Models and Simulations as tools in physics learning

Pablo Alejandro Lonngi V.[1] *and Dolores Ayala Velázquez*[2]
[1](plov@xanum.uam.mx)
[2](dav@xanum.uam.mx)
Departamento de Física, División de Ciencias Básicas e Ingeniería
Universidad Autónoma Metropolitana, México

Abstract

We discuss some simple models using Modellus that have been useful in various university courses, spanning from an initial propedeutic course to experimental physics and a simulation laboratory. The different role of models is shown at those various levels of knowledge and expertise. Examples of application of Modellus in more difficult problems, such as the initial value problem giving rise to river meanders and the analogous boundary value problem for the flexural deformation of a long bar, are included.

Introduction

Many freshmen students have defective knowledge and understanding of basic concepts in science and poor mathematics skills. However, most of them are highly motivated and even skilled at using computers and their interest in computer applications can be used to improve their fitness and chances to succeed in their studies, thus helping us to reduce the failure and desertion rates of Science and Engineering freshmen. This paper addresses the use of models and simulations using Modellus, by Duarte et. al., in three settings: 1) a propedeutic course offered before their actual first trimester enrollment, to improve their communication and problem solving skills; 2) our experimental method courses at the second and third trimester where simulations are used as tools to support teaching and promote a better understanding of the model and the data analysis; and 3) a simulation laboratory course at the third trimester, to introduce students to models, their similarities and range of applicability to problems in different fields, including the simulation of meanders and elastic curves. The simulation files are available upon request. In the last part we give conclusions based on our experience.

Simulations supporting problem comprehension and formulation

Lack of comprehension of a problem by students prevents them from successfully translating it into mathematical terms, as a previous step to writing the right equations to solve, and thus reach its answer. The examples in this section exhibit some concrete obstacles impeding the student's progress to the solution and show instances of how simulations, using just the evaluation and graphing capabilities of Modellus, lend themselves to gradually advance their understanding of concepts and problems as well as of the solution methodology.

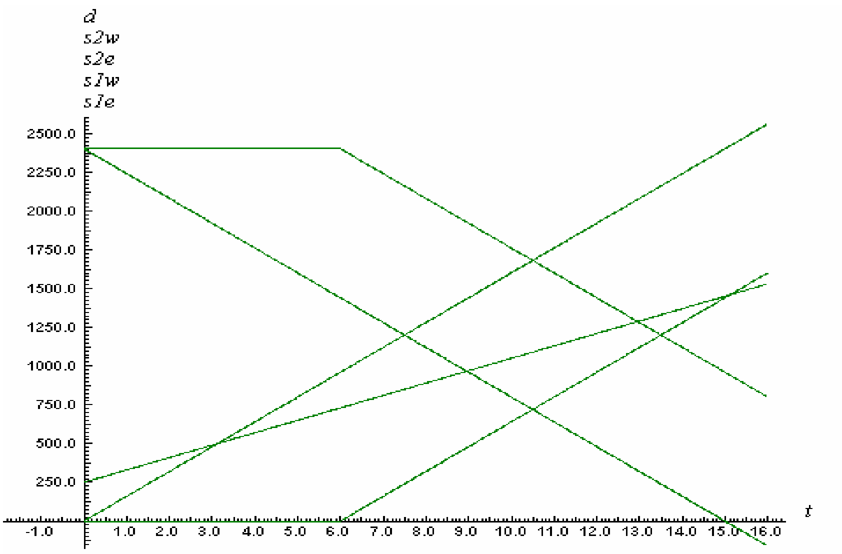
Problems giving raise to linear equations or relations

The type is well exemplified by the following two problems, taken from Perelman (1970), the first from kinematics:

≪As I walked on the sidewalk beside the tram track, I noticed that every 12 minutes a tram passed me, while every 4 minutes a tram went in the opposite direction. How often do trams leave, assumed to be the same, from the terminal station at each end?≫

Since no values of the tram and walking speeds are given, most students assume that these are unnecessary for its solution and their attempt to solve the problem fails. Assuming that these speeds are known and constant, one can write the expression for time between two successive trams going either way and work out the algebraic solution, which yields that this *lapse T* is the harmonic mean of the passing to crossing times *independently* of the speeds and further, that *any pair* of speeds with the ratio of (tram speed **:** walking speed) = 2**:**1 is associated with any pair of successive passing to crossing times in the ratio 3**:**1. The simulation just applies constant rectilinear motion and shows that the position of the successive trams going each way plotted as a function of t are two pairs of parallel lines, that the walker requires different times to intersect, according to their direction of motion. The triangles with horizontal and vertical sides determined by the intersections of the line representing the walker's position with the parallels offer a shortcut to the solution. Figure 1 shows a set of speeds giving a crossing time of 4 minutes and a passing time of 12 minutes, as given in the quoted problem statement.

Figure 1. Passing and crossing of a walker by successive trams leaving the terminal stations every 6 minutes.



The second problem deals with mixing solutions with a different concentration:

≪Determine the amount of two solutions, one of 3% concentration and the other of 30% concentration, necessary to obtain a 12% solution.≫

Here, the amounts of the given and of the desired solutions are not stated. To solve, mass and volume conservation is required. This problem let us recognize that some students do not understand the concept of *concentration*, and they required the instructor's help just to recall and understand the defining relationship between solute volume, solution volume and concentration, and the availability of the interactive simulation to show their relation was a great teaching and learning support, allowing the instructor to apply various strategies and stages to control the solution properties.

Models in the physics laboratory

Our initial experimental laboratories are highly biased towards developing skills and knowledge in metrology and data handling, while keeping most lab activities based on using very simple measuring instruments. Video cameras and electronic sensors are available and used in some classes and computer simulations, allowing the idealized problem to be studied in detail, guide in planning and conducting the experiment, as well as in clarifying the data analysis.

Bouncing ball

The common occurrence of a ball bouncing off the floor is a very attractive phenomenon to study. The simulation helps to recognize that controlled conditions are required to obtain sensible answers, e.g., the value of the inelastic coefficient r, the ratio of velocity after to that before the contact. It also assists students to grasp why the (t, y) graph for balls dropped with any horizontal velocity is always a set of parabolic arcs and its difference from a stroboscopic picture. The simulation considers different values of the inelastic coefficient in the various cases, while keeping, for simplicity, all the other quantities the same allows students to be asked to recover the value of r from the slope in a log (height) vs. bounce number graph.

Lucas-Washburn law

This law addresses the absorption of water by paper and the advancement of the wetting front, which is easily performed experimentally (Fanelli et. al., 1990). The model considers nearly perfect force balance between the wetting force, assumed constant, and a resistive force proportional to position and speed of progression of the wet front, which is easily integrated by separation of variables to yield a power law, namely, x proportional to the square root of t. Numerical solution is here for the equation $dt(x)/dx$ but not for $dx(t)/dt$, because the initial condition x=0 at t=0 gives an indeterminacy for the latter. The simulation here offers students the opportunity to understand the effect in the $x(t)$ and in the log-log plots of a small systematic error due to the fact that the initially measured x deviates from the assumed condition.

Models in the Simulation Laboratory

Since 1999, at our Science and Engineering Division we have taught the Simulation Laboratory course as a compulsory subject. Important features of this course are a) attempt to develop students' ability to understand and apply models, and b) to acquaint with symbolic mathematics computer tools. Since many of the examples considered in the course yield quite easily to numerical solution, we have found that using the purely numerical application Modellus is fruitful, enlightening and simpler for students to work with. Examples of the simulation creating an environment in which students can measure and invites comparison with results from the real world experiment, follow.

Pendulum with an arbitrary amplitude of oscillation

The simulation affords a simple way to study outside a physics laboratory the dependence of the period of a (frictionless) pendulum with amplitude of oscillation and gives some training for conducting the experiment because the procedure is the same, namely, to measure the time required for N complete oscillations.

This and the following simulation were provided originally by Ribeiro and Veit (2000), and a graph with phase-space trajectories was added in order to introduce students to this concept and type of representation.

Analysis of the amplitude of a forced oscillator near resonance

Resonance of mechanical, acoustical and electrical oscillators is a very important model, although quite difficult for freshmen to grasp theoretically and to work with experimentally, beyond a qualitative demonstration. In the simulation, the very important effect of a static force and the steady state amplitude of oscillation at different frequencies of the external force are determined in order to graph points of the resonance curve. Easy and quick comparison between the various cases with different frequency is very useful, for which the phase space graph allows a different perspective.

River meanders and bending of an elastic bar

River meanders are the loops formed by the riverbed as it flows downstream. Meanders can be described as curves whose tangent line makes an angle with the river mean axis that is proportional to the sine of the river length (Leopold and Langbein, 1966). The equilibrium shape of an elastic bar under an applied bending moment gives rise to a similar second order differential equation (Feynman et al., 1964). Both equations are similar to the equation of motion of a frictionless pendulum for arbitrary amplitude of oscillation, except that bending is a boundary value problem. However, we have used the initial value problem solver built in Modellus to show most of the interesting features of both systems (some of which may be studied following the guidelines to explore, describe and answer in the *Notes* window of meander.mdl) and, by trial and error parameter adjustment, we obtained very good approximations to the shape of bars with zero deflections at both ends.

Other examples

The logistic model of population dynamics due to Verhulst turns out to be quite realistic with respect to the slowing down of population growth, the attainment of a steady or equilibrium population and the decrease from an initial overpopulation condition. Comparisons with national or world census data for, e.g., the 20th century is quite reasonable and differences allow for conjectures about the effect of health care and wars to be made. Other simulations that have been found helpful in supporting or developing students' understanding are the superposition of harmonic oscillations giving rise to beats and the numerical solution of ordinary differential equations describing coupled chemical reactions.

Conclusion

Use of simulations helps to pursue deeper and wider understanding of physical phenomena, models and concepts in students, and are a valuable diagnostic tool to test their understanding and preconceptions. Simulations also improve and develop enquiring, observing, experimental and analysis skills and empower the students to conduct and perform better experimental activities. Premade simulations may be very useful to help the less gifted students to better understand problems and to build those skills. In addition, promotion of collaborative and teamwork in class allows the more gifted students to be willing to help their peers.

Simulations are more profitable if flexible didactic strategies are set forth and we are able to identify the class' and individual's needs and respond accordingly. The ability to repeat them as often as needed lends great help to understanding and correcting misconceptions. Resorting and relying in the presentation of simulations should become a wider and more often used practice, even more so in theoretical and experimental classes.

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