INTEGRATING VIRTUAL AND TRUE LABORATORY IN SCIENCE AND TECHNOLOGY EDUCATION

Slavko Kocijancic[1], Colm O'Sullivan[2]

Abstract *— Considerable pedagogical advantage may be gained by the integration of the different ICT tools commonly used in teaching science and technology, particularly by integrating 'true' and 'virtual' laboratory activities. In the context of this paper, 'true' laboratories involve benchtop experiments utilizing data acquisition systems while 'virtual' laboratories entail interactive simulations based on Java applets. Examples of two such integrated activities are described; namely, (i) the study of wave phenomena using sound and (ii) a study of biomass growth. Such integrated computerized teaching tools also provide an opportunity for a greater level of integration of different science and technology disciplines.*

Index Terms —Data acquisition, computerized experiments, technology teaching, physics education, integrated science.

INTRODUCTION

Classroom use of Information and Communication Technology (ICT) for teaching science and technology has increased dramatically in recent years and has proved to be a very effective tool in a variety of situations [1]-[4]. The most commonly employed pedagogical uses of ICT fall into two apparently distinct categories which may be classified, respectively, as 'virtual laboratory' and 'true laboratory' applications. In a 'virtual laboratory' computers are used, for example, to simulate or animate specific scientific phenomena; pupils normally engage in hands-on activities which are directed towards increasing their understanding and insight of the principles involved. Computer utilities may also be used to simulate complicated, expensive and/or inaccessible devices (for example, a nuclear reactor) or to replace environmentally hazardous laboratory experiments. Such educational materials are often integrated within interactive html documents for web-based learning.

The importance of traditional laboratory teaching involving practical experimentation and hands-on work ('true laboratory'), however, has in no way decreased as a result of the use of computerized simulation experiments. If anything, computers equipped with data acquisition and control systems have had the effect of increasing the level of hands-on experimental activity in science laboratories at both high school and university. Supported by a variety of sensors and actuators, these systems have been shown to be pedagogically effective, particularly where higher level learning skills are concerned. Computerized experiments tend to change the emphasis from routine, often tedious, data collection towards interpreting skills, enhanced scientific thinking, creativity and problem solving [5].

We believe that there is considerable additional pedagogical advantage to be gained by the integration of the various ICT tools and concepts available, particularly by integrating 'true' and 'virtual' laboratory activities. In addition, ICT based teaching tools provide an opportunity for a greater level of integration of different science and technology disciplines than heretofore. In either context, however, it is important that methodologies adopted be chosen appropriately to the specific learning goals and age of the students involved.

For this purpose novel state-of-the-art hardware, software tools and courseware are under development by the ComLab-SciTech project [6]. The study of sound as a wave phenomenon is outlined below as an example of a topic involving the integration of data acquisition experiments and simulations. The integration of science and technology disciplines is illustrated by a second example in which the phenomenon of biomass growth is studied.

WAVE PHENOMENA IN SOUND

We first describe a set of computer based experiments and related computer simulations directed towards the study of sound which were prepared for pupils at secondary school level in Slovenia. An initial discussion with the pupils on the nature of sound usually progresses to a debate about of its speed of propagation. Students describe some of their own experiences from which they conclude that the detection of a sound signal is delayed with respect to its emission. Pupils raise many well known examples of such phenomena, such as the delay between lightning and the subsequent sound of thunder or echoes resulting from reflection of sound from a wall or cliff. After this discussion, a simple experiment is introduced using standard laboratory data acquisition (DAQ) apparatus. The digital output of the system is used to trigger sound emission using the piezoelectric loudspeaker. A microphone is placed up to three meters from the loudspeaker and the amplified signal from the microphone is connected to analog input of the DAQ system (Figure 1). A software package (called HiScope) enables the generation of the digital output signal to the loudspeaker as well as graphical display of the

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captured data from the microphone in a manner of computer based oscilloscope.

The distance between the loudspeaker and the microphone can be varied and the corresponding time delay determined (see Figure 2). By using piezoelectric loudspeakers emitting sound of different frequencies, the time delay for a fixed loudspeaker-microphone distance can be measured for each frequency.

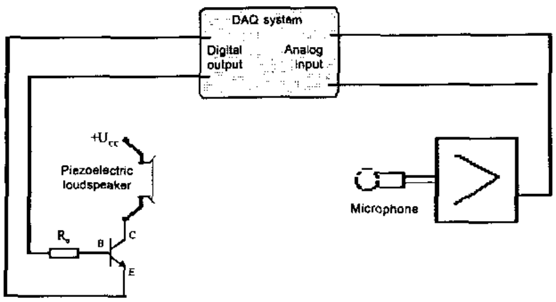

FIGURE. 1
EXPERIMENTAL SETUP FOR DETERMINING THE SPEED OF SOUND BY MEASURING THE TIME NEEDED FOR SOUND TO REACH THE MICROPHONE.

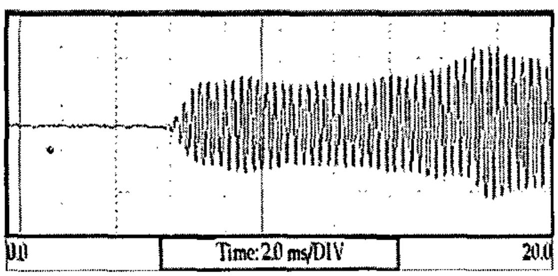

FIGURE. 2
SIGNAL DETECTED BY A MICROPHONE ABOUT 2 M FROM THE LOUDSPEAKER.

The results of the experiment lead pupils to form the following conclusions:

- The time delay is proportional to distance; furthermore, speed of sound is about 340 m/sec,
- The speed of sound does not depend on frequency of the sound.
- The amplitude of the sound decreases with distance from the source.

At this point, the term of wavelength is introduced by the teacher as general wave concept, not specific to sound waves. The wavelength of sound cannot be observed directly, so the relationship between the speed, wavelength and frequency can be best visualized via a computer simulation. The animated simulation used for this purpose is a Java applet developed and designed in co-operation with the MT Servicios company [7]. The simulation enables two parameters, speed and frequency of waves, to be varied while wavelength is seen to depend on both ($\lambda = c/f$). Two charts are presented on screen (see Figure 3): (i) the variation of the disturbance (y) from equilibrium as a function of distance from the source of the waves and (ii) the time dependence of this disturbance at chosen fixed distance from the source.

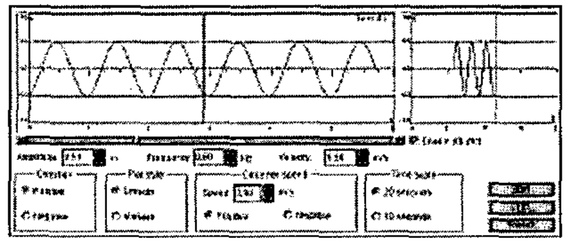

FIGURE. 3
COMPUTER SCREEN DURING THE SIMULATION OF WAVE PRPAGATION.

Continuing the study of sound, two loudspeakers are connected to two independent sine-wave generators each emitting sound with different frequency and amplitude. The signal from the microphone is initially observed with only the first loudspeaker turned on, then with the second loudspeaker alone and finally with both loudspeakers are turned on simultaneously. While both loudspeakers are turned on, the students are asked to find a situation for which the signal appears to be approximately periodic and then where it looks completely non-periodic (such is the example shown in Figure 4). At this point, the Fast Fourier transform utility of the HiScope software is introduced in an empirical fashion, that is with emphasis on what it does without consideration of its mathematical foundation.

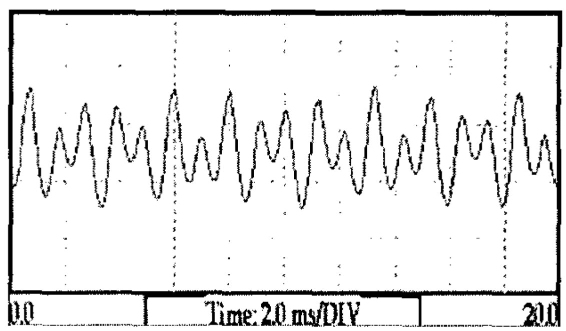

FIGURE. 4
NON-PERIODIC SIGNAL FROM THE MICROPHONE FOR TWO SUPERIMPOSED TONES.

The concept of superposition of waves is then clarified with a computer simulation in which the user can combine of up to ten sinusoidal waves. All have the same speed of propagation while the frequency, amplitude and phase of the waves with respect to the first wave can be varied. An example of such superposition of the two waves is shown in Figure 5.

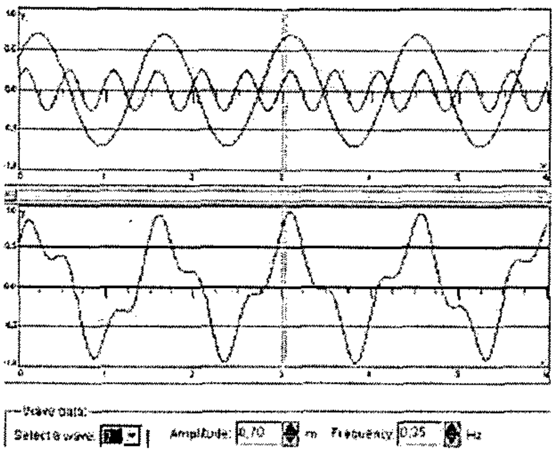

FIGURE. 5
SIMULATION OF SUPERPOSITION OF TWO WAVES.

Students are made aware that superposition of two or more sinusoidal sound emitters is not the only way to obtain a non-sinusoidal signal at the microphone. Experimentally it can be shown, that signal obtained for human vowel sounds are periodic but not sinusoidal. Again, observation of the Fourier transform of the digitized input signal can be used to illustrate that single sound sources can generate 'superpose' sound.

The next experiment encountered by the pupils involves the study of sound in a pipe. The apparatus used for this comprises a fixed loudspeaker emitting sound at one end of a Perspex tube (Figure 6) while a miniature microphone incorporated at the end of a long stick is inserted from the other end. Again the data acquisition system is used to monitor the signal from the microphone on a computer screen. When position of the microphone along the axis of the tube is varied, the amplitude of the signal significantly changes from very small (node), to much bigger (anti-node), back to small, etc. The positions of minimum (and maximum) amplitude are observed to be equidistant. These experimental observations are then explained as resulting from the superposition of direct and reflected waves; this phenomenon can be animated by means of simulation software in which two waves of equal frequency but traveling in different directions are superposed. The simulation shows that the distance between the two adjacent nodes is half a wavelength.

The study of standing waves is then concluded with another computer based experiment. An a.c. signal from the microphone is converted to a d.c. voltage proportional to the amplitude of the signal, the latter voltage being a measure of sound intensity. The position of the microphone is monitored using an ultrasound distance sensor. The intensity of the sound signal as a function of position along the axis of the tube is then plotted in real time on a computer screen as shown in Figure 7. The observed curve can be used to determine wavelength of the sound; since the frequency is known, the speed of sound can be calculated. The result us usually consistent with the value obtained in the time-delay experiment described above.

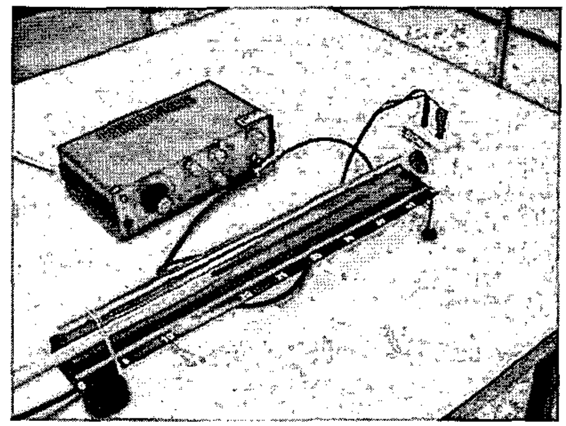

FIGURE. 6
APPARATUS FOR STNDING WAVES IN A TUBE.

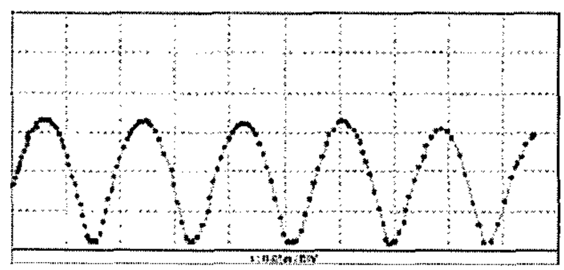

FIGURE. 7
CURVE REPRESENTING AMPLITUDE OF THE SIGNAL FROM THE MICROPHONE DEPENDING ON ITS POSITION IN A TUBE.

INVESTIGATION OF BIOMASS GROWTH IN A SCHOOL LABORATORY

Biomass is a term usually mentioned in connection with alternative energy sources. As such it is a good starting point in classes where a number of different science and technology disciplines can be closely integrated. But what are the dynamics of the biomass growth and what can influence this? Is it possible to perform an investigation on such topics with limited resources in equipment, time (and knowledge)?

A simple project to study biomass growth was begun recently at the Faculty of Education in Ljubljana (Slovenia) involving trainee teachers of physics and technology. Since no simulation has yet been developed, there is no 'virtual' component of the experiment at this stage. The starting point of the 'research' involved a study of the mass of a flowerpot with some soil and then some seed is put in it. During growth of a plant, the mass of the 'flowerpot' is observed to increase, but the aim of the project was to investigate the increase in mass as a direct consequence of the changing biomass as distinct from fluctuations of water present in the soil, etc.

Initially students were asked to decide which plant to growth (barley was approved suggestion), what kind of apparatus to use to measure the mass, etc. One of the first productive suggestions was to have a pot hanging on a string, the weight of the pot being an adequate measure of the mass. The next problem was to decide how to supply water continuously to the soil in an attempt to achieve stationary conditions in relation to the amount of the water within the soil. A suggestion by one student, approved by the most of the other students, was to supply water to the soil via a length of textile fabric placed at the bottom of the pot and dipped in water at the other side. Capillary action was determined to be a convenient mechanism to achieve a reasonably constant supply of water to the soil. At this point it was observed that evaporation was a complicating phenomenon; changes in temperature, humidity, airflow, etc. clearly influence the water content of the soil. The conclusion reached by the students was that some reference system was required. It was decided that a second flowerpot under the same environmental conditions but without plants could be used to compensate for the most significant influences on the mass of the pot containing the plant.

After addressing these general problems, it was obvious that it was time to proceed to the 'engineering' part of the project. Discussions about measurement instrumentation quickly focused on the need for a computerized measurement system, since measurement frequency of a few times per hour for a duration of more than a week would be required. Two force sensors were clearly required; one to measure the mass of the control pot and a second to measure the mass of the pot containing the plant. Since output voltage of the force sensor was proportional to weight applied to it, and hence mass, it was necessary to measure the difference between weights of the pot containing the plant and the pot without a growing plant. That implied a need to measure the difference between the voltages outputs from the two force sensors. Since the range of the sensor employed was 20 N, the differential voltage was too small to be determined directly and thus it was clear that a differential amplifier with an amplification gain about 100 was required. Before a usable signal was finally achieved, some further problems involving noise, filtering, etc. had to be overcome.

In the final stages of the project, a program in Delphi was developed to enable the capture data from the mass difference, temperature and light intensity sensors. Data was recorded every second and average values were calculated for intervals of ten minutes. The barley plant was illuminated with four lamps for fourteen hours during the daytime and was left in close to total darkness for ten hours each night. Unfortunately the temperature stability was not perfect, being controlled by a low-cost room electric heater.

Although the apparatus was largely improvised, the results obtained during our first experiment turned out to be quite interesting. The curves shown in Figure 8 are based on arbitrary units. The square shaped curve in Figure 8 presents the changes in light illumination (high in 'daytime', low by 'night'). The reasonably constant curve represents the temperature. The remaining curve is the most important one, showing the difference between the mass of the pot with the growing barley and that without.

The growth curve looks different for the first five days compared to the later behavior. While the plant is small, its mass does not significantly change as a result of the light being is turned off or on. Furthermore, the mass also increases during the night as well as in the daytime. Later on, the plant appears to lose mass after the light has been turned off; in darkness the mass remains fairly stable but, after the light is turned on, the mass increases once again.

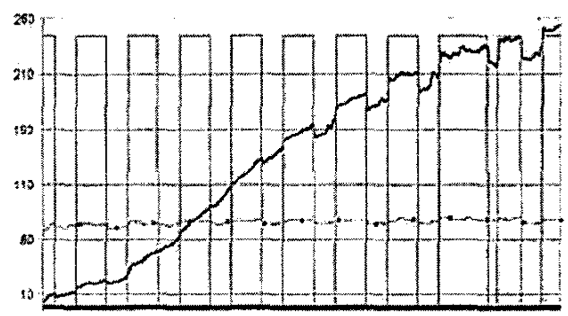

FIGURE. 8

THREE CURVES PRSENTING VARIALES DURING BIOMASS GROWTH EXPERIMENT. SQUARE SHEPED PRESENTS ILLUMINATEED AND DARK PHASES, ALMOST CONSTANT CURVE PRESENRTS TEMPERATURE, REMAINING IS A CURVE OB BIOMASS GROWTH (ALL ARBITRARY UNITS).

The most positive outcome of the students' project was the questions raised from the results of the experiment. The curves presented in Figure 8 raised several interesting questions. The most straightforward were:

- What are the mechanisms that increase the mass of the pot with the barley?
- Why the average mass growth is the most extensive after a few days and not at the beginning or later?
- What are the mechanisms that cause fluctuations of the mass when light is turned on or off?
- What are the processes that cause the overall growth of the mass?

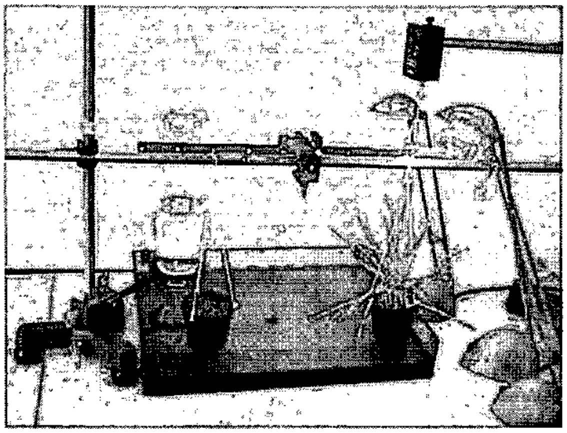

FIGURE. 9
IMPROVED APPARATUS FOR MEASURING BIOMASS GROWTH.

The project has continued to evolve in two distinct directions. Firstly, an invitation was extended to trainee teachers of biology to participate in the project, since the trainee teachers of physics and technology did not feel themselves to be sufficiently familiar with photosynthesis, plant respiration and other processes in plant biology. In parallel with that development, a number of students developed improved apparatus for the experiment (see Figure 9), one feature of which was to remove the need for the second force sensor.

CONCLUSIONS

The integration of data acquisition experiments with closely associated computer simulations has proved to be particularly effective in the learning process. The experience of the biomass experiment, in particular, highlighted the need for biology, physics and technology practitioners to co-operate in the development of such projects in order to share their specialist knowledge from their individual disciplines.

ACKNOWLEDGEMENT

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