Contribution of Digital Simulation in Visualizing Physics Processes

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ABSTRACT: In our experience of teaching physics for engineering at university level we have learned that the mathematical relationships between the parameters that control a process are important, but not sufficient, to understand a process. Such knowledge will only be consolidated if the new concept is incorporated by student in his field of study. Simulation programs, especially through visualization, can help to attain this target. We have developed three programs using Visual Basic. One of them is devoted to fitting experimental data and is complementary to experimental work; the others focus on dynamics, translation, and rotational movement, helping to understand the Newton's laws. ©2002 Wiley Periodicals, Inc. Comput Appl Eng Educ 10: 45–49, 2002; Published online in Wiley InterScience (www.interscience.wiley.com.); DOI 10.1002/cae.10016

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INTRODUCTION

In recent decades, pedagogical tendencies have changed so that teaching focuses on the student rather than the subject. In this context the teacher acts as a guide, giving the students the tools and showing them the different ways they can apply themselves to the learning process. The teacher has to choose the best way to allow the student to construct and understand the solution to practical problems. This tendency is named constructivism [1]. The teacher does not transfer the knowledge to the students, but helps them to construct, or at least interpret, the reality of the body of knowledge based on their experiences. As Hestenes suggests, the most important factor when teaching with interactive engagement methods is managing the quality of classroom discourse [2] and this requires careful planning and preparation, as well as skill experience [3].

New technologies can help, providing a new tool for the communication between teacher and student. Many articles outline how new technologies (interactive tutorials, Internet, forum...) can be used in the teaching process [4–6]. The principal advantage is the possibility of integrating different means of communication (visual, auditive) in different supports (text, mathematical expressions, graphics, diagrams, photographs, video, animations), either individually or mixed.

Besides their availability, in common with books or video tapes, new technologies offer the interactivity and the non linearity that favors learning by individual discovery. If the program is well designed it keeps the student's attention and motivates the new generations, who are used to multimedia systems.

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The computer is now a common instrument, present in all the aspects of daily life. At first the scientist visualized them as stymied tools to solve calculus problems. Later, their improved numerical and graphical abilities made them essential, both for research and the professional work in scientific and technological fields. Internet has opened a window to global communications.

In this context, teachers have the chance to take advantage of the pedagogical possibilities afforded by these new technologies. The digital simulations [7,8] are part of a wider experience that affects our teaching methodology. It ranges from changes in evaluation to connection between theory and reality by demonstrative experiments in lectures that mix theoretical and experimental work in specially prepared classrooms. We try to obtain the maximum benefit of the computer by using simulation programs, PowerPoint presentations, 3D animations, distance learning, forum, World Wide Web sites, etc.

In the present work, we analyze the contribution of digital simulation programs to the visualization of complex physical processes and how these could contribute to a better understanding of physical concepts.

DIGITAL SIMULATION

In the field of engineering, scaled and simplified models are commonly used to understand and test complex problems [9]. In the teaching context, the analogical and digital simulation provides an interesting tool to understand the physical concepts implied in a real process.

Digital simulation provides a very useful connection between the mathematical expressions and the real problem. The calculus together with the graphical options lead to an in-depth simulation that provides a complete visualization of a problem. This has important advantages when teaching the complex problems that are frequently present in a physics curriculum.

From the point of view of the teaching methodology, we think that the student must do experimental work. However, this is not recommendable in some special situations, for example, because it could be dangerous—like starting to teach a pilot to fly; it could be very expensive—like nuclear studies; or, perhaps, because certain circumstances have lead to a lack of money. In all these cases digital simulation could replace experimental work, but in general it offers a complementary point of view to the theoretical and practical work, establishing a bridge between them [10].

We use the simulation programs in our teaching work in the following way: after a theoretical study of a subject, Newton's laws for instance, we propose a practical problem to the group of students. They try to solve it by means of equations and once they have done this, they start to work with the simulation program. They select the same value of the parameters and ask the computer for the correct answer. They complete the information about the problem by plotting graphs and visualizing the animation of a relevant aspect. Following the teacher's instructions, the students vary some parameters and obtain an immediate response of how this affects the problem. Later, they can use the simulation programs whenever they need them.

We try to incorporate this material in a cooperative learning style. They usually work in groups and we encourage them to interpret new learning situations based on their previous knowledge and experiences.

DEVELOPED PROGRAMS

The developed programs have been chosen to cover a range of problems that are present in a physics syllabus at the university level. They focus on the aspects of the subject that prove difficult to students, specially if these difficulties are related to the visualization of the problem.

As a first step, we have developed three programs: least squared fitting, translation dynamics, and rotational dynamics. Information related to some other programs will be published elsewhere.

The program design is based on combining the following characteristics: they present an intuitive interface that makes them simple to use and training time is not required; they simulate relatively complex physical processes; they provide visual references by means of animations.

The main screen of each program shows the parameters that the user can vary with a limited range of values. With this limitation one gets two positive effects: it provides a guide for inexperienced users and avoids possible artifacts in displays.

MINCUA

The least squared fitting is a very useful tool to deal with experimental data. Different options allow the user to fit to several types of function: linear, power, exponential, or logarithmic. The experimental data and the graph can be saved on a file and recovered later on; they can also be printed, or exported to another program. The configuration (colors, fonts...) can be chosen by the user. The program is used daily in the experimental work, because the laboratory is equipped with computers. The students introduce the experimental data immediately after the measurements. Then they establish the relation between the theory and the experiment (for instance a linear relation between two variables). This program has the advantage that it is easier to use than the conventional worksheets (Microsoft Excel, Microcal Origin...) and offers first-year students an immediate response to the treatment of experimental data. Figure 1 shows an example of the fitting of five points to an exponential curve. It is very easy to change the number of points or the type of curve. The ρ^2 parameter expresses how good the fitting is.

Translation Dynamics

The translation of a two-dimensional solid is a typical problem in a course on mechanics [11]. The variables that let the user define the problem are: mass, length, and height of the body, slope of the inclined plane, coefficient of friction between both surfaces; value, direction, and application point of an external force. As a result, the program gives the values of the normal reaction, its application point, the frictional force and the acceleration (see Fig. 2). The program allows one to study the application of Newton's laws to one body system. As a consequence of the applied forces, the solid can move or stay in rest. In the case of movement one can show the plot of variables, like the speed as a function of the position or time, the energy (kinetic or potential) and the work done by the different forces applied. Another interesting problem to study is how the application point of the external force influences the equilibrium conditions of the system.

Rotation Dynamics

The program let us study the rotation movement of a wheel that lies over a surface. The wheel moves under the action of up to four different forces: weight, normal reaction force of the plane, frictional force, and an external force of arbitrary value, direction and application point. The unknown variables are the normal reaction force, the frictional force and the linear and angular acceleration. Figure 3 shows the main screen of the program, where one can see a plot of the problem, the variables and the results for the unknown values. The program gives a qualitative description of the movement: the wheel can roll with or without

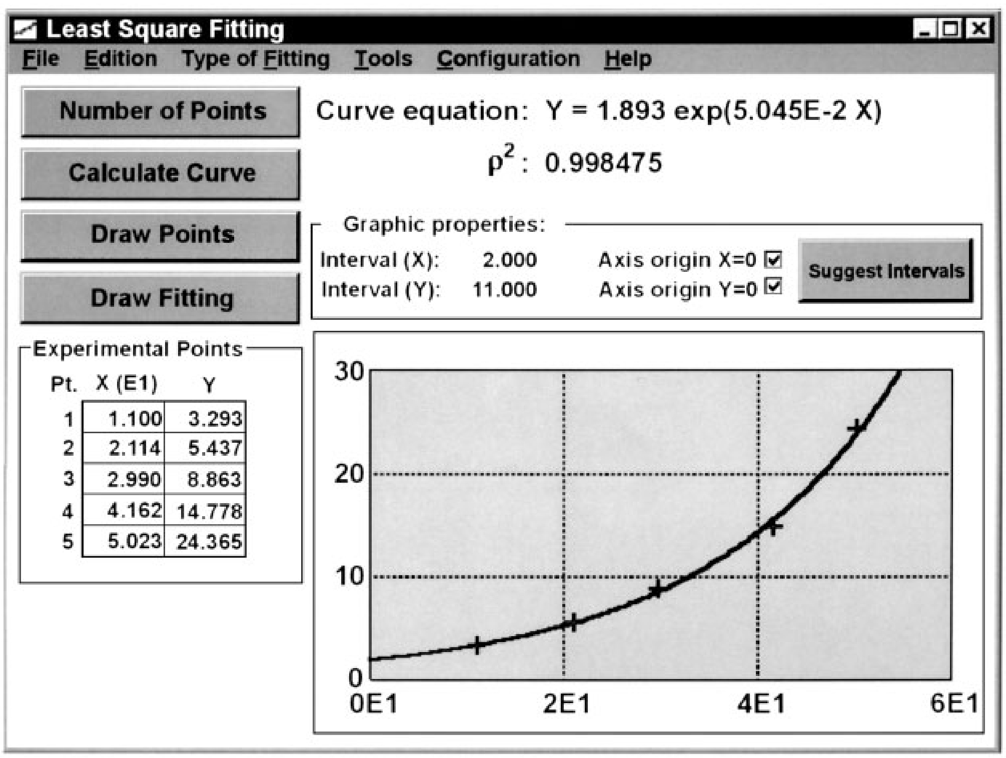

Figure 1 Example of application of the program to the fitting of five experimental points to an exponential curve.

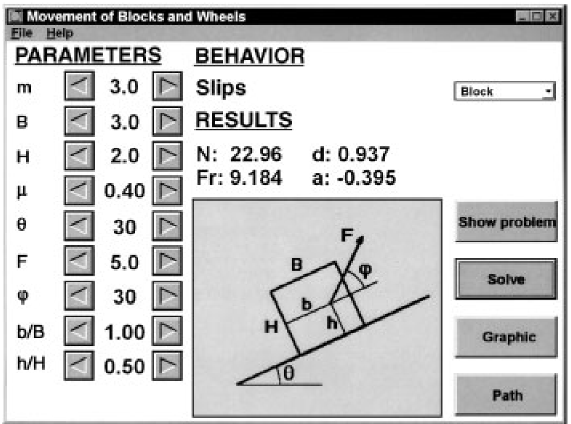

Figure 2 Application of the program to the movement of a block that goes up by the action of an external force.

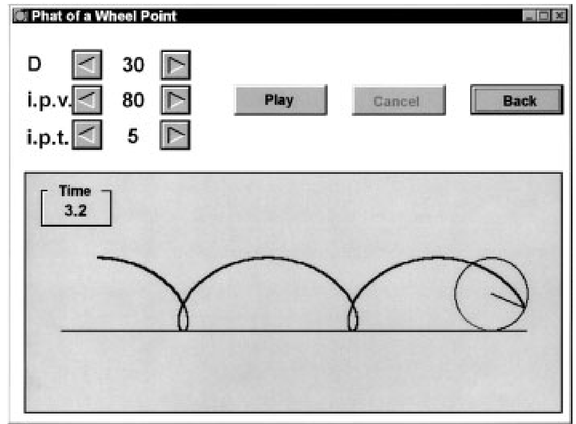

Figure 4 Trajectory followed by a point of the wheel. The parameters are those shown in Figure 3.

slipping, rise, or stay motionless. The user can select the graph options and see the representation of speed, acceleration, energy, or work as a function of either time or position. The button "path" presents a new screen where the program simulates the movement of the wheel while tracing the path of a selected point (in Fig. 4 the wheel roll with slipping). The program allows one to change the scale of representation, and the speed and smoothness of the simulation. For a better result, the movement is shown as uniform; however, the clock indicates the actual time.

CONCLUSIONS

Students can use the program at any point during their apprenticeship and as many times as they need it. It has been shown to be highly efficient when used after knowledge of the theoretical basis of the phenomenon has been acquired. We suggest solving the problem numerically, and then using the computer.

From our point of view, using simulation programs has two principal advantages with respect to other materials: (a) the users are able to study the influence of the different variables of the problem without having to solve the entire problem every time, and (b) the visualization of the process is very useful in understanding the results. The least squared fitting program has proved to be a very useful tool to deal with experimental data. The students can try different relationships between the variables (linear, exponential, power...) and immediately see the experimental points and the fit curve. The translation and rotational dynamics can help to understand basic concepts in Newtonian physics.

With respect to learn strategies, the program allows the use of different and integrated techniques that help to reach a greater variety of students.

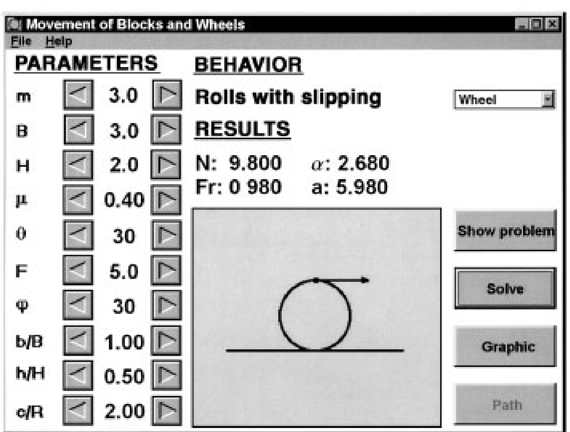

Figure 3 Main screen of the program "wheel." In this case the wheel rolls with slipping.

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BIOGRAPHIES

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