Development of an Interactive Learning Environment for Introductory Physics in Engineering

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Abstract: - We present the development of the project "Física Interactiva" (Interactive Physics) that addresses the special needs of students that enter at a Polytechnic University with a deficient background in Physics. The project tries to make an interactive tool available to the students through a web site. We choose Moodle as the Course Management System due to its cooperative philosophy and its open-source and free development model. The emphasis is put on fundamental concepts of first year Physics: vector character of magnitudes, point mechanics, electric and magnetic fields. Interactive materials (developed as Flash animations) are conceived to reinforce concepts through critical thinking and active enrolment. We discuss our experience developing these materials, with the pros and cons of the tools chosen, and preliminary results of the use of the site with students at our University.

Key-Words: - e-learning, b-learning, Teaching Physics, Moodle CMS, Flash animations

1 Introduction

In this paper we describe the work of our group in the field of teaching innovation in Physics for engineers. We present the development of an interactive tool for freshman Physics students at the Polytechnic University of Madrid (UPM).

Our experience in teaching Physics at the UPM shows that the initial step in engineering studies is hard to pass: there is no smooth transition from secondary school conceptual models in Physics to First year University Physics. Students have to adapt themselves to a new teaching/learning environment, and at the same time they have to overcome shortages and misconceptions of the previous state. This too often translates to a high number of failures and desertions. Even when some students manage to pass through academic filters, it is not guaranteed that they have reached an adequate level in Physics, as a basic tool for Engineering.

New students entering the University are then a suitable target for an experience in Innovative Teaching that tries to contribute to the solution of the aforementioned problems. The new paradigm of active learning can be fostered with the help of e-learning technologies, which take advantage of the familiarity of the students with computers. Transforming or adapting traditional contents of a scientific subject to an electronic interactive format accessible via internet is one of the challenges of Physics Education Research.

The organization of this paper is as follows: first, we give a brief review of the state of the art in Physics Education Research; after that, we present an overview of the main ideas that are useful to take care of the special needs of Physics for Engineering; then we introduce the goals of our work and give details of the main features of the project and of the tools used: Moodle as course management system and Flash as a preferred format for animations and interactive exercises. Finally, we state some conclusions.

2 Physics Education Research in the XXI century

The history of Physics Education Research is usually regarded to begin around 1960, when several projects funded by North American universities were developed: the Berkeley Physics Course or the MIT course in the context of Physical Sciences Study Committee [1] for example. There followed a great interest in using the materials (books, films, lab demonstrations). But a decade later interest declined as results of tests were not very encouraging. Sometimes the culprit was thought to be the teacher-centric approach.

In the years around 1990, a new generation of ideas in Physics Education Research arose with an emphasis on the student as the center of the teaching-learning process and the teacher as a facilitator of the process. Several key projects include Eric Mazur's *Peer Instruction* at Harvard University [2], *Workshop Physics* from Dickinson College [3] and *Tutorials in Introductory Physics* [4] from the PER Group at the University of Washington.

These projects share an approach centered in the student and give proposals to change the traditional way of teaching using only classes. Many studies and tests try to assess the benefits of these ideas [5].

For our purposes, we find these ideas stimulating and challenging. Although they are not easy to fit in our classes, we think that they are worth trying in a new environment.

3 Interactive Tools for Teaching and Learning Physics

In recent years, many groups have developed tools for teaching and learning Physics at different levels using interactive environments. For instance, many of the college level textbooks offer some kind of online or interactive tools. Some examples are:

- Halliday, Resnick, Walker *Fundamentals of Physics* (Wiley) [6]: **Interactive Learningware.**
- Tipler, Mosca *Physics for Scientists and Engineers* (W.H. Freeman) [7]: **Physics Portal.**
- Young, Freedman (Sears, Zemansky) *University Physics* (Pearson) [8]: **ActivPhysics** and **Mastering Physics.**

These tools are available for students or instructors that buy the book, and contain chapters, exercises, tutorials, demonstrations … They are intended to supplement the test or the instructor that uses the book in his/her classes. In some cases, there are assignments and students can follow their grading.

There are some other resources online. One example, in Spanish, is "Curso Interactivo de Física en Internet" by Prof. A. Franco [9]. In its web site, there is a complete course of Physics, with many Java applets and video demonstrations, but it lacks questionnaires and more exercises for the students, with grading capabilities.

We could bring out many other examples. These are given only to emphasize that the application of Information and Communication Technologies to

Physics Teaching and Learning is no longer a dream or a science fiction story.

From another point of view, that we commented upon before, last years have witnessed a renewed interest in Physics Education Research. Aside from peer reviewed journals, there are many research groups trying to improve classes, problem-solving strategies and evaluation. In this approach, several pedagogical ideas are blended together to give a cognitive model based upon constructivism. For references, see [10] and [11].

Therefore, we find ourselves in a very active moment, in which many of these ideas are being tested, and many different kinds of interactive or online materials are being developed, but there is a need for new contributions and contrast of ideas. There our work may find a place.

For example, related work in the development of multimedia resources is discussed in Ref. [12] and an example of the development of interactive tools for e-learning in Mathematics can be found in Ref. [13].

Also, trying to catch the train of new technologies and find some use for them in their classes imposes a new burden on teachers. Many of them have to learn to use new tools and to transfer their subjects to the new computer tools. An urgent need for training them in ICT also means that Physics Education Research includes thinking how to convince teachers of the benefits of this change. We have found that this is not easy for many teachers who think that their classes are good enough and who feel that their students finally pass the exam after all (even if they really don't know Physics).

4 Physics for students entering a Polytechnic University

Syllabus for High School Physics (at least in Spain) has not the same structure and goals as Physics for Engineering found in first year of University.

There are some optional subjects in the year before entering University (in Spain, these are Mechanics and Electronics for prospective Engineering students) that could be very helpful for our students going to an Engineering School, but they are seldom chosen.

In a simplistic view, we can say that, at least in Spain, Physics in pre-University courses is oriented towards Physics as a science to understand the Universe and that Physics for Engineering has to be oriented towards Applied Physics, as a tool for technologies.

In our experience, these differences serve to explain some of the problems that make harder the adaptation process of new students.

In more specific words, we have identified the main faults of new students arising from their previous background:

- Leveling: they have different backgrounds and previous interests.
- Reasoning: how the student tries to use his/her knowledge in a problem (many times this is only trying to find the suitable formula).
- Math Operations/Algebraic capabilities: they have some basic faults in elementary manipulations of math expressions, or they feel unsecure with results.
- Problem solving: problem level or exercise types are harder than the typical exercises found before.

In many Universities in Spain some actions have been taken to address these problems. One of those actions, in which some of us take an active role, is known as Preparatory Courses or Zero Courses. This consists in some weeks of intensive training in Physics, Chemistry, Math and Technical design, during the month of September, before regular term starts.

However, even though these courses are useful, they are too short to remedy all the deficiencies. A throughout analysis of the impact of a similar course in the incoming students at our University can be found in Ref. [14]. After those short weeks, students have to look after further help.

We consider these Preparatory Courses useful and even necessary, but their duration and contents should be complemented with other tools.

5 Moodle as an integrated system for active learning

The contents of our Project are integrated in a web server that runs Moodle [15]. Moodle is a popular system for online learning (www.moodle.org) that is used worldwide.

Since the beginning of the use of computers in education, a number of tools have been developed to blend together learning materials and exercises with graphics and multimedia resources. With the birth and growth of the World Wide Web, many tools that serve as an interactive platform used by the students are available. These tools are known as Course Management Systems since they do not only show materials on the computer screen, but also serve as tools to follow the learning path of the student, tracking their responses to quizzes, grading them and providing tools for communication between teachers and students. Some of the best known systems are WebCT, Blackboard, Moodle and Sakai. A comparison among several of them can be retrieved at ISU Instructional Technology Resource Center [16].

We have chosen Moodle as our CMS (course management system) for the following reasons:

- Moodle is Open Source and free: everybody is free to use it.
- It is very easy to install and administrate, so it has no administrative expenses.
- It has growing popularity and high number of users.
- It has advanced tools for content creation, which include web pages, quizzes, lessons and multimedia contents.

These features make Moodle an ideal tool to concentrate efforts in developing contents and not waste time and resources in programming and planning a web tool.

Also, we find very convenient to use a CMS built on sound pedagogical principles, taken from constructivism. Most of the resources built on Moodle take advantage of this approach.

Some other features in Moodle include:

- Mathematical input in LaTeX format.
- Many different types of questions and exercises with numerical answers, automatically corrected.
- Rich editor for web pages.
- Forums and other tools to communicate with students.
- Convenient way to administrate users and roles within a course.

A very helpful feature of Moodle is its tools for administrating the course, both for contents developed by the teachers and for allowing students to enter the site. Also, communication tools such as forums and private messages are worth using. We have found that well thought forums improve active involvement of the students and make easier for them to stay longer in the platform and try harder to solve the problems.

Part of our project has been to install and configure an experimental Moodle server. We have seen by ourselves some of the goodies of Moodle, in the easy installation and configuration tasks.

But also we have found some other not-so-easy-to-solve "features": there is some unexpected

behavior in HTML editor and some resources are less flexible. Although many of these are not strictly "bugs" in Moodle, the Open Source nature of it and the large community of users around the world have proven invaluable in solving them.
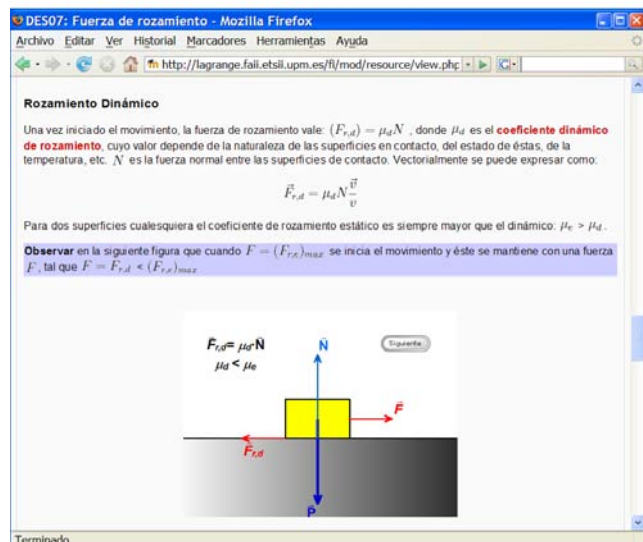

Fig. 1. Web page inside our Moodle platform showing rich content: embedded animation, equations, and colors.

In Fig. 1, we show an example taken from the contents explaining Dynamics. We can see a rich web page with a flash animation embedded and some equations formatted with LaTeX filter. Some of the most demanding contents for a web page are mathematical formulae, and these are easily written in Moodle using its LaTeX filter, that is also well known in Physics community.

Some of the problem types we have developed fit into one of the Moodle formats. For example, multiple-choice questions are very easy to integrate in a Moodle course. But for some other problem types (in particular, the step-by-step problems described later) we haven't found a Moodle module that can be used. So we have had to develop a way to integrate that kind of problem into the course.

6 The Project "Interactive Physics"

The Project "Física Interactiva" ("Interactive Physics") is an effort to develop an interactive online tool to provide the help needed when the student enters our University to study a branch of Engineering.

Our long experience as teachers of first year Physics in different Faculties and Schools of our University has made us aware of the problems mentioned in section 3.

Our first goal is to reinforce basic concepts that remain obscure and unclear after secondary school. We are not writing just another Physics book, not even an electronic one. We pretend to give new students a tool for self learning or active learning, available for them from the moment in which they enter University all the way through their first year.

We pretend that the students work in an active way; therefore, contents and structure of the course are chosen to promote an active methodology adapted to reinforce or complement previous knowledge. As this tool is not a traditional course in Physics and we don't have to cover a given syllabus, we think that students will cover more or less contents according to their needs. Of the traditional contents of first year Physics, we put emphasis on vector character of physical magnitudes, Mechanics and Electromagnetism.

Topics are structured trying to take advantage of the constructivist philosophy of Moodle and to make easy that students "flow" or navigate through what they need. As an example, one of the Units in which the site is organized upon may include the following items:

- Short graphical scheme of contents.
- A beginners' quiz to test previous knowledge.
- A detailed exposition of fundamental concepts evaluated in the preceding quiz.
- Step-by-step exercises that the student has to solve.
- More advanced problems selected by the platform and quizzes to reinforce concepts.
- New contents that are not covered in High School but we judge essential in first year of University.

Moreover, some complementary contents are included, as mathematical tools and physical units. Particular care is taken to assure that contents are friendly and clear for the students. The choice of some elements is fixed by the theme selected in Moodle (text, size, organization of the screen,…) but we have developed a unified style for colors and headings, to emphasize the type of resource (a reminder of the theory involved or a solved exercise) and to give the student a sense of "knowing where we are".

As an example, we show in Fig. 2 a screenshot of a Flash interactive object to calculate trigonometric functions embedded in a help page. This example lets the student explore the relation between the definition

of sine, cosine and tangent and their values shown in the unit circumference.

In the following sections we are going to describe in detail some of the most interesting contents.
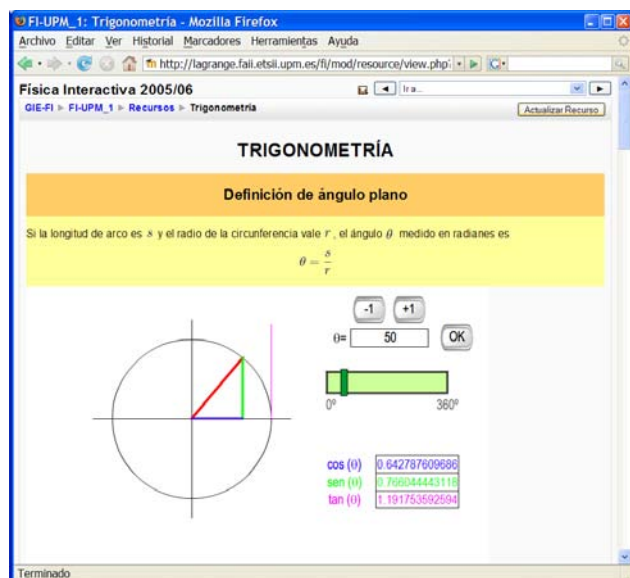

Fig. 2. An embedded interactive object to help in calculating trigonometric functions and showing them in a circumference of unit radius.

7 Types of problems and exercises in first-year Physics

The types of problems and exercises that students find in Physics are very different between secondary school and University.

Typically, students are accustomed to very simple problems with some data and only one question at a time. Most of these problems are solved using some formula that states a physical law in terms of the data and the unknown magnitude. Sometimes, students memorize formulas just to solve a given type of problem: Newton laws for solving problems in Dynamics, Gauss theorem for Electrostatics, circuit laws, and so on. This strategy helps in passing the exam, but not in learning Physics.

7.1 Step by step problems

We want to develop in the students the ability to solve problems with several questions that refer to a given physical situation, in a stepwise manner. A justification of this kind of problems as suitable for first year Physics can be found in [17]. This type of problem is more difficult for the students, but gives a closer idea of how real problems are tackled.

An example of this kind of problem with graded hints and a solution explained step by step is shown in Fig. 3.

In this example, taken from an exercise in DC electrical circuits, the student first finds a screen showing the statement of the problem and a schematic of the circuit considered. He or she is supposed to take pen and paper and try to solve the questions asked. This involves relating concepts, remembering formulas and making calculations. Perhaps the student gets lost in some of those steps. Then he or she has some help available, in the links that appear in the left panel of the screen. This further help serve as a reminder of concepts in the first place, graded in several steps. For instance, a first help can be a reminder of the physical laws involved, then how to relate the laws to the data given, and finally set the equations that solve the problem.

The student has also available the final (numerical) solution of the problem, in case that he or she has worked out the problem and only wants to check the answer. Also, a detailed and explained solution of the problem is available in the links in the left part of the screen. This last resort is there for students that are stuck even when they see previous help screens.

This kind of problems is integrated with the rest of the course and may include graphics and other multimedia content.
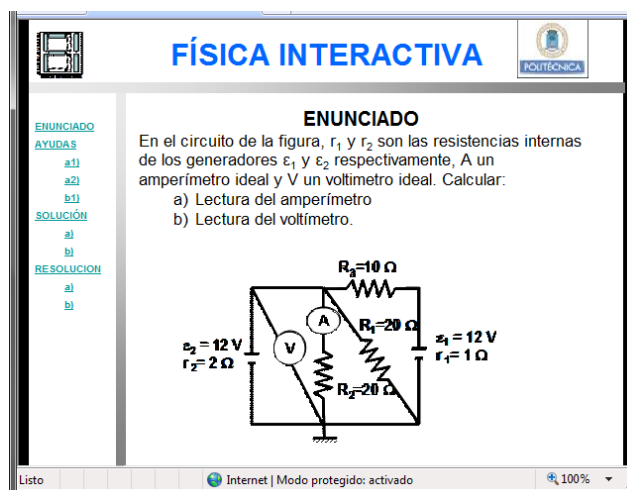

Fig. 3. A problem with several questions to be solved step by step with corresponding hints and a solution.

In short, the process of writing, editing and integrating one of these problems into our Moodle site can be summarized as follows:

- The author (teacher) writes the problem (using a PowerPoint template): that includes text, equations and graphics.
- Once the number of questions is fixed, he/she

writes a number of help steps, cutting into pieces the thinking process that the student is supposed to follow.

- The author also checks numerical solutions.
- After completing the template, it is exported to HTML.
- Inside Moodle, this set of HTML pages are linked within the course guideline and given an informative name.

7.2 Multiple choice questions

Also we have written quizzes, with a number of multiple-choice questions. These are intended as a quick check of previous knowledge or as self evaluation. At the beginning of every Unit we place a quiz of basic questions for the contents of the Unit. The automatic result of the quiz gives the student a clear idea of his/her knowledge and of the need for studying the Unit.

In Fig. 4 we show an example of a multiple-choice quiz. This example has been edited using standard Moodle tools. When the student chooses an answer, the system may give some help (if the answer is wrong) and gives points or penalties. Questions, and items inside questions, can be randomly sorted.

Moodle uses a database of questions, classified into categories, to gather all types of preformatted exercises. In this way, authors can develop a large number of questions, and then use them in different quizzes.

In our case, we have written questions in three levels of difficulty: basic, intermediate and advanced. These are used in quizzes with ten questions randomly chosen among the ones with a given level of difficulty.
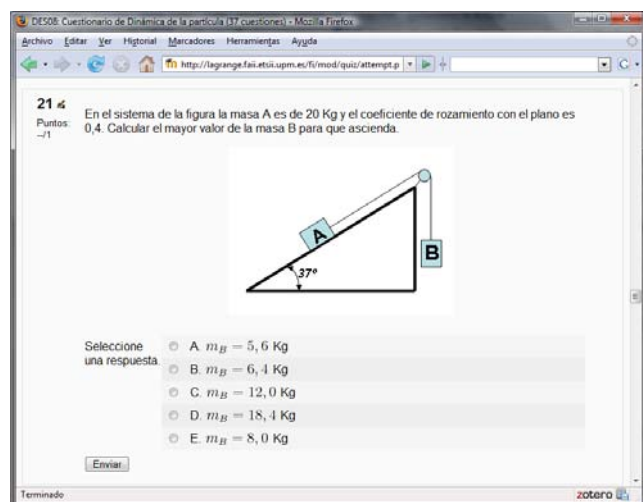

Fig. 4. Multiple-choice question in a quiz using standard Moodle tool.

As a third kind of problems or exercises, we have written some guided exercises in which the student doesn't have to give answers, just to think about the problem and learn how to solve it as the system is also showing the solution step by step.

The thinking process that the student should follow to solve a problem is not unique, and problem solving is an art, but also a technique that has to be mastered.

8 Interactive learning materials and animations

The methodology endorsed by our Project is active: we want to achieve active participation of the students. One way to reinforce this is using interactive objects embedded in web pages or Moodle resources that demand responses from the students. This methodology, applied to another project, is detailed in [18].

We think that interactive objects play a crucial role in the learning process, but they have to be linked with other resources, like problems or exercises. We don't find useful to play with animations without having to think about what is happening. An authoritative analysis of the use of interactive simulations for teaching Physics can be found in [19].

We have developed a large number of interactive animations in Flash format. Although Flash is a proprietary format (from Adobe, formerly Macromedia) it is a well established format in web pages and lighter and easier to create than a Java applet.

The most convenient way to develop Flash objects is to use Adobe software, which provides an intuitive canvas, with tools similar to the ones found in many other programs. Although the easier animations use the idea of timeline and frames to develop animations, one can write more complex objects using a language called Actionscript (similar to Javascript) to program interactions and move objects that obey physical laws.

We think that it's important not only to show things moving of "flashing" but to make that motion realistic, according to the laws of Physics. In this regard, an animation of the trajectory of a point in gravity should give a correct sense of the velocity and acceleration, which helps in correcting misconceptions.

There are a large number of Flash animations in the web, but we have chosen to create our own collection of interactive Flash animations. We think that it is essential to integrate the animations or

simulations with other contents. For example, a simulation makes sense when it helps to visualize the physical situation stated in a problem, or as a tool to predict the evolution of a system when some parameters are changed.

8.1 Animations with little interaction with the student

We have developed two kinds of Flash animations: a simple one to show in a sequential mode steps in some explanation, in the way we draw graphics in a blackboard when giving a class; and a more complex one that permits student interaction, input of data or changing parameters.

In Fig. 5 we show an example of the first kind, showing forces acting on a car on a curve. This animation shows stepwise the forces on the car: weight, reaction of the road and friction, and how these combine as vector magnitudes to give a net force pointing inwards.

Another example can be seen in Fig. 1, in which the web page has an animation embedded that also show forces acting on a block sitting on a table with friction.

This kind of animations is well suited for explaining concepts, like free-body diagrams, simple movements, circuits, etc. Interaction is limited to a button, typically of "Next" type, to go to the next frame.

Surprisingly, students find these simple animations very useful, much more than a picture. Perhaps a reason may be that they are unobtrusive and almost impossible to misuse. The simplicity of the interaction keeps also simple the concept presented. They work only if needed, and explains one thing at a time.
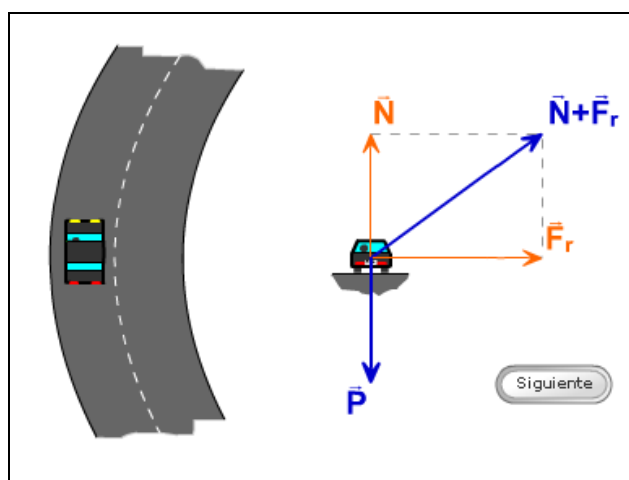

Fig. 5. Flash animation showing forces on a car that is taking a curve.

8.2 Interactive objects

In Fig. 6 we show and interactive example of the method of energy conservation applied to a problem in point Dynamics.

Here the student can place a mass sliding on an inclined plane in three positions: A, B and C. Then the animation starts and shows the energy (kinetic plus potential) in every position in terms of data. Finally, it is shown how to obtain velocities in B and C using energy conservation.
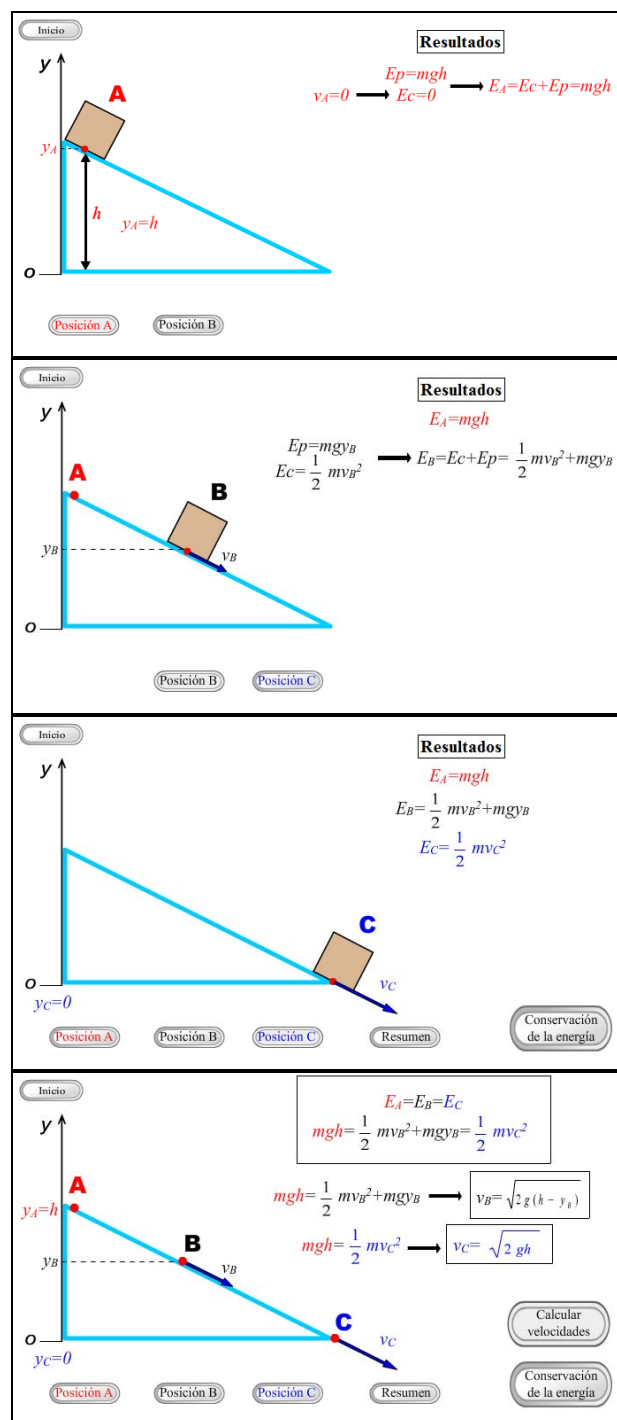

Fig. 6. Four steps in a Flash animation to explain energy conservation method in Dynamics.

Let's explain in more detail the buttons and the interaction of the student. To learn how to apply energy conservation, the student can press buttons "Position A" or "B" or "C". The screen shows the energy of the block in terms of height or velocity. After showing positions, it is shown how to obtain unknown velocities in terms of data.

This example is used in some problems involving that fundamental concept.

Using Flash animations embedded in web pages that contain mostly theory makes that pages friendlier for students, and makes those resources more interactive and motivating. Although screenshots may give the impression of a book inside a web page, the user experience is very different, and the conceptual advantage of including even a simple sequential animation is huge. We find that these animations are appreciated by the students.

Let's discuss another example: projectile motion in a Flash animation. In Fig. 7 we show four steps in this interactive object. As can be seen, usual graphics of projectile motion are shown together with appropriate equations.

But in this case, interaction of the student is more complex and gives richer possibilities.

First, the student selects initial conditions: initial velocity and angle with respect to the horizontal. The values selected are shown (top right) and also in the size and orientation of the vector representing initial velocity (left).

Afterwards, the student presses the button "Fire" and the projectile follows the well known trajectory (which is drawn with the exact equations, and takes the correct time to reach maximum distance from the start).

Then comes the "reflexive" part: the student can select "equations of the velocity", "equations of the position" and also relations that give maximum height and distance in terms of data. Values of these parameters are given in terms of the initial conditions selected and components of the velocity are shown along the trajectory.

Equations appear stepwise, and colors relate them to the graphic part. We include these equations in the animation to help students that don't have them at hand or are too lazy to write them by themselves. We emphasize that this kind of animation is not to be used on its own, but used as a help tool in solving a problem, for which a way to visualize the physical situation involved may give the student a clue to begin the resolution, and having at hand the equations that he or she may need can serve as a "cheat sheet" allowed.

We would like to remember that the students have more help tools available: forums are monitored by teachers, and as problems and quizzes are assigned, the students can try to get help from other students, their peers.
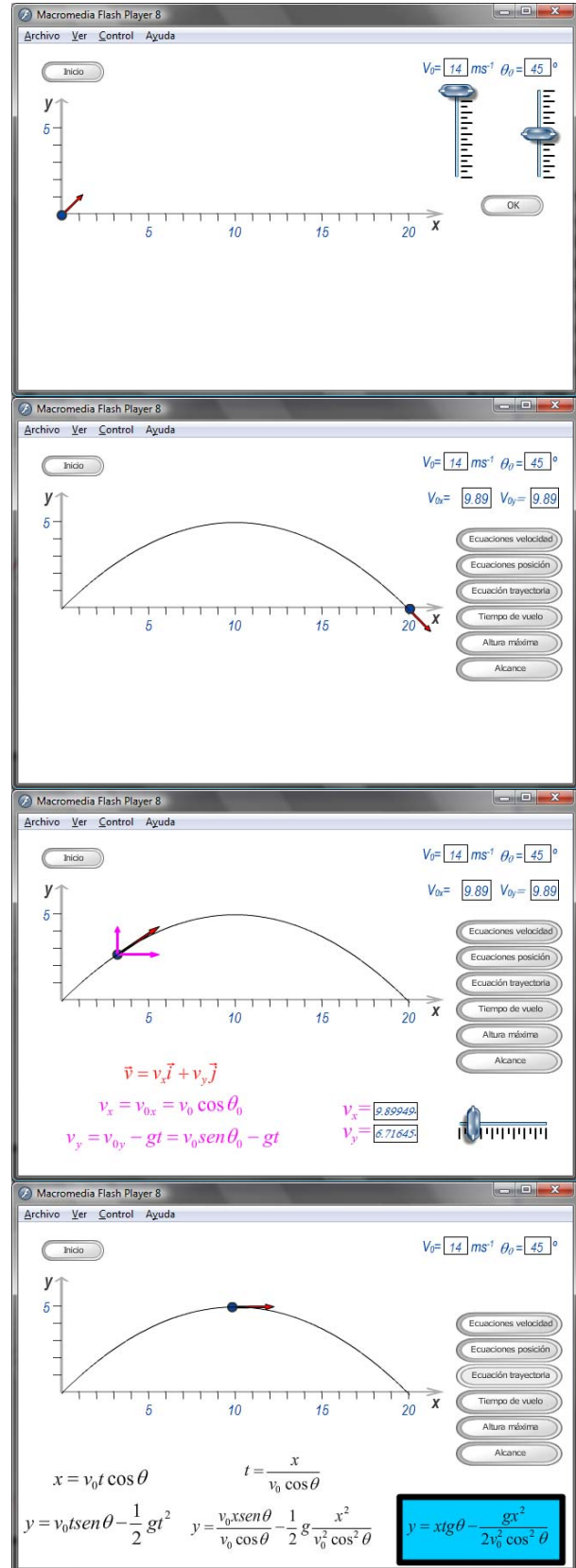

Fig. 7. Four steps in a Flash animation that helps in studying projectile motion.

Most of the resources included in the course (quizzes, Flash animations…) are developed with the help of students that evaluate them before making available the web site to larger groups. Further details can be found in some other works of our group. See References [20] and [21].

9 Results

Although this project will be used in real groups at our University beginning next term, we already have some first-hand accounts of some students that have helped us in the developing phase. We have evaluated their comments on the "usability" side of the platform.

Main results so far are:

- Students find difficult to follow a lengthy theoretical discussion that fills several screens, and find more useful short "boxes" that refresh a concept or present relevant equations or physical laws.
- The thoughtful use of color helps in navigating the site and relating resources of the same kind. For example, students said that a uniform color code in figures makes easy to give them an uniform meaning.
- Multiple-choice questions should be given a level of difficulty in terms of time needed to solve them, or can be classified into conceptual and numerical questions.

We would like to emphasize that the main point of this paper is discussing the methodology developed to build the interactive learning environment. We think that our expertise in teaching Physics makes possible to develop a useful tool for our students. We don't present more practical results, because we have to wait until we carry out extensive surveys in the near future.

10 Conclusions and directions of future research

We have presented the development of a Project to help students in their first year Physics in Engineering, as an example of the use of e-learning technologies in that context.

We have shown in this paper the main building blocks of the project (Moodle as the Course Management System, concept-oriented short and interactive web content, stepwise problems with guided help system). Also we have given details of some remarkable examples.

We have plans for large scale evaluation of our platform, starting at the beginning of the next academic year. We hope that this platform may be useful at our University, and nevertheless we will use it to complement our (traditional) classes.

In the meantime, we will keep on developing materials and refining edges of the interaction and presentation aspects.

Our project uses Moodle to integrate contents: problems with several questions and guided help, quizzes, web pages with rich contents and interactive objects.

We believe that ICT will have a profound impact on education in coming years, and that implies the need of new tools for every subject. Our project focuses in University Physics and we try to identify our special needs, but some of the lessons we have learned may be of general interest.

Also we want to remark the impact of ICT on the formative process of new and old teachers, who have to add to their teaching and research burdens the need to master these new tools.

Acknowledgements

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