

# VIRTUAL LEARNING ENVIRONMENT FOR PHYSICS INSTRUCTION

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Abstract: In this work the characteristics and educational applications of a virtual computer-assisted environment teaching related with the motion of projectiles subjected to the force of the air (<http://rabfis15.uco.es/lvct/descargas/fisica/17/>) is presented. This web portal has been designed as an interactive tutorial system including several modules (simulations, problem resolution, knowledge evaluation, etc.), it has been applied as a complementary teaching aid for the subject Physics in the first year of Engineering and it is aimed to improve the understanding of the influence of the friction forces which vary with the speed of the two-dimensional motions. The software presented has all the following features: integrative character, self-evaluation tests, personalized and active learning process, adaptability to teacher's aims, versatility as a teaching tool, multimedia resources and simplicity. This study has been carried out with students of the Higher Technical College (in Spanish: *Escuela Politécnica Superior, EPS*) Cordoba (Spain), with highly favourable results when compared with students who did not use the software.

## 1 INTRODUCTION

Many researchers (Andaloro, G., et al., 1991, Fernando Espinoza 2005, Dahlmann N., 2007, Sharma, S. V. et al 2007, Murphy T.D., 2008, Anastasiades P.S., et al. 2008) have shown the usefulness of computers as an interactive communication means permitting an access to all kinds of information (texts, images, different types of data, graphics, etc.), as an instrument for problem resolution and exercises, as a tool for carrying out simulations of physical phenomena and experiments, or to measure and monitor laboratory experiments.

The computer applications in education have been greatly extended adopting (Baker, D.R., 1991, Bacon, R.A., 1992), in most cases, a technological educational model in which it was assumed that the learning process can be improved as the means and procedures for presenting the information go on improving (Sharma, S. V. et al 2007). To sum up, computers can also be a tool to help students to be the protagonists in the progress of their own learning process (Hicks and Laue, 1989; Li, 1998, Murphy T,

et al. 2002).

From this perspective, our work line has been focused on the development and evaluation of tutorial systems including the development of interactive simulation laboratories (Martinez Jimenez, P. et al., 2004, 2006).

Students' learning difficulties related to projectile motion have already been dealt with in many research studies for many years (Borghi L. et al 2005; Sharma S.V. , 2007). Furthermore, although many computer programs have been developed in Mechanics (Gillet D., et al. 2005), using simulations of force and motion, but the motion of bodies subjected to variable friction forces in resistive media has not received much attention up till now, either in the didactic research field or in education training. In spite of this, the analysis of the characteristics of this phenomena is an activity of great educational value in university physics since it makes students study speed-dependent forces and the influence of the different variables affecting the motion (Marion, 1992).

For all these reasons we have conducted an educational investigation process related with the

development, application and evaluation of a web system devoted to the study of projectile motion in resistive media.

## 2 OBJECTIVES

The general aims intended in this process were:

- To provide free access, via Internet, to upgraded teaching tools related to engineering and its teaching.
- To create a single environment in the web joining together all the simulation computer programs in the field of Science and Technology, as well as the virtual laboratories.
- To incorporate a single evaluation system (evaluation manager), and an examination executor.
- To relate the theoretical and practical aspects of teaching.
- To upgrade engineering curricula looking for more logical links among their subjects and promoting the methodological change towards an education system based on self-learning.

The educational objectives that this tutorial system aims to develop are the following:

- To understand the influence of the friction coefficient, the initial speed and the flight angle of a projectile subjected to a resistive force of the air proportional to the speed.
- To understand the influence of these factors for the case of a projectile subjected to a linearly dependent force of resistance of the air and also proportional to its square.
- To find out and assess the advantages of different mathematical methods (analytical, graphic and numerical) which permit the resolution of the problem of projectile motion in resistive media for high and low velocities.

## 3 ANALYSIS OF PHYSICAL PROBLEMS AND STRUCTURE OF THE PROGRAM

The software for the simulation of the motion of projectiles with a speed-dependent force is included in the web portal <http://rabfis15.uco.es/lvct/index.php?q=node/22>.

This software offers the main Windows facilities: interactivity and versatility. It comprises four different parts that can be reached from the program's main menu: Previous Knowledge (In

Spanish "Preconceptos"), Tutorial (In Spanish "Tutorial"), Simulation (In Spanish "Simulación") and Evaluation (In Spanish "Evaluación"), i.e. all the tasks carried out in the educational process. As they are intended for students, the programs are highly user-friendly.

In addition, the program opens with an animation representing the phenomena studied with the aim of attracting the students' attention from the outset and obtaining a high degree of interaction between the user and the physical simulation implemented. In the second screen (Figure 1) students can select the type of approximation to perform: a) linear dependence or b) quadratic.



Figure 1: Main menu of the program.

Simulation has two sections; a study of the motion of projectiles for resistance forces whose dependence with respect to the velocity is linear, and the second in which the correlation is quadratic. We have thus applied and compared different numerical methods as a function of the value of the velocity exponent. Help on program functioning is always available, animated icons illustrate the uses of different buttons and the window calculator and the text processor Word are accessible from the program. With these last features, the student has direct access to a list of exercises, hints, complementary explanations, etc., which can be written by teachers in order to fit the software to their own pedagogical aims. The setup of the physics problem to be simulated is also carried out in a completely interactive way since users can choose and design the work conditions.

In this application, the problem of projectile motion in resistive and non-resistive media has been used to make an approximation to Computational Physics. The solution has been found with the implementation of different numerical methods such as the Newton-Raphson, the Iterative Fixed-Point, the Euler and the Runge-Kutta methods.

The air resistance force over a projectile is a linear dependence function of the velocity when this is under 24 m/s. Furthermore, when the velocity

is over this limit, the force of the air friction is proportional to the square of speed. Firstly, the motion of a projectile was studied in the atmosphere in which it was supposed that the force of resistance was linearly speed-dependent. It is aimed to determine the decrease in the range as well as the influence exercised by the velocity on that decrease both on the module and on the direction. The equations defining the motion are:

$$mx'' = -Kmx' \text{ and } my'' = -Kmy' - mg \quad (1)$$

Where m represents the mass,  $x''$  and  $y''$  the components of the acceleration,  $x'$  and  $y'$  the components of the velocity, K is the constant of the air resistance and the g is gravity acceleration. The solutions to these equations are

$$x = \frac{V_{ox}}{K} (1 - e^{-Kt}) \quad (2)$$

$$y = -\frac{gt}{K} + \frac{Kv_{oy} + g}{K^2} (1 - e^{-Kt}) \quad (3)$$

The range of the projectile R is determined by calculating, first, the time T (flight time) necessary for the object to complete the whole trajectory and substituting this in equation 1 corresponding to the displacement.

$$T = \frac{Kv_{oy} + g}{gk} (1 - e^{-KT}) \quad (4)$$

The complexity of the procedure is presented in the solution to equation 4, which is transcendental. The mathematical methods used for obtaining the analytic expression of the projectile's flight time are the following:

a) Graphic: in which the flight time is obtained as a graphical solution of the system of equations, as observed in Figure 2.

$$y_1 = T, \quad y_2 = \frac{Kv_{oy} + g}{gK} (1 - e^{-KT}) \quad (5)$$

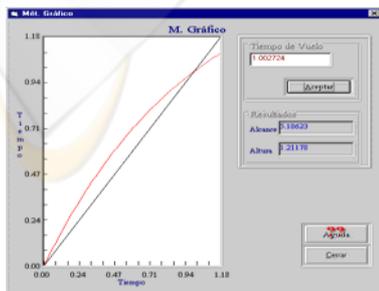


Figure 2: Graphic method for solution of flight time.

b) Approximate: in which by a sequential evolution and taking limit when k tends to zero, the following linear approximations are obtained.

$$T \cong 2 \frac{v_{oy}}{g} \left( 1 - \frac{Kv_{oy}}{3g} \right) \quad (6)$$

$$R = \frac{2v_{ox}v_{oy}}{g} \quad (7)$$

$$R' \cong R \left( 1 - \frac{4Kv_{oy}}{3g} \right) \quad (8)$$

This program can make a representation of factor  $\Delta R/R$  versus the friction constant for the linear approximation and for the real values ( $\Delta R=R'-R$ ), this approximation is only valid for constant values equal to or under 0.01; above this value the deviation of the real range with respect to that calculated rapidly increases and, thus, the linear approximation becomes unfeasible.

The linear projectile motion screen presents five superimposed files, which permit the introduction of the data of five different projectiles. For each of these are obtained the numerical results corresponding to the flight time, range, etc., by the analytic method (approximation) graphic method, the Iterative Fixed-Point and Newton-Raphson methods. Also, the errors in each method are studied and all of them are compared with the Newton-Raphson method, which is the most accurate one, and the computation of each algorithm is timed.

For this physical approximation, two numerical methods have been implemented: the Iterative Fixed-Point method and the Newton-Raphson method (Curtis F. Gerald and Patrick O. Wheatley, 2003). The function solving the first numerical method is based on the Graphic Method. Its way of working is to drag the two functions looking for the cross section which indicates the flight time value, and then replace this, T, in the equations 3 and 4 to determine the maximum height and range. Likewise, we make the calculation of the flight time and range by the Newton-Raphson method.

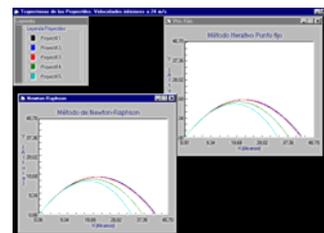


Figure 3: The projectile Trajectories.

The graphic results permit users to visualize the trajectories of all the projectiles studied for each of the methods implemented (Figure 3). It is necessary to point out that with this program the user is able to understand the significance of the mathematical model in the design of the physical model and, therefore, in the understanding of the reality.

For velocities of over 24 m/s the force of resistance of the medium, the air, is proportional to the square of the speed:

$$F_a = -Kv^2 \quad (9)$$

Using simple algebra and trigonometry, we find that:

$$a_x = -Kv \cdot v_x \quad \text{and} \quad a_y = -g - Kv \cdot v_y \quad (10)$$

The solution methods of these equations are the numerical methods: the improved Euler or Heun and the Runge-Kutta method, the 2<sup>nd</sup>, and 3<sup>rd</sup> orders.

When the force of resistance of the air is proportional to the square of the speed (section 2) the operation is the same as in the first part of the simulation. In this second section the improved Euler and the Runge-Kutta methods, 2<sup>nd</sup>, and 3<sup>rd</sup>, are implemented.

#### 4 EDUCATIONAL APPLICATIONS OF THE PROGRAM AND PROPOSED WORK METHODOLOGY

This virtual laboratory has been designed as a support tool for the subject of Physics in the first year of sciences or engineering.

Before doing the practical, the student downloads the department's web page (<http://rabfis15.uco.es/deptfisica/eps/>) the program guide for the practical, it is an open document (included in the portfolio of the system) which can be modified by any teacher.

In general, it is recommended to begin by the problem of low-speed projectile motion, in which the friction force of the air is proportional to the velocity. Students can find out the analytical solution offered by the program and analyze the results obtained by the Iterative Fixed-Point and Newton-Raphson methods, attempting to interpret the errors predicted in each method. It is interesting to analyze the results obtained in the graphic method (Figure 2) and to explore how the graph obtained

changes as the resistance of the air is modified. It is also desirable to analyze the errors obtained in each resolution method. Finally, it is necessary to access to the graph of the trajectories of the different projectiles (Figure 3) with the aim of analyzing their physical significance and draw the pertinent conclusions.

In second time, the students can go on to study the behavior of moving objects with an initial high speed which are subjected to a friction force proportional to the square of the speed. This problem can be resolved by the numerical methods of Euler and Runge-Kutta.

In order to assess the educational value, a comparative analysis was made (2006-2007, 2007-2008) of the learning results achieved by students who had worked with this tool (experimental groups GE1 and GE2) and other students at the same level who followed a traditional teaching method (control groups GC1 and GC2) based on a theoretical exposition. The two experimental group students worked in small groups with the simulation program, following the instructions in an activity program guide.

The evaluation of the learning program was made through an analysis of the individual reports of each student on finishing the experiment and a complementary questionnaire on the understanding of the phenomenon studied. The same evaluation process was followed with the control group students.

The analysis of the evaluation data was made from a classification of the results obtained by the different students. Four learning categories were established: I (deficient), II (acceptable), III (good) and IV (very good) (figure 4). On analyzing the first results it was observed that the students in the experiment groups generally achieved better results than those of the control groups.

From these results, the greatest differences were seen in level I (deficient) this being much greater in the control groups, and in level III (good), notably

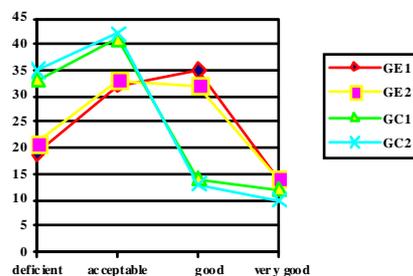


Figure 4: Results of educational experience.

higher in the experiment groups.

From these facts, it is deduced that the instruction process followed in the experiment groups enabled students to achieve a higher progress level than in the control groups and that the program used constitutes a useful instrument for improving the learning process.

The results show that the program is a useful tool for improving the learning process in this subject.

## 5 CONCLUSIONS

This paper has described the creation process of a tutorial system, carried out in several stages and based on the computer simulation of projectile motion in resistive media. The software has been applied in a real teaching context, as a complementary aid to the teaching of Physics in first-year Engineering.

In this article we have shown the structure of the tutorial system and described the characteristics of the user's interface and the physics problems simulated. We have also shown its possible didactic applications, establishing a methodological proposition for using the system.

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