

# Creating Web Experimentation Portals

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**Abstract**— There are two main obstacles for supporting lab experimentation in distance learning institutions, such as the Turkish Anadolu University, the UK Open University and the Spanish Open University (UNED): (i) their high number of students, and (ii) the fact that students are usually scattered around the world. Both problems make impossible to provide the scientific and technical courses with traditional labs at a reasonable cost. To overcome those problems, we propose an approach to developing web-based, deploying them into a learning management system and reducing their cost by reusing software intensively.

**Index Terms**— Collaborative learning tools, educational technology, e-learning, virtual and remote laboratories

## INTRODUCTION

In terms of number of students, the Spanish Open University (UNED), with more than 260,000 scholars, is the biggest university of Spain. To support their students, UNED is composed of a network of associated learning centers scattered around the world (more than 60 centers distributed across Spain, Europe, America and Africa). Unfortunately, the geographical dispersion of the students makes impossible to provide the scientific and technical courses of UNED with traditional labs at a reasonable cost. To overcome those limitations, we have created a systematic approach to developing web-based labs able to support effective experimentation for distance learning.

Nowadays, web-based labs are well established in many technical and scientific fields since they help to visualize phenomena that require difficult-to-assemble or costly equipment [18]. There are two complementary approaches for web-based labs:

1. **Virtual Labs (VLs)** provide computer based simulations which offer similar views and ways of work to their traditional counterparts [9]. Nowadays, simulations have evolved into interactive graphical user interfaces where students can manipulate the experiment parameters and explore its evolution.

2. **Remote Labs (RLs)** use real plants and physical devices which are tele-operated in real time [21].

Some works present simulated experiments in different fields of Physics. For instance, [6] use computer simulations for enhancing the learning of fluid mechanics, and [5] proposes an optical-system simulation software that provides a VL for studying the effects of propagation. Nevertheless, real experiments are not considered in previous works. Other works focus on introducing computers into labs for analysis and data acquisition but not for distance learning [16]. Only in the last few years, RLs are being more commonly considered (e.g., [17]). However, most of the RLs are either individual experiments or limited to a particular field, such as electronics [13, 14] or optics [10]. Moreover, VLs and/or RLs are not enough by themselves. Distance students

require a complete web experimentation portal, qualified for stimulating both practical individual and collaborative work. While VLs/RLs serve for the first, the second can be granted using a Learning Management System, (LMS) [12].

An important concern about VRLs is their high cost. Developing a VRL from scratch and creating its collaborative support requires a huge effort. Although software reuse alleviate this problem, it is not common for web labs. In [8] a survey of forty-two different works about remote labs concludes that every project implements its own software architecture with no reuse.

This paper proposes a systematic approach to developing web-labs that overcomes the former problems (i.e., creation of VRLs/RLs, lab deployment in LMSs and cost reduction through software reuse). Furthermore, to support such approach we have extended two valuable open source software applications for e-learning and lab development: Moodle and Easy Java Simulations (EJS). Moodle is a widespread used LMS (more than 50 million registered users, according to its official webpage) that supports constructivist learning, offering its users communication and interaction facilities. EJS [1] is a tool designed for the creation of discrete computer simulations. During the last few years, EJS has grown for helping to create web-accessible labs in control engineering education. With this objective in mind, recent releases of EJS support connections with external applications, such as LabView and Matlab/Simulink. Hence, EJS not only is useful to create virtual labs, but also the GUIs of their remote counterparts [20].

A stable release of our open source software (i) has been checked, approved and published by Moodle, and (ii) has been included in the last official EJS release 4.3.7. To check our approach, we have developed the UNEDLabs web portal, which hosts a rich network of VRLs for students of UNED and other Spanish Universities, such as the Leon University and the Almeria University. All labs in UNEDLabs have been developed using the approach this paper presents. For Control Engineering learning, UNEDLabs includes a DC motor, a three coupled tanks system and a heat-flow system. For Physics learning, UNEDLabs includes a motorized optical bench for determining the focal length of a thin lens, laws of reflection and refraction experiment and a springs' elasticity experiment. Each of those labs requires different hardware tools. To reduce costs and simplify the construction, some of them (the springs elasticity experiment, for example) were built using LEGO NXT Mindstorms pieces, which is a nice solution when a limited budget is one of the restrictions to design the experimental setup [2, 3, 11, 15]. Other setups use aluminum pieces, stepper motors and controllers, force sensors and/or circuit elements. Our approach supports controlling the hardware with different software tools, such as LabView or Matlab.

The remainder of this paper is structured as follows. Section 2 summarizes our approach. Section 3 exemplifies our approach by describing a VL/RL for a thin lens experiment, which is included in UNEDLabs. In Section 4, students' assessments are presented and analyzed. Finally, Section 5 sums up our conclusions.

#### CREATING WEB EXPERIMENTATION PORTALS

EJS is a freeware, open-source tool developed in Java, specially designed for the creation of discrete computer simulations. The architecture of EJS derives from the Model-View-Control (MVC) paradigm, whose philosophy is that interactive simulations must be composed of three parts:

The model describes the process under study in terms of (i) variables, which hold the different possible states of the process, and (ii) relationships between these variables, expressed by computer algorithms.

The view provides a graphical representation (either realistic or schematic) of the process states; i.e., the GUI of the simulation.

The control defines certain actions that a user can perform on the simulation.

EJS makes things even simpler eliminating the control element of the MVC paradigm and embedding one part in the view and the other one in the model. Applications are created in two steps: (i) the building of the model to simulate by using the built-in simulation mechanism of EJS, and (ii) the construction of the view to show the model state and its reactions to the changes made by users.

From a practical viewpoint, developers can create advanced interactive applets using EJS since it provides a simplified program structure, custom model tools (such as an advanced differential equation editor), and drag-and-drop view elements that let developers work at a high level of abstraction, thus speeding up the creation process. Developers input the qualified information on the simulation that only a human can provide (e.g., math equations, the initial model state, the GUI's design...) and the program takes care of all the computer related aspects of creating a finished, independent Java applet.

Although EJS was originally designed for developing interactive simulations in physics, during the last few years additional plugins/complements have been developed for helping to create web accessible laboratories in control engineering education. With this objective in mind, recent releases of EJS support connections with external applications, such as LabView, Matlab/Simulink, SciLab, and SysQuake [4, 20]. Hence, EJS not only is useful to create virtual labs, but also the GUIs of their remote counterparts. Fig. 1 depicts the client-server architecture our approach follows.

To support the deployment of EJS applets into Moodle, we have extended both tools. In particular, we have developed the EJSApp module which supports:

Deploying labs written in EJS. This feature has an enormous potential. For instance, the Open Source Physics (OSP) repository [1] offers more than 400 simulations that can be directly deployed into Moodle with a single button click.

Controlling user access to the deployed labs. EJSApp supports setting the start and end dates when a lab will be accessible to the students, the minimum grade students

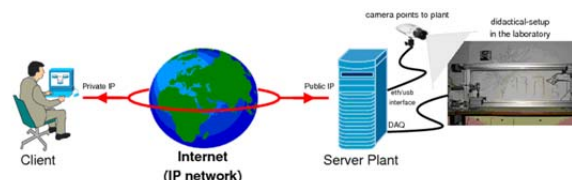


Figure 1. Communication is based on the TCP/IP protocol. The server runs the remote experiment while the virtual one is locally running in the client side.

need to get in other activities as a previous condition before having access to the lab...

Backup and restore. EJSApp provides maintenance facilities for labs, packaging them into Moodle course backups.

Supervision and statistics. Access from Moodle users to EJSApp activities are recorded and can be used for performing statistics and supervising the time students spend working in each lab.

#### A LAB EXAMPLE: THIN LENS EXPERIMENT

The focal length,  $f$ , of an optical system is a measure of how it makes light converge (focus) or diverge (defocus). For a thin lens in air, the  $f$  is the distance from the center of the lens to the lens focal points. If the lens is converging,  $f$  is positive, and its value is the distance at which a collimated beam will be focused to a single spot. The value of  $f$ , the object distance from the object plane to the lens ( $s$ ), and the image distance from the lens to the image plane ( $s'$ ) are related by:

$$\frac{1}{f} = \frac{1}{s} + \frac{1}{s'} \quad (1)$$

By means of this VL/RL, students can:

1. Determine the focal length of a thin lens (*method 1*). Users collect several measurements of  $s$  and  $s'$  (listed in the Data tab of the applet) when the beam is focused over the screen. Then, performing a linear regression  $f$  is obtained.
2. Determine the focal length using Bessel's method (*method 2*). If the distance between the object and image planes,  $L$ , is greater than  $4f$ , we can find a second position for the lens in which the beam is also focused over the screen (Fig. 2). These two positions are marked with blue arrows in the experimentation applet. Let  $d$  be the distance between those two positions of the lens, then:

$$f = \frac{L^2 - d^2}{4L} \quad (2)$$

3. Visually check the focal length. Students can move either the screen or the lens to a certain position, shift the other element (screen or lens, respectively) to a distance of  $f$  (determined in the previous steps), and check if the beam focuses over the screen. Students can compare the precision of measuring the focal length by both methods.

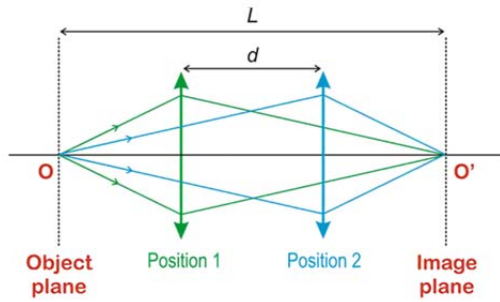


Figure 2. Explanatory scheme of method 2



Figure 7. Didactical setup of the thin lens experiment

Fig. 3 shows the didactical setup for this experiment. Basically, a two axis motorized bench is used for setting the position of the lens and the screen independently. A relay is connected to the laser to switch it on or off when a user connects or disconnects from the RL. A diffraction grating is used to split the laser beam into several rays. Finally, two webcams are used: one for giving a general view of the experiment and another one, situated close to the screen, for watching whether the rays are focused over or not.

### Virtual Lab

Fig. 4 shows this lab working in simulation mode when using the first method for determining  $f$ . It also shows the integration of the laboratory applets into the LMS. The virtual representation of the system shows a laser at the left part. Next to it, a diffraction grating splits the laser beam into several rays. The lens and the screen are the other elements over the rule. Users can change their position moving its corresponding slider or clicking with the mouse over the visual element and dragging it. There are two views of the screen: a side one and a front one (represented by the white rectangle). In this last view, students can check if the rays focus over the screen or not. Fig. 5 shows: 1) the tool for performing linear regressions with the collected data and 2) that same data collected during the experimentation with method 1. In the left image the result obtained for  $f$  by means of the linear regression is displayed. It must be noted that the points plotted in the graph do not fit exactly to a line even though data were collected from a simulation; this is due to that finding the positions for the lens and the screen in which the rays focus to one single point over the screen is an approximate method that depends on how well you can distinguish the separation between the rays points over the



Figure 6. Thin lens VL GUI within UNEDLabs (method 1)

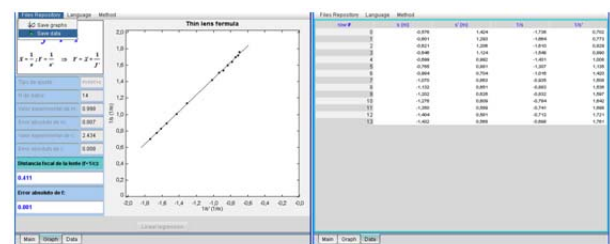


Figure 5. Thin lens VL GUI within UNEDLabs (method 1)

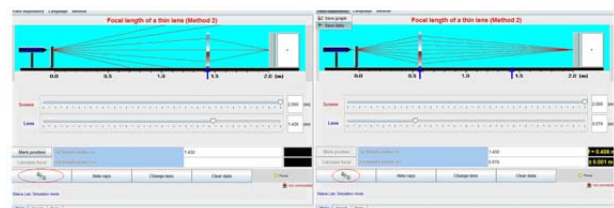


Figure 5. Thin lens VL GUI. Method 2. Blue arrows mark Bessel's positions

screen. Therefore, there are errors associated to the measurement of the focal length even in simulation.

Graphs and data can be saved into .jpg and text files, respectively. This is done by pressing the Files repository button on the top menu of the application (see the left image of Fig. 5). In the particular case of this experiment, two files will be saved and sent to the My Private Files Moodle block, with these default names: *Lentes1Sim\_graph\_1.jpg* and *Lentes1Sim\_1.txt* (these files appear in the block in Fig. 7).

Fig. 6 shows the VL when the second method is being used. In the left image, the first of the two Bessel's positions is found and marked. In the right image, the second one is found and the value of  $f$  is determined by means of equation (2). As expected, the results given by both methods are very similar.

### Remote Lab

RLs are operated by means of the same application as the VLs. Students must click on the Connect button (marked with a red circle in Fig. 6) for changing from the VL to the RL. A booking system checks if that user has a reservation to access that particular RL for that day and hour. If that is the case, the GUI changes and shows the view associated to the RL. Fig. 7 shows a snapshot of this

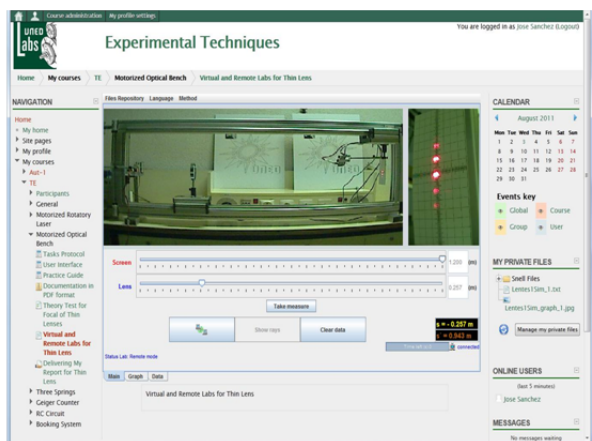


Figure 7. Thin lens RL GUI within UNEDLabs (method 1)

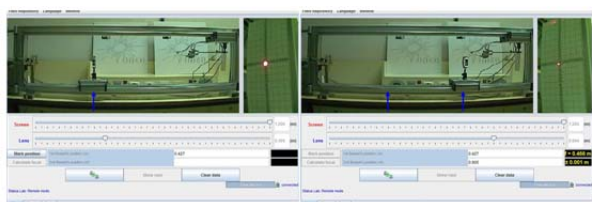


Figure 8. Thin lens RL GUI (method 2). Blue arrows mark Bessel's positions

web-lab working in remote mode when using the first method for determining  $f$ . Note that the user interfaces are almost identical in simulation and remote modes, which facilitates the work of the students with the application. Also note that the files saved in the step taken in Fig. 5 are present in the My Private Files block, an online files repository users can access from any computer when they access the LMS. The webcam image on the right part of the EJS application shows several points when the lens and the screen are positioned (Fig. 7), which tells students they must keep on moving the lens before taking a new measure in this first method for determining the focal length of the lens.

Fig. 8 is the equivalent of Fig. 6 for the remote mode. The two Bessel's positions are found and marked and therefore, the focal length is determined. When preparing the laboratory report, students are asked to estimate the errors in the measurements and compare the ones obtained for each method in remote mode with the ones obtained in simulation mode.

#### STUDENTS' ASSESSMENT

This portal was tested by 20 of our students during their first grade year. They were granted access to the laboratory presented in this work (and two more of the Experimental Techniques course) for four months. They were asked to fulfill an opinion poll with different questions about their experience with this system. In this opinion poll, they were asked to mark several statements with numbers from 1 to 5, being 1 that they completely disagree with the statement and 5 that they completely agree with it. Four of the more important questions and answers are shown in Fig. 9, where  $Q_i$  are:

- Q1: Overall, I am satisfied with the clarity and use easiness of the system and the environment.

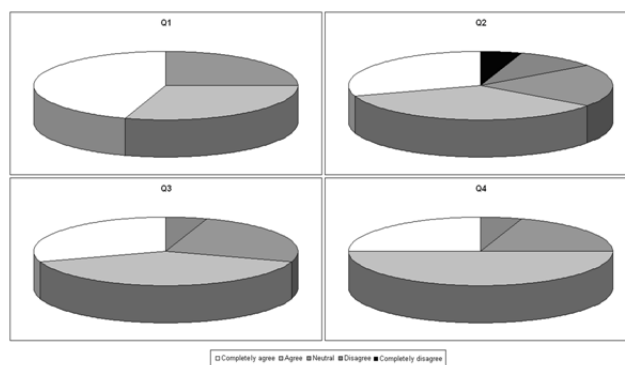


Figure 9. Students answers to questions about their perception of UNEDLabs

- Q2: I was able to solve all the tasks only using the material given in this system.
- Q3: The simulation (VL) has served to make clearer how to work with the RL.
- Q4: Overall, I am satisfied with this way of performing the experimental activities.

Q1 presents the best results with a 45% of students that completely agree and a 30% that agree with the statement. Q2 shows that almost all the students were able to resolve the experimentation tasks without any other help than the one given by the material provided in UNEDLabs, which proves that the portal is suitable for distance education purposes. Q3 reveals the importance of simulations as a first experimental contact for the students in order to make clearer the use of the RL for 70% of the students agreed or completely agreed this statement and only 5% of them disagreed. Finally, Q4 may serve as a conclusion of the whole opinion poll: 75% of the students agreed or completely agreed that UNEDLabs satisfied them as a way to perform the experimental activities.

#### CONCLUSIONS

This paper presents an approach for creating web labs and deploying them into Moodle. Theory lessons, grades and reviews by instructors can be easily added thanks to the LMS. A web portal (UNEDLabs) and a VL/RL (the thin lens experiment), created with this approach, were presented as examples. The only required software tools are: EJS, Moodle (with the EJSApp plugin for adding the EJS labs and automatically connecting them with My Private Files block), the JiL or JiM applications and LabView or Matlab for controlling the hardware of the experiments. Only the last two software tools are not free.

Data collected during their simulated and real (remote) experiments can be saved in the cloud and accessed through the web portal thanks to the EJSApp plugin. Having these data, students can compare the theoretical results with the real ones, which constitutes one of the fundamental issues of the scientific method. This work showed a VL/RL for determining the focal length of a thin lens. Others are already available (DC motor, a three coupled tanks system, a heat flow system...) or in development (a RCL circuit, rigid pendulum, etc). All these experiments (with both VLs and RLs) are easily integrated into UNEDLabs thanks to the EJSApp plugin and because they all use the same structure and software tools, even though the hardware is different.



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