LABS-ON-THE-WEB – A MULTIDISCIPLINARY PROJECT TO EVALUATE THE PEDAGOGICAL EFFECTIVENESS OF ON-LINE LABS

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On-line labs and the Labs-on-the-web project

An *on-line lab* may offer remote, virtual or mixed-reality experiments in various areas of science and engineering. *Remote labs* offer web access to a workbench hosting the experiment at the campus lab, while *virtual labs* provide a simulation framework that may be hosted in the e-learning server itself, or downloadable to the client's computer. *Mixed-reality labs* offer a combination of simulation models and physical devices / equipment. The *Labs-on-the-web* project (November 1st 2006 – June 30th 2008) addresses the first type and was prepared in response to a call for proposals aiming to improve pedagogical success in higher-education degrees. The project rationale was that web access to lab workbenches will facilitate experiments and other practical assignments proposed to engineering students, enabling them to better understand and consolidate the underlying theoretical knowledge.

Teacher training and evaluation of pedagogic effectiveness

The project workplan recognised the need to offer to the teachers a sound background on pedagogical and technical aspects of on-line labs. An accompanying training programme was therefore developed, including three training actions, each comprising 5x2h sessions: *Pedagogical principles*, *E-learning via Moodle*, and *On-line labs*. Teacher training took place between February 21st and June 27th 2007, involving a total of 103 teachers. To evaluate pedagogic effectiveness, the students were asked to fill a questionnaire at the end of the semester. The grading scale comprised 7 levels and the items that were presented addressed various aspects dealing with learning in remote contexts, organised in accordance with the following 4 dimensions: **i)** *Knowledge and skills* (e.g. acquisition of new knowledge; development of Information and Communication Technologies skills; possible development of new alternatives / solutions); **ii)** *Learning process* (e.g. understanding the theoretical concepts underlying the remote experiments and the cause / consequence relationship that explains a given result); **iii)** *Peer cooperation* (assessing the importance, the existence and the possibility of collaborative interaction among students); and **iv)** *Teacher interaction* (which includes items related to the importance of collaborative work between students and teacher and to the availability of the latter).

Conclusions / future research directions

The student responses to the questionnaires were moderately positive with respect to all our evaluation dimensions and support the conclusion that they recognize the pedagogic benefits of remote labs. On the other hand, we also concluded that comprehension of the learning process is an important dimension in what concerns remote experiments, which is in itself worth to consider as a pedagogical research direction. It is important to stress that benefits regarding the learning process were the most valued. The results have shown that our evaluation dimensions are significantly correlated. Of particular significance is the very strong association between building knowledge and skills, and the comprehension of the learning process, suggesting that the students who think that remote labs promoted their knowledge and skills, also consider that there are positive effects on understanding the theoretical assumptions; and the fact that collaborative work (between students and between students and teacher) is related both to knowledge and skills, and to learning processes. The project has shown that there is still room for improvement concerning development and usage of remote labs to support practical assignments – seamless integration into e-learning platforms, scripting support for teachers, formative assessment features and accessibility are the areas where the need for further work is recognised. Accessibility in particular remains largely unsolved, even in the case of mainstream solutions that are frequently employed within a wide application spectrum. Embedded formative assessment features is an important research direction with this respect, since the experiment and equipment interface panels may gather data about student skills and make it available both to the students and to their teachers.

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Abstract

On-line labs provide 24x7 access to real or virtual workbenches, enabling the students to complete, rehearse or repeat practical assignments outside the physical space of the campus labs. Many on-line experiments in science and engineering courses have been described in the literature, but there is still room for further work and innovation, both in technical and pedagogical areas. The latter are particularly important and have largely been left aside, since the vast majority of research projects in this area were set up by technical institutions. This paper describes the work and results of the Labs-on-the-web project, a cooperative research effort set up the Faculty of Engineering and the Faculty of Psychology and Educational Sciences of the University of Porto, under the framework and support of the POCI 2010 programme[1].

1. Introduction

Much has been said and done concerning on-line experiments in science and engineering [1:3]. In general terms, on-line labs comprise a range of real or virtual resources, including various types of test and measurement equipment, and complement the theoretical contents offered by e-learning platforms. On-line labs may provide access to real workbenches supporting web access (so-called remote experiments), to simulation environments (virtual experiments) or to a combination of both (mixed-reality experiments). However, most of the work done in this area was essentially of a technical nature, supported by engineering / computer science institutions, with a small or non-existent participation of educational sciences. As a result, the literature concerning pedagogical evaluation of on-line labs is very scarce [4], and the arguments pro and con are largely based on common sense arguments, without supporting evidence from field trials. The rationale of the Labs-on-the-web project consisted of preparing such trials and gathering evidence to identify the benefits and limitations of offering web access to workbenches used by engineering students.

The following section provides informative material concerning on-line labs in general, and briefs the reader on the pedagogical benefits that are informally associated with such educational technologies. Section 3 presents the Labs-on-the-web project and identifies its goals within the overall framework of on-line experiments. Pedagogical evaluation work and results are then described in section 4, with an emphasis on the assessment methods and on the interpretation of the available results for a specific case study. Section 5 summarises the conclusions drawn from this project and identifies promising directions for further research. The paper closes with a section containing bibliographical and webliographical references.

2. On-line labs

Figure 1 shows a general block diagram of an on-line lab and may be used to represent the three types of on-line experiments that were referred in the introductory section – remote, virtual and mixed-reality. A *remote lab* offers web access to the workbench hosting the experiment in the campus lab [5]. A *virtual lab* provides a simulation framework that may be hosted in the e-learning server itself, or downloadable to the client's computer [6]. *Mixed-reality labs* are the most complex and offer a combination of simulation models and physical devices / equipment [7]. The following aspects are particularly worth of mention concerning Figure 1.

[1] The POCI 2010 (*Programa Operacional Ciência e Inovação*) programme is run by the Portuguese Ministry of Science, Technology and Higher Education, with support from the European Social Fund.

1. *On-line* means that the users carry out the experiment via a communications network, irrespective of the physical distances separating participants and equipment. Students and teachers may or may not be present in the university campus.
2. On-line labs may or may not include a real campus lab. The *lab server* and the *workbench* will not exist in the case of a virtual lab, but will be present in the case of remote or mixed-reality labs.
3. On-line experiments are of little use just by themselves. An experiment is intended to consolidate theoretical knowledge, provided by an e-learning platform under multiple forms (slides, lecture notes, quizzes, group activities, etc.). Any on-line lab should therefore be associated with an e-learning server, offering the theoretical framework that supports the experiments proposed to the students.
4. Remote labs comprise one or more workbenches with web access. In very simple cases, the workbench equipment may contain its own web server (e.g. in the case of experiments based on microweb server technology [8]), but the usual solution consists of combining a workbench with a lab server (e.g. in the case of NI-ELVIS workbenches [9]).
5. The e-learning server and the lab server may or may not be interconnected (dotted line in Figure 1). The former is a preferred solution, since it enables the remote experiment to be seen by the students just as another e-learning content. In this case, the e-learning server will also offer a scheduling application that enables the students to book access time, therefore helping them to plan their activities.

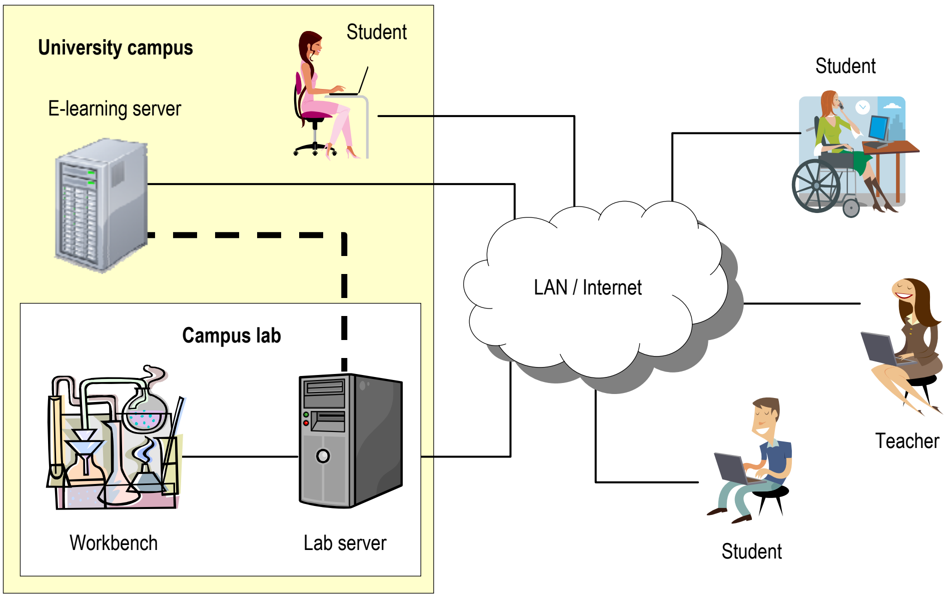


Figure 1 Block diagram of an on-line lab

Two main questions arise when considering to set up an on-line lab: Is it worth, considering cost x benefit? And if so, which type is best (remote, virtual, mixed-reality)? The first question is indeed the main reason underlying the Labs-on-the-web project that will be introduced in the following section. Although there is a notorious scarcity of data to support one view or the other, pedagogically speaking, there are a few reasons that may be stated in favour of this technology. On-line labs offered in a blended-learning context enable the students to continue an assignment which they were unable to complete while at the lab. They may also carry it out entirely from home or elsewhere, if they were not able to come to the lab. Additionally, they may repeat it to gather new data in the case of unreliable or doubtful measurements, or even rehearse it before going to the lab. Benefits concerning safety and security are also unquestionable for some application areas. Finally, institutional benefits may be exploited if access is granted to external institutions, particularly through programmes involving less-favoured areas or developing countries [10]. Economic-wise, arguments run both ways. Money invested in equipment is better used when the workbench supports web access, since it can be used even when the lab is closed. The cost of providing web access varies, and there are cases where the additional cost is very low, e.g. when the workbench equipment supports LabView interfaces that can be published on the web [11]. Technically speaking, there is an added degree of complexity when an experiment is to be made available on-line, and the necessary expertise may go beyond the technical skills of the teacher. This is not equivalent to say that further technical staff is needed to support the on-line features of campus labs, in particular if the support technicians already available can be trained to provide help with this respect.

Pedagogical aspects play a main role when discussing cost x benefits and deserve to be addressed independently of cost and technical factors. Enabling a higher percentage of students to achieve the learning goals set up for each course is hardly translatable in terms of economic performance, but would strongly advocate in favour of this technology. Surprisingly or perhaps not, a few pedagogical errors are just too frequent and may not only hamper the expected benefits, but also discredit this technology:

- On-line labs are not meant to replace real campus labs, but rather to complement them, much in the same way that e-learning resources are not a replacement for face-to-face activities.
- An on-line experiment is always a means to achieve a learning goal, and not an end in itself. In other words, an on-line experiment should never be offered on a stand-alone basis, but rather as a building block that comes attached to its accompanying theoretical counterpart.

Assuming that the benefits of on-line labs outweigh their cost, it is still necessary to decide which type of experiments should be supported: remote, virtual or mixed-reality. There are cases where a remote lab is clearly in disadvantage concerning a good simulation package, e.g. when studying a basic electronic circuit, where sophisticated simulation packages offer a wide range of tools to stimulate, understand and visualise its operation. Virtual experiments are unquestionably the best choice in such cases. Digital control systems involving mechanical parts or other non-electrical sub-systems represent an example of multidisciplinary applications where a remote experiment may be much easier to build than its equivalent simulation model. Finally, those cases where the same sub-system, easily represented by a simulation model, interacts with a variety of other non-electrical sub-systems, may justify the extra complexity of setting up a mixed-reality experiment. Notice also that more than one approach may co-exist in the same application area – although virtual labs represent the best choice for introductory electronics courses, checking if a given device complies with its specification can not be done unless the *real device* is used (either locally in the lab or through a remote experiment).

3. The Labs-on-the-web project

The Labs-on-the-web project was prepared in response to a call for proposals aiming to improve pedagogical success in higher-education degrees. The project rationale was that web access to lab workbenches will facilitate experiments and other practical assignments proposed to engineering students, enabling them to better understand and consolidate the underlying theoretical knowledge. The project workplan comprises three main areas:

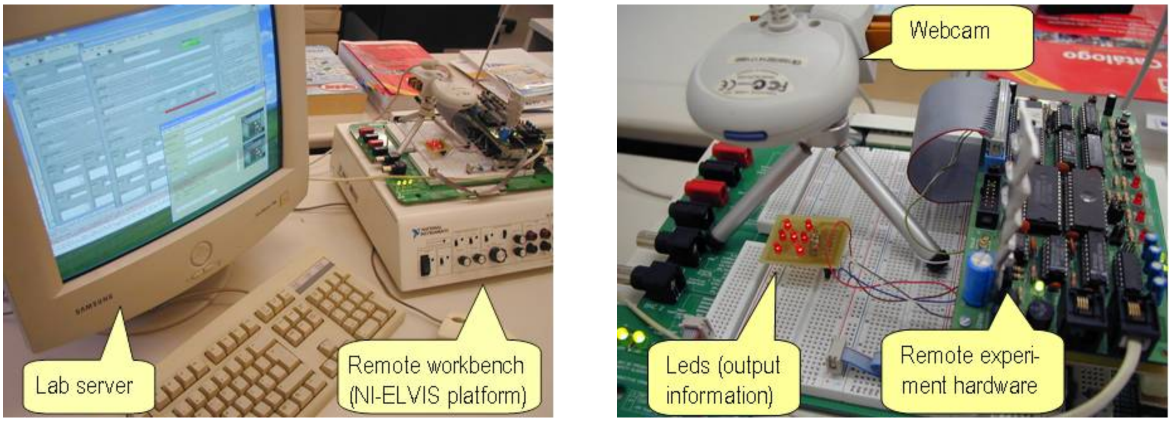
1. The technical work needed to set up a range of remote labs in various engineering degrees
2. Teacher training, to ensure appropriate perception and use of the technology
3. Pedagogical evaluation, including the development of the methods and instruments to be used on field trials, data gathering and analysis.

Tasks 1 and 2 proceeded simultaneously, and so did the development of the pedagogic evaluation methods and instruments involved in task 3. Half-way through the project, field trials were initiated, and data started to be gathered. Analysis and reporting closed the project, which lasted from November 2006 to June 2008.

3.1 Technical work

Both existing and newly developed remote workbenches were used in field trials, mostly in the areas of mechanical and electrical engineering. Figure 2 shows a workbench that was set up to support remote experiments in a microprocessor course offered to second year electrical and computer engineering students.

The remote workbench illustrated in Figure 2 provided real-time video feedback using the webcam shown in (b) above. After scheduling their access time on Moodle (the e-learning platform selected to host theoretical contents and lab scripts), the students did their assignments using the interface windows shown in Figure 3 and Figure 4.



(a) Lab server and workbench hardware (b) Close-up view showing the webcam and leds

Figure 2 Microprocessor-based remote experiment

Figure 3 shows the code upload / execution command window. Since most microprocessor lab assignments are proposed as team work, the interface panel shown in Figure 4 supports videoconferencing and text chat. Figure 4 also shows the real-time video feedback provided by the remote workbench webcam that is visible in Figure 2.

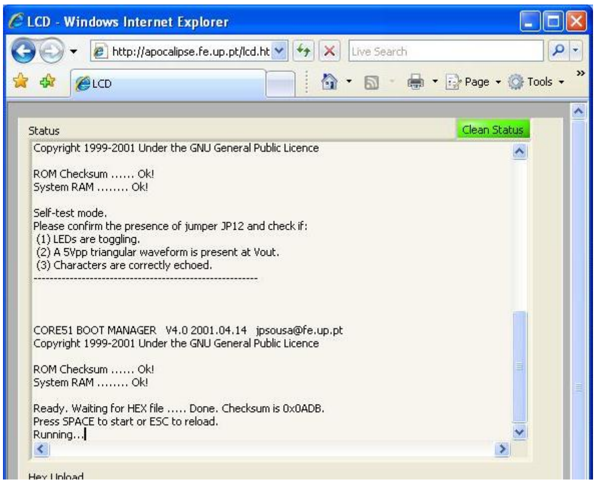


Figure 3 Code upload and execution command

Figure 4 Input / output control and video+chat conferencing

3.2 Teacher training

The Labs-on-the-web workplan recognised the need to offer to the teachers a sound background on pedagogical and technical aspects of on-line labs. A training programme comprising three 5x2h-session training actions was developed to address *Pedagogical principles*, *E-learning via Moodle*, and *On-line labs*. The attendants to each session were proposed homework tasks estimated to require approximately the same time as the in-class presentations. The *Pedagogical principles* and the *E-learning via Moodle* sessions were interleaved, to enable the "practical" application of the "theoretical" concepts presented in the pedagogical presentations. Teacher training took place between February 21st and June 27th 2006, involving a total of 103 teachers, who were allowed to build individual training plans, according to their knowledge profile and application goals. Interviews with the trainers and questionnaires filled by the trainees (teachers) were used to evaluate the teacher training actions. The interviews depict the general belief that the training sessions were important moments of reflection with respect to the teaching practice. This idea is reinforced by analyzing the data in the trainees' questionnaires, which indicates that the trainees indeed believe that the training sessions largely contributed to the reflection about teaching practice and, in some cases, even to its reconfiguration. The trainers considered that the reconfiguration potential was largely dependent upon the trainee's personal appropriation of each session. Therefore, the possible effects of the teacher training plan – in what concerns the reconfiguration of teaching practice – are not always measurable. Nonetheless, the creation of spaces facilitating self and hetero analysis, concerning the potential benefits and weaknesses of virtual learning contexts, is considered essential to engineering teachers.

3.3 Pedagogical evaluation

To evaluate the pedagogic effectiveness of the remote workbench offered within the Microprocessors course, the students were asked to fill a questionnaire at the end of the semester. The grading scale ranged from 1 (low level of agreement) to 7 (high level of agreement), and the items that were presented addressed various aspects dealing with learning in remote contexts. A total of 54 valid questionnaires were received, and the data obtained was inserted and processed with SPSS (Statistical Package for the Social Sciences). The items included in the questionnaire were organised in accordance with the following 4 dimensions:

1. Knowledge and skills (e.g. acquisition of new knowledge; development of ICT skills (Information and Communication Technologies); possible development of new alternatives / solutions).
2. Learning process (e.g. understanding the theoretical concepts underlying the remote experiments and the cause / consequence relationship that explains a given result).
3. Peer cooperation (assessing the importance, the existence and the possibility of collaborative interaction among students).
4. Teacher interaction (which includes items related to the importance of collaborative work between students and teacher and to the availability of the latter).

Table 1 presents the statistical data concerning each of these 4 dimensions and Figure 5 shows the average classifications given by the students.

Table 1 Descriptive statistics

	N	Minimum	Maximum	Average	Std. Deviation
Knowledge and skills	54	1,00	6,33	4,2994	1,18622
Learning process	54	1,00	6,33	4,4864	1,17111
Peer cooperation	54	1,00	7,00	4,2160	1,33358
Teacher interaction	54	1,00	7,00	4,3056	1,48393
Valid N (listwise)	54	1,00			

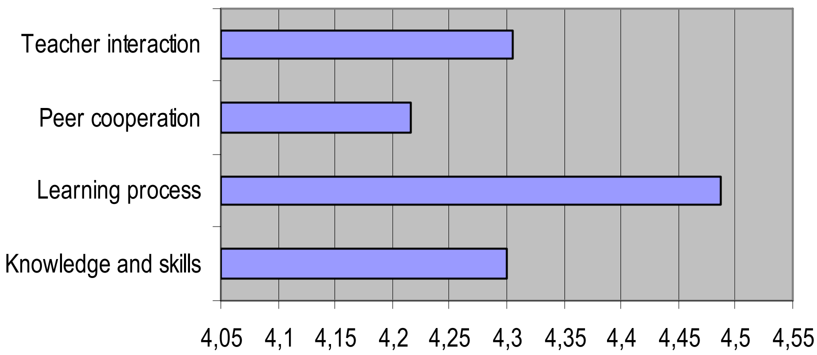


Figure 5 Item grading (average values) after using the remote workbench

Table 2 Correlation data

	knowledge and skills	learning processes	peer cooperation	teacher interaction
Knowledge and skills	1	0,793 (**)	0,388 (**)	0,360 (**)
Learning processes	0,793 (**)	1	0,400 (**)	0,333 (*)
Peer cooperation	0,388 (**)	0,400 (**)	1	0,468 (**)
Teacher interaction	0,360 (**)	0,333 (*)	0,468 (**)	1

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

The data presented shows what might be described as a moderately positive evaluation. It is important to stress that benefits regarding the learning process were the most valued. Additionally, Table 2 also shows that the 4 dimensions are significantly correlated, which means that there is a strong relationship between them. Of particular significance is the very strong association between building knowledge and skills, and the comprehension of the learning process, suggesting that the students who think that remote labs promoted their knowledge and skills, also consider that there are positive effects on understanding the theoretical assumptions; and the fact that collaborative work (between students and between students and teacher) is related both to knowledge and skills, and to learning processes.

4. Conclusions / research directions

The student responses to the questionnaires are moderately positive with respect to all our evaluation dimensions, concerning the remote microprocessor workbench, and support the conclusion that students recognize the pedagogic benefits of the use of remote labs. On the other hand, we also concluded that comprehension of the learning process is an important dimension in the use of remote experiments, which is in itself worth to consider as a pedagogical research direction.

The Labs-on-the-web project has shown that there is still room for improvement, concerning development and usage of remote labs to support practical assignments in engineering courses. Technically speaking, there are various areas where the current generation of remote workbenches is not entirely satisfactory – seamless integration into e-learning platforms, scripting support for teachers, formative assessment features and accessibility are the areas where further work is recognised. Accessibility in particular remains largely unsolved, even in the case of mainstream solutions that are likely across a wide application area [12]. On-line labs are frequently a replica of the corresponding real labs, instead of upgrading that paradigm towards an enhanced educational experience. Embedded formative assessment features is an important research direction with this respect, since the experiment and equipment interface panels may gather data about student skills and make it available both to the students and to their teachers.

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