Teaching Physics Modelling with Graphic Simulations Tools

José M. Zamarro, Gregorio J. Molina, María J. Núñez
Universidad de Murcia. Departamento de Física.
Facultad de Química. Campus de Espinardo. 30071 Murcia. Spain
jmz@um.es, gregoriovi@eresmas.com, maripepa@um.es

Abstract. *The language of Physics is Mathematics, this feature can be an extra effort for beginners students. To build interactive graphic simulations can help to overcome some obstacle from Mathematic formalism. In this paper we will see some tool that allows users to concentrate their effort in the model, making easy to build an interactive graphic interface, it will be also shown what problems can be faced. At the same time, using tools for modelling Physics problems helps the students to become familiar with Mathematics.*

Keywords. Graphic simulations tools**,** Java Physics Simulations**,** Modelling with computers.

1. Introduction

Computers are used in different ways to teach Physics [1] [2] [3] [4], it can affect drastically the way of teaching Physics, a very good example is the Advancing Physics course [5], a contemporary course developed by the Institute of Physics, it is a huge effort developed by more than thirty teachers to use the technologies of information and communication to introduce Physics in a new, modern and attractive way. Our interest is concentratated in the use of authoring tools to develop interactive simulations that allow the learners to concentrate their effort in the model of the problem. In this paper we shall focus in the use of simulation authoring tools by science students to create simulations by themselves.

Not all the science phenomena are interesting to be attacked with simulations, those that need animation, interactivity, three dimension representation have especial interest for us. We also try to develop simulations following the spirit of the CoLoS (Conceptual Learning of Science) project [6], to proceed from basic principles.

Visual environments to develop interactive simulations allow concentrating the learner effort in building the model of the problem; they facilitate the creation of interactive graphic interfaces for people with little knowledge in software development. These simulations can face issues that are difficult to be treated by other ways because their abstract character or because their needs for animation. Many examples can be found in fields like the introduction of dynamics, waves, thermodynamics, quantum mechanics, electromagnetic fields etc.

Physics problems are mainly described in terms of differential equations. To manipulate these equations a big theoretical effort must be done. One option to facilitate handling these equations, is to introduce the students into the basic principles of numerical computation using simple algorithms to discretize the differential equations. This procedure has shown not to be difficult, and it is well accepted by students without previous knowledge of the numerical methods to treat differential equations [7].

There are many tools to produce simulations, but not so many that gather all the following features: to be easy to use, inexpensive, with good graphic capabilities and oriented to build interactive simulations for learning science.

2. The graphic simulation tool Ejs

Easy Java Simulations (Ejs) [8] [9] is an interactive tool developed for the conceptual learning of science. Ejs is not designed for professional programmers, but for teachers and students who want to create (or modify) scientific simulations. With Ejs, they can concentrate their effort on writing and refining the relations in the underlying scientific model, and dedicate the minimum possible amount of time to the programming techniques.

Ejs, is an authoring tool that creates automatically html files with the applet embedded; students are introduced to these html files so that they can modify the default one created by Ejs to personalize it.

Ejs allows the creation of sophisticated interactive animated interfaces, even in three dimension, with the mouse. To make interactive the interface is an easy task, we do it clicking on

icons and relating the properties of the graphic interface with the variables of the model.

3. Developments

Not all the issues treated in lectures of a course of General Physics are of interest to be treated with simulations. Those that have one of the following features: needs of animation, interactivity, three dimensional representation, abstract concepts sensitive of graphic representation are good to be the object of a simulation. In a first year course of General Physics the topics that fit better this features are: relative motion, dynamics of a particle, waves. quantum mechanics, dynamics of charged particles and field representation.

3.1 Relative motion.

There are topics that are easy to implement as simulations and are difficult to see without animation, for instance relative motion. In figure 1 we can see the trajectory of a particle that has constant velocity in an inertial reference frame, the trajectory is a straight line.
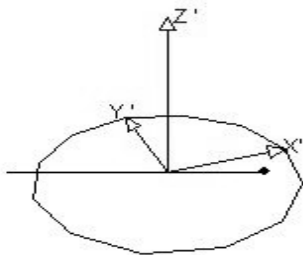

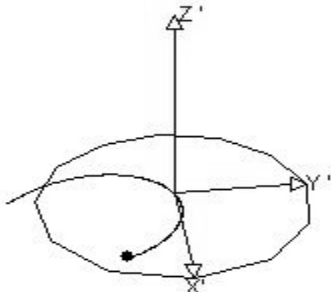**Figure 1. Trajectory of a particle that has constant velocity in an inertial reference frame.**

Figure 2. Trajectory of a particle that has constant velocity in an inertial reference frame observed from a frame that is rotating.

The same movement observed from a reference frame that is rotating, is a curve as we can verify in Fig. 2 that has been taken from the simulation. This example is a good one to introduce in a qualitative way the non inertial forces that are usually bad treated in previous courses.

Other nice example of relative motion is the outer planets seen from the earth. All this examples are simple to be simulated by students and serves as an introduction to the authoring tool, they have animation as the main feature.

3.2. Dynamic of particles: differential equations.

This is a topic especially interesting to be treated by students to create their own simulations. First of all, animation is a main characteristic of this subject and the mathematics that describe the model are second order differential equations, to approximate this equations by algebraic expressions is well accepted by students, for instance, from the definition of velocity:

$$v = \frac{dx}{dt} = \lim_{\Delta t \to 0} \frac{x(t + \Delta t) - x(t)}{\Delta t}$$

We obtain an algebraic expression accepting the approximation:

$$v * \Delta t = x(t + \Delta t) - x(t)$$

This algebraic equation is easily translated to computer code as the recursive expression:

$$x = x + v * dt$$

it gives the chance to explain students that for the computer this expression is not a mathematical one but an assignment for the value of the variable x, each iteration the value of x is incremented $v*dt$. In an identical way we can transform the differential equation that defines the acceleration. If the student develops the simulation by himself, he is forced to define some initial conditions to run the simulation, this is an important fact of differential equations.
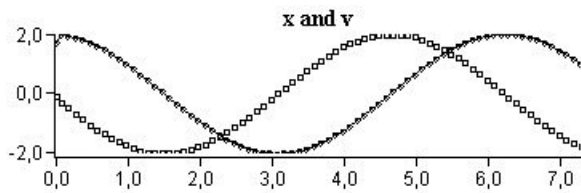
Figure 3. A car linked to a spring. Graph of the displacement and speed versus time.

A wide variety of problems can be faced using this simple numerical integration of velocity and acceleration just changing the value of acceleration. With a constant acceleration students can solve all the dynamic of particles at the earth surface. If he define the acceleration proportional and opposite to the displacement he arrives to the harmonic motion where he can introduce friction forces and forced oscillations to investigate resonance.

3.3. Waves

All teachers know how much we miss animation an interactivity when we explain this topic to our students using only the blackboard. The main feature of a wave is that a "perturbation" is transmitted, this means that the perturbation at a time at a place is the perturbation that had a previous instant at the previous point. The model for this condition is basically a line: $y[i] = y[i-1]$, we create a page that is running continuously:

```
y[0] = perturbation;
for(int i=N-1; i >0; i--) {
y[i] = y[i-1];
}
```

To get a way propagating to the left, just invert the last equation. If we link the value of y[0] to the position of a slider this position will be transmitted to the points of the line as it is shown at Fig. 4.

Figure 4. Propagation of the displacement of a slider.

If you link the first value, y[0], to a harmonic function you will get the typical pattern than you can see in most simulations.

3.4 Quantum Mechanics

In the first year University, students of Physics do not have a deep knowledge of Mathematics, Quantum Mechanics is an abstract topic that use mathematics not easy for students of first year university, simulations can help them. We can find very good simulations introducing basic concepts of quantum mechanics with Physlets as the Interactive Quantum Mechanics Exercises for Just-in-Time Teaching at Davidson College [10].
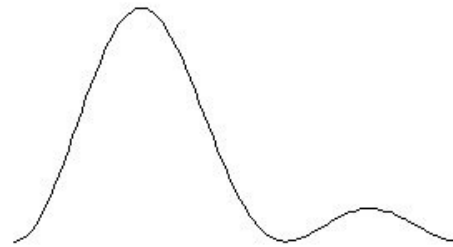

Figure 5. Time evolution of the superposition of two stationary states..

Our students solve numerically the Shrödinger equation in simple situations like the stationary states in a box, in a potential step and the temporal evolution of a state formed by a superposition of states as it is shown at Fig. 5.

3.5. Electric and magnetic fields: dynamic of charged particles

Once students have solved problems of dynamic with mechanical forces, dynamics of charged particles due to electrical and magnetic forces are solved straightforward. Students like to build cyclotron, mass spectrum, and perhaps the most spectacular one the Earth's Van Allen Belts approximating the Earth's geomagnetic fields by the field of a magnetic dipole. Particle stay trapped by this field as we can see in Fig. 6.

Figure 6. Simulation of the Van Allen Belts

To represent electric fields created by particles is a good exercise for students, this is not a trivial thing to simulate but there is a case easy form them, to create particles at their interest and represent the field by an arrow clicking with the mouse on a point of the simulation window.

9. References

[1] M. F. Iskander, *Technology-Based Electromagnetic Education*, IEEE Transactions on Microwave Theory and Techniques, V. 50 nº 3, p. 1015-1020, March (2002)

[2] F. Esquembre, *Computers in Physics Education*, Computer Physics Communications 147, 13-18 (2002)

[3] de Jong, T. *"Learning and Instruction with Computer Simulations"*. Education & Computing, 6, 217-229, (1991)

[4] S. F. Almeida Barretto, R. Piazzalunga, V. Guimarães Ribeiro, M. B. Casemiro Dalla and R. M. Leon Filho, *Combining interactivity and improved layout while creating educational software for the Web,* Computers & Education, Volume 40, Issue 3, Pages 271-284, April (2003)

[5] Advanced Subsidiary (AS) Course & Advanced Level (A2) Course. J. Ogborn, M. Whitehouse. Institute of Physics Publishing. (2000)

[6] Härtel, H., "COLOS: Conceptual Learning Of Science". de Jong T. Sarti L. (ed): Design and Production of Multimedia and Simulation-based Learning Material. Kluwer Academic Publishers, pp 189-217, (1994).

[7]. J. Dias de Deus, M. Pimenta, A. Noroña, T. Peña, P. Brogueira, *Introducción a la Física*, 2ª Ed., Mc Graw Hill, p. 475, (2001)

[8] F. Esquembre, J.M. Zamarro, *EJS: Authoring Tool to Develop Java Applications*. Computers and Education. Towards an Interconnected Society. M. Ortega and J. Bravo (Eds.) p 143-148. ISBN: 0-7923-7188-7. Kluwer Academic Publishers. (2001)

[9] Hwang FK, Esquembre F, Easy Java Simulations: An Interactive Science Learning Tool. Interactive Multimedia Electronic Journal of Computer-Enhanced; 1998.

[10] Interactive Quantum Mechanics Exercises for Just-in-Time Teaching http://webphysics.davidson.edu/qmbook/ Mario Belloni, Larry Cain, and Wolfgang Christian.