Distributed Virtual and Remote Labs in Engineering

Michael Auer
Andreas Pester
Carinthia Tech Institute
Europastrasse 4, A-9524 Villach, Austria
[m.auer | a.pester]@cti.ac.at

Doru Ursutiu
Cornel Samoila
University Transylvania
B-dul EROILOR nr.29, RO-2200 Brasov, Romania
[udoru | csam]@unitbv.ro

Abstract– **Laboratories are important elements in science, engineering and technical education. They allow the application and testing of theoretical knowledge in practical learning situations. Experimentation and experience-based learning is also performed in many other subject areas, for example in economics where students lead virtual companies and compete on a simulated market.**

Active learning by means of online laboratories is especially valuable for distance education students and learners in the workplace. They can access the labs without traveling. This flexibility is important for life long learning, because it allows learners in the workplace to fit learning phases into a full work agenda. Using online laboratories has the potential of removing the obstacles of cost, time-inefficient use of facilities, inadequate technical support and limited access to laboratories.

1 Introduction

Laboratories are important elements in science, engineering and technical education. They allow the application and testing of theoretical knowledge in practical learning situations. Active working with experiments and problem solving does help learners to acquire applicable knowledge that can be used in practical situations. That is why courses in the sciences and engineering incorporate laboratory experimentation as an essential part of educating students. Experimentation and experience-based learning is also performed in many other subject areas, for example in economics where students lead virtual companies and compete on a simulated market.

Up to now there is no common characterization of laboratories from an eLearning point of view. There is still some overlapping in the concepts, but we suggest the following characterization of laboratories, where we distinguish between local, remote and virtual laboratories (Figure 1).

The laboratories in the right column we call online laboratories [8]. That means, that the most important mode of use of these laboratories is the online mode via Internet or Intranet. Online labs are software simulations or hardware based experiments in real time at specialized distributed servers. Obviously there is still need of further investigations to have a full characterization and taxonomy of online labs and the learning with such labs.

	Experimenter local	**Experimenter** remote
Experiment real	Traditional Lab	Remote Lab
Experiment virtual	Local Simulation	Virtual Lab

Figure 1: Characterization of labs

Online labs are typically organized in a Client-Server-Architecture [1]. In most cases every experiment needs its own experiment server. If the experiments and its servers of a lab are at different locations, so we call it a distributed lab.

Furthermore there are different levels of the distribution of work between servers and clients (Figure 2).

Factors, which influence these distributions are e.g.: performance of the clients and the servers, bandwidth between servers and clients, license policy, administrative needs a.o.

	Server or Server-Cluster	Client	Comments
Level 1	content	Web-Browser, application	slightly flexible, costly administration
Level 2	content, part of the application, e.g. simulator	Web-Browser, part of the application, e.g. schematic entry	licenses, performance of the computers
Level 3	content, full application	Web-Browser	highly flexible, central administration

Figure 2: Distribution of work between server and client

2 Learning in Lab Environments

Dealing with learning in laboratories, using real-time experiments and/or interactive simulations, it is necessary to determine the additional values of online laboratories for cognition and learning. Also we had to show, where are drawbacks of this approach for learners.
In an ideal learning environment for laboratories there is a mix of several learning elements and strategies.

1. Repetition of theoretical knowledge which the experimenter needs for understanding and designing his experiment.
2. Application of theoretical models and concepts to a practical situation, in which the experimenter proofs the validity and limits of the theoretical (as usual mathematical) model.
3. Training of practical (technical) skills composing the needed elements and instruments for the experiment, working with measuring, testing and control instruments and also with laboratory software.
4. Training of practical social and communication skills, because experiments as usual are done in teams.
5. Critical reflection about the results of the experiment, the used model and methods (error calculation, precision of measurements etc.)
6. Last but not least the learning process in laboratory situations also includes the training of writing skills (technical writing and documentation). This is a good occasion to train in a complex situation logical reasoning, exact expression and language skills.

So the learning situation in laboratories is highly complex, but also well structured. The learning methods, usually used in this situations, depend on the situation, but in 1., 5. and 6. self-directed learning prevails, in the other points it is a mix of self-directed and collaborative learning.

This situation is well known in local laboratories and their learning environments. The question is, if we design online laboratories, are there some additional learning values, we get and are there may be also some drawbacks for the learning process.

3 Learning in Online Lab Environments

A theoretical framework for learning in online lab environments could be taken from the theory of action learning and action research (experiential learning). [9] However, these theories were constructed for learning in and with "social" environments. In the case of online labs, we have to deal with the hard facts of nature as usual. Nevertheless, the experiential learning cycle (action → reflection → action) [10] is also important for online lab learning. But the result is not a plan for changing the behavior or the organization, but the enhancing and deepening of the understanding of nature and technical artifacts (setting on our prior understanding). Further investigations about the best way to implement the structure of action learning and open learning environments in online lab education are needed.

Other approaches like self-directed and collaborative learning are discussed in [5] and [11]. They have a strong connection to the open learning environments, we found in online lab learning, but these approaches do not strongly reflect the experiential "side" of learning in online lab environments. A developer of online labs needs here the help of learning theory to get a systematic approach to learning in online lab environments.

Our experience in designing and using distributed virtual and remote laboratories shows, that some aspects of the described above ideal laboratory learning situation are more emphasized others are weaker.

For the repetition of theoretical knowledge the learner needs well-trained skills in self-directed and sometimes also in collaborative learning. The author and instructors need skills in precise and short expression of the theoretical material. The point in this situation is, that many communication channels we have in an face to face (f2f) situation, fail. There are only text, graphic and interactive tests. As usual there is no direct possibility to query the instructor in cases when the learner didn't understand the material or the test questions well. Exact descriptions, interactive group and individual tests and a strict moral imperative of honesty (no cheating) can solve these problems.

The learning possibilities in Point 2 are in an online situation broader, because the student can repeat his simulations or experiments with rather parameter values several times. What he need is a plan for testing the experiment under several conditions. This is because he is online and his access time could be limited. But he can work in the lab 24 hours a day and seven day a week, so the opportunity to get access is higher as in the case of local labs. The prerequisites he needs for this are only a web browser and access slot, which he gets from a brokerage software. By working in a distributed lab environment he can also use experiments from other universities, which he never will find in his home university. But one problem arises in the online mode. Up to now the influence of the experimenter of the experiment set up is restricted. In a local situation as usual he had to compose the experiment by a given plan or by his own plan. In online situations the experiments and simulations are as usual predefined and the variability is limited. This means with respect to learning, that his meta-cognition in this situation is not so well trained as his special knowledge and skills. This is a restriction to the learning process.

In the case of online laboratories we have a lack in training the practical skills of composing an experiment. Naturally there is no access to the real equipment. Only in the case of remote robot control this could be a part of the learning process, but this is not the common situation. In virtual labs there is no access to real equipment at all and in remote labs only in the case described above. In the best case the experimenter can program his own simulation and test it in a remote mode. We realized such a situation for electronics with the VELO project.

In the case of a remote lab most of the processes are automatic and a training of practical skills is limited to the measurement and may be testing and control procedures. May be in the future a lab robot can help.

On the other side, the communication skills and the skills in collaborative learning are better trained in an online lab situation. The splitting of the communication channels in such a complex situation stresses a learning process to handle this communication lack in one or more direction emphasizing the communication with the team-partners over other channels. Designing online experiments, the developer has to model these situations, because the capabilities for collaborative learning, teamwork in a teleworking situation had to be trained additionally. But the situation is as usual well structured and it is not expected too much to the learners.

In the other points we don't see any additional values for learning with distributed online laboratories.

We elaborated online labs in two projects – VELO and REL.

4 The VELO Environment as a Realization of a Virtual Lab

With the "Virtual Electronic Laboratory" (VELO) the possibility to accomplish laboratory work independently of time and place is given. This is done on the basis of multimedially prepared lecture/exercise modules and simulation tools. With the help of an evaluation tool a direct feedback (formative, summative) over success in learning is given.
Together with other partners Carinthia Tech Institute implemented the project VELO. The binding of various tools for simulation is made by Web interfaces [2].
Some simulators (for example MATLAB) have already a Web interface. So it is easy to use it in the lab configuration [7]. One of this simulation screens you can see in 5 .
For others, like ORCAD, with the help of the Citrix Application Server [4]. This solution is applicable for all Windows based simulators and programs.

In VELO the tools MATLAB, ORCAD and PAC-Designer are supported at present.

All experiment descriptions, tasks and background materials are presented as HTML documents. Thus at the client side (student, user) only a standard web browser is needed.

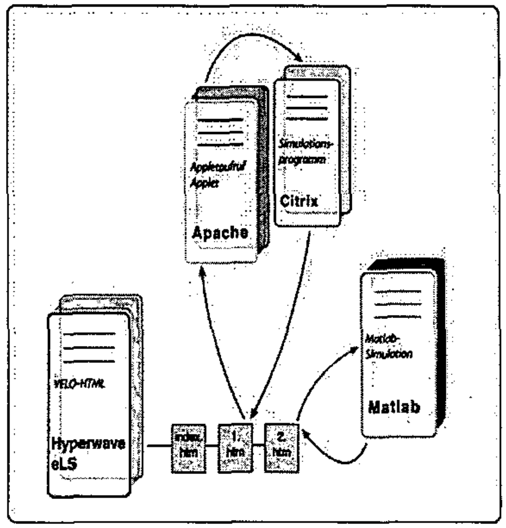

Figure 3: Binding of simulators in the project VELO

Part of the virtual lab is furthermore a new Web-based evaluation tool. It supports both the tutors preparation and the implementation of the evaluation with the students . The following queries are possible: multiple choice (text and graphics), value, keywords. It is possible to define query-pools and to compose tests from this pools. The test results are graded automatically by a 2-, 5- or 6-grade system (to be chosen by the test author). Former tests can be reread by the student.
To give the possibility to use the tool also in other applications, user interface, data storage and Web page design are strictly separated. The system supports different tracking functions.
The great advantage for the student with the use of the online laboratory is, that he can use it independently from place and time. Such courses are distributed via the Internet or CD (Web-based leaning, Computer-based learning).
The problem for the lecturers is, that they now are authors of eLearning material. But the design and scripting of so-called eLearning courses is very complicated work.

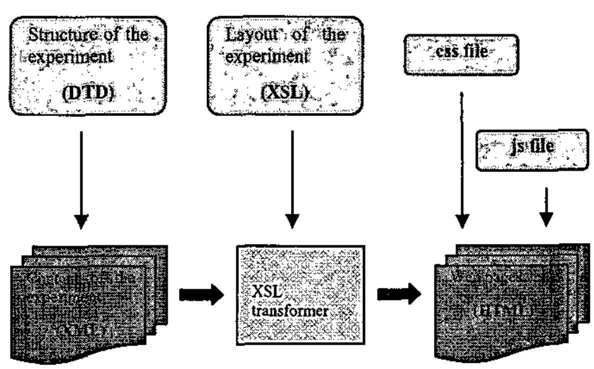

Figure 4: Transformation of a XML document

Furthermore different document formats needed, the eLearning material is interactive (simulations) and special knowledge for example in html programming is necessary.

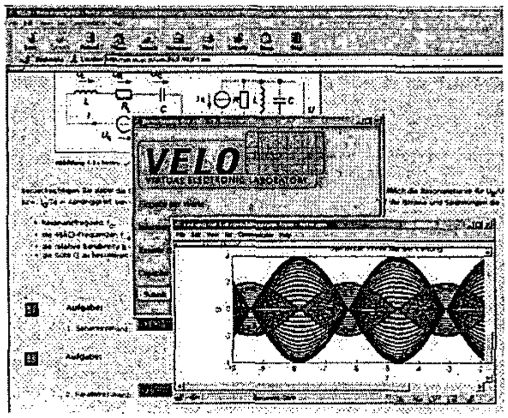

Figure 5: Simulation within the Virtual Lab VELO

So it is a hard job for a lecturer to design his lab work as an electronic one. In this context it is a good idea to use XML (Extensible Markup Language). So, all documents of the VELO project are written in XML. In this way it is possible to generate different output formats from the same (content) source [3]. Such output formats are for example HTML, PDF, WML, WAV a.o. This approach allows to organize a modularized and standardized workflow for the design of the documents, tests and links to simulation servers and remote experiments under a unique interface.

5 The REL Environment as a Realization of a Remote Lab

The Remote Electronic Lab (REL) is a system for carrying out electronic experiments via the Internet in the context of distance education. It is based on remote control of real laboratory instruments and not on simulation. Minimization of the effort of administration and software needs at the client side are required. Therefore HTML-files with embedded ActiveX-controls in a common Internet browser are used exclusively as a user interface. For the server-side control of the instruments LabVIEW is used. The communication between LabVIEW as a "server" and ActiveX-Controls as a "client" is carried out via ComponentWorks DataSocket.

During the preparative phase of the project, some basic requirements arose:

- An integration of the project in the existing as well as other systems should be achieved. This means that a standard internet browser has to be the interface to the user.
- No additional applications should be required for the user, in order to minimize the administrative needs at the client side.

The REL-server is a PC with a GPIB interface. A power supply, a function generator, a digital multi meter (DMM), and a oscilloscope are connected to it. 6 shows the REL-Server configuration.

The essential software running on this computer is LabVIEW 5.1. The instruments are controlled by means of LabVIEW-GPIB-drivers.

The necessary parameters and the gained measurements have to be exchanged between user and server to enable remote control. The new DataSocket technology is suitable for that demand.

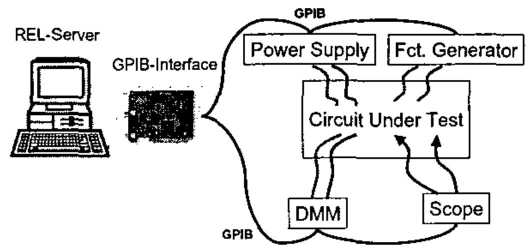

Figure 6: Schematic of Remote Lab

For coordinating the exchange of data, a LabVIEW-VI (Virtual Instrument) has been developed. The instrument-drivers are integrated as sub-VIs.

The interface to the user at a remote computer are ActiveX-controls. ComponetWorks offers a number of ActiveX-components having a similar appearance as controls and indicators in LabVIEW-front panels. Finally these controls are embedded in HTML-files and displayed in MS Internet Explorer 5.

On loading the ActiveX-controls at the client-computer, they connect to the DataSocket-Server, if no other user is currently online. Now the student may set some parameters for the instruments and click "Enter" in order to transmit the information to the DataSocket-Server from where the REL-Server can call it.

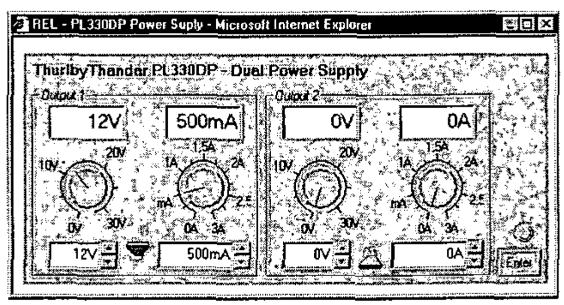

Figure 7: User interface "Power Supply"

The REL-Server checks the DataSocket for updates continuously. If any connected client-control has put new data on it, it is read and the appropriate instrument-driver is activated. After having finished controlling the instrument, a sort of confirmation is given back to the DataSocket. In case of a measuring instrument, the measurements are put on it. Then the client recognizes an update and calls the available information from the DataSocket-Server. This information can be a certain number of single values or, in case of an oscilloscope, a vector with 2000 values. Now the ActiveX-control displays the data either as numeric values or as a graph in the appropriate indicator.

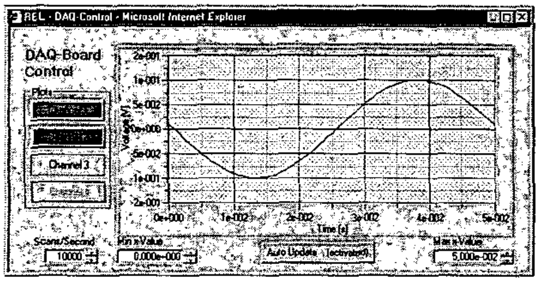

Figure 8: User interface "DAQ-Board"

In Figure 7 you can see the power supply control of the experiments and in 8 the output signal waveform.

Remote Electronic Lab already offers a quite interesting substitution for local experiments. Beside from distance education it is obvious that it can be used in any other field of application too. REL lab exercises are available from Carinthia Tech Institute and University Transylvania Brasov as so-called distributed lab.

6 What did we learn from VELO and REL

First of all we found out, that there is a very strong connection between the concept of learning and the technical realization of online labs. It is not possible to separate this parts one from each other. It is not possible to say, the pedagogical part is more important than the technical or vice versa. The success of online labs as advanced eLearning solutions depends directly this understanding.

Our experience shows that the following parts of lab work can be better learned in an online environment:

1. Structuring the situation, how to provide the experiment, because its better for the learner in advance to plan his approach
2. Collaborative learning and team work skills in remote labs with group work

The practical skills of composing an experiment, providing measurements etc. are still better trained and learned in local labs. But this can be done in basic lab units and is independent from special experiments.

In the part reflection and documentation of the experiment results the meta-cognition should be strengthened and had to be a part of the written report. This is because this reasoning doesn't be an outcome in a natural way and this kind of reasoning hat to be learned in a discussion with some instructor.

From the technical point of view it is very important consequently to separate the experiment from the so called environment. This means it is necessary to develop and to use standard tools for the online lab development. So the lab user has only to master his own hard- and software and not some sophisticated network products. Only in this case online labs will be used by a greater number of lecturers. VELO as well as REL are examples for the design of such standard environments.

The development costs and time for online labs are very high. No university and no enterprise can solve this problem alone in a proper way. This is one of the reasons to develop distributed online lab solutions. To connect them, an intelligent brokerage interface will be used. And again the success of this work depends from a broad common understanding of the learning and cognition processes in experimental situations.
By the way: This type of "online engineering work" will become more and more typical not only in learning but also in industrial environments.

- Expensive and complex instruments can be used from different locations of a company.
- Complex experimental systems, including specific media addition such as cooling, inert gas maintained by specialist staff at a specific location, can be directly controlled from the scientists office.
- Team members, working at different locations can take advantage of the same test-run results without extra travelling.
- Long-term trials (reliability, failure performance) can be comfortably supervised from home, e.g. at weekends.

So the presented solutions in this paper are part of new area of engineering work, the so-called "Remote Engineering"

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