

Globally Distributed Pendulum Experiment as an Educational Resource on e-lab

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Abstract—e-lab is a remote laboratory platform that provides access to several remote experiments in basic or advanced physics. Recent upgrades to its interface and new features introduced make it more accessible and appealing, but experiment's attractiveness for teachers and students has been an issue. A new experiment intended to improve this aspect was introduced: the World Pendulum. Consisting in multiple identical pendulum apparatuses connected to e-lab and scattered throughout different locations across several countries. The World Pendulum is intended at exploring a unique feature allowed by remote experimentation – experimental repetition in different locations.

Index Terms—e-learning, experimental education, remote laboratory, pendulum.

I. INTRODUCTION – E-LAB

e-lab^[1] is a remote laboratory in operation at IST since 1999. This remote laboratory is based on a software framework called ReC^[2] that allows for a seamless integration of different remotely connected experiments and laboratories.

On the client side e-lab offers students and teachers a unique client that may be used to access and perform all available experiments. During the execution of an experiment the user may set all the variables to run it and will receive in real-time all the experimental data including errors and the live video feed of the running experiment.

The user may afterwards view, treat and save all the collected data. e-lab's software client already offers basic options for (i) viewing in graph or table modes, (ii) zoom and data exploring options on the graphs and (iii) the usual save and print options.

A number of external tools or programs offer a deeper exploitation of e-lab's remote experiments. Currently (iv) video streaming is supported by VLC video application; and the data export and save options allow for using (v) other supporting technical computing tools for data analysis like Origin, MSeExcel, MatLab, SciLab, IDL, Octave, Fitteia among others.

These tools as well as other content are offered by an external site^[1] that supports e-lab's framework. It is where experiments are described and the knowledge database exists, serving:

- Content Repositories;
- Access to external tools;

- Experiments wiki^[3];
- e-lab main FAQ^[4];
- Image and video galleries;

In light of more recent developments and integration in different projects, e-lab underwent a new revision to what concerns platform stability and implementation of new features, both on the client side as well as on the developer's end.

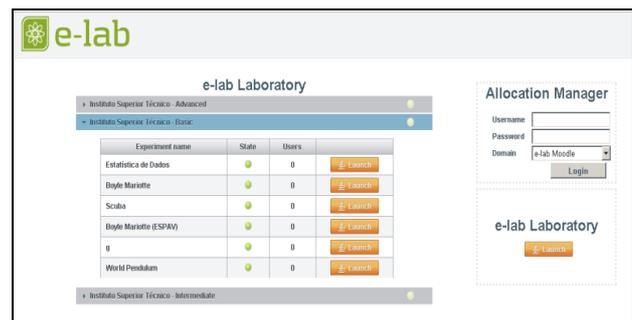


Figure 1. The *rec.web* interface main page. Providing access to the experiment's client applications.

As such a newly developed web platform called (vi) *rec.web* was developed (figure 1). In addition to intending to offer a brand new image to e-lab, *rec.web* allows users to have a much easier and user friendly navigation of e-lab's full framework and implements a full (vii) *backoffice* for managing e-lab, mainly to what concerns^[5]:

- Privileged users: it is possible to create different sets of users with different kinds of accesses to e-lab. For instance allowing certain privileged users to book an experiment. Nowadays a Moodle integration is implemented allowing for a set of teachers and students to log in to e-lab with their Moodle account settings.
- Scheduling options for privileged users. Such users may reserve an experiment for a time slot up to 120 minutes, during which no other user is allowed in that experiment without permission;
- Backoffice* management of scheduled sessions;
- Real-time management of connected users, allowing, for instance, for an e-lab administrator to *kick-off* users for inappropriate conduct;
- Real-time management of all on-line live experiments and laboratories.

Other newly added features include mainly:

- f) Sending an automatic e-mail with all the collected data;
- g) Direct access to an experiment from the *rec.web* platform, avoiding previous access to a specific laboratory;
- h) Improved optimized exploring options for the previously performed experiments on an e-lab session.

These features, both on client and developer side, as well as the unique software platform that allows experimental apparatuses to be quickly connected to a single client over the internet that are intended to be explored with the new World Pendulum experiment.

Furthermore, even though the interface now allows for more advanced and appealing features, the evaluation of e-lab under a pedagogical context is missing and extremely necessary.

II. WORLD PENDULUM EXPERIMENT

The World Pendulum experiment was conceived with the purpose of offering a globally distributed remote experiment. Its main objective is to observe the variation of the acceleration of gravity with a location's latitude^{[6][7]}.

For that purpose several different pendulum apparatuses are distributed across different locations and covering different latitudes, which can be operated via the internet using the e-lab framework. At the moment the following locations are included:

- Lisbon, Portugal, Marine's Museum Calouste Gulbenkian Planetarium. Latitude: 38.7°;
- Ilhéus, Brasil, in the Univerity of Ilhéus. Latitude: 14.8°;
- Faro, Portugal, in the Faro's "Ciência Viva" Science Museum. Latitude: 37.0°;
- Sines, Portugal. Latitude 37.9°.
- São Tomé e Príncipe. Latitude 0.3° (*planned*);

These locations already offer a sufficient latitude distribution so that an interesting comparison of the value of 'g' – the acceleration of gravity –, can be made.

The pendulum will be operated via e-lab where a user can select the initial displacement for the mass – between 5 and 20 cm –, and the number of oscillations to be sampled – between 10 to 500. The measured period of the oscillation can then be used to determine the value of the gravity acceleration at the pendulum's location^[9].

This experiment can serve different educational approaches according to the level of its users:

A. Basic

At a basic or secondary education levels a teacher can use it to simply demonstrate to students how to calculate the value of g from the data acquired.

B. Intermediate

On a more advanced level a teacher can have students deal with experimental uncertainty or precision concepts, since the experiment is meant at registering very small changes in the value of gravity from place to place and the collection and treatment of a great number of samples will always be required to effectively observe this variation, by

statistically treating data and correct accounting of experimental errors.

An interesting note on this, when first assembling the pendulum structure, collected data showed a secondary oscillation with a larger period in time. It was in fact an oscillation in the structure itself^[8]. In this example the unforeseen existence of an extra oscillation as noise doesn't have to be necessarily seen as something that needs to be corrected and that makes the experiment unfeasible. This can actually be seen as an interesting feature for enriching the experiment on an educational perspective, since, from the tests made, it was possible to conclude that the noise does not interfere significantly with the experiments results. So, for instance, the observation of this parallel oscillation can be enriching if users wish to observe, study or treat such a systematic error on the data values.

C. Advanced

Finally, more advanced level students can take the calculated values for g and adjust them to a mathematical function that describes the variation of gravity with the planet's latitude. A very commonly accepted formula for this variation is given by the spherical harmonics approximation in terms of the latitude:

$$g_n(\phi) = 9.780326772 \times [1 + 0.00530233 \cdot \sin^2(\phi) - 0.00000589 \cdot \sin^2(2\phi)] \quad (1)$$

Also more advanced correlations of the "noise" oscillation referred can be undertaken.

Furthermore the geographical distribution of the pendulums may also be correlated with altitude variations and moon and tide positions along the year, providing an extremely rich experimental grid, easily accessible by students all around the world, that allows to directly study our planet.

On this perspective a shared spreadsheet^[10] was created in order to centralize experimental results on the value of gravity. The results are shown in *figure 2*: the current measurements for the 4 Pendulum apparatuses tested in relation to the expected value from equation 1. The acceleration values in Sines were only possible to collect with two decimal places so far. Hence the error is too large and the average value falls far outside the expected area.

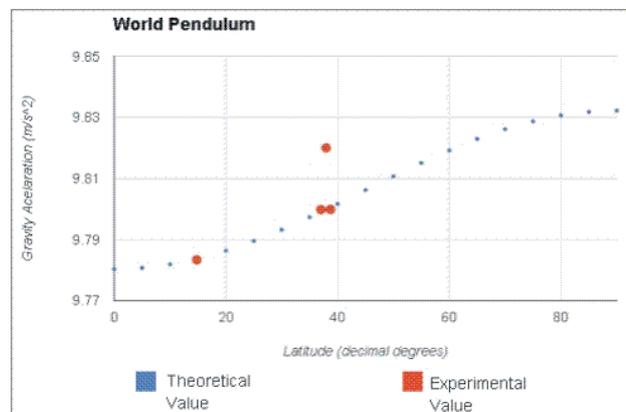


Figure 2. Estimated value of the 'g' acceleration with latitude variation. Showing the collected data points for each city.

The didactical advantages of this experiment are directly linked to the global distribution with a centralized simultaneous connection under e-lab: an important feature uniquely offered by remote experimentation.

Taking this into account the experiment was made in order to produce a more accessibly replicable apparatus to potentiate network expansion. Furthermore the implementation of new apparatuses should be relatively quick under e-lab. And under this perspective some specific features could also be further developed that would potentiate such distributed project, such as:

- On-line courses on the experiment, aimed at different level users;
- Creating a graphic interface for exploring the *rec.web* interface, would allow to provide a large repository of experimental data with these values, available for large scope projects over space as well as over time;
- The spreadsheet shared between the yet few participants in the World Pendulum network could evolve to a seamless web resource under the *rec.web* application services, directly integrated with the data repository;

This experiment can more easily provide a solid and more oriented base for e-lab's pedagogical evaluation, mainly because such a network would enable integration under different educational contexts ranging distinct levels of education; or further exploration of planetary events increasing its attractiveness, such as (i) studying the value of g with altitude; (ii) with moon and tide positions; or (iii) during eclipse occurrences.

III. FINAL REMARKS

The increase in available services and a more user friendly interface on e-lab is not enough to make an attractive Remote Laboratory platform. The implementation of the World Pendulum experiment aims at offering a unique globally distributed experiment available on-line from anywhere.

e-lab's intrinsic characteristics for scalability enable to replicate experiment's and build a network of pendulums relatively quickly. Making e-lab the ideal supporting platform for such project.

This experiment can also serve different levels of education aimed at experimental pedagogy and increase significantly the attractiveness to teachers and students., an aspect that should become more significant as the network scales This makes it the ideal candidate to carry out a larger evaluation of e-lab's platform in the context of pedagogical activities.

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