

Use of simulation software for Physics teaching

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Abstract - *The utilization of computer simulations is not a new subject, but its importance has increased in the industrial as well as in the educational field in the last years. The academic use of this tool in Physics is already very disseminated, although its educational use is still restricted. One of the major reasons for this, is the restricted number of good computer applications tailored for the University level, especially in Portuguese and a lack of pedagogical plans to use them. In this scenario, the Physics Department of FEI (Faculdade de Engenharia Industrial) decided to begin a long-term research project to produce and to apply computer simulation in Physics teaching. We have already produced six computer applications and four of them (simple pendulum, friction force, ballistics and damped oscillations) have been used for the last two years by the entry level engineering students at FEI, as part of their Physics laboratory activities. The simulation sessions take place at the computer rooms and the students usually work alone in this activity. Although the programs developed do not have all the features of a commercial program, in some aspects they show advantages to those. Five out of the six programs developed are real time simulations. The main reason to implement this feature is that we have observed a higher attraction to programs that simulate an event in the same time scale that the real one. The real time programs also have animations to illustrate and to allow a better understanding of the phenomenon. Some preliminary qualitative results have shown that the students are more involved with the classes and that they are more interested in the subject when computer simulations are employed. These good results are driving us to create new simulations. We are planning to create versions of these applications using the Java language, in order to make them a powerful tool to help in distance learning projects. We are also planning to proceed in the near future a quantitative analysis of the pedagogical results.*

Introduction

Laboratory activities have been employed for a long time to help students to learn science. In the Physics field, laboratory activities allow students to better understand the models created to represent a given physical phenomenon. In Physics lab classes,

students are invited to build and to manipulate pieces of equipment to collect data, therefore participating actively in the learning process.

In principle, laboratory classes should be highly stimulating, and would be important to motivate the students in theoretical classes. In practice, this expected response sometimes is not observed. Sometimes, the laboratory activities are so tiresome that they can even make the learning process more difficult.

The use of new technologies in laboratory classes can help recovering its importance. New experiments focusing some aspects of modern Physics, the use of computers to collect and to analyze experimental data and the use of computer applications do simulate many physical properties, are just a few of the new trends in experimental physics new pedagogy [1][2][3].

The use of computers in Physics teaching has been investigated and applied as long as 15 years ago in the US [1][2][4]. In Brazil its application in teaching is a relatively recent subject, although its potentiality in general education has also been studied for a long time [5][6][7][8]. But even in the US, the main target in the application of computers in teaching is usually the elementary and high school students, not the university students. Therefore, there is a lack of research in this segment and it seems to have a lack of good educational computer applications to be used by the university students and there still have a lot of work to be done.

We have started a long-term project, where one of the major goals is to develop computer systems that can allow the learning process to occur in a more individualized and efficient way. We started this project by introducing computer simulations in Physics laboratory classes. The application and potentiality of these tools has been already reported in Brazil and US [9][10][11][12].

There are some commercial computer applications like Interactive Physics and Working Model that are suited to build simulations to university students. Although some very powerful simulations can be created with these packages (specially with Working Model), we decided do not use them for the following reasons: Its high cost (usually we have more than 60 students using the software at the same time), the need to have a powerful hardware to have fast simulations, the lack of

real time capability and the language used in the software (English).

Simulations used in this project were developed at the Physics Department of FEL, and they were tailored to fulfill students, professors and the Institution needs. Therefore, the programs were designed to fit the classes and the computer structure available, not the opposite. All the experiments were created in order to emulate the way experiments were performed in the conventional lab, not just to reproduce in the computer the same physical system. With this approach we intended to minimize the "technophobia" that usually dominates teachers when computers are introduced in their courses.

Applications of simulations

The simulation of a physical system is a technique that has been largely used in the recent years, especially after the popularization of the microcomputers. We can observe many situations where a simulation can replace the real phenomenon with advantages. It can be used, for instance, to:

- Help the visualization of a transient behavior: some effects are so fast that they can not be visualized directly. Sometimes it is necessary to use an expensive piece of equipment, just to capture and to show a simple behavior. The simulations allow visualizing such effects in a very easy way.

- Reduce cost: you can create experiments that in the real world would take many pieces of equipment or would imply in the utilization of expensive materials. The use of a simulation is particularly interesting, when the purpose is just to show a property or to skill a given ability.

- Amplify a behavior that can be masked in the real life: there are some effects that can be concealed by noise or by experimental errors. They also can be studied with the assistance of computer simulations.

- Have higher experimental precision: using simulation software it is possible to create conditions where the instruments do not show the usual physical limitations. It allows obtaining results with a precision good enough to understand the phenomenon studied.

- Enable the user to transfer repetitive activities to the computer. Some activities like data manipulation, graph construction and so on can be performed by the computer, allowing the student to be focused in the meaning of the results obtained.

Its utilization in education can make use of all these advantages listed above, and many interesting results have been reported already [3][11][12]. But as any other pedagogical tool, it needs to be used correctly in order to obtain the best efficiency. Besides, choosing the correct software can make the difference between success and fail. There are some features that would be highly desired to be found in such applications.

Features worthwhile having in a computer simulation

There are some features that we believe would be important to incorporate in simulation software, and that would make it very powerful to be used as part of a laboratory course. Some of these features can be found in the computer applications that we developed, and some are planned to be incorporated in the near future. These features include, but are not restricted to:

- Real time: we can classify the simulations in two wide classes: simulations that are performed in real time and the simulations that are not. In real time simulations the sequence of events simulated follow the same time scale that the real phenomenon. This is particularly interesting when the temporal effect is an important part of the application proposed. This kind of computer application usually demands more resources of the computer and/or a more efficient algorithm and it has to be carefully planned in order to show reasonable results. As we intended to use the software as part of a laboratory course, it was highly desired that the simulations were performed in real time, allowing the students to have the temporal sensation of the effect studied. Besides, since the experiments involve a measurement of time, it could be performed using a real chronometer instead the one present in the software. If the effect is too fast to be seen, a slow motion capability would also be advised.

- A clean user interface, easy to use and to understand: the most important aspect for us is to use the data processing capabilities as a tool to understand some physical concepts. If the software is too complicated and has too many options and parameters to be changed, students lose much more time learning to use the software than using it.

- A common user interface: as we intended to make the use of computers as an important activity of the course, it was required that all computer applications developed shared a common user interface. This would make the utilization of the computer applications easier and more productive.

- A very high interactivity: we wanted a program that would allow students to experiment with many different parameters, giving them the possibility to change the parameters in a wide range of values.

- Possibility to collect experimental data: some simulations allow the user to change parameters, but sometimes it is not an easy task to collect data as a result of a simulation session. As the primary utilization of the software is a laboratory tool, it is important to have the possibility to collect data to make a further analysis.

- Presence, whenever it is possible, of an animated representation of the phenomenon: this makes the understanding of the simulated experiment easier and the experiment more realistic.

- A good printed documentation: in order to allow the users to exploit all the features of the application program it is necessary to have a very

good documentation. Besides, it helps the teachers to create new activities using the software.

- A good guide: to help the students to follow the proposed activities and to allow them to use the simulation in an effective way.

Technical aspects of the simulations developed

We have already developed 6 simulations programs regarding the subject “Classical Mechanics”. Four of them have been used by the students at FEI for the last two years and the other two (energy conservation and spring pendulum) are planned to be incorporated in the laboratory activities next semester. The first generation programs were developed using the C language for DOS environment, and we intend to substitute all of them by the second generation Windows versions, before the end of this year (the coding is finished already, and we are finishing the tests). The biggest problem in this case is that the Windows environment makes some tasks a little bit more difficult than the DOS environment. To create real time simulations, we had to use the API functions, since the Windows timers were not fast and precise enough to our need. We have also observed that although some actions (like moving the mouse during a simulation session) can sometimes make the animation to have a jerky behavior, the results (graphs and data points) are accurate.

All simulations share a common user interface, and the commands are restricted only to the necessary, in order to make the screen easy reading and the software easy using. A graphical plot of the results is available as well as an animated representation of the experiment. The student has also the option to save the data to a disk file to make a further analysis. Some parameters can be measured directly in real time using an external chronometer or by using a software chronometer that has a 1ms precision. Any collected point can be extract from the graph through a simple click over the data point.

The way simulations are used at FEI

The Physics course that is given to the engineering students at FEI is divided in four parts (Physics I to Physic IV). Each part has duration of around 4 months and it includes theoretical classes as well as laboratory classes and it explores all the basic concepts needed in a college level physics course.

The simulation programs are used by the entry level engineering students, as part of Physics I and Physics II laboratory activities. In each semester we have to offer these lab classes to more than 1200 students. In order to do that, we use the computer labs of the school that has 6 classroom and in each classroom there are 30 computers. The experiments are performed by the students just like any other ordinary experiment, except that they are performed in the computer labs.

In all simulations, the idea is to reproduce experiments that were already used by the teachers in their laboratory classes. Therefore, we try to make just a few modifications in order to avoid big changes in the teachers routine. The main reason to this is that they are usually not familiarized with computers and prefer not to use this tool. They fear the students will know more than them about computers and this will make their classes worthless. Therefore, this was also an opportunity to make them comfortable using this kind of technology in their classes. We are planning to introduce before the end of this year some new simulations programs that were already developed, since they were well accepted by instructors and students. For each simulation there is a set of predetermined activities that the student is supposed to follow. The specific subjects explored with these simulation programs are the following:

Simple Pendulum: In the experiment “Simple Pendulum”, the student is asked to simulate a simple pendulum for different lengths of the string. For each length, he obtains the period of oscillation using a chronometer in the software. If he wants, he can also use his own wristwatch to measure the period of oscillation. Then he has to do the same study for different values of the gravity acceleration. In this activity he is also asked to compare the period of the pendulum when it is swinging in the moon, and to compare it to the earth. This is particularly interesting, because he can study this system in conditions that are not easily obtained in a laboratory.

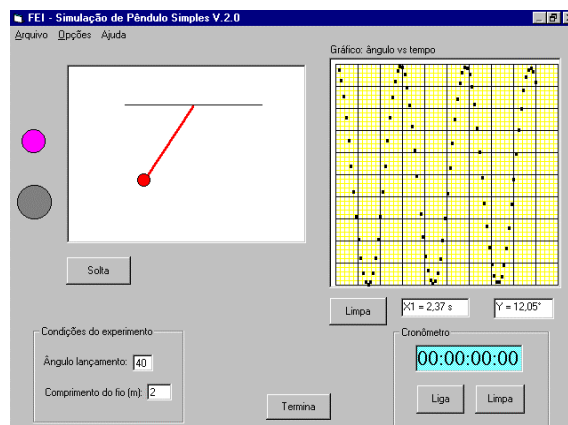


Fig. 1 – Screen printout of the “simple pendulum” simulation program.

As a final activity, the student has to observe the behavior of the pendulum when the swinging angle is not small (e.g. above 20 degrees). In this condition he can observe that the expression $T = 2 \sqrt{l/g}$ is not accurate to describe the period of the pendulum. This activity is particularly interesting because it is very difficult to observe such a behavior in the conventional lab, since the experimental errors are so high that they masquerade the effect. Once he has finished the experimental

activity, he is asked to prepare a printed report. In this printed report, he has to describe all the procedure used in the experiment, to show the results and to discuss them using the small oscillations model. The teacher can build empirically the law that describes the period of oscillation for small angles as well as conduct discussions regarding the validity of the model.

Frictional Forces: Another example of utilization of the computer applications developed is the “Frictional Forces” simulation program. In this program, the user has an inclined plane that can be moved up and down through the keyboard. The step change in the angle can also be controlled. In this plane there is a block that is hold in its positions by the friction force. After a given critical angle, the block starts to slide down the plane and it is possible to obtain the static friction coefficient by calculating the tangent of the angle indicated. At this time an internal chronometer is also started and the time that the block takes to get to the end of the plane is measured. Therefore, the dynamic friction force can also be obtained using this information. An alternative way to obtain this coefficient is to move down the plane (after the block started to slide down) looking for an angle where the velocity is constant (the plot on the right side is the velocity of the block against the time). The tangent of this angle gives directly the dynamic friction coefficient. It is important to note that this procedure must be done while the block is moving. Since the simulations are in real time, the student has to find a convenient plane size in order to make possible to obtain constant velocity before the block reaches the end of the plane.

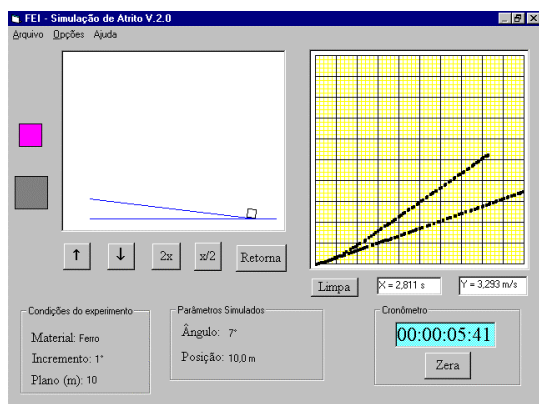


Fig. 2 – Screen printout of the “static and dynamic friction force” simulation program.

Ballistics: In this system the student can simulated the behavior of a projectile when it is launched from a given height with an initial horizontal velocity and subject to free fall. It is possible to observe many different types of graphs like the trajectory described by the projectile and its vertical velocity as a function of time. The simulations can be performed for different values of gravity force, mass and initial velocity, and the results can be compared.

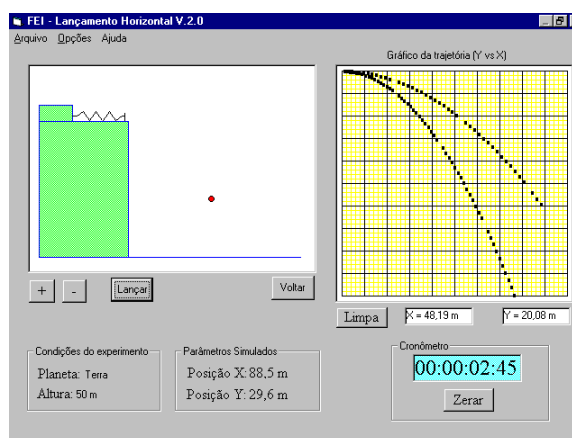


Fig. 3 – Screen printout of the “Ballistics” simulation program.

Damped Oscillations: It is possible to study the behavior of a block-spring oscillator connected to a vane that is immersed in a viscous fluid. The vane exerts a damping force on the oscillating block. The student can adjust the different parameters in order to observe the system behavior, going from a sub-critical oscillation (when the damping is small) to a supercritical behavior (when the damping is too high). Graphs of position, velocity and acceleration can be observed simultaneously on the screen.

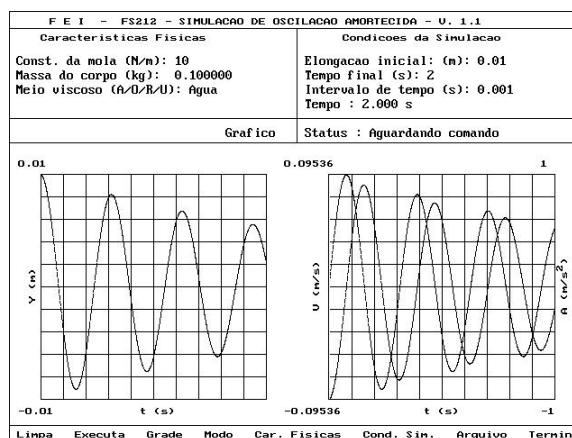


Fig. 4 – Screen printout of the “Damped oscillations” simulation program.

Some qualitative results observed

As we said before, these computer applications have been used at FEI for the last two years. We still did not make a quantitative analysis of the results obtained, although some expressive qualitative results have arisen. Some of these good results are related to he students and others are related to the teachers.

One important aspect observed is that teachers get more involved with the classes and they start suggesting new experiments to be implemented using

simulations. This also allows teachers to rethink the way they are used to give classes. The use of computers is still a restraint for many teachers, but they start to feel more comfortable using this tool. This also decreased the teacher resistance to innovations and changes.

Some observations show that students get more involved with their classes, they feel comfortable using computers and they like doing it. Therefore the classes in the computer room are usually full because they avoid missing classes. Besides, since the instruction is more self-paced and it respects the student learning velocity, they usually result in reports with fewer errors.

It is still interesting to observe that although we can not assume that students have had a previous contact with computers, it is not necessary to be concerned about their ability to use such devices. The students that never had the opportunity to use computers easily get involved and do not show any difficulty to use the machines (at least to use them in the way proposed in this activity).

Further development

We are planning to enhance the computer applications developed and to develop new ones too. One of the things that we already started working is the addition of a help system using a hypertext-based structure. This help system will contain explanations about the theory necessary to understand the experiment, instructions to use the program as well as a set of activities proposed to get the most out of the software. The inclusion of multimedia capabilities, with movie, sound and illustrations will also make the simulations more interesting, attractive and efficient too.

We are also planning to create Java versions of the programs, in order to make possible to the student to run his experiment out of the school. This would help to develop tools for distance learning projects.

We also intend to create a way to have a quantitative description of the results that we achieved using these simulations. This is not an easy task, since we have to give to all students the same opportunities and it makes difficult to have a control group to compare the results.

A new printed leaflet is also being created, to allow the students to have a better documentation that will make possible to them to use all the potentiality of the software.

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