The 2nd International Symposium on
Integrating Research, Education, and Problem Solving: IREPS 2012

Research, Education and Problem Solving as a Virtuous Circle

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ABSTRACT

The world is concerned about science and mathematics education for both secondary and university students, in order to become the future workforce. Since many years, several attempts to describe smart tutorial systems have been made. Present technologies are needed to assist learners.
The National Science Foundation has supported the Innovative Technology Experiences for Students and Teachers Program in order to call for proposals about this subject matter. The present authors, inspired on this Program, submit innovative experiences for sciences and mathematics learning.
A change in spaces with combined classroom and laboratory facilities is needed in order to implement an automatic system for data acquisition, processing and representation.
Open educational resources are designed with new technologies for representing, manipulating, and communicating data, information, and ideas focused on practices in STEM fields. Technology should be used to support student interaction with STEM content in ways that promote deeper understanding of complex ideas, engage students in solving complex problems, and create new opportunities for STEM learning.
The present paper contents some examples on how to deal with real life problem solving at the intersection of various sciences disciplines, technology, engineering and mathematics.
These open educational resources are free and can be used by those teachers who have been trained during several workshops.

Keywords: experiences, sciences, mathematics, technology, teachers, students.

1. INTRODUCTION

The World is very much concerned about the application of present technologies as tools for students´ performances both in high school and university. Several proposals for helping student´s learning, particularly in science and mathematics, have been done (Cataldi 2009) (Chipan et al., 2005), and more recently, U.S. Department of Education, Office of Educational Technology, *Transforming American Education: Learning Powered by Technology* (DOE, 2010).
The new students´ generation is using video games and they have acquired practice in dealing with simultaneous processes in very short times with high density knowledge. So, if a new tutorial system will be designed, it has to be according to those practices.

2. APPLICATION OF SCIENTIFIC METHOD FOR SCIENCES AND MATHEMATICS TEACHING

The application of scientific method to sciences and mathematics teaching has been applied for a long time, but the way it is applied at present is no longer valid, according the way scientific research is dealing with in the XXI Century. Technology is now present in almost any research, in contrast with science and mathematics teaching. This is not motivational and students find it boring.

3. OPEN EDUCATIONAL RESOURCES DESIGN AND MANAGEMENT

Our Education Research Group in Basic Sciences has implemented a Program based on a tutorial system for experimental sciences and mathematics learning according to STEM Pedagogy (Science, Technology, Engineering and Mathematics).(George Washington University 2009), (CRS Report for Congress, 2006), (Meet the Future Summit 2010), Success in STEM Education 2011). This Program is inspired on the National Science Foundation “Innovative Technology Experiences for Students and Teachers (ITEST) Program” (NSF, 2011).
According to the US Department of Education Report (DOE, 2010), new technologies for representing, manipulating, and communicating data, information, and ideas have changed professional practices in STEM fields. Technology should be used to support student interaction with STEM content in ways that promote deeper understanding of complex ideas, engage students in solving complex problems, and create new opportunities for STEM learning.
The value of open educational resources is now recognized around the world, leading to the availability of a vast array of learning, teaching, and research resources that learners of any age can use across all content areas.

4. LABORATORY EXPERIMENTS

In contrast with most of Sciences and Mathematics textbooks, we emphasize experimentation, as it permits to work with concepts, laws and processes and applications to real life (Duschl, 2004), (Lederman, 2004). The instructional unit engages the students in a carefully structured sequence of hands-on laboratory investigations interwoven with other forms of instruction.

For each ***Experimental Session***, a sequence of experiences is presented, in order that each one gives rise to the following, that is to say, they are linked between what has been done and what will be done.

According to this sequence, students learn how to observe, how to register information, how to introduce a scientific model, and how to arrive at conclusions, in such a way that they acquire the scientific method.
These Series of Experimental Sessions have the objective

- To provide students with sufficient activities to develop scientific knowledge and concepts on sciences and mathematics;
- To acquire attitudes of inquiry and data analysis in order to create, test and refine models;
- Scientific modeling is a core element in several innovative laboratory- centered science curricula that appear to enhance student learning.

The development of each experiment encompasses the following activities

- Experimental arrangement assisted by new elements and new technologies for automatic data processing and representation;
- Experiment performance with automatic and simultaneous representation of data gathering;
- Derive a model and its predictions;
- Fitting model predictions with experimental data;
- Derive conclusions and propose new experiments.

The use of these resources and graphics interpretation constitutes an important tool so that students are encouraged to measure, to experiment, to discover relationships between variables, making hypothesis, derive conclusions, and communicate them.

5. LABORATORIES AND EQUIPMENT

Combined laboratory-classrooms can support effective laboratory experiences by providing movable benches and chairs, movable walls, peripheral or central location of facilities, wireless Internet connections and trolleys for computers, fume hoods, or other equipment. These flexible furnishings allow students to move seamlessly from carrying out laboratory activities on the benches to small-group or whole-class discussions that help them make meaning from their activities. All computers may be equipped with Computer Algebraic Systems (CAS) (Hohenwarter, M., 2004); Wolfram Research Institute, 2011).

6. EXAMPLES OF REAL LIFE PROBLEM SOLVING

Among different kinds of problem solving, one chooses the real life scientific problems, the solution of which is done through model conceptions.
In order to conceive a model one needs to apply a scientific method: parameters identification, measurements, data logging, data processing, algorithm proposal and solving, predictions, again experiments to check the predictions. In turn, to follow this sequence we need to perform some research to create a new set of knowledge suitable for the problem to be solved.
In order to show the results, we need discussions with peers and many others people. The whole interaction and iterations between research, model, people and experiments, will give rise to a model proposal and, finally, to a problem solution.

These procedures promote student reflection using collaborative tools to reveal and clarify students' conceptual understanding and thinking, planning, and creative processes.
These studies must be performed at technology-enriched learning environments that enable all students to pursue their individual curiosities and become active participants in setting their own educational goals, managing their own learning, and assessing their own progress.
Classical experiences must be re created into new experiences oriented to "real-life problems solving". For this purpose new teaching prototypes must be developed.
The aim of our Program is to give some examples on how to deal with real life problem solving at the intersection of various sciences disciplines, technology, engineering and mathematics.

7. Motion of a body falling down to earth

Generally, the motion of a body of mass *m* subject to a force **F** through a trajectory *s* during time *t* is described by the integral equation

$$\int_{so}^{s} \frac{ds}{\sqrt{w}} = \sqrt{\frac{2}{m}} \cdot t \qquad \text{Eq. (7.1)}$$

$$\boldsymbol{W} = \int_{so}^{s} F \times ds = \frac{1}{2} \cdot m \cdot v(s)^2 \qquad \text{Eq. (7.2)}$$

If the force **F** is a conservative force derived from a potential function V(s), then

$$W = \int_{so}^{s} -dV = V(so) - V(s) = \frac{1}{2} \cdot m \cdot v(s)^2 \qquad \text{Eq. (7.3)}$$

The equation of energy conservation results

$$V(so) = V(s) + \frac{1}{2} \cdot m \cdot v(s)^2 = E_T \,, \qquad \text{Eq. (7.4)}$$

Where E_T is the system's total energy (invariant).

Let consider the motion of a body subject to the earth gravitational force **F** and potential V(r).
If the initial conditions are:
H(0) the distance from earth where the body is launched without initial velocity;
V(t)=m.g.h(t) the body potential energy corresponding to a distance h(t) from the earth; then, equation (2.4) becomes

$$V(H) = m \cdot g \cdot h + \frac{1}{2} \cdot m \cdot v(s)^2 = E_T \qquad \text{Eq. (7.5)}$$

In order to validate equation (7.5), let take a body that falls from the distance H = 2,4 m down to a distance h = 1,3 m from the experimental table; let consider the following experimental arrangement shown in Fig. 1. A ball is falling down; the position and velocity of it are registered by ultrasonic radar. The corresponding values are displayed in Table 1. Fig. 1 represents the energies graphs from data given in Table 1.

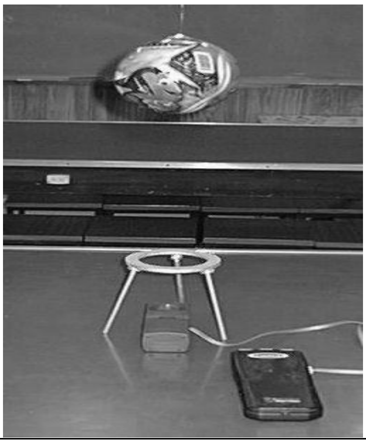

Figure 1. Experimental arrangement for displacement and velocity registration of a falling body from a distance of 2,4 m down to 1,3 m. Registration is taken by ultrasonic radar coupled to an interface and computer.

t (s)	disp (m)	veloc.(m/s)
0,75	2,40	0,09
0,8	2,37	0,30
0,85	2,35	0,65
0,9	2,31	1,08
0,95	2,25	1 ,54
1	2,16	1,99
1,05	2,05	2,44
1,1	1,91	2,87
1,15	1,76	3,30
1,2	1,586	3,70
1,25	1,39	4,09
1,3	1,17	4,47

Table 1. Displacement and velocity values registered corresponding to the ball fall from height 2,4 down to 1,3 m during almost half second.

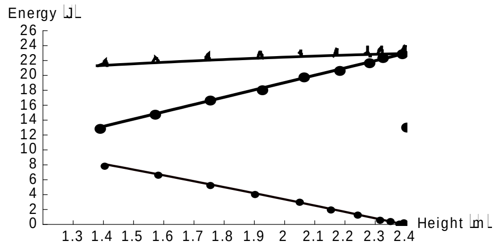

Figure 2. Graphs representing the body potential, kinetic and total energy vs. height.

The kinetic energy does not fit exactly with a linear function since there is a sensible friction of the ball with air. Consequently total energy is constant at the beginning where both velocity and friction are low. When velocity increases, friction too, and total energy is reduced up to 5 %.

8. Motion of a body falling down within a fluid

We studied the displacement of a body falling down within a fluid due to the gravitational attraction. In this case there exists a drag force pulling up the body against the gravitational force.

In the experimental set up, we choose a coffee filter as a body and the atmospheric air as a fluid.

We use an automatic system to determine the body's velocity and displacement. Ultrasonic radar is coupled to an interface connected with a computer. A corresponding program is used to determine the variation of the abovementioned parameters as function of time.

Fig. 6 shows the experimental arrangement. Fig. 7 illustrates the velocity graphics as function of time showing the velocity limit reached by the body. At he beginning, the velocity varies linearly with time, and later changes linearity, approaching the velocity limit

$$v_\ell = 2,97\ \frac{m}{s}$$

First Assumption

We developed a mathematical model assuming that the drag force acting on the body is proportional to its velocity. That is to say, the total force **F** acting on the body has two components.

The resultant force is expressed by

$$\mathbf{F}(t) = m\cdot a\cdot \mathbf{e_y} = m\cdot g\cdot \cdot\mathbf{e_y} - k\, m\cdot v\cdot \mathbf{e_y}. \qquad \text{Eq. (8.1)}$$

where $\mathbf{e_y}$ is a unitary vector pointing down to the earth's center.

From eq. (8.1) a differential equation is derived

$$\frac{dv}{(g-kv)} = dt, \qquad \text{Eq. (8.2)}$$

with the initial condition for t = 0 is $v = v_0$; $y = y_0 = 0$. From the experiment is $v_0 = 0$, then

$$v = \frac{g}{k}(1-e^{-k\cdot t}). \qquad \text{Eq. (8.3)}$$

The velocity limit is

$$v_\ell = \frac{g}{k}. \qquad \text{Eq. (8.4)}$$

Replacing the experimental values one gets

$$v(t) = 2{,}97\cdot(1- e^{-3{,}3\cdot t}), \qquad \text{Eq. (8.5)}$$

Second Assumption

We developed another mathematical model assuming that the drag force acting on the body is proportional to the square of its velocity. The resultant force is expressed by

$$\mathbf{F}(t)= m\cdot a\cdot \mathbf{e_y} = m\cdot g\cdot \mathbf{e_y} - k\cdot m\cdot v^2 \cdot \mathbf{e_y}.$$

giving rise to the differential equation

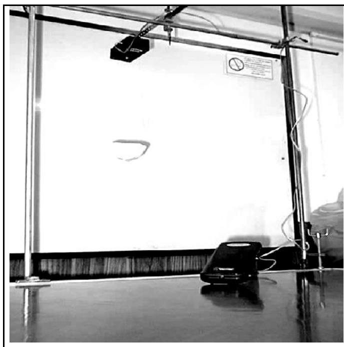

Figure 3. Experimental arrangement for body's velocity and displacement registration.

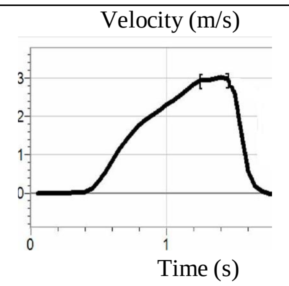

Figure 4. Body's velocity registration as function of falling time.

$$\frac{dv}{(g-k\cdot v^2)} = dt \qquad \text{Eq. (8.6)}$$

In order to homogenize the forces acting on the body, the *k* constant is expressed as function of two parameters g y α^2 so that $k = \frac{g}{\alpha^2}$. The constant α must have a velocity dimension; we choose its value being the velocity limit $\alpha = 2.97\ \frac{m}{s}$. Then the differential equation is set

$$\frac{dv}{\left(1-\frac{v^2}{\alpha^2}\right)} = g\cdot dt\ . \qquad \text{Eq. (8.7)}$$

with the initial condition for t = 0 is v = v_0 = 0.

The solution of Eq. (8.7) is obtained through the use of the Computer Algebra System given by

$$\left[\alpha \cdot tanh^{-1}\left(\frac{v}{\alpha}\right) - \alpha \cdot tanh^{-1}\left(\frac{0}{\alpha}\right) = \frac{g}{t}\cdot\right]$$

v (t) = 2,97·tanh(3,3·t). Eq. (8.8)

Two hypotheses have been assumed, one, the drag force acting on the body is proportional to its velocity, and the other, to the velocity squared. The graphics from Fig. 8 shows the representation of both functions (8.5) and (8.8) and the experimental one from Fig.5, within the time interval where the drag force is acting clearly on the body, that is to say in the time interval [1,1 ; 1,5].

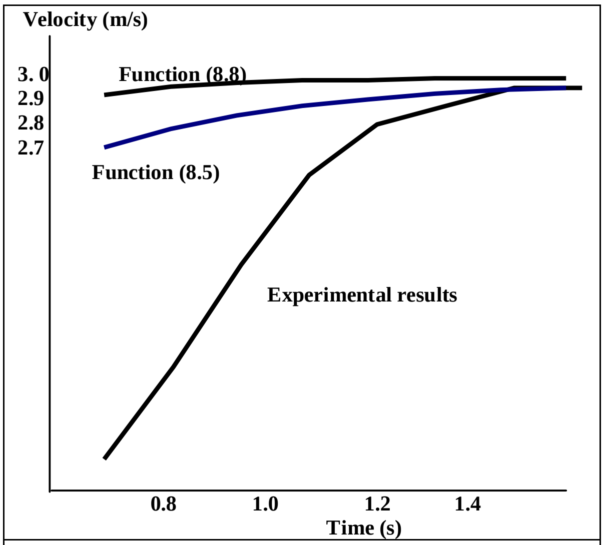

Figure 5. Falling body's velocity graphs according to experimental results and functions Eq.(8.5) and Eq.(8.8). In the time interval between 1.1 and 1.5 s one observes that function Eq.(8.5) approaches more to the experimental function than function Eq.(8.8).

According to these graphics we arrive at the conclusion that the most plausible approximation is that the drag force is proportional to the body's velocity, at least according to the experimental arrangement of Fig. 3.

DISCUSION AND CONCLUSIONS

Open educational resources for teaching sciences and mathematics have been proposed by means of application the scientific method assisted by electronic and information Technologies.

The experimental sessions are performed with an automatic registration system (Computer Based Laboratory). Scientific models are proposed to predict the system's behavior and confronted with experimental data. A CAS is used to solve differential equations raised from mathematical models.

The examples shown provide an idea on how an open education resource may be written in the future. First of all, formulas appear as consequence of a physical system study. Second, a model proposition arises from a system description. Thirdly, the model prediction must always be validated by experiment. One has to prove that the differential equation's solution is correct from the mathematics standpoint of view and is correct from the real life problem point of view. Multidisciplinary focus in accounting for a solution of a real life problem is a way that promises to be more attractive to students.

If one assumes that this is the way to conduct science and engineering education, getting the corresponding feedback to improve model and problem solution, one has created a virtuous circle between research, education and problem solving.

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