Use and Design of Virtual and Remote Free Access Experiments: World Pendulum Alliance and DLab in Times of COVID 19

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Abstract
Since 2019, the COVID-19 pandemic has made the search for efficient learning spaces and tools for distance learning more relevant than ever. In Physics, experimental teaching is considered essential for secondary and higher education. This has given a sense of urgency to the development of new pedagogical and technical strategies for experimental distance education. This work presents preliminary results of the World Pendulum Alliance project, whose aims is to build a global network of remote experiments. The implementation of the remote experiment was made by a MOOC environment and a virtual distance laboratory (DLab) designed by the authors accompanied by the inquiry learning teaching method. To evaluate the efficacy of the pedagogical strategies proposed, two groups of students were evaluated. The perception of students for the virtual environment is presented and the approval and dropout results are presented for the MOOC course. Preliminary results show that the remote and virtual modalities are a good complement to the teaching of hands-on laboratories but need to have a very good pedagogical platforms for its implementation in order to engage the students.
Keywords
MOOC, Remote experiments, distance learning, World Pendulum Alliance, experimental physics

1. Introduction

Inside the World Pendulum Alliance (WPA@elab) eight countries through fourteen institution shaves built a constellation of pendulums remotely accessible. These high precision pendulums allow the measurement of the gravitational variation across the globe for any student accessing the network [1]. The ERASMUS+ Grant given by the European Commission to the alliance focus on the capacity building in the field of higher education. In the first stage of the project, The Universidad Nacional Abierta y a Distancia (UNAD), in Colombia, as part of the consortium, has been working in the development of educational instruments and tools to support the use of the constellation. The work has been done through the ReEx Science Dissemination Center, a scientific team led by the UNAD whose aims is the best use of the remote experiment mainly in secondary and higher education [2, 3].

COVID-19 quarantine measures have affected almost all the educational systems over the world, increasing the urgency of the development of virtual and remote labs that can perform well under the new conditions and efficiently use the industry 4.0 technologies [4,5,6,7]. The possible pedagogical approaches for such laboratories are multiple, although recently have had an increasing interest in the Inquiry Learning Space (ILS) one and its studies and technologies [8, 9, 10, 11, 12].

For the implementation of the remote experiment, Instituto Superior Técnico (IST) creates a MOOC environment, offered by the servers of the University, whose alpha version was launched in 2016 by

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IST to its students [13]. In 2020, UNAD participated in the evaluation and correction of the beta version of the MOOC in Spanish Language (Física Experimental -FeX-ES). The need of creating smaller and more focused laboratory environments addressing the oscillatory phenomena has been seen in order to complement the material inside the MOOC. In this context, a virtual distance laboratory (DLab), is being built at ReEx, set as a free online non-guided ILS which is oriented to compare the behaviors of mass-spring systems and pendulum systems. The first novelty of our approach is focused on learning process around a creative process: autonomous experimentation design made by student, instead of the teacher. Although the concept is not entirely new [14, 15, 16].

In this article, the World Pendulum Alliance (WPA@elab) is briefly presented and its implementation thorough the MOOC environment accompanied by the inquiry learning teaching method. The paper details the implementation and the results. Finally, the discussion and conclusions will focus mainly on the perception of students, completion rates and possible causes for dropout.

2. FeX-ES MOOC with the WPA@elab

This section describes the WPA@elab system in a general way, for more technical details, read [1]. In addition, presents the main characteristics of the MOOC in its Spanish version (FeX-Es).

Global Constellation: WPA received its ERASMUS+ Grant in 2019. Development of Science Dissemination Centers in Portugal, France, Czech Republic, Spain, Brazil, Panama, Chile, and Colombia has been made for locating more than 100 pendulum experiments in different latitudes and altitudes. Inside WP@elab network, every remote experiment is in located a different geographical spot aiming to provide a wide test of gravitational variability upon certain variables.

Remote Experiment Set-up: The pendulum consisted of a2kg±75gbob attached to a string of length varying between [2609.8−2827.5] mm ± 0.5 mm whose movement is controlled by the DC motor of a mechanical launcher. Infrared sensors register in a micro-controller the passing of the bob, calculating the oscillation period with 5 significant numbers. Data transmission from and towards users is achieved using IST servers.

e-Lab software: To control the remote experiment is used a software called e-Lab that also permits displaying the set-up, measurements, graphs of the variable in real time. The displayed interfaces for controlling parameters and visualizing variables are the ones in Fig. 1-a. Variables and Analysis The main two measured variables: the period $T$of the movement and the velocity$v$at the bottom point of the moment (equilibrium position for the bob), are displayed by the e-Lab interface in plots against time equivalent to samples, Fig.1 b-d. Together with these measurement outcomes, the relevant parameters defined in settings are complemented by the bob's diameter, string material characteristics and temperature.

Data treatment can be used not only for a simple pendulum modeling. Besides allowing to compare simple pendulums with different accelerations due gravity, the energetic losses can be calculated with the value of velocity at the bottom. For instance, were taken 500 velocity samples clearly not only show a loss of energy that a student can accurately analyze in secondary school, but a possible study of the variation of this energy loss. In the case of advanced university students, even corrections due the torsion of the string or the non-instantaneous character of the velocity measurements can be estimated, yet in the context of a local experiment. In the framework of WP@elab as a global experiment, the different latitudes and altitudes provide a good input for laboratory experiences on gravity variation across the globe. Having into account that the total maximum variation in gravity over earth's surface is roughly 0.7% according to GRACE/GOCE/EGM2008 data [17], the 5 significant numbers of the T value in WP@elab constellation produce a 5 significant numbers estimation of gravity. If air friction and single plane oscillation are ensured for the Primary Pendulums, this type of variation of the order of 0.1% are easily detectable for students.

The sample uncertainties are not higher than the expected dispersion [≈0.5ms]. The flexibility of the WP@elab experiments depends on the design of the learning space which use the network. This thematic flexibility, partially commented in a previous paper [3], could go from the identification of the value of the scientific method and quantitative methods to the characterization and experimental

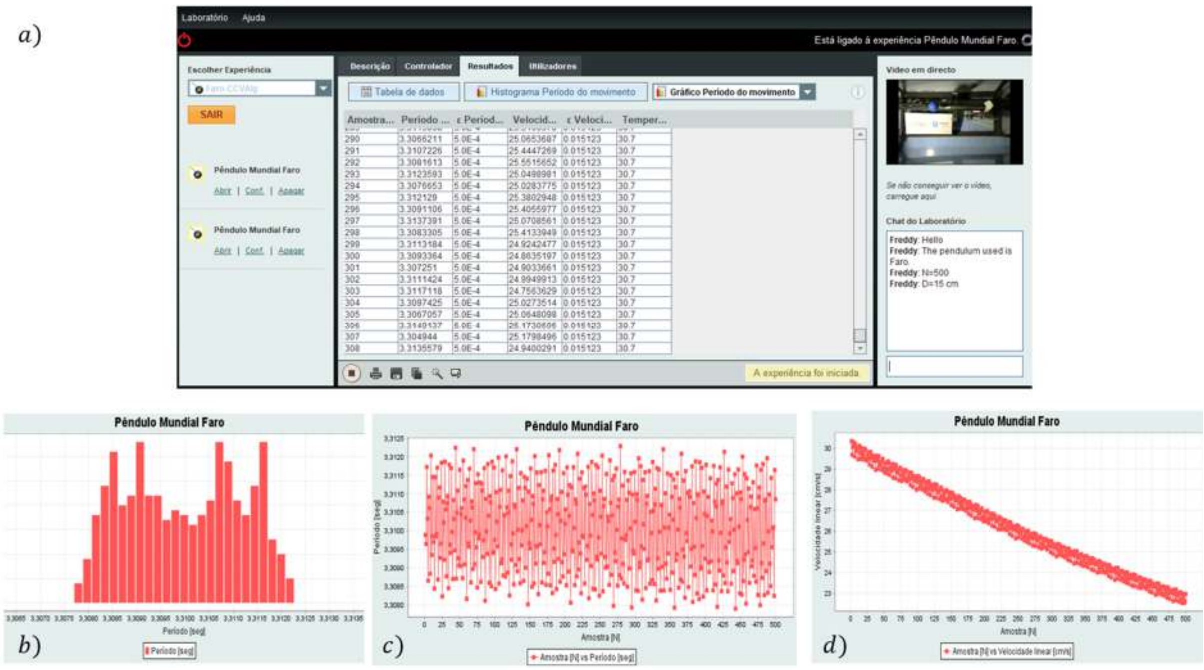


Figure 1: Graphics extracted from remote experience with the pendulum from Faro, Algarve (Portugal). The subfigure's a) Results panel, which presents the data in the form of a table, b) the histogram of period, c) plot of period over 500 samples and, d) periodic fluctuation in the measurement of maximum velocity at the lower position of the pendulum, measurement taken from Faro experiment.

analysis of gravity variation across our planet, possibly identifying error sources as dissimilar as friction, string torsion, temperature changes, variable oscillation planes, among others. Details about a more tangible assessment of this flexibility are presented in section III. WP@elab work operating inside the DLab framework could still help to evaluate student's experimental abilities, as other studies have recently done [18].

3. DLab as an inquiry learning space

Distance Laboratory (DLab) was created to complement the MOOC FeX-Es content and deepen students' knowledge.

Interface and platform: Each virtual experiment was programmed as a series of three simulations regarding relevant aspects (i.e., variables or parameters) of the generic mass-spring system. The correspondent codes were put online under free access policy in the Wolfram web page. The codes were developed in the programming language Mathematica. These codes are presented in a very simple way, as scientific professional plotting, without any color or user-friendly treatment, apart from clear and simple controls. Every control is referred to a parameter and every plot is a 2D graphic of a variable versus another. This means that we have3 mass-spring systems, each one exhibiting a different motion case (forced, damped and natural oscillation). Each one has 3 different controllable plots. One of the interactive graphics can be seen in Fig. 2, which corresponds to the energy in a Simple Harmonic Oscillator (SHO).

The initial design of the implementation is made for high school and first year undergraduate students, equivalent to secondary education students and first-time-on-physics- class university students. We glimpse this first stage of DLab as a combination of e-Lab global experiment and the virtual natural and damped simulated systems. Every inquiry space must be accompanied, not with a traditional guide, but a contextualization. Assuming three different levels of pre knowledge, the contextualization also divides in three: beginner, basic, intermediate.

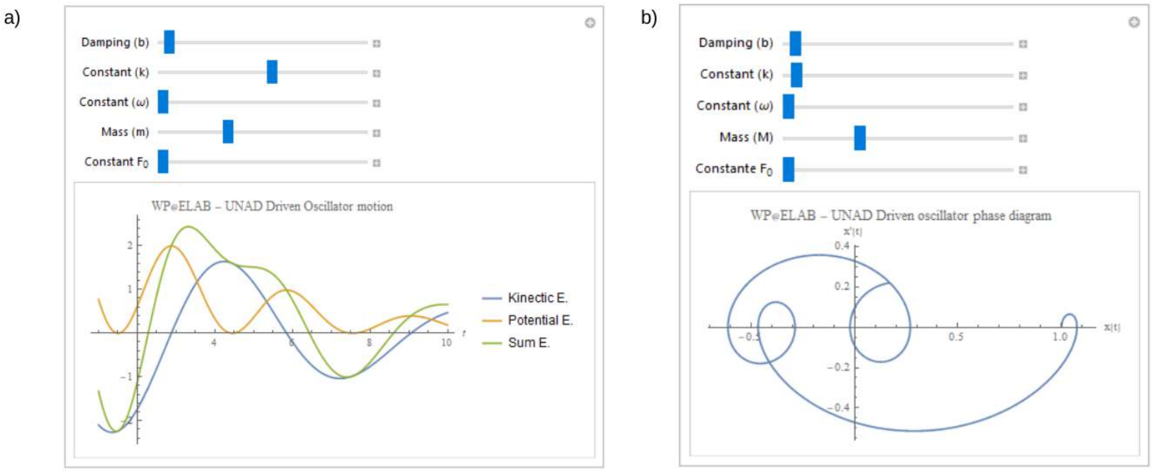


Figure 2: DLab interface. a) Simple Harmonic Oscillator, second interactive object: mechanical energy, and b) phase diagram for the damped mass-spring system, simulated in one of our interactive virtual graphs with two different sets of parameters. Moving the controls, the student can identify the change in the convergence speed and associate it with physical parameters and variables.

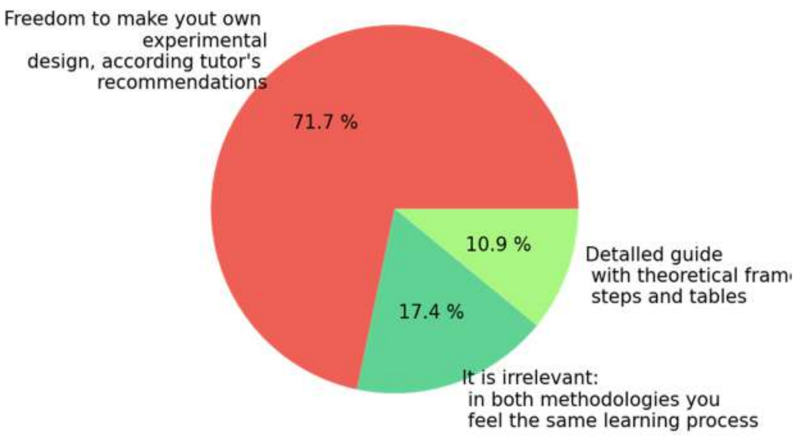
The means-context-feedback structure is not something entirely new. The contextualization moment as a key part of learning have been considering by many authors, researchers, and tutors [8-21], in dissimilar fields going from science to communication. Below we present the projected articulation of our means-context-feedback structure with the three previously commented levels of prior knowledge. All three teaching-learning models are the same and use the same Experimental Design Strategy for Novices. The steps lists are meant to encourage a systematic line of thinking rather than to be a recipe-like text.

- *Beginner level:* For those students with null skills on physics and almost null abilities in math. We require, however, that the students know some arithmetic and be able to graph data from tables, identifying dependent and independent variables. The pre-recognizing of the virtual and remote environment is a step 0 of the IBED space.
- *Basic level:* For those students with almost null skills on physics but certain minimum abilities in math.
- *Intermediate level*: For those students who are completed at least the 70% of the theoretical part of a typical Physics course. Here we are referring to the simple kinematics and dynamics of uniform and projectile motion, Newton's laws, and dynamics of circular motion. The start of the contextualization refers to the uniform circular motion, as it was studied by the students. The students must discover what variable correspond to each axis of the natural oscillator's phase diagram, through analysis or experimentation.

4. Implementation of the Educational Distance Strategies

The implementation of two pedagogical strategies was carried out in the General Physics course at UNAD. The General Physics is a virtual and distance course, asynchronous and interdisciplinary, the thematic contents are based on Task-Based Learning (TBL). The structure of the course is divided into two components: one theoretical (75%) and the other experimental (25%). The topics covered are measurement and kinematics, Newton's laws, and energy conservation theorems. Although distance learning is used for the theoretical part of the course, three long presential sessions of laboratory are programmed for the students to develop the experimental component before the Covid-19. In the course, the interaction between professor and student includes written guides where the student fills tables and responds questions based on a carefully detailed experiment which is already mounted in the laboratory.

For the implementation, two groups were evaluated, in the first one, it was used the MOOC FeX-ES together with the designed virtual DLab together with ILS. The second one, it was per formed in pandemic times ant it was realized out only with the MOOC FeX-ES. In this section is shown the main results obtained for each group of students.



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4.1. DLab with WPA@elab

The idea of this pedagogical strategy was to complement the remote experience with a virtual simulated one, as well as to show the general perspective of science to students, in front of experiments, and to have inexperienced students making systematic experimental designs. This would be done after reading a short generic text of recommendations.

The re-focus towards the scientific method in the teaching approximation model was applied to 46 students in 2018 year but was authorized just for one of every three experiments originally planned for the academic period. In this way, the other two experiments served as a control group of traditional learning experiences (guided pre-designed experiments). A decreasingly guided structure was followed: the first session is more guided than the second one, and the third one is totally free. The target population were students ages between 16 and 26 years old, as it is usual among distance education first year learners. In order to create a learning path, a questionnaire with four relevant questions was implemented on the design of the possible experimental guide. The questionnaire sent to the students as a survey was the main instrument used for the evaluation of the methodological experience. A translated version of the compiled answers is visualized here; the first important results can be summarized in Figure 3. Preliminary results shown that students are more attracted to design their own experiments than following strict step-by-step indication written in the guide.

4.2. MOOC FeX-ES

The implementation of the MOOC FeX-ES was carried out on a sample of 56 students, who enrolled voluntarily. The MOOC had a total duration of 30 days from May 1 to May 31, 2021.The course structure is divided into four scenarios listed in Table 1.

The course has a maximum grade of 100 points, of which the student passes and is certified with 60 points. The results obtained displayed in Figure 4 are listed below:

i. *Course approval:* In figure 4-a was obtained that 28.6% approved the course obtaining a qualification greater than or equal to 60 points, 21.4% failed when obtaining a qualification less than 60 points and 50% of the students did not interact in the course since its enrollment.
ii. *The participation rate in the Learning Assessment:* Figure 4-b shows the participation throughout the nine tasks developed, which were guided and oriented asynchronously. For

Table 1
Pedagogical structure of the MOOC FeX-ES

e-Learning scenarios	Learning Assessment	Teaching-learning activities
Course Preparation (Pre-task)	Initial perception questionnaire. Reserved use of the IST.	Introduction Required materials e-lab (remote laboratory).
1 – Essence	E1 - Essence: 4 Conceptual Questions (True/False).	Uncertainty in Indirect Quantities.
	E2 - Essence: 7 Conceptual Questions (mathematical analysis).	Uncertainties in Graphic Representations and Linear Fittings.
2 – Am I lighter at the equator?	The activity is not qualifying.	Introduction.
	E3 - Problem: conservation of mechanical energy (1 question)	Dimensional Analysis
	E4 - Resolution: mechanical energy conservation	Your pendulum and energy balance
	E5 - Problem: Height as a function of initial displacement	Energy Balance
	E6 - Problem: maximum speed at source	The World Pendulum in e-Lab and energy balance
	E7 - Local acceleration of gravity(s)	The World Pendulum in e-Lab
	E8 - Experimental determination of the acceleration of gravity Part I	The World Pendulum in e-Lab
	E9 - Experimental determination of the acceleration of gravity Part II	The World Pendulum in e-Lab
3 – The network test	No learning assessment	Numerical fitting of functions: fitteia
Final perception questionnaire	Final perception questionnaire. Reserved use of the IST	Final questionnaire

each activity there was a deadline for delivery. In Table (1), the activities are classified from E1 to E9. The graph indicates the students who presented or not each activity. From the sample of active students, excluding those who did not interact, it is possible to analyze that activity E4 was not carried out for 39.3% of the total sample, being the one with the lowest academic participation and, otherwise, E5 was the only activity that counted with 100% student participation.

iii. *Approval by exercise:* Finally, 4-c depicts the approval for every of the nine tasks, E2 had the highest student approval with 78.6% (22 students) of the total sample and E9 the lowest approval rate with 39.3% (11 students)

4.3. Discussion and Conclusions

During the implementation of the remote experiment World Pendulum with MOOC FeX-ES course, it was seen a learning difficulty of the students of the General Physics course of the UNAD. It was evidenced in the statistical analysis and interpretation of previous concepts. The high disapproval

(21.4%) and desertion (50.0%) reflect the need to modify the structure of the MOOC pedagogical scenarios, due to mathematical shortcomings in the interpretation of experimental data.

On the other hand, the results reflect the need to train students, prior to the beginning of the course, in the domain of virtual learning environments and installation of specialized software, aimed at remote experimentation, since the rate of students who did not interact with the virtual platform after enrollment was significant (50.0%), reducing the participating population. As a strategy to mitigate the indicators, the implementation and improvement of the D-Lab environment, accompanied by the design of a tutorial for use and installation, will be able to mitigate those conceptual flaws that may encompass teaching-learning problems in e-Learning spaces. In the present case of our DLab, the main abilities to promote are graph interpretation, systematic handle of quantitative information, application of mathematical models and experimental planning. Or, summarizing, scientific method skills: scientific thinking in context. Moreover, there is a long tradition of prioritizing the learning of physics topics rather than the physicist thinking skills, even if the students will not use the specific knowledge in any posterior course at all in their undergraduate studies [22-26]. The scientific method focus of IBED is an idea embedded even in the Inquiry definition itself [27-29]. The process of designing an experiment can be taken as the main structure or a new generation of Inquiry Learning Spaces if the method is proven effective to develop XXI century expected competences [14]. Although current curriculum and courses planning do not always reflect the importance that Physics teachers see in scientific reasoning, there are multiple evidence of efforts and attention put in this regard [23-30]. We think that an IBED space can achieve very good learning results in this matter, once the method has been optimized.

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