Virtual Laboratory for a First Experience in Dynamics

http://dx.doi.org/10.3991/ijes.v2i3.3820

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***Abstract*—New technologies contribute to the learning process of scientific disciplines. In particular Physics learning may take advantage of these techniques by implementing experimental practices in simulation environments. Our presentation is made under the premise that computer simulations should not be used as substitutes for direct experience with physics apparatus.**

We are presenting here a set of two simulation based virtual laboratories to look into the empirical foundation of classical dynamics. The first practice is designed to revise the operational definition of inertial mass. The second practice proposes the determination of the dependence law of the interaction force between two cars on their distance separation.

There are presented the experimental design and the results obtained in the implementation in a first Physics course at Universidad Tecnológica Nacional, Facultad Regional Córdoba, Argentina.

***Index Terms*—Learning Objects, Physics Learning, Simulations, Virtual Laboratories.**

I. INTRODUCTION

Engineering careers have been considered priority in Argentina since year 2005 due to their entailment with development and technical innovation. In engineers education basic subjects such as Mathematics and Physics are of great importance. For this reason it is worth of dedicating efforts to upgrade teaching and learning processes.

New technologies (ICT), in permanent evolution, give place to new perspectives in education and, at the same time, pose tremendous challenges to physics teaching and learning. ICT irruption in every social and cultural context requires permanent reassessing of teaching methods and practices. ICT allow a more involved participation of students changing from a receptive role in traditional lectures into a participatory and collaborative role.

The possibilities that computers offer for new teaching methods in Physics have been and are continuously explored. The challenge is: how can we, as Physics teachers, incorporate ICT to our courses? What benefit or upgrade can we obtain from this incorporation? A diversity of computer applications have been developed and used in teaching physics such as the use of spreadsheets, computer-based laboratories or simulations [1].

As a factual science, Physics learning requires experimental practice to comprehend phenomena and processes on which concepts are based on. In Richard Feynman [2] words:

"The principle of science, the definition, almost, is the following: *The test of all knowledge is experiment* … Experiment, itself helps to produce these laws, in the sense that it gives us hints. But also is needed *imagination* to create from these hints the great generalizations …"

As summarized by the American Association of Physics Teachers, the introductory Physics laboratory goals are [3]

1. The art of experimentation
2. Experimental and analytical skills
3. Conceptual learning
4. Understanding the basis of knowledge in Physics
5. Developing collaborative learning skills.

The usage of computers may help in achieving the goals previously enumerated by a diversity of applications:

1. Computer aided laboratories: microcomputer is interfaced with experiment. Students may collect data and make graphs on line.
2. Remote laboratory: computer allows remote connection with experiment.
3. Simulation based virtual laboratory: the essential functions of laboratory experiments are carried out by a computer.
4. Computer simulations: experimental situations are analyzed. Students are allowed to propose analytical models and to compare the output with experimental results.
5. Experimental videos: a laboratory experiment is filmed and uploaded into a web site. Students may collect data in a deferred way at any time.

Each of these approaches is usual practice in scientific work. We consider it worth that students make contact with these techniques in his early stages of education.

In our working group we are developing experiences based on Simulation Based Virtual Laboratory (SBVL) and on Experimental Videos. In this communication we present a proposal of two SBVL to introduce the empirical foundation of classical dynamics, a central issue in a first course of Physics.

With SBVL we intend to transfer and/or generate conceptual and procedural knowledge. We expect that SBVL will also facilitate the discovery of new content and new assessment or known information by means of discovery learning; construction of general principles from experimental work and approach of problems difficult to tackle by traditional learning methods.

It should also be pointed out that, in spite of teachers' opinion, the number of experimental practices in Physics courses is generally not enough to accomplish the objectives [4]. Computer based activities emerge as a valid alternative to reduce the negative effects of extensive contents stipulated for each course, budget restrictions, teaching posts restrictions or large number of students conspire with an adequate traditional laboratory practice.

It is important that students assume a participative role. Hake [5] defines Interactive Engagement (IE) as:

"methods as those designed at least in part to promote conceptual understanding through interactive engagement of students in heads-on (always) and hands-on (usually) activities which yield immediate feedback through discussion with peers and/or instructors",

IE provides a framework for the design of SBVL to encourage students active participation in the learning process. Learning support has important effects in simulation based learning [6]. We design our laboratory guide in the experiment prompting model.

We produce our SBVL in a Learning Object (LO) schema. We define a LO as a digital resource, representing reality aspects and significant for the learning fellow, self content and versatile to be joint with other digital resources. LO, an idea originally proposed by Gerard [7], have been given several definitions, among which we mention that proposed by Chiappe:

"A digital self-contained and reusable entity, with a clear educational purpose, with at least three internal and editable components: content, learning activities and elements of context. The learning objects must have an external structure of information to facilitate their identification, storage and retrieval: the metadata."[8]

Reusability is the central issue in LO definition.

Patterns are a well-known design technique in the fields of architecture and software engineering. In a similar way, patterns for the design of LO can be used to facilitate the design of SBVL with an uniform structure [9-10].

In this way we design our virtual laboratory practices following a pattern of three activities to be described later. There exists a great offer of simulation software in internet that can be appropriate to implement SBVL. Among many alternatives we mention here the Physlets project[11], Compadre [12], PHET [13] or myphysicslab [14]. For this reason we have concentrated our effort in selecting the appropriate software and generating the learning support material [6]. Software selection is a central and unavoidable task for the teacher designing the experimental activity. The subjacent model must fit to the academic requisites pursued with this activity. We prefer software that can be run remotely or eventually that can be downloaded and locally executed with the only requisite of having set up JAVA. These computer programs may be executed in a navigator environment.

It should be mentioned at this point a central statement: digital computer is an important tool of inquiry in scientific research and so in scientific education. However computer simulations should not be used as a substitute for direct experience with physics apparatus [15]. All Physics students should have the opportunity to operate Physics apparatus, confronting the difficulties emerging at a material reality laboratory.

The communication is organized as follows: in next section the Physics problem to be considered is presented. This will be a short introduction, since the Physics discussion is not the central subject of this communication. It is just included to give the academic context to the SBVL designed. In section III the SBVL is presented with a description of the particular aspects considered in its design. Also the LO pattern is described. In section IV the results of an implementation test are included. Finally our conclusions are presented.

II. EMPIRICAL FOUNDATIONS OF CLASSICAL DYNAMICS

We summarize in this section the main aspects of the discussion included in [16] about the foundation of classical dynamics, the central subject of a first course in Physics. A previous topic in such a course should be kinematics, the physical description of motion. Having passed this stage, the formulation of dynamics should follow. Two alternative paths may be followed: *i)* one starting with the concept of momentum, giving priority to the concept of mass and *ii)* those starting with the so called Newton's laws giving priority to the concept of force.

Conservation of momentum (**Principle A**) rests on the possibility of defining operationally a scalar magnitude called mass while Newton's laws (**Principle B**) rests on the definition of force. In **B** it is required to grasp the concept of "same force", a concept quite deceptive.

Mass admits a simple and clear operational definition in **A**: a particle is made to collide with another particle chosen as reference (unit of mass) and the velocities are measured before and after collision. Mass definition in **B** is accomplished by applying the "same force" to both particles and calculating the quotient of the corresponding accelerations.

An intermediate alternative was proposed in the work of Mach [17]: the two particles are made to interact and the mass ratio is defined as the negative inverse ratio of accelerations.

Conservation of momentum is a fundamental principle of Physics associated with translational invariance, surpassing the limits of classical mechanics. On the other hand Newton's laws as fundamental principles of dynamics are limited to classical mechanics. It should also be mentioned that in Newton's Principia the concept of force is closer to the nowadays concept of impulse (variation of momentum) [16,18].

In addition to the previous considerations, the extension of the fundamental principles to new theories of Physics is clearly in favor of **A**.

From the foregoing arguments it is concluded that **Principle A** is conceptually, operationally, logically, historically and fundamentally preferable as a starting point of classical dynamics.

The concept of mass is difficult to understand by students [19]. Therefore it is intended to facilitate its comprehension with an experimental activity that reinforces lectures discussion. Additionally the measurement process is reviewed by considering its components. The experimental design chosen, in accordance with **A** is that proposed in [20] and illustrated in figure 2: two cars initially at rest on a horizontal rail are joined by a string and so the spring between the cars is kept compressed. At a given instant the string is cut off and the velocities of the cars are measured after the interaction between them through the spring has ceased.

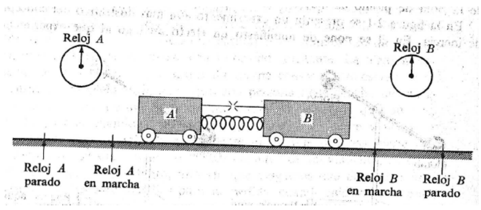

Figure 1. Experimental setting for inertial mass definition as proposed in Ingard and Kraushaar [20]

The mass ratio of the cars is defined as

$$\frac{m_A}{m_B} = -\frac{v_B}{v_A}$$

This experimental design is in the line of the foregoing discussion.

The concept of force also presents difficulties to students as has been detected [21]. The above experimental design may be reused for characterization of the force dependence on the distance between the cars while the interaction is not null. This can be inferred from the measurement of the acceleration as a function of separation. The implementation of both experiments through a simulation of the Physlets project [11] is described in the following section.

III. VIRTUAL LABORATORY

We present in this section the virtual laboratory developed to introduce the empirical foundation of classical dynamics in the sketch presented as **A** in the previous section. The SBVL proposed consists of two experiences designed: *i)* to review the inertial mass definition and *ii)* to determine the force dependence on the separation of two interacting bodies in different situations.

To implement the SBVL we have selected the animation included as "exploracion 7.10" in the Physlets Project [physl]. The selection was made since the simulation included reproduces very accurately the experimental design proposed in [20] and described above. It is a rather simple software but with graphics that are clear and easy to understand. Additionally the software can be easily adapted by modifying the .html component. In this way the original software was modified to accomplish the experience requirements. The modified environment is shown in figure 2. The original text has been removed to leave a clean working area. The loading of the cars, originally made by typing a number, is made by adding "calibrated weights" by means of the buttons at the sides of the cars windows. Masses may be added or withdrawn to let the students make their experimental arrangement. Although in precise proportion among them (1:2:5:10), the information is not provided to the student. It has also been incorporated the option of adding an unknown mass, randomly generated in each execution. Also the interaction between the cars may be modified by selecting one of four alternatives.

With the "equipment" depicted there are proposed two activities to students. In the first activity the inertial mass definition is gone over: students have to calibrate the system by establishing the quotients among the different calibrated masses provided and choosing the unit of mass. The second step in the activity is the determination of the value of the unknown mass. Finally, to complete the first activity, students must verify the independence of the mass definition on the interaction between the cars. To accomplish this they are suggested to repeat the measurement of the unknown mass with different interactions. This is a good opportunity to review the concepts involved in the measurement process and the definition of a magnitude in physics.

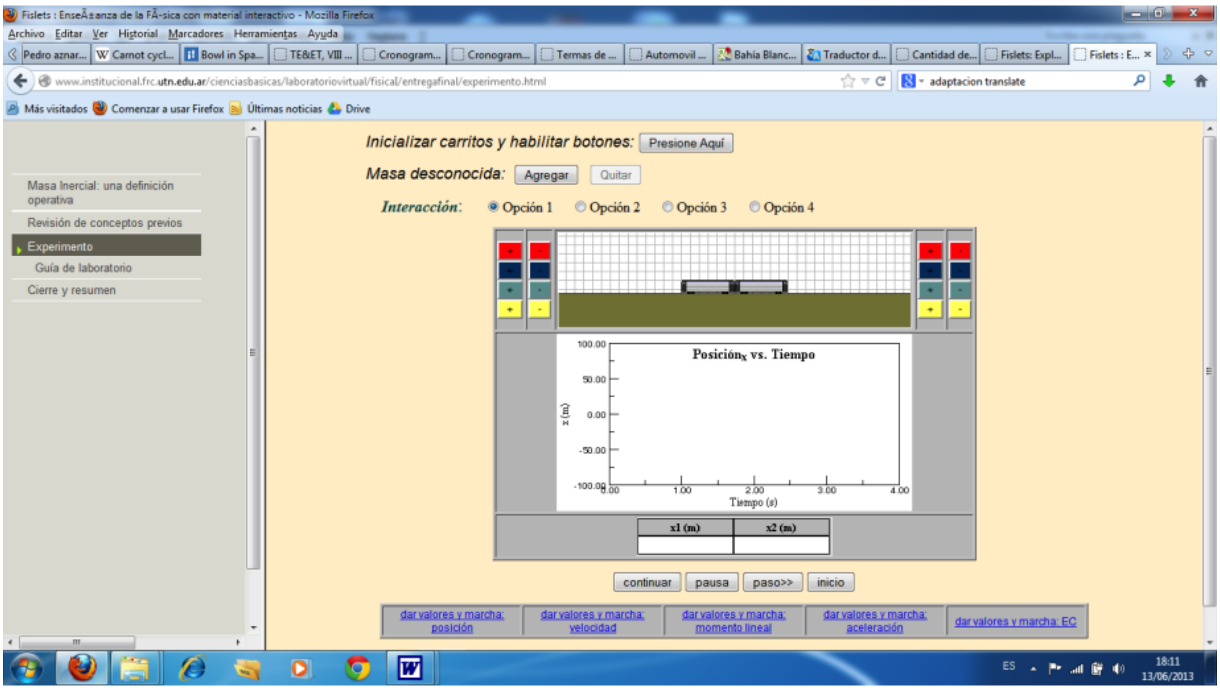

Figure 2. Environment for the virtual laboratory experience. Modified from exploration 7.10 in Physlets.

In the second experimental work students are prompted to discover the dependence of the interacting force between on their separation. This may be achieved by measuring the acceleration and position of the cars as a function of time and generating from these data a graph of force vs. distance. From the graph students should discover the function dependence and adjust the parameters. In three of the four options the interaction is the same (a spring type force: proportional to deformation) in different conditions. Thereby they should recognize the underlying law. The other interaction (option 3) is a d^{-2} law. So force does not equal zero at any distance and students should decide when ending the data collection.

In each practice students are asked to complete an inquiry pre and post experience to evaluate the activity. They must also prepare a technical report to pass the practical work.

A. Learning Object schema

The SBVL are presented in a LO schema developed following a uniform pattern of design developed for the virtual experiences to be carried out. The pattern design include three stages: *i)* an overhaul of concepts; *ii)* the experimental activity and *iii)* a closing activity with some suggested extra reading. The pre and post inquiries are included in the first and third stages making use of the form facility in google drive. These inquiries are included as an intend of evaluation of the activity itself. The experimental activity is oriented by a laboratory guide included in the second stage. In this way the SBVL is self contained. The LO was developed using the tool exe Learning. This tool generates the .html code.

In section Overhaul of concepts there are included texts with preliminary information for the experience fulfillment. Texts are selected from the literature and/or generated ad-hoc. As a subsection the preliminary inquiry is included here.

In section Experiment the "experimental device" is accessed and as a subsection the laboratory guide is included. As already mentioned a modified animation of the Physlets project has been selected.

In section Summary and closing alternative activities, connected to the fulfilled experiment, are proposed to the interested student allowing an individual exploration. Here is asked the student to prepare a technical report. Through this report the student performance is evaluated. A report schema is provided to help the student in his task.

The activity for mass definition is accessed in the address http://www.institucional.frc.utn.edu.ar/cienciasbasicas/laboratoriovirtual/fisicaI/entregafinal/index.html while the corresponding to force characterization in http://www.institucional.frc.utn.edu.ar/cienciasbasicas/laboratoriovirtual/fisicaI/labfuerza/index.html

IV. RESULTS

The SBVL was tested in the course "Física I" (Physics I) of the Chemical Engineering Career. This course includes the usual topics on Elementary Mechanics. The test was repeated for two years and students worked in groups made of two or three individuals to promote discussion among them. There were assigned two hours in the computers laboratory to finish the first activity. This time was adequate for all the groups involved in the experiment. Nevertheless the SBVL is available at any time and students could access it in case they wanted to review or repeat some measurement. During the completion of the experiment students showed themselves enthusiastic and interested in some aspects not included in assignment. In figure 3 the results from inquiries are included. It can be inferred that an improvement in the comprehension of inertial mass concept and its operational definition is got after the experience.

The second activity was left as homework to students. The delivery time was set up to two weeks. Students were prompted to work with the same partners as in the first experiment. In the meantime students could discuss with the instructor about doubts or technical details. Particular care was taken to advise students to consider only values for $a \neq 0$ when recording data. This is a usual mistake made by students. They were also asked to answer previous and posterior inquiries in this work. Results are shown in figure 4. It can be inferred that an improvement in the comprehension of force concept and/or the relationship between force and mass is achieved.

Finally, after completing both activities students were asked to answer individually an appreciation inquiry. Results are summarized in figures 5 and 6.

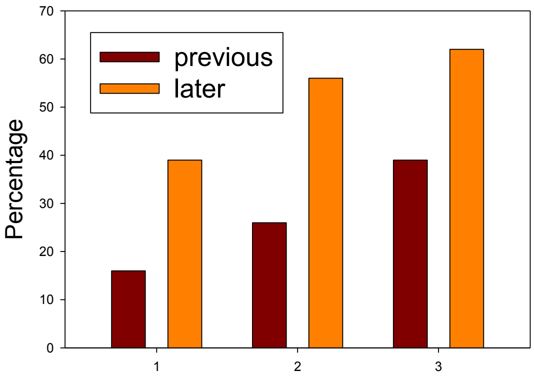

Figure 3. Results from evaluation of inquiries previous and later of experience. Percentages of correct answers are compared for different topics:

1- Inertial mass concept and operative definition of a magnitude.
2- Procedural knowledge.
3- Calibration notion

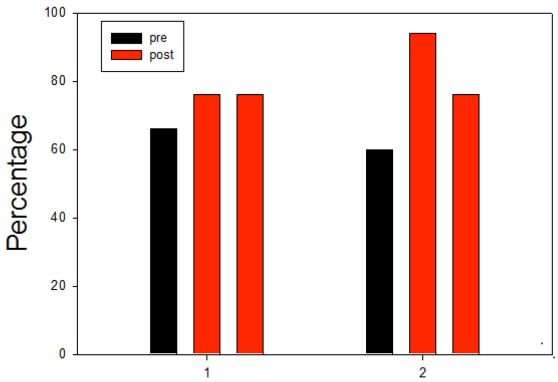

Figure 4. Results from evaluation of inquiries previous and later of experience. Percentage of correct answers are compared for different topics:

1) force concept
2) mass force relationship

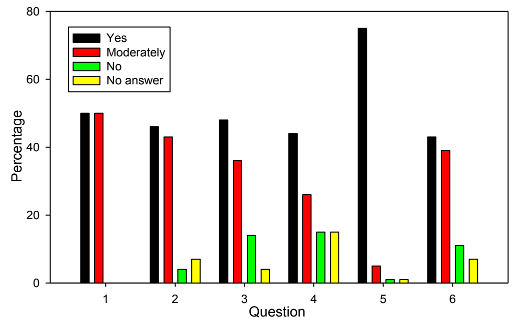

Figure 5. Results from evaluation of appreciation inquiries on SBVL. Percentage of answers to the following questions:

1- Do you think that SBVL have helped you in understanding the foundations of mechanics?

2- Do you think that the SBVL environment is appropriate and that it contributes to the development of experimental skills?

3- Have SBVL encouraged you to deepen in your knowledge?

4- Do you find quite different the activities carried out in SBVL from those of physical laboratory?

5- Do you think that SBVL is a good complement in your learning process?

6- Do you consider convenient or significant to include SBVL in other courses of your career?

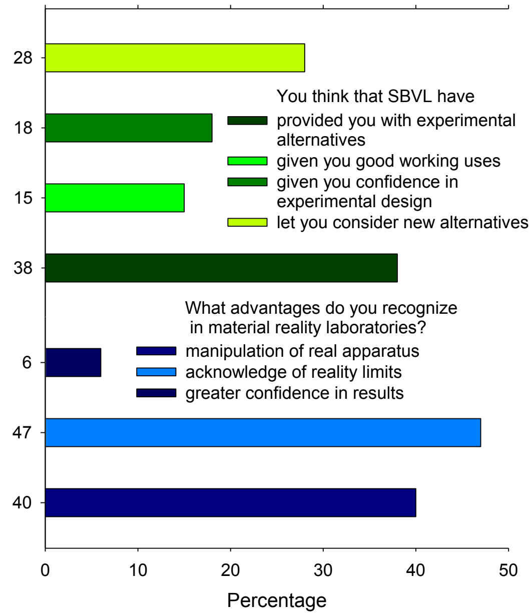

Figure 6. Results from evaluation of appreciation inquiries on SBVL. Percentage of answers to questions. Multiple selection was allowed.

In figure 5 we appreciate a positive consideration of SBVL activity with nearly 50% of positive answers and a greater percentage if we include the moderately option. It can be noticed a really low number of negative answers. In figure 6 we asked students for advantages and disadvantages of the use of SBVL. It could be concluded that in students opinion new alternatives if the most important aspect in SBVL. On the other hand the acknowledgement of reality limits is considered by students the main contribution of physical laboratories.

V. CONCLUSIONS

A set of two SBVL to explore the empirical foundation of classical dynamics have been designed, implemented and tested. Experimental design reproduces traditional proposals in material reality physics laboratory for operative mass definition. The same experimental design was employed in the force law determination in the second experimental assingment. In this case the experimental design is not usually implemented in material reality laboratories due to its dificulty and/or costly implementation. In this way virtual reality laboratories offer the opportunity of proposing new problems to students to get a greater insight in fundamental concepts in physics. Activities were oriented by a laboratory guide in the line of experimental prompting and under the interactive engagement schema.

The designed SBVL were tested in the "Física I" (Physics I) course of the Chemical Engineering career with satisfactory results. The first experimental activity was carried out at the Computers Laboratory, a general facility for students of all careers. The activity was supervised by an instructor. Students' performance was evaluated from the laboratory report that each group had to present. The activity was assessed from the inquiries requested to the students. Also individual opinions were asked to students in personal interviews and through an appraisement inquiry. It turns out to be a widespread opinion among the participating students that the laboratory helped them to comprehend theoretical aspects not completely understood in ordinary lectures.

The results obtained encourage the continuity of this project extending it to other courses.

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This work was supported in part by Universidad Tecnológica Nacional by grant UTI 1400. It is an extended and modified version of a paper presented at the ICBL2013 International Conference on Interactive Computer aided Blended Learning, held 6 - 8 November 2013, in Florianópolis, Brasil. Submitted, March 6, 2014. Submitted 29 April 2014. Published as resubmitted by the authors 07 August 2014.