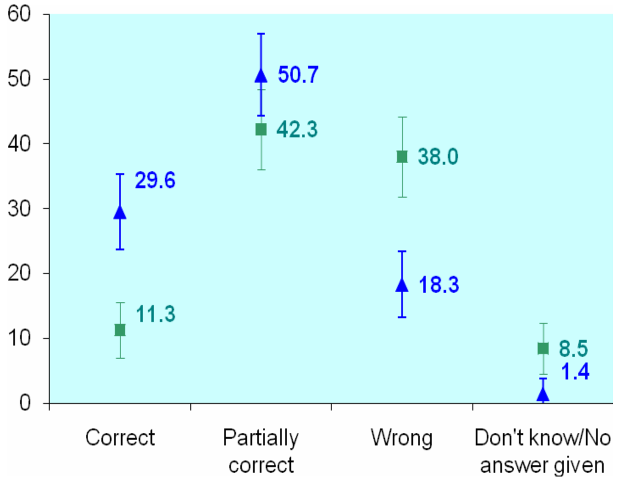

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Figure 20. Q7. Reflection of sound waves by curtains inside big halls (theatres, cinemas).

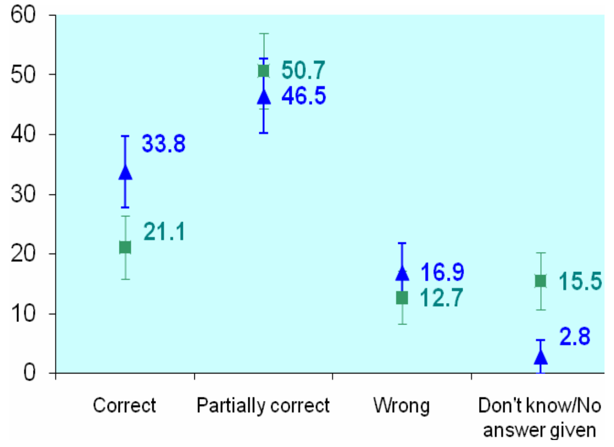

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Figure 21. Q11. Reflection of sound wave by sponge-like material on walls.

IX. DISCUSSION AND CONCLUSIONS

By reconsidering all the aforementioned points, one can combine all and derive the main conclusion of the present study, which is as follows: There is a significant improvement in students' understanding of physics concepts related to sound generation and sound propagation phenomena, as a result of the teaching intervention proposed herein. This can be directly attributed to students' involvement with the setting-up of parts of the experimental apparatus (which was especially designed for this experiment), as well as to the use of ICT for collecting, transferring, processing, and presenting the experimental data and primary-processed results. It should be stressed here that all educational measurements made involve the computation of the total experimental measurement errors for each and every point presented, and that we have been extremely strict in making any inferences: No educational conclusions were drawn in cases where differences measured do not exceed these total experimental errors.

As a secondary conclusion, and on the face of the evidence already presented, one has to reluctantly accept that students could still find it considerably difficult to define the concept of sound and to comprehend the mechanism of propagation of sound waves, even after the instructive intervention proposed. We can only assume that a more rigorous approach as to the nature of the phenomena is still essential in order to grasp such difficult concepts. Such approaches still lay in the realm of University tuition, as they would necessitate practices totally alien to secondary education. Nevertheless, even under such University-Lab environment, a lot could perhaps be gained by following a teaching approach similar to the one presented herein.

Furthermore, it would also seem that pictures that students may have seen in films like simulation of sound waves reflected on room walls, or the propagation of sound waves in empty space, may create strong influences in students' perception. This is a two-edge sword, in that such influence may be constructive or destructive (either influencing towards the scientifically correct perceptions, or unfortunately reinforcing misconceptions).

An interesting educational observation concerns the enthusiasm exhibited by all students involved, concerning this experimental teaching. This was all too apparent, and greatly contributed to students' learning experience, goodwill, and overall satisfaction.

It cannot be overstated that it was precisely the students' active involvement with the experimental apparatus, as this was specifically designed for this experiment, which considerably altered their perceptions and improved their ideas concerning sound.

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AUTHORS

Ch. Tsihouridis., M.Sc. and Doctoral Research Student, Department of Special Education, University of Thessaly, Argonafton & Filellinon, 38221 Volos, Greece

(e-mail: hatsihour@uth.gr).

D. Vavougios., Ph.D., Associate Professor, Department of Special Education, University of Thessaly, Argonafton & Filellinon, 38221 Volos, Greece

(e-mail: dvavou@uth.gr).

G. S. Ioannidis., Ph.D., Associate Professor, Head of Science Laboratory, School of Education, University of Patras, 26500 Rion, Greece

(e-mail: gsioanni@upatras.gr).

S. Paraskeuopoulos., Ph.D., Professor, Department of Special Education, University of Thessaly, Argonafton & Filellinon, 38221 Volos, Greece

(e-mail: pstefano@uth.gr).

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