Computers in Physics Teaching at the University of Lund

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We describe two completely different implementations of computers in teaching physics aimed at two very distinct target groups. First, a program with the aim to teach physics and analytical thinking to non-physics majors is described, and second a large-scale research school focusing on distance teaching at the graduate level is presented. Both are from the University of Lund, in Lund, Sweden.

Physics teaching at the undergraduate level: implementation of computational numerical tools in introductory and advanced curriculum

Although computing has played an important role in physics research and in graduate education, until the recent explosion in commercially available numerical computation and visualization software computers were implemented mainly in experimental physics laboratories in the undergraduate level. The University of Lund has made a number of well-established program packages generally available for all students and educators. A university wide agreement makes the educational release version of a large number of packages (*MATLAB*, *Maple*, *Mathematica*, *MathCad*) available free of charge through the university computer resources centre (CITU). This 'toolbox' of ready-to-use computational software, numerical tools, visualization and algebra software puts the solution of both simple and complex physics problems close at hand for students with a wide variety of computer experience. Such packages are an integral part of many courses in the school of engineering and physics. Here we describe one example in which students with essentially no previous computer experience and mathematics skills at the high school level are able to analyze sound waves from a function generator or from musical instruments and get a picture of basic digital sound technology.

The introductory physics course for non-majors is structured in a traditional format including lectures with demonstrations, tutorials several times per week and laboratory sessions focusing on physical phenomena. The students were recruited from groups with a background in nontechnical fields, and 50% of the students were women. Most students had little or no mathematical background and a mathematics course was included in the first year program. The goals of the physics course include:

- stimulation of interest in physics;
- ability to break down and solve problems, especially in physics;
- development of analysis techniques;
- utilization of computers for visualization including graphical presentation;
- integration of computers in 'active' demonstrations of physical phenomena; and
- increased competence in modern computational and numerical packages.

Most students with a technical background understand the process of going from concept (physical laws) and model to solving a given problem. This is the skill which we found most difficult for students with little mathematical or scientific background. Using computers and the ability to easily go from concept to calculation and to be able to change the value of variables and simulate the results of a given problem we tried to put the focus upon the use of physical laws to understand phenomena, and take the emphasis off of the mathematical solutions.

In this course two main commercial products were used: *MATLAB* (visualization, numerical calculation, industrial relevance) and *Science Workshop* (real-time measurement presentation, analog and digital signal recording and processing). The particular system is not central to the program, although consistent use of the package throughout the course is important, and a well-structured presentation of the package is essential. An introduction to *MATLAB* was included as a part of the course. Several modules were developed in which students used *MATLAB* for simple mathematical calculation, string manipulation and general exploration of the basic capabilities of the package. Each student could take home a copy of the program for home use, and university computers specially reserved for the course were available to all students.

Homework problems were developed in which *MATLAB* based solutions were suggested, and in many cases required. Computers were made available to all students during working hours. Problems in wave mechanics, electricity and magnetism, classical mechanics and atomic physics were solved as a part of homework sets and laboratory exercises. Despite fundamental difficulties arising from lack of experience with computing, mathematics and structured analysis most students succeeded in utilizing *MATLAB* for simulation and for simple calculus (derivation).

In wave mechanics, for example, the problem of separating complementary variables (position and time or wavelength and frequency) becomes clear when a calculation is made since most of them expect a sine function. The students worked problems focussing subjects such as simple harmonic motion, free and damped fall, friction, and driven harmonic oscillators. In the laboratory where data is acquired via computer a graphing package is of great value. Again, using *MATLAB* to present measured data, and the treated or fitted data allowed students with little technical background to achieve a deeper understanding of the physics without 'getting stuck' in the mathematics. It is possible, of course, to use specially written compiled programs for data taking and analysis in laboratories, but the use of commercial products has other advantages. The students can control the data collection after studying the documentation for the system. They learn to understand some basic principles of sampling and signal amplification. By learning to use such a system a foundation for future learning is laid. The structured thinking necessary to write a script in *MATLAB* must be developed. The data must be presented logically, and the treatment of data must be consistent. Another important point to keep in mind is that *MATLAB* is widely used in industry. Any contact which students have with this system is an advantage. Since MATLAB has been used for many years in academic and industrial research a large number of tools have been developed. These tools are readily available through the web.

By use of real-time demonstrations other concepts contained in the mathematics may be visualized. One example is the simple pendulum. Using the *Scientific Workshop* system the position of the pendulum as a function of time is monitored and presented graphically. Many students with less mathematical background can not extrapolate from simple equations, and see the relationship between different variables in a function. Visualization can provide a new way to get such insight. In the case of a simple pendulum or an oscillating mass on a spring a powerful demonstration of the phase relationship between position, velocity and acceleration can be made in real time. The position of the object as a function of time is presented graphically in real time. Even such a simple demonstration can be illuminating for non-physics students. The velocity of the oscillator derived directly from the position data can be plotted on the same time axis. The phase relationship between position and velocity then becomes perfectly clear. The turning points are easily identifiable and even the damping of the oscillation amplitude is apparent. The graphs are aesthetically pleasing as well! The students are then encouraged to find 'every day' examples of such behavior.

The measurements are made using a motion sensor (PASCO CI-6529 sensor) which uses ultrasonic pulses to measure the position of the object. The sensor is part of a modular set of sensors with a general interface box and a simple user interface for monitoring digital and analog sensors (*Science Workshop*). A typical measurement and 'active' demonstration is shown below.

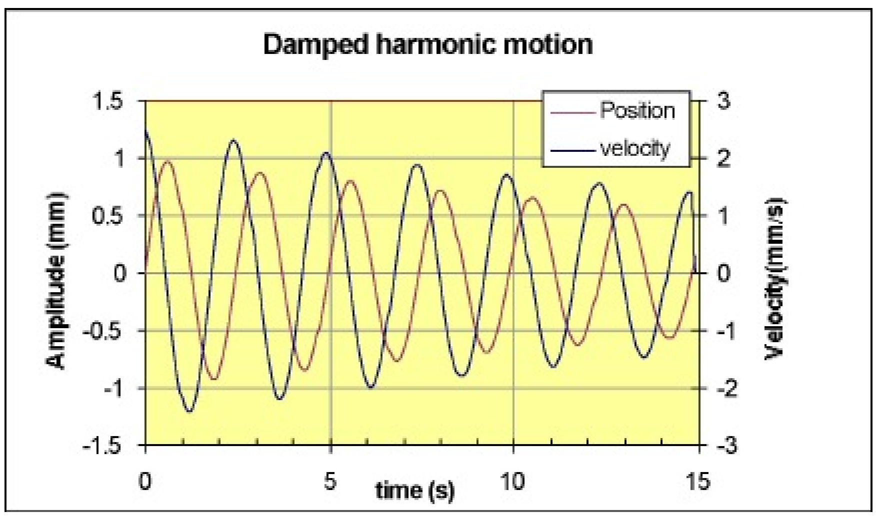

Figure 1.

Measure the period of oscillation of the pendulum in seconds.

When is the first maximum of the position reached?

When is the first maximum of the velocity reached?

What is the phase difference between the position and the velocity?

Concepts of great complexity may be presented in a more accessible manner using analytical tools. A laboratory focusing upon the physics of sound waves, an admittedly abstract concept, was presented in a more accessible fashion by taking advantage of the tools outlined above. By making musical instruments the objects of our study a relaxed and exciting atmosphere was created. The concept of standing waves in open and closed pipes was studied first, and the basic phenomena were identified. Then the sound from different musical instruments, including the singing voices of the students, were recorded and analyzed using analytical Fast Fourier Transform (FFT) techniques which are readily available in these packages. Very few students were capable of understanding the mathematics of the FFT but the 'black box' idea of sound signal in, frequencies and amplitudes out, is comprehensible. Basic measurement principles are also brought out in the laboratory; the frequency of sampling must be compatible with the frequency of the signals. The concept of overtones in musical instruments was studied. The frequency spectrum of flutes, recorders, whistles, guitars and violins were measured. The spectrum of the human voice was measured and a simple model for reproducing the voice based upon fundamental wave mechanics and the FFT is discussed. Most students left the laboratory with a new and exciting insight into music, sound, and even digital sound technology.

The danger of using computer based resources lies in the additional problems included in using computers and computer programs. The assistants for the courses must make sure that the foundation is laid and students have the skills necessary to use the packages. There is a wide variation in the students' abilities to 'plough through' the instructions and get a working script. Here it is important to utilize students to assist each other, and to encourage writing well documented scripts. One method which can help is after writing a script, students exchange and try to interpret the other group's script. They are encouraged to criticize and suggest improvements.

For students with only high school mathematics skills such demonstrations would be beyond comprehension without the powerful tools offered by computers. Most of them will never experience the months of programming behind the apparently simple commands entered in the laboratory. The goal of bringing out the physics and the method of analytical thinking is made easier by implementing such tools. Proficiency in the use of such tools is also a part of education in the technical sciences and an important part of preparing for industrial careers. We are enthusiastic about the future possibilities for using real time data acquisition and visualization in physics courses. The capabilities for more advanced courses are even more interesting.

CECOST: The Centre for Combustion Science and Technology - Distance learning in northern Europe

The CECOST program commenced in 1997 with the aim to establish coherent research activities on a national level involving the main engineering institutes in Sweden. It is the result of a successful collaboration between researchers at several universities in Sweden (Lund, Gothenberg and Stockholm) and university computer competence. The goals of the centre include a program for the study of combustion technology in close collaboration with academia and industry (see below). A very important aspect of CECOST is the establishment of a new graduate school, in which engineers will be educated and trained at the doctoral level.

Goals for research:

- focus on industry and industrial research;
- cooperation within several institutions; and
- utilization of competence from several universities.

Goals for PhD students:

- prepared for leadership;
- attract students with industrial vision (80% employed in industry);

- develop project management skills;
- increase number of female PhD students (> 20%);
- international and industrial experience; and
- students active in planning visits to industry and foreign institutes.

The most obvious solution to the large geographical distribution of students and faculty, if technologically feasible, is to utilize the World Wide Web to connect students at universities and in industry with resources developed mainly at Swedish universities. Use of the web should expand the geographical boundaries even more. This requires a working system including administration, multimedia platforms for presentation of course material and tools, discussion forums, media available for all students, progress-monitoring capabilities and internal communication (email). An additional requirement is that all technical solutions be as platform independent as possible and that existing software and hardware is utilized in a standard fashion.

The format for CECOST is computer/Internet-based education utilizing easily accessible distance educational tools (http://www.fysik.lth.se/cecost/). The final product was a platform called *LUVIT*, which provides the structure and tools necessary to realize such a 'school' (http://www.luvit.se/).

The structure of the course has now developed in a standard way as follows:
Distance learning: Internet-based (*LUVIT*)
Seminars at University

- introduction to course and technical basics;
- laboratory demonstrations and visits to university research laboratories;
- seminars from prominent lecturers;
- scheduled video lectures; and
- final seminar day with presentations and summaries.

Interactivity

- course material available on network site;
- students work in groups which share material, discuss via email, chat and video conferences;
- students monitor progress through available material and scheduled events; and
- critique pages in connection with material on web site.

Examination
Course evaluation and dialogue via Internet

The program consists of a number of courses (presently seven) concentrating on different aspects of combustion science (http://www.fysik.lth.se/cecost/welcomeed2.html). The courses are given every two years. Additional courses in leadership and project management are also offered. A board of directors oversees the overall program and curriculum with representatives from industry and academia. The courses are partially interrelated, and are structured by level of specialization. Within the framework of the distance learning format each course has the following characteristics:

- Several teachers share course responsibility, one of whom is the 'main teacher' who coordinates and plans the course.
- All teachers are required to complete a program focussing on the use of computers and networks, and pedagogical fundamentals. The *LUVIT* platform is included in this course. The course includes:
- *LUVIT* Lecture Guide;
- Design issues;
- HTML programming;
- Copyright on the WWW;
- Shareware sites; and
- Software sites.

The courses are synchronized with other courses within CECOST. Presently the following courses are offered via *LUVIT* and CECOST:

- Combustion Science;
- Combustion Devices;
- Turbulent Combustion;
- Momentum, Heat and Mass Transfer;
- Chemical Kinetics;
- Measurement Techniques; and
- Numerical Simulations of Turbulent Reacting Flows and CFD.

Use of the Internet in teaching

In the first year of the course material produced in standard formats such as Adobe .pdf were made available on the Internet. Students were responsible for reading material and downloading files to their home computers. Video lectures were scheduled and students were assigned to work on group projects via the *LUVIT* site. The introductory meeting provided participants with basic technical skills, presented the concept of the course, introduced teachers and included special seminars and laboratory demonstrations. The introductory meeting took one entire day.

In the successive years more courses have been developed, and new methods of utilizing the computer based education have been designed. It is imperative that participants provide feedback to the organizers so that problems can be solved quickly. Most of the technical problems were solved via *LUVIT*. Pedagogical and organizational problems remain the responsibility of the teachers.

Each course finishes with a final seminar day in which group work is presented and seminars are given.

Course evaluation

The course has been evaluated extensively via the Internet (*EVA* system, CITU, University of Lund). The result is overwhelmingly positive, 75% rate the course as good or excellent. The literature overview, seminars, Internet links, and industrial relevance were rated highly. The coordination, interactivity, laboratory and demonstration work could be improved.

Summary of CECOST project

After two years the original goals of the consortium have been realized. The framework of the *LUVIT* platform has been essential to the success of the project, and increased contact with other European students and teachers will characterize future developments. Experts in different areas of combustion physics have provided a resource centre based upon the Internet, which is available to students in many universities, and from industry. The project undergoes constant development, but one aspect, which can be expanded, is the use of new pedagogical approaches, which utilize information technology. The web should allow for efficient teaching but new methods that exploit the Internet for more than geographical distribution lie in the future of web-based distance teaching.

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