Physics teaching with simulations in HTML5

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Abstract

One of the functions of the Center of Distance Education of the School of Engineering of the University of Buenos Aires is the design of educational materials using various technologies, so as to facilitate the teaching and learning of science. In this context, a proposal of basic physics simulations design is presented. Previously, simulations were developed in other languages such as Java and Flash. The objective of the initial search was oriented to find open source simulations that can be easily customized or authoring tools such as GeoGebra or EJS. It is intended to avoid implementations from scratch since it is time consuming and difficult to implement in the short term. In particular, a process of development of simulations with HTML5 was started. The reason leading the change was the need to have educational materials that could be used from any terminal, particularly from mobile terminals so that students can make use of the simulator anytime and anywhere. An example of a simulation of a pendulum is provided which main objective is that the student could manipulate variables, observe the behavior of the pendulum and make inferences that help them understand and apply the physical model under study.

Keywords: authoring, customization, physics, HTML5, simulation.

1. Introduction

Simulators are exploratory learning environments; students using simulations are free to control variables and it is through this exploration that they develop scientific knowledge. This more dynamic and interactive approach best meets the need to teach science as an active process that involves research rather than an expository class, and that helps develop higher cognitive learning skills [1].
Technologies that control how a learner responds are often associated with more behaviorist approaches to teaching and learning. However, when working with simulations students can take control of parameter settings while technologies restrict the context of the experience. Moreover, the level of teacher guidance, student-student and student-learning material interaction can derive in a more constructivist approach to teaching and learning where higher order cognitive learning can take place.
Therefore, by exploiting the possibilities of learners' interaction with learning materials, the time students spend on learning increases, which tends to lead to increased learning. Moreover, when the activities proposed to students are well designed, the time the teacher needs to spend on interacting with each student can be reduced.
In addition, there are other skills that students can develop within a broader computing environment:
- decision-making skills through the use of simulations and/or virtual worlds;
- skills of reasoning, evidence-based argument, and collaboration through instructor-moderated online discussion forums;
- skills of experimental design, through the use of simulations, virtual laboratory equipment and remote labs;
- skills of knowledge management and problem-solving, by requiring students to find, analyze, evaluate and apply content, accessed through the Internet, to real world problems [2].

These pedagogical characteristics are useful for teaching many of the skills students need in a digital age but also useful in everyday life; computing enables students to have more power and choice in accessing and creating their own learning and learning contexts. These skills are necessary, not only for scientists or science students; a person who has a notion of scientific knowledge works in a society where science has a great role and impact socially and globally.
Literature shows that simulators have great educational potential. However, in order to get these advantages, certain factors must be considered when planning the simulator such as: the pedagogical design, the simulator design, the simulator learning environment and the skills, attitudes and conceptual understanding [3].
The inquiry-based learning is defined as a process based on exploring the natural world leading to questions and discoveries, and also on performing rigorous approach to testing those discoveries in order to comprehend or understand the phenomena

studied. Interacting with simulations fosters in students a scientific perspective and a proactive attitude towards their own discoveries that generates knowledge by activating and restructuring their mental models [4]. This type of learning shares with research some cognitive processes such as:
• Orientation (identification of variables and relationships).
• Generation of hypotheses (formulation of statement or set of statements, perhaps as a model).
• Experimentation (manipulation of variable values, making predictions, and interpretation of results).
• Drawing conclusions (on the validity of the hypothesis).
• Feedback (reflection on the process of learning and acquiring knowledge).
• Planning (outline the research process).
Simulations are inherently "active" as they encourage students to respond. In a simulator, students manipulate parameters to test hypotheses, make all the experiments they want with different variables in a convenient time frame and also more spontaneous experiments because there is no risk to run. They compare the results of a series of experiments contributing to their theoretical understanding by repeating the same experiment under different conditions. Therefore, it is possible to infer through experimentation the characteristics of the phenomenon studied. Moreover, students can learn at their own pace and can make mistakes that lead them to reflect on their own learning; thus those questions can guide their exploration within the simulator in order to improve their understanding. Thus, their way of thinking becomes more sophisticated and is not simply a random trial and error but a more reflective thinking [5].

2. Context

The example presented below is part of an institutional project of educational material design that is being carried out with the integration of ICTs (communication and information technologies) at the School of Engineering of the University of Buenos Aires with the participation of different departments and chairs since 2003.

The objectives of this project are to:
• encourage technological skills development from the first years of study;
• improve the conditions of attendance and retention of students taking advantage of the possibilities offered by ICTs, in order to reduce dropouts and delays in their studies;
• expand and increase flexibility in undergraduate course offer, through different modalities with the use of teaching and learning environments, tools and digital resources open to the whole university community;
• work on specific learning difficulties presented by students, integrating ICT into the classroom, for understanding the structural scaffold of courses;
• promote the creation of a network of teachers through which they can exchange experiences, ideas, knowledge related to the use of new technologies in the classroom or outside the classroom [6].
Spreading knowledge through computer networks changes the perspective of education and modifies the access to academic materials. Teaching strategies and materials developed by teachers are elements that mediate the relationship between all actors in the educational process. The design of materials allows adapting representations to the characteristics of the students facilitating an environment of mutual learning.
When developing undergraduate courses of basic sciences in different modalities, it is necessary to design and develop materials that support, complement, expand, evaluate and meet the teaching and learning needs. For this reason, at the Center of Distance Education of the School of Engineering - UBA, different tools for the development and implementation of educational materials are being studied to provide support to courses offered at the university. One of the pillars of teaching strategies are the activities designed for the classroom-laboratory and the classroom-virtual environment, that may include actual experiences, simulations, videos, self-assessments and tutorials [7].
Some of the stages of this design process can be detailed [8].
• Integration of ICT technologies to the didactic design process such as electronic resources customized for data collection and for the calculation, processing and presentation of data.
• Adaptation and incorporation of materials to the virtual teaching and learning environment Moodle 2.4, active in the domain http://campus.fi.uba.ar. New software can help create materials that are increasingly interactive. This evolution includes not only content presentations but also own and adapted simulations using Java, Flash and other languages. Simulations apart from facilitating the observation and analysis of certain physical phenomena, they are also integrated to problem-solving activities favoring the selection of alternatives by changing the original parameters.
• Intensification of the relationship between the technological design and the pedagogical design of educational materials. Development of multimedia materials, particularly video in different formats and simulations in Geogebra and EJS.
• Development of remote laboratories and simulations in HTML5.

3. Development

During 2015 and according to above mentioned stages, the Center of Distance Education at FIUBA identified the need to start replacing simulation programs developed in JAVA, Flash or other languages by simulations developed in HTML5. The reason to implement this change was to convert educational material in other formats that could be used from any terminal, particularly from mobile terminals so that students can make use of the simulator anytime and anywhere.

In order to develop simulations, authoring tools as well as pre-designed and open simulations which can be customized were used so as to avoid scratch implementations that is to say programming all the details of the simulations from the beginning. This is because the software creation process can become very complex, depending on its size, characteristics and criticality; being the fundamental idea behind the proposed methodology that time and complexity of development were reduced to the minimum and that the focus were placed on developing the physical concept and on the implementation for student work.

It was decided to implement this innovation on a course of the Physics Department that was already being offered in a blended learning modality, and where different educational materials have been designed and tested since 2006.

In this course, a self-assessment quiz originally designed with HotPotatoes and built with Java applets was replaced by a quiz in the native format of Moodle with simulations developed with Geogebra (open authoring software) and then customized in HTML5.

3.1. Simulations designed with Geogebra and HTML5

The design process oriented to replace applets is detailed below. Recently, Oracle introduced some updates and modifications to plugins for browser in Java SE 7 Update 21, however, there are still many unresolved issues related the security of applets. From this review of Java, an applet that is not signed (even applets that run within the sanbox without the need of any special permission) produces multiple warnings that “alert” the user. Sometimes, even in applets with a legitimate digital signature (which is very expensive for an educational institution) the plugin does not work properly. This problem and portability were the reasons to resort to another language.

An applet designed in HTML5 to illustrate a problem of Rigid Body Dynamics is introduced in figure 1.The design of the activity includes some questions that are related to the friction force orientation, the angles where the body rolls in different ways or where it is in balance.

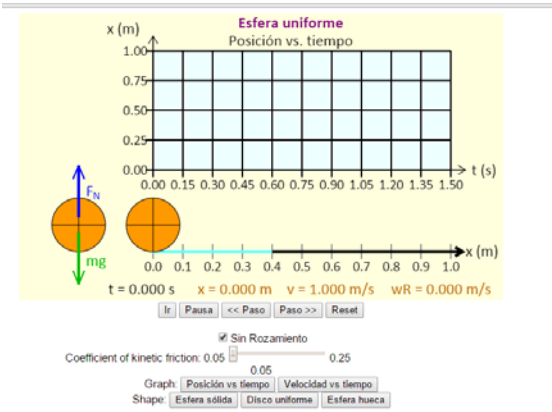

Fig. 1 Simulation environment.

An applet designed with GeoGebra to illustrate the same topic is shown in figure 2, where a symmetrical body performing a rotation and translation movement along a horizontal plane is observed. This software allows converting simulations to HTML5 language. In order to complete the activity, the student needs to vary the angle of the rod in relation to the vertical line

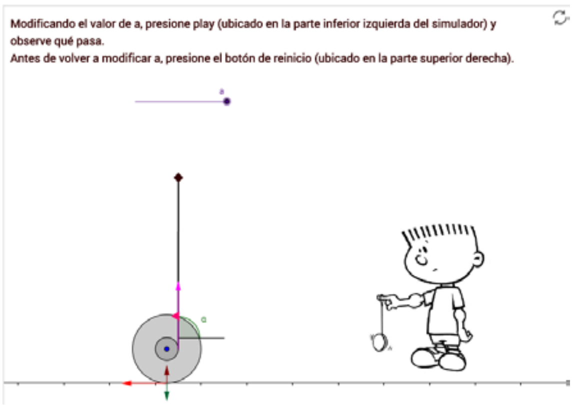

Fig. 2 Modify a value, press play and observe what happens. Before changing a value again, press re-start.

The student can change the type of body, its moment of inertia and the coefficient of friction. By observing in the graph the position and velocity in terms of time, it can be easily identified and analyzed when the body begins to roll without slipping, to what position and how fast. In the proposed activity, questions are related to the friction force, provided that rolling is without slipping and with an angular momentum for different rigid bodies.

These concepts are somewhat complex for students. Therefore, simulations have to be designed to be a valuable cognitive resource that could address specific difficulties of students and propose activities accordingly. That is to say, the conceptual design, the interactions design and technological or techno-pedagogical design have to be taken into account as some authors suggest [9, 10].

In the interaction design, some of the principles of Mayer´s cognitive overload for multimedia learning (2005) were taken into account since different media are integrated in the simulation environment and in order to apply effective representations to produce meaningful learning and at the same time to avoid that students are exposed to too much information at too complex level or too quickly so they do not properly absorb it [11].

One of the principles state that learning is more effective when it results from the simultaneous processing of visual and verbal information; however, computer simulations focus all resources on the visual channel since students reflect on the physical phenomena by modeling the simulation. Therefore, orientation to guide the processing of information may facilitate the explicit learning and reduce the cognitive overload and work memory when feedback comes from the teacher or from collaborative validation thus facilitating long term memory.

According to the author not all multimedia representations are equally effective in producing meaningful learning. Those that minimize the cognitive load and consider how learners cognitively process multimedia are the most successful.

The interactions of students with the preparatory educational material, with the simulator itself, with the learning environment and with other students and tutors were considered in the design process.

3.2. Activities to be completed with simulations in HTML5 before the lab practice

A simulation of a mathematical pendulum is introduced before the practice in the Physics Laboratory with a real pendulum and after students have read and studied the topic from a theoretical perspective in a face to face class. The conceptual design corresponds to the study of the movement of specific bodies, so students have to manipulate variables and observe the behavior of the pendulum. The parameter to be changed is the rod's length and it is expected from students to apply the corresponding physical-mathematical model for the analysis of the graph.

The first interaction of the students with the simulation is through the reading/listening of the problem definition, the identification of the main objective to be observed or analyzed, and the visual identification of the graph. In this stage students are expected to set hypotheses and to approach the problem qualitatively so as to solve their foundational knowledge that may be not sufficient to understand the conceptual core of the physical phenomena and to solve any misunderstanding before starting interacting with the simulator.

In the second level of interaction with the simulation, students manipulate parameters, analyze data and draw conclusions. Specifically in our example, they verify how the period changes according to rod's length, so they can compare and relate graphs in angular positions in terms of time for pendulums of different lengths.

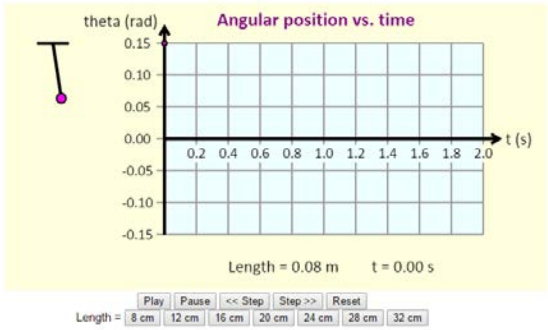

Fig. 3 Angular position vs time.

In this stage, the learning environment offers to the student optional documentation (physics tutorials, e-books), synchronous and asynchronous teacher guidance, external links, collaboration tools like forum and chat as well as questionnaires embedded in a web page that may provide support to the discovery process and opportunities to validate results.

Finally, students have to formally present conclusions about their observations, explorations and analysis as well as informally socialize and interact with other students and tutors about the experiment and related topics that may arise from this experience. This activity is a preparatory activity that has to be completed before the laboratory-classroom practice, where experiences are carried out on an actual pendulum.

4. Formulas

The ideal pendulum period formula (Eq. 1) is used to build the simulation.

$$\omega = \sqrt{\frac{g}{l}} \quad \Rightarrow \quad T = 2\pi\sqrt{\frac{l}{g}}$$

(Eq. 1)

Students can complete this table by reading and analyzing the values period obtained (see Fig. 3):

Table 1 Values *T(L)*.

L	*T*
(m)	(s)
0,08	*0,56*
0,12	*0,69*
0,16	*0,79*
0,20	*0,89*
0,24	*0,97*
0,28	*1,05*
0,32	*1,12*

5. Conclusions

It is observed that in agreement with previous research works, the use of simulations provides an opportunity to introduce infrequent open problematic situations in the face-to-face and virtual classrooms. Simulations are at the service of deepening learning processes, especially in very abstract or complex topics.

The main advantage of simulations in HTML5 is that they offer various elements to interact with in the simulator through buttons, scroll bars and text boxes that can be read in real time, as well as various media in the simulator environment; apart from the fact that they can be responsive and viewed from any terminal without any restrictions. Moreover, simulators have local storage, so they can save the values of the simulation in the terminal where it is run, replacing this way cookies and avoiding the use of database servers and more complex languages as PHP.

Another important aspect of implementing simulations in the Physics Class is that they pose teachers the challenge of software customization that gives them the opportunity to explore more deeply the technical aspect of the development and implementation of educational materials with the new educational technologies, and that they help students to develop the technological skills necessary for the digital age engineer professional profile.

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