Didactic strategies using simulations for Physics teaching

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Among the objectives of Physics teaching, in the context of university education, we can point out the use of models and laws to solve problems, the characterization and modelling of the relationships among magnitudes, and the training in abstract thinking and critical reflection. In order to reach these aims, simulations are potentially useful in the teaching and learning processes at the basic university level. However, adequate didactic strategies are required to use these resources. In this paper, a critical and reflexive analysis of strategies for mechanics, optics, electricity and contemporary Physics teaching is presented. These strategies integrate free computational simulations with real laboratory experiences and pencil and paper problem solving.

Keywords: Physics; simulations; models; didactic strategies; critical analysis

(Spanish Abstract) Entre los objetivos de enseñanza de la física en el nivel universitario, podemos destacar el uso de modelos y leyes para resolver problemas, la caracterización y modelado de las relaciones entre magnitudes, y el entrenamiento en el pensamiento abstracto y la reflexión crítica. Para el logro de estos objetivos, las simulaciones son potencialmente útiles para la enseñanza y el aprendizaje en el nivel básico universitario Sin embargo, se requiere desarrollar estrategias didácticas adecuadas para usar estos recursos. En este trabajo, se presenta un análisis crítico y reflexivo de estrategias para la enseñanza de temas de mecánica, óptica, electricidad y física contemporánea. Estas estrategias integran simulaciones computacionales de uso libre, con experiencias de laboratorio y resolución de problemas de lápiz y papel.

Palabras clave: Física, simulaciones, modelos, estrategias didácticas, análisis crítico

1. Experimentation, simulation and problem solving in Physics teaching

Being Physics an experimental science, observation, measuring and theoretical speculations are processes that cannot be separated from the physical knowledge construction, even in the classroom. Thus, the didactic proposals designed or selected to teach Physics must correspond to those processes.

Multiple purposes are achieved through real experiences: to encourage students' interests in "knowing" and "doing"; to promote the observation, explanation and interpretation of different phenomena, and to apply their knowledge to new situations of practical and technological interest. On the other hand, the problem of teaching and learning Physics nowadays cannot be separated from the use of information and communication technologies (ICTs) as they are resources of our culture.

We have already noticed that the excessive emphasis on the communication function given to the ICTs has darkened its potential in the knowledge construction [1]. The question is not only "how much and how" we interact externally with the resource, but also how much and how its use promotes the processes that make us understand, explain, predict and build our knowledge. So we need adequate didactic strategies in order to promote meaningful learning. Simulations used in Physics teaching are computer programmes that have an implicit model of the behaviour of a physical system and that allow students to explore and to visualise graphic representations. The operator can interact with the system modifying its state, changing parameters and observing the results of this manipulation. Because of the flexi-

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bility and great speed of computers, students can make a great number of simulations in a short time. They may work in an exploratory way, trying to solve relatively open problems, which are practically impossible to solve through real experiments or numerical calculus.

There are basically two types of simulations: the programmes that need to be installed previously in a computer, and the so-called “fislets” (a contraction of Physics and applet), which can be used directly from the web page. The fislets are simple programmes that are easily loaded in the computer. They can be handled highly intuitively, and so people can learn how to use it in a short time [2].

Through the manipulation of parameters and the use of different types of representations in the simulations, comprehension of the relationships among concepts, variables and phenomena can be fostered in the students. At the same time, phenomena which would not be possible to experience in a classroom or laboratory can be investigated [3].

Simulations are not conceived here as substitutes of the real laboratory experiences. Their use as a complement of experimentation can be highly profitable, especially to enlarge the field of experimentation, as a group of variables can be handled at will, and this cannot always be made in a real experiment.

On the other hand, the pencil and paper problem solving (PS) as investigation [4] involves the elaboration of hypotheses that must be contrasted with the results obtained.

In this paper we describe computational simulations integrated with lab work and with PS. These activities are developed in basic Physics courses for Engineering and Sciences students in Argentine. The proposal was designed for mechanics, optics, electricity and contemporary Physics teaching. The activities are aimed to promote a critical analysis of the models involved in solving simple problems, the comparison of the results derived from a qualitative analysis of the problem, with those ones obtained from the simulations, and with experimental results.

2. Mechanics

In order to study the movement of solid bodies in different fluids, the programme Fall of Spherical Particles (FSP) was used. This simulator was developed at the Universidad Nacional del Litoral, at Argentine (www.fiqus.unl.edu.ar/galileo/download/software/fluidos.zip). The FSP allows students to simulate the falling movement of different spherical bodies in vacuum, in the air, and in liquids. The activities were designed to promote students to understand the influence that a fluid exerts on a moving body, and compare these movements with the free fall in vacuum. This kind of activities helps students to understand certain phenomena, for example how fog particles, atmospheric dust or clouds “float”.

The following issues are raised: a) Determine the differences observed between the fall of bodies in the air and in vacuum, and in what conditions those differences are more important. b) How can the supposed stability of particles with density higher than the air (atmospheric dust) be explained? c) How is the movement of a spherical particle falling in a liquid? How does the fluid’s viscosity influence on it?

Figure 1 shows a screen of FSP where we can see the speed and position graphs related to time for the movement of an ice sphere with a radius of 0.5 cm, falling from a height of 80 m.

As a real experience the dynamic study of a small sphere falling in a viscous liquid, such as an oil or glycerine, was proposed. A glass tube with glycerine, of known density, and small steel spheres of known mass and dimensions were used. If we consider the movement of a small sphere in a fluid inside a container with dimensions higher than the diameter of the sphere, three forces appear acting on it: a friction force, called Stokes’ force (it depends on the radius of the sphere, the fluid’s viscosity coefficient and the instant speed of the sphere along its path), the weight force and an ascending force or push force.

Stokes found the following empiric formula for the viscous friction force for the movement of little spheres in a fluid inside a big container: $Fv = 6\pi rnv$, where r is the radius of the sphere, n the viscosity coefficient and v the instant speed. Considering this force, it was suggested that the student should first find the expression of the time-position relation and then the terminal speed that it gains when it moves inside a viscous fluid, because of the characteristics of the fluid and the sphere. We propose to the students the experience consisting in letting a sphere fall in the fluid, and determining, with the help of a chronometer and a ruler, the limit speed that the small sphere reach. Then the students could estimate the viscosity of the fluid. This experience is simple but presents limitations such as variations of the dimensions or density of the particles and visualization of movements in the air or low viscosity fluids.

Simulations let us explore phenomena which are difficult to be done experimentally, namely the movement of bodies in the air, as considerable distances are needed so that they reach the limit speed.

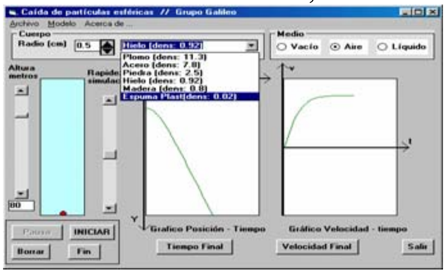

Fig. 1 Screen of the programme Fall of Spherical Particles

3. Optics

In this section an activity related to the teaching of how the compound microscope works is described.

With this activity, the students are expected to design an experience that allows them to reproduce the functioning of a compound microscope. The materials required are: convergent lenses of different focal distances, a candle, matches, modelling clay, a screen, papered tape, a ruler, a pencil and paper.

The didactic sequence includes some former activities such as the practical and experimental determination of the focal distances of the convergent lenses, the assembling of centred optics systems and the theoretical revision of the basis of the compound microscope. These activities consolidate in students certain competences and previous knowledge which are essential for the successful of the experience.

The lenses that work as objective and ocular should be selected carefully and all the elements should be lined up. A lightened candle, which emits light of enough intensity, is used as an object.

It is interesting that the students observe the real image of the object produced by the objective in a screen, because this image cannot be seen when they are working with a real microscope, and it facilitates the focussing of the whole optic system. Once the screen is removed, it is advisable to guide the students to observe other elements different from the candle through the microscope.

We want to point out that the students think this practice is highly positive as it allows them to design and to build a compound microscope with low cost equipment. The enlargement achieved and the qualities of the final image depend on the lenses used and their combinations.

As a complement to this experience, we suggest the use of the virtual optics bank available in the following web site:http://webphysics.davidson.edu/alumni/MiLee/java/ob_mj12.htm

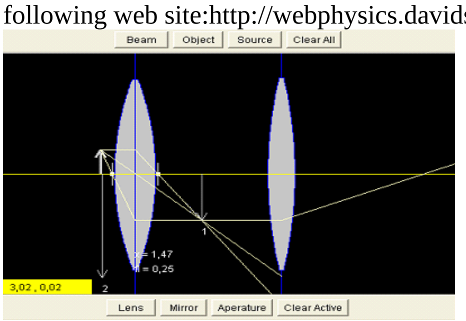

Fig. 2 Screen simulating the formation of images in a compound microscope

One of the greatest advantages of this bank (Fig. 2) is that it allows the user to analyze, in a relatively short time, varied situations which are sometimes complex to reproduce in a laboratory. However, we would like to point out that the position of the elements is not referred to the lenses (as generally is presented in textbooks) and that the implicit model in the programme is limited to the treatment of paraxial rays and thin lenses, that's why it is not possible to analyze neither the geometric nor the chromatic aberrations present in real experiences. We want to highlight that the practices made up to this moment are encouraging, and the transformation of the positions of the elements do not present difficulties once the system of reference has been identified.

4. Continuous current circuits

The activities related to this topic are oriented to the study of simple circuits. The software of free use recommended is Crocodile Clips (Croco) (www.crocodile-clips.com). It is a very basic programme that allows the user to simulate continuous current circuits. Neither the measuring instruments nor the oscilloscope are included, but the variation of resistance with temperature is took into account in the model involved, generators are modelled as constant tension sources with insignificant internal resistance and there is available only one type of lamp.

The proposed simulations are presented as problems. One of the problems to be approach consists in connecting a generator to a lamp -situation (a)- then adding to the circuit another equal lamp in series with the initial one -situation (b)-. In a first stage it is asked to analyze and justify theoretically the values of the current intensity in both situations, and then to verify the answers with the software Croco.

As regards the theoretical analysis, the first attempt of the students consists in analysing qualitatively the value of the current intensity using the Ohm law, taking into account the electromotive force of the generator and the resistance of the lamps. From this analysis, the students conclude that the current intensity with both lamps connected in series it is half of the corresponding to the case of the current intensity when only one lamp is connected. The results obtained from the simulations with Croco, indicate that the current, in the case of the two lamps, is larger than half of the current when one lamp is connected. We suggest solving the problem experimentally to clarify the discrepancy in the results. It is asked to compare the current values obtained in the three instances and elaborate conclusions.

The students do not hesitate to accept the experimental values as valid but, why are the values of the current intensity obtained from the real system incompatible with the theoretical analysis results?, and why are those values similar to the results obtained with Croco? To answer these questions we mention the fact that the lamps of metal filaments get hot when they are connected to different tensions. Thus the students identify the temperature as a variable on which the electric resistance depends.

Taking this into account, the students approach the problem considering that in situation (b) the difference of potential in each lamp is half of situation (a). For this reason, the temperature reached by the filaments is lesser in situation (b) than (a). This is equivalent to say that in (b) the equivalent resistance is lower than the double of the resistance in case (a), so it is assumed that the intensity of current in the case of the two lamps in series is greater than half of the current intensity when only one lamp is connected.

As the situation stated is simple and easy to reproduce experimentally, it can contribute to foster in students a deeper analysis of both, the experimental and theoretical results and the implicit models in the simulation programme.

Another activity for discussing the limitations of the model involved in Croco consists in connecting directly (only in the simulation) a LED (Light Emitting Diode) to a 9 V battery and registering the values of intensity and power (given by the software). We find absurdly high values without the accusation of any deterioration of the LED in the software, something that would surely happen in practice.

5. Contemporary Physics

The main point in the selection of experiences and simulations of contemporary Physics, is the concept of quantification. We describe three activities: the experimental determination of the Planck constant, a computational simulation of quantum phenomena and the potential barriers and wells problem solving.

For the measuring of the Planck constant (h) we select an experience that requires the use of unsophisticated equipment and materials that can be easily found in the market at a very low cost [5]. An incandescent lamp is used as black body, due to its property of emitting almost all the electric energy it recieves as radiation. The intensity (I) of such radiation is a function of its frequency (ν) and the temperature (T) of the body. Starting by the Planck formula for the energy spectral distribution and for a frequency selected with a filter, it could be calculate the Planck constant by measuring *I* in function of *T* [5]. A piece of red cellophane paper is used as a filter and *T* is varied by modifying the applied voltage.

The analysis of the validity of models, laws, hypothesis and procedures used, is particularly enriching for students: black body model for the lamp, the Ohm law applied to evaluate its resistance, etc. Once the circuits are set, the stated problem requires students to obtain, through the pencil and paper PS the mathematical expressions that relate the variables to be measured.

On another hand, the Albert programme developed by M. Wullenweber (ChessBase GmbH Hamburg) was selected to introduce the hypothesis, models, equations and mathematical procedures which allow students to solve quantum Physics problems. The use of this programme was free in 1996 but it is no longer so. The programme allows the operator to simulate the density of probability in terms of the wave function (y) for a free particle, and for a particle subjected to a potential well or barrier.

The movement of the particle is described by a wave packet. The model used is a Gaussian packet, built with flat waves whose spatial parts are solutions to the non-dependent time Schrödinger equation. This packet can be normalized and located, something that cannot be made with a flat wave.

Numerous simulations can be made with this programme, but its greatest potential is the possibility of introducing a variable potential $V(x)$ and showing how it causes the scattering of the wave packet. We can simulate potential barriers by showing the tunnel effect, and potential wells by observing the simulation of the resonance phenomenon.

The screen allows students to see graphically the potential barrier (well) and simultaneously, the temporal evolution of the wave packet. The programme calculates the transmission coefficient for the values selected by the operator, for the width and height of the barrier (bottom of the well) *Vo,* and for the energy of the packet *Eo*. Those values can be compared with the values obtained by students when solving the problems of barrier and rectangular well in one dimension with pencil and paper as of the stationary functions which are exact solutions to the Schrödinger equation.

According to our proposal, the use of the programme requires the professor to get acquainted with the used model, the fact that it is not a flat wave but a wave packet, and to aware the students of it.

6. Conclusions

We have presented activities for mechanics, optics, electricity and contemporary Physics teaching and also some considerations related to its conceptual and methodological treatment in the classroom. The activities are conveniently integrated to promote meaningful conceptual and process learning.

The pencil and paper SP, the lab work and also the use of simulations make up didactic resources of great potentiality for the students, who are not always conscious neither of the modelling they make, nor of the validity and scope of the models they use. The promotion of these basic capacities would facilitate the development of indispensable competences for their future professional practice.

On the other hand, the simulation programmes allow the professor to make his own didactic design, including not only the qualitative observation of the phenomena but also the solving of quantitative problems. To perform this task it is essential for the professor to know not only the conceptual contents but also the models involved in the simulation programmes they used. We wish other professors would use these resources which can be used to develop critical analysis competences in students.

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