VIRTUAL LABORATORIES, AN AUTHENTIC LEARNING IN ENGINEERING EDUCATION AT THE TECHNICAL UNIVERSITY OF MADRID

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ABSTRACT
The current technological society has transformed both learning places and learning timing, which have extended beyond the classroom. In this context, the virtual world offers students a wide range of motivating as well as stimulating possibilities. Thus, the Technical University of Madrid (Universidad Politécnica de Madrid, UPM), focused on engineering education, launched some years ago a Virtual Laboratory Platform that was granted with the Computerworld 2016 Award in the educational innovation category. The virtual Physics Laboratory was included in the aforementioned platform. This paper depicts the laboratory and the results of its use within in the course of Classical Mechanics, a compulsory subject in the undergraduate curriculum of Aerospace Engineering studies, compared to the traditional laboratory. The outcomes are greatly positive, with better results for those students who carried out the virtual lab compared to those who performed the traditional one. However, results might be influenced by different workload and grades obtained in both laboratories.

KEYWORDS: Opensim, physics lab, secondLife, traditional lab, virtual lab

INTRODUCTION

There is widespread consensus that laboratory sessions are important for students education because they allow direct experimentation. At the laboratory the students solve problems by “doing”, applying theoretical knowledge under the rules imposed by the scientific method (Rosado and Herreros, 2005).

In today's society, where technological advances allow us to extend both learning spaces and times beyond the classroom, traditional laboratories (TL) coexist with virtual laboratories (LV) in which the reality is simulated.

There is a lot of literature analysing advantages and disadvantages of both types of labs (Medina et al, 2011), so it can be found a frequent recommendation to consider the use of virtual labs as a complementary activity in theoretical-practical subjects (Fernández et.al, 2014; Infante, 2014).

The Universidad Politécnica de Madrid (UPM), focused on engineering education, has developed a considerable number of virtual labs among which is the Virtual Physics Laboratory. The purpose of this paper is to present the results of the use of these labs in the education of students of Undergraduate Degree in Aerospace Engineering. In this case, both types of laboratory, LV and LT, coexist without being complementary, but they are mutually exclusive.
Like other universities, the UPM has a platform called UPM [3DLabs] that allows its students to carry out laboratory experiments from anywhere with internet connection. Its development began in 2010 with the Educational Innovation Project “PEIA-UPM: Plataforma de Experimentación para los Estudios de Ingeniería y Arquitectura de la UPM” that may be translated as “Experimental Platform for Engineering and Architecture Studies at UPM”, in which teachers from different UPM centres participated (Berrocal, 2011).

Since 2013, Tele-Education Cabinet (GATE-UPM) is in charge of this 3D laboratory service. It works together with the teachers who design the experiments (Catalán, 2014; Contreras et al. 2015, Fernández-Avilés et. al, 2107). It is worth mentioning that this service granted the Computerworld 2016 Award in the category of educational innovation due to its contribution to the incorporation of opportunities and advances offered by current technology regarding education.

The platform includes several labs of different types, among which we can find the Virtual Physics Laboratory with an experiment based on the gyroscopic effect. It is not a procedural experiment, but a conceptual one in the sense that its fundamental purpose is to exemplify and get an in-depth knowledge of the gyroscopic torque concept, analysing those variables involved and noting their effect on its movement. In particular, once the students have created their avatar and enter into the virtual “scenario” of the Physics lab, there is a room with a virtual screen in which the basic theoretical concepts explaining the gyroscope movement are shown. Later on, they go to another room in which there are several spinning tops with different geometry and diverse materials and there they can select and represent various parameters values affecting their movement. By pressing a series of buttons, the student chooses which magnitudes they want to visualise, launch/start the spinning top and observe the movement, the change of its module and the vectors direction. They also get the graphs in which they compare the behaviour of each of them. From this information they are asked to answer a series of questions related to the concept of the gyroscopic effect. In each of them, after their answer, they are provided with immediate feedback. Once they have finished this activity, they are proposed to move to a hangar where they receive instructions on how the gyroscopic effect modifies the helicopter movement. Finally, they are asked to “pilot” a helicopter to perform some previously established routes. Only if they know and apply the principles of the gyroscopic effect they are able to get it. It is important to point out that, although students freely decide what they want their avatar to do, throughout the activity they can access a guide whenever they want and they are advised about the tasks they have done and those they still have to do.

The main objective of this paper is to present the use, during the 2017-2018 academic year, of the Physics virtual lab previously described in future engineer education and, for doing this, those results obtained have being compared with those of the traditional lab. The experience has been carry out during lab sessions in the course of Classical Mechanics, a
subject belonging to the Degree in Aerospace Engineering taught in the School of Aeronautics and Aerospace Engineering (Escuela Técnica Superior de Ingeniería Aeronáutica y del Espacio, ETSIAE) at the UPM. The course includes the realization of laboratory experiments in which student performs three different modules, two of them regarding simulation in the computer room and the third in the instrumental laboratory.

In the latter case, and over several academic years, students have been offered the possibility to choose between the traditional face-to-face lab and the virtual session lab. This initiative arose due to an extraordinary situation during works carried out in the laboratory building that enormously reduced the equipment availability, as well as the number of student seats per lab (more than 500) to be distributed in small group sessions over a period of two months. Incorporating the virtual lab shows a specific example of the real advantages of having such educational tools.

During the 2017-2018 academic year, a total of 546 students took part in lab sessions in the traditional instrumental lab, of which 178 freely opted for the virtual lab while 357 choose traditional face-to-face laboratory. The relative weight of lab is 5% of the final mark.

The following is a description of the operation of each type of laboratory, traditional and virtual, and finally a comparison regarding the students’ perception with respect to their learning experience has been included.

VIRTUAL LABORATORY. WORK METHODOLOGY AND OPERATION ASSESSMENT

As stated above, virtual experiment focuses on gyroscopic effect. Student choosing this type of lab has about two months to individually complete both the experiment and the report thereof, which are the only two items contributing to their mark. Naturally, and within the deadline, they can carry out the experiment at any time. However, there are available computers in the traditional lab so students may conduct the experiment during the lab opening hours. Besides, in order to avoid platform saturation, virtual laboratory has a booking system where the students make a reservation for their session. For the experiment to be carried out, students have some resources available in Moodle such as:

- Physics Virtual Laboratory Users’ Manual, with instructions regarding the platform operation and the steps the student should follow
- An explanatory video of Physics virtual lab and viewer configuration
- Booking Manual
- Virtual report template

They also may ask their teacher or email lab staff of Tele-Education Office (Gabinete de Tele-Educación, GATE as per its Spanish acronym), responsible for maintaining the platform, so they can send inquiries about technical issues.

For grading the virtual experiment, two reports with a different weight are taken into account:

1. The one that is automatically produced collecting their results while the students carry out different tasks or tests (60%)
2. In addition, each student has to upload to Moodle a brief report answering the questions in the template (40%)
In relation to academic results, the average mark of those 178 students performing the virtual lab was 8.81 out of 10.00, all of them graded by the same teacher.

On the other hand, in order to know the students’ opinion, once the course was finished and the marks were published, they were asked to complete a survey in Moodle regarding some aspects of the course. 40 responses have been collected. The results are presented below in relation to the issues that are considered most relevant related to specific aspects of the virtual lab operation (Figure 1). Questions related to learning and the overall assessment of the experience will be shown in a later section, along with a comparison with those obtained for the traditional lab.

![Figure 1. Students' opinion regarding virtual lab operation](image)

The students' assessment of virtual lab operation is quite positive. Regarding the user-friendliness, 100% consider that the information provided was adequate, 98% said that it has been easy to handle objects of the virtual world and only 28% said they had any issue while executing the actions they commanded. In these latter cases, only 2% consider that emailing to GATE solve their problems but not as prompt and satisfactory as it ought to be.

Accordingly, the immersion perception is very positive. 98% state that the visual elements served to capture their attention, 85% that virtual world is convincing and 70% keep their senses involved in the experiment. Another feature that has also contributed is meeting other students in the virtual world, 80% liked it that way.

With regard to the system reliability, some difficulties were identified in terms of availability as 32% claim to have had accessing problems due to disabled server. The viewer software is also a source of problems although to a lesser extent (22%). On the other hand, they are very pleased with the answer times to their actions while practicing.

Finally, it must be noted that 90% consider the booking procedure is really simple and only 10%
indicate that they had to wait a long time before using the lab. Given the large number of users, these results allow us to make a positive appraisal regarding the administrative management of the virtual lab.

**TRADITIONAL LABORATORY. WORK METHODOLOGY AND OPERATION ASSESSMENT**

It is a traditional face-to-face lab with eleven positions in which students can work in pairs. There are six different: five Maxwell Discs, three Gyroscopic Effects, one Flywheel, one Torsional Oscillations Equipment and one of Rotational Dynamic Equipment. Therefore, the experiment carried out by students in the traditional lab is different, depending on which one was assigned to them when dividing students into random groups.

Although each system has a particular activity to perform, the procedure to follow is similar in all cases.

1. Students have at their disposal a guide including the experiment purpose as well as those theoretical foundations needed for their work; the procedures to be followed to obtain the measurements they have to take. There is also a video for each experiment in which the experimental procedure is described step by step.

2. First thing we do when starting the lab session is remind students about the lab rules and a teacher also reviews the most important aspects of uncertainty calculations. Each session lasts 2 hours, after which the sheet with their acquired data is stamped.

3. The lab mark is obtained from the corresponding report (whose template is provided). Experience from previous years shows the great difficulty they have found throughout the process of calculating uncertainties. Therefore, in order to solve this issue, and prior to the final report hand over (two weeks after the lab session), there is a draft hand over where a teacher review their work in person and in pairs.

The report they have to submit is not a document where they have to fill in the blanks or answer a set of questions, but are rather the students the ones who must select and organize the document content. To this end, in addition to the questions student may ask their teacher, they are provided of a Manual on Uncertainty Calculation, a template with the description of the minimum content of the lab report and a self-evaluation guide that must be completed before handing the final version over.

The number of students who carried out the instrumental experiments during 2017-2018 academic year is 357, with an average mark of 5.64 out of 10. Table 1 shows data corresponding to the different teams. It is worthy to note that all reports have been evaluated by the same teacher, which is different from the one that assessed those of the virtual lab.
<table>
<thead>
<tr>
<th>Equipment</th>
<th>Number of students</th>
<th>Average Mark (out of 10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maxwell Disc</td>
<td>162</td>
<td>5.39</td>
</tr>
<tr>
<td>Rotational Dynamic</td>
<td>33</td>
<td>6.55</td>
</tr>
<tr>
<td>Gyroscopic Effect</td>
<td>93</td>
<td>6.18</td>
</tr>
<tr>
<td>Torsional Oscillations</td>
<td>33</td>
<td>5.80</td>
</tr>
<tr>
<td>Flywheel</td>
<td>36</td>
<td>4.42</td>
</tr>
</tbody>
</table>

*Table 1. Number of students who completed the traditional lab and their academic marks for 2017-2018 academic year*

In all cases, average marks are significantly lower than those obtained in virtual lab (25% lower at best), resulting in a source of consternation of some students who opted for the traditional lab. Undoubtedly this is an element that must be reviewed for next years. However, it also should be noted that within the average scores of the reports for different teams of traditional lab, the difference between maximum (6.55) and minimum (4.42) exceeds 30%, when the basic difference is that data they work with corresponds to one different variable.

Similarly, those students were asked to complete a survey through Moodle at the end of the course. Fifty responses have been obtained, from which some of the most relevant ones related to the lab aids and resources have been extracted (Figure 2).

*Figure 2. Students’ opinion regarding traditional lab resources and aids (being the worse: 1 and the best: 4)*
From these results, it may be said that all resources at their disposal to carry out lab experiments are useful for students, although not all of them to the same extent. Procedural videos where students can follow the process of data acquisition step by step were highly valued (3.4) as well as its written version, the experiment guide (3.16). Aids they consider less valuable are Self-Evaluation Guide (2.52) whose purpose is for them to check out they really have taken into account all those aspects to be evaluated and teacher’s explanations at the beginning of the lab session (2.46).

The report draft review with the teacher a week before the submission of the final report has also been highly rated (2.82), but at the same level as the document on uncertainty calculation (2.9) and the report template (2.82). The point was also made that being an activity where we promote students personal attention, we expected a higher valuation than that of printed resources.

**STUDENTS’ SATISFACTION AND PERCEPTION LEARNING WITH VIRTUAL AND TRADITIONAL LABS**

Both surveys, regarding virtual and traditional face-to-face labs, include common questions which will allow us to compare and thereby having a more objective criteria with which to assess results. Figure 3 shows average values of some of the questions we considered most relevant, disaggregated by lab type:

![Figure 3. Comparison of students’ opinions regarding virtual and traditional labs (being the worse: 1 and the best: 4)](image-url)
First result indicate that, in relation to the operation of both labs, virtual and traditional, the attention they receive or the ease of carrying out the experiments, the students’ perception is positive and similar, and differences in no case reach 10%.

Obviously it appears that most outstanding difference can be seeing in the flexibility that virtual experience allows them compared to the fact that they have to physically attend traditional lab in order make measurements with a fixed time schedule. However, differences about 30% both in grading as in the time spent show the need for reviewing the workload and our levels of expectation in traditional lab reports, which are consistent with lower marks obtained in those reports.

Another key element arise when they are asked about those activities they carry out during lab sessions and about their contribution to improving their lab training, since the students’ having conducted the virtual lab shows higher values than those attending traditional lab (the difference is 16% and 20%, respectively).

In this same way, when asked if they have been curious to try alternative ideas to those required in the lab guide, we can see that both laboratories have succeeded in motivating students, and awaking the interest of the students in learning doing different things than those the teacher indicated. But while virtual labs achieve it in 75% of students, traditional lab only gets 58% (Figure 4).

**Awaken Interest**

<table>
<thead>
<tr>
<th>Question</th>
<th>Virtual Lab</th>
<th>Traditional Lab</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>75%</td>
<td>58%</td>
</tr>
<tr>
<td>No</td>
<td>22%</td>
<td>36%</td>
</tr>
<tr>
<td>Do not Know/No Answer</td>
<td>2%</td>
<td>6%</td>
</tr>
</tbody>
</table>

*Figure 4. Results for question “I have been curious to try alternative ideas to those required in the lab guide”, disaggregated by lab type.*
Finally, when asked to indicate if they would recommend this lab to other students, while virtual lab students would do it unanimously (100%), in the case of the traditional lab only 60% will (Figure 5).

![Graph showing recommendation rates by lab type](image)

**Figure 5.** Results for question “In general, I would recommend this lab to my colleagues”, disaggregated by lab type

**FINAL THOUGHTS AND PROPOSALS FOR THE FUTURE**

During 2017-2018 academic year, the students of the course of Mechanics were allowed to choose between carrying out a laboratory experiment face-to-face or using the UPM platform [3DLabs] and working in a virtual way. The objectives of both practices are different. In the first case, it is a traditional laboratory in which students make direct measurements with which, later, they will calculate those variables requested and where the uncertainties calculations are important. In the second one, lab has more conceptual bias, to reinforce concepts understanding through their application in “real” situations.

Results of the experience presented throughout this work, may not be considered as conclusive given the study limitations, but do allow us to extract valuable information to improve the teaching practice. One first conclusion is the mismatch existing in the students’ workload as well as in grades obtained in both types of labs. This gap has been shown by students even in the open answers of the surveys when they were asked to indicate items that could be improved. They answer that the reports evaluation and the great difference of difficulty between both types of labs (virtual and instrumental), which is possibly reflected in the results we have obtained.

Another relevant outcome is that the valuation performed by students who have attended the virtual lab is more positive than that of those who perform the traditional one in all cases. This positive difference in favour of virtual lab also occurs when they are asked about the usefulness of their education or whether it served to motivate them to learn, which are the key elements in determining if an activity is suitable for their training.
In this scenario, in which 100% of students who followed the virtual lab recommend it to their peers, a response that may be influenced by a “privileged” situation over the traditional one, our proposal is to extend the use of this experiment, the gyroscopic effect, to all students of the course. Also face-to-face lab has to be reviewed regarding its methodology and evaluation in order to adjust the level of demand to the time the students have available. The contrast of the results we will obtained compared to those we have for this academic year, will possibly clarify if this positive students’ valuation is maintained for next years.
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