Luís Gomes and Javier García-Zubía (eds.)

# Advances on remote laboratories and e-learning experiences

WHAT IS ADDED VALUE OF
REMOTE EXPERIMENTATION TO EDUCATION?

$\boxed{\text{GUSTAVO'S THEOREM}}$

EDUCATIONAL VALUE ↑ → { Groupwork with foreign students; Share good pedagogical practices }
– COSTS ↓ → { Share experiments; Reuse software }

ADDED VALUE ⇑

q.e.d.

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The cover has been designed using an idea of Gustavo R. Alves, who presented it in the ETFA 2005 conference in Catania (Italy).


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# Contents

# Preface

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Nowadays, computers and consumer electronics are present in an increasing number of our daily activities. This is due to sustained decreasing on costs and sustained increasing on performance. According with Moore's law, the computational resources per unit of area have been doubled every eighteen months during the last decades. In this sense, it has been possible to have "more for less". Also the role of computers has been changing, from the "central computer" concept to the current "networked computers" attitude where the Internet and the World Wide Web allows the effective support for collaborative work, even at different locations. So, from the "old days", where the computer was seen as a number-crunching machine and batch processing was the regular procedure, we come to current situation where computers and electronic systems are used everywhere, real-time operation is possible and the availability of on-demand on-line services is a reality.

Currently, most universities have e-learning environments ready to be remotely accessed through the web. On the other hand, also many industries make similar usage of the web for supporting their products and services.

Coming to engineering education activities, the role of experimentation is a key concept. However, physical experimentation is most of the times expensive, hard to maintain, and need in most of the cases a specific guidance through the experiment in order to avoid malfunctions or injuries to the operator. That could lead to an increasing usage of simulators within engineering teaching activities. This attitude is supported by the belief that simulators can replace physical experimentation. However, even true for specific topics, physical experiments are mandatory for most of engineering education areas in order to allow students to fully understand the physical laws and/or to get acquainted with design procedures. In this sense, due to different constraints and goals, physical experimentation and simulation can both contribute within engineering education and can both be integrated within the same computer-based environment, the e-learning platform. Also computer-aided guidance to conduct the experiment can be provided by the e-learning platform in order to avoid malfunctions and injuries.

Remote laboratories (also know under different aliases) can provide remote access to experiments (and to simulators as well), and can allow students to access experiments without time and location restrictions, providing the necessary guidance and constraining operation in order to avoid dangerous situations (both from the set-up integrity and from the user's point of view).

Having the remote experiments ready all the time, the remote laboratory concept also provides a tool to sustain the shift towards a student-centric teaching approach, which is more and more relevant in higher level education, nowadays.

This book provides a comprehensive overview on several aspects of remote laboratories development and usage, and their potential impact in the teaching and learning processes using selected e-learning experiences.

The book is based on the presentations and discussions carried out at "International Meeting on Professional Remote Laboratories", which took place in University of Deusto, Bilbao, in the period of November 16-17, 2006. Apart from chapters based on the presentations, some others have also been included in this book. In this way, we hope to give a broad, well balanced and up-to-date picture of the current status of remote labs and their role within the e-learning paradigm. http://weblab.deusto.es

The book is divided into five sections, covering the above mentioned aspects. Section I, "Remote labs: past and future", includes two chapters providing a survey on remote labs and a comprehensive discussion on collaborative remote labs. Section II, addressing "Remote labs impact within the learning process", contains two chapters, while Section III, devoted to "Remote labs development issues", addresses specific issues on the development of remote labs, and contains three chapters. "Remote labs in use" is the subject of the four chapters of Section IV, while Section V concludes with three chapters devoted to "New challenges".

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Many thanks to University of Deusto publishing services for efficient handling of this book. Last but not least, we would like to thank the Institute

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# SECTION I

# Remote labs: past and future

# Large and small scale networks of remote labs: a survey

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**Abstract**

*The advantages of networking are widely known in many areas, i.e. from business to personal areas. One particular area where networks have also proved their benefits is education. Taking the Higher Education level into consideration, it is easy to find many successful and fruitful examples of networks both in the long and short past. More recently, the advent and wide use of the Internet has brought an all new range of opportunities to sustain and expand existing networks and also to create new ones. We consider the boom effect the Internet had on educational networks, and the emergence of a new educational resource known as remote experimentation to explain the recent appearance of a new type of network, i.e. remote experimentation networks. After introducing the basic building blocks for this network type, we describe how small- and large-scale networks of remote labs have been forming actively, since the last decade, and present some illustrative examples. In the conclusion we consider new directions for these networks.*

## Introduction

Education in science and engineering requires practical experimentation. While this has been carried out in laboratory or in the field for ages, the use of computers has recently introduced two new approaches based on simulated laboratories and remote laboratories. A simulated laboratory corresponds to one or more computer applications providing a graphical representation of both the instruments and objects under experimentation, and returning results according to a model description of the behaviour and interaction of those elements. A remote laboratory corresponds to the situation where the control & observation of the physical instruments and objects under experimentation is mediated through a computer and adequate remote access to that computer is provided through a specific communication network. In a recent comparative literature survey on hands-on, simulated and remote laboratories, carried out through a web search in three electronic databases (IEEE, ACM, and ScienceDirect) and several educational journals, Ma and Nickerson [1] were able to identify over 1000 articles related to this issue, with a majority addressing technical implementation aspects. From this initial set, Ma and Nickerson extracted around 170 references that provide a good background reading for understanding the educational value of hands-on, virtual, and remote labs. In a second refinement, 60 articles were selected (20 on each category) for full-text review and coding, and for initially observing that "*most of the laboratories discussed fall into the engineering domain*", "*there is no standard criteria to evaluate the effectiveness of labwork*"; and "*there are advocates and detractors for each lab type*". They then discuss: "*the relative educational value of each category; the fact that even hands-on are becoming increasingly mediated, in addition to that of simulated and remote experiments, which are always computer-mediated; how each category relates to the real world and how belief may be more important than technology in understating that link; and finally how collaboration methods may interact with the lab technology type*." The authors present their findings on the previous topics and suggest, as a conclusion, that there is room for more research, namely on the combination of the three lab types and on the interactions that lead students to a sense of immersion.

At this moment, Institutions of Higher Education (IHE) are using one, two, or the three laboratory types, either in an isolated way or in combination, to improve students performance and to reduce operational costs. Given the cost factor associated with each lab type, it is easy to perceive that trying out combinations requires a huge investment of both manpower and equipment. We also note that the problem of creating a sense of immersion (common to the three lab types) has not been entirely solved. An abstract view of this panorama allows us to identify two major factors that lead to collaboration among IHEs, as suggested by Reid [2]:

1. sharing of developmental costs; - this can be in the form of material, licences, systems, staff, developmental or management costs;
2. increased range of skills and of curriculum arising from the various strengths of the different partners, and hence an increase in the quality of provision.

Sometimes these collaborative actions assume a formal aspect in the form of a *network*, and in that sense, if virtual and remote labs are in the basis of such collaboration, one may speak about networks of virtual and remote labs. While it is possible to address the two network types (or one, if combined), we will only consider the second one (networks of remote labs) because:

— Ultimately, as virtual labs are based on software, they can be replicated and installed at almost no cost, if allowed by its owner. This is not the case with remote labs as equipment is involved and therefore its acquisition cost must always be considered.
— Very often the virtual lab acts as an antechamber to the remote lab, allowing the student to practice his/her skills on a safe environment and then, when confident enough, try out the same actions on real equipment and/or devices. Bruns and Erbe, and Noguez and Sucar, provide two very good examples of such combination in [3,4] and [5,6], respectively.

This chapter addresses the formation of networks of remote labs and its added value to education. It starts by identifying several educational networks and the boom effect the Internet had, in such a way that it is possible to distinguish two time periods, i.e. the pre- and post-Web periods, as indicated in section 2. Section 3 presents the building blocks for a remote experimentation (RE) network, which allows to distinguish regional and national networks of remote labs, described in section 4, from continental and intercontinental networks, described in section 5. Finally, section 6 concludes the chapter with the final remarks and some future directions.

## 1. **Educational networks: the e-boom**

There are two types of educational networks: horizontal and vertical. These two types are sometimes combined to form a third one that covers the two dimensions. Horizontal networks include institutions providing education at the same level, e.g. high school level or university level. Vertical networks include institutions providing education at different levels. Furthermore, networks may be classified according to their area of influence, i.e. they may be local, regional, state, national, continental, or inter-continental networks. The driving forces for setting up an educational network are multiple and diverse, therefore the following list is only tentative:

- — Financial – share a certain needed service or equipment.
- — Political / strategic – co-operate with other institutions to increase the educational process quality, by sharing good pedagogical practices, student and teacher mobility, information on funding opportunities that call for consortium proposals, etc.
- — Administrative – e.g. the body ruling a set of institutions grouped under a regional area may create a network where students that enter one particular institution, when moving up in their education, are first selected from other institutions belonging to the same network.
- — Emotional – apart from the previous rational reasons, the decision to form a network may be based on emotional ones, where the persons responsible for the institutions decide to form a network so as to maintain close relational links, building upon their own personal links[1].

A network necessarily entails communication channels to allow for collaborative work and information dissemination among its members. In that sense, the quantity and quality of the available communication channels influences the number and dimension of existing networks. Building upon this rationale, it is important to consider the most important milestones in communication to evaluate their impact on networks. Leiner *et al*. [7] refer the ‘telegraph’, ‘telephone’, ‘radio’ and the ‘Internet’ (for connecting computers) as important milestones in communications[2].

> *“The Internet has revolutionized the computer and communications world like nothing before. The invention of the telegraph, telephone, radio, and computer set the stage for this unprecedented integration of capabilities. The Internet is at once a world-wide broadcasting capability, a mechanism for information dissemination, and a medium for collaboration and interaction between individuals and their computers without regard for geographic location.”*

Considering the scope of this chapter, where computers are omnipresent, we will focus on the Internet appearance and evolution, as depicted in figure 1 ([7]). The Internet, in itself, has appeared in the earlies 70’s (20$^{th}$ century) connecting a few computers, at start. Given the fact this

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[1] In all cases, it is difficult to trace apart these reasons, as any document will only refer objective and rational reasons.

[2] Although the television may be considered as another important milestone, we are assuming a bidirectional communication channel and in that sense we (and presumably Leiner *et al*. [7]) excluded it from this list.

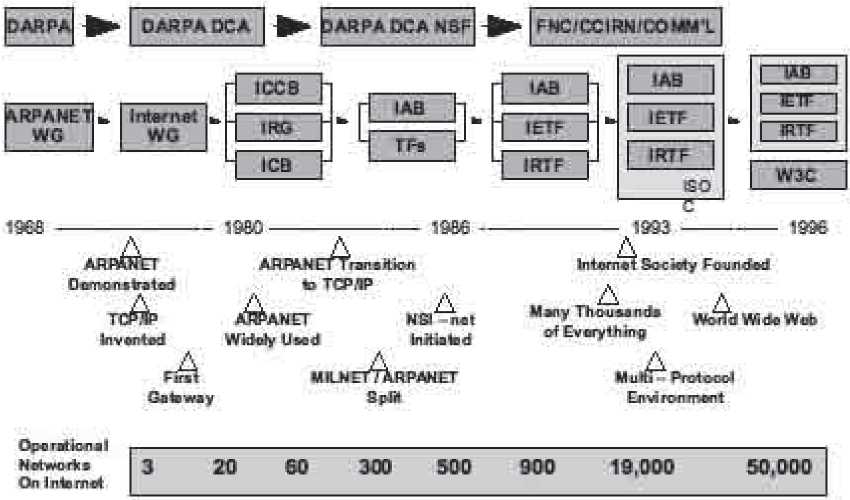


**Figure 1**

Internet appearance and evolution in time

was a highly technological achievement, only a few institutions (and staff members) were benefiting from it, at that time. Adding the existence of few tools and standards and the need for technical formation, the impact of the Internet was to remain confined to a rather small community until the emergence of the World-Wide Web (WWW), in the early-mid 90's ($20^{th}$ century), as defended by Segal in [8]. It is precisely the appearance of the WWW[3] that brought this technology to the mouth of the common citizen and to the everyday language. With this in mind, we describe the overall panorama of educational networks in two distinct sub-sections: one referring to the period before the appearance of the WWW and one referring to the period after.

## 1.1. *The pre-Web period*

Leiner *et al*. trace "*the first recorded description of the social interactions that could be enabled through networking*" to "*a series of memos written by J.C.R. Licklider of MIT in August 1962 discussing his* 'Galactic Network' *concept*" [7]. A lot of collaboration then followed in North America

[3] Associated with the widespread use of PCs and the appearance of web browsers and simple web authoring tools.

to develop the ARPANET, with some IHEs being involved in the process. As knowledge arises from Research & Development (R&D), the findings associated with computer networking were among the first educational contents to be shared among those IHEs, in a new type of educational network. By that time, Europe was still lagging behind in computer networking, with CERN being the first European institution to be involved in the process, as exposed by Segal in [8]. It was through CERN that Europe first connected to North America, creating the first intercontinental computer network. It was also at CERN that Tim Berners-Lee developed and installed the first web-server in 1991. By that year, Aburdene *et al*. envisaged "*laboratory experiments being operated remotely and shared among universities*" [9], although at the same time there were already on-going discussions at the U.S. about a network of collaborating laboratories. This idea, coined as "collaboratories", was initially presented in 1989 and can actually be seen as the first national network of remote labs, in the broader sense [10,11]. But it was not until 1993, when CERN decided to freely open the WWW to anyone, that *all* IHEs had the opportunity to share knowledge and start working together, without restrictions, in a collaborative way, through the Internet. With a wider dissemination of tools, equipment, and concepts, there was a considerable boom in the formation of educational networks, in general, and RE networks, in particular, as described in the following subsection.

### 1.2. *The post-Web period*

Figure 1 illustrates the explosion in the number of operational networks in the Internet, just before 1993. The following years witnessed a considerable growth in activities related to using the web for supporting education, in general, and also experimentation, in particular. Large educational networks started being formed, and activity grew even more with public funds being injected in massive quantities. The following bullet points contain a few illustrative examples:

- European Schoolnet [12] – a network of 28 Ministries of Education across Europe – that also operates the Xplora portal dedicated to science education, in particular [13]. The Xplora portal is supported by the PENCIL project, which is funded by the European Commission's Directorate General (EC-DG) for Research. The PENCIL project is part of the wider Nucleus framework, a cluster of science education projects including Europe's major research laboratories. The EC-DG for Education and Culture supports another large portal dedicated to e-learning [14], and also several projects dealing with RE, run by large consortia, through the Socrates and Leonardo da Vinci programmes. Some of these projects will later be described in section 5.

— PROLEARN [15] – a 'Network of Excellence' (NoE), financed by the EC Information Society Technology (IST) programme, dealing with technology enhanced professional learning. This NoE includes a workpackage dedicated to online experiments, again described in more detail in section 5. The IST programme has also financed several other projects dealing with educational networks, e.g. the K2 project devoted to European E-Learning Networks and Observatories [16].
— The MIT OpenCourseWare (OCW) and iLab initiatives [17, 18, 19]. The OCW is a database with more than 1,100 online courses available to the overall educational community, which was developed in 2001, with an initial funding of US $11 million. According to Wasserstein, OCW users are now spread by more than 215 countries, with more than 31,000 people subscribing the monthly update newsletter [19]. The MIT iLab is also a world reference in terms of remote labs and thus will be described in more detail in section 5.

Noticeably, these are a few examples from the all universe returned by a simple web search. Using, for instance, the expression "education network" on a web search with Google® we obtain almost 1 million hits. By applying appropriated filter terms and expressions (e.g. "universities" or "higher education"), it would be possible to narrow down the obtained search results, although it is obvious that a thorough analysis would be quite time consuming and yet would only be based on information available in electronic format. The central point of this section is that educational networks are breading spaces for other types of collaboration, namely for sharing resources related to practical experimentation, particularly in science and engineering fields. As in many other domains, the route to establish such a network may actually come from an initial collaboration in developing something (engineers are particularly keen in building up things, i.e. they enjoy it) and then formalising that relation by forming the network. In this way, one may think of two distinct, yet combinable, approaches to create networks of remote labs: bottom-up, i.e. technology driven, and top-down, i.e. educationally driven. In the first case, collaboration may come from the need to connect different technologies, solve remote control problems, among other reasons [20, 21]. In the second case, collaboration may come from the need to develop practical experiments to support science & engineering related contents, available through e-learning systems [22, 23]. With these two approaches in mind we will describe in the following section the building blocks for a RE network.

## 2. Building blocks of a RE network

Irrespectively of its dimension, a RE network contains a discrete number of basic building blocks. Figure 2 illustrates a general architecture indicated by Schmid in [24], which includes the following ones:

— An experiment or instrumentation server – this connects directly to the experimental apparatus either through an Ethernet port (in which case one may consider an Intranet) or through other computer communication ports. If there are several remote experiments available at the same time, from one single place, then one may speak of a remote lab, in which case it may contain several experiment servers, or, more recently, several micro web servers, which reduces the overall costs [25].

— A media server – this provides audio and video feedback from the remote experiment. Sometimes this is not present as the remote experiment may not imply such a feedback, e.g. a purely electronic experience in which the inputs and outputs are electrical signals. The experimentation server may also accumulate this function, but this option is avoided in most situations due to performance penalties, which also suggest placing the collaborative tools on a different server. An aspect not depicted in figure 2 is the presence of a lab tutor, which may be in another location. This is another potential collaborative aspect in a network of remote labs, where one institution (not having a single remote experiment) may contribute with manpower in the form of a lab tutor, or more recently with the development and provision of an intelligent tutor system [26].

— A web server – this contains all the information the student (or any other user) needs for running the experiment. It also provides the situated learning environment that places the remote experiment within a certain theoretical background.

— An access server – this prevents unauthorized users from accessing the remote experiment, by requiring a login and a password. It may also contain a booking system that allows managing the access from various students. Although it may be implemented on a different server, there are examples of installing the booking system on the web server. For instance, Ferreira and Cardoso have developed a booking system that may be attached to the Moodle Learning Management System (LMS) and that is available as shareware [27].

— A provider server – this acts as the portal providing access to a pool of remote experiments supplied from different Institutions. It is the front page of what can be a small or large network of remote labs.

— The user clients – these can either be students, running the remote experiments so as to do the practical work associated with a given theoretical content, or lecturers, using the remote experiment within a certain lesson to stress the practical effect of a taught theory or formula.

The building blocks depicted in figure 2 can be spread by many IHEs, with the possibility of some being replicated, namely the experiment server, as a network may share more than a single remote experiment.

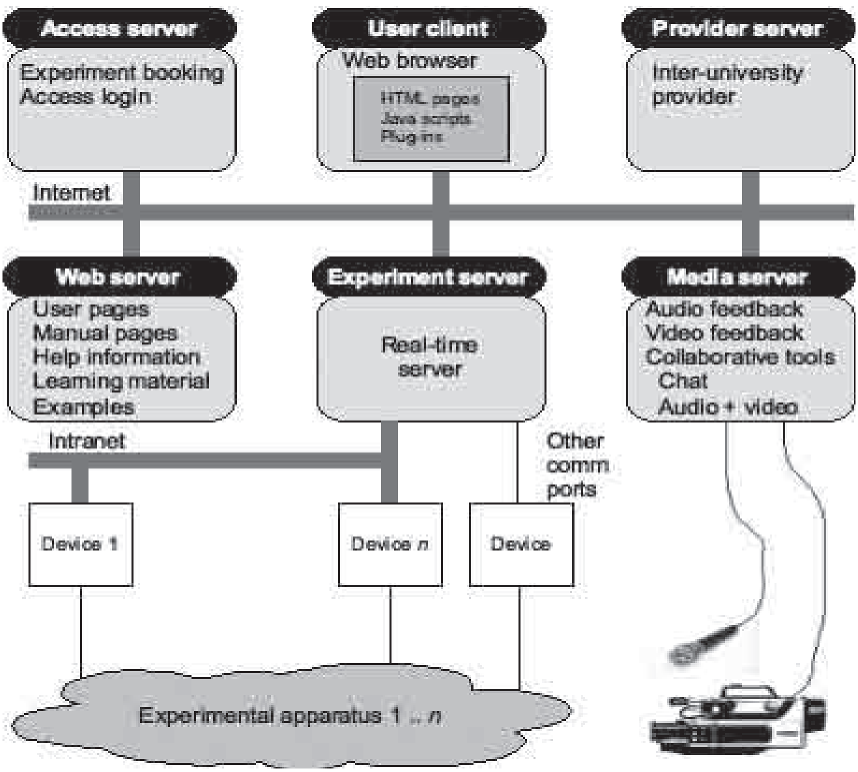


**Figure 2**

General architecture of a remote lab (network)

The existence of a provider server (1), the number of available experiments (2), and the number of user clients (3) could be part of the criteria to distinguish “large” from “small” networks of remote labs. While the first two elements are easily recognisable and measurable from the outside, the third one is somewhat more difficult to control or measure. Even if the network defines an initial target audience, including its size, it is not clear if all potential clients will actually use the resource, the point being that usage is a very dynamic parameter. Another problem is that sometimes it is difficult to trace apart who provides what in a network. Therefore, and although we have used the title "large and small networks of remote labs" for this chapter, we decided to distinguish regional and national networks from continental and inter-continental ones, in the two following sections, the reason being precisely the facility to catalogue them according to this criterion, from the information that is usually available in electronic format. An inevitable criticism is that it is difficult to compare networks of remote labs established in one country such as the U.S. from another one established in, for instance, Germany, given the significant differences in area and population. Notice that in both cases we will be referring to a national network of remote labs, as all nodes pertain to a single country, even though it may have a continental dimension.

## 3. **Regional and national networks of remote labs**

While it is easier to identify regional and national networks of remote labs when the interfaces and contents are written in English (or in any other language familiar to the authors), there are many networks of this type that use the native language of the region or country they are implemented in. Very often, this happens when:

- the institutions or groups owning the remote labs received funds from state or national funding agencies, and internationalisation is not a key factor;
- the resources are to be made available to students who are not fluent on a foreign language;
- there is an intention to preserve resources available on the web from a wider (ab)use.

Apart from political or strategic reasons, there are presently few arguments to sustain the decision of restricting the use of one web-based educational resource, like a remote lab, to a single region or country. Even if initially built with no internationalization requirements, it would take one single remote lab from a certain regional or national network to enter into a continental or intercontinental network to blur the initial definition. At this point it is easy to accept that remote labs developed in English-speaking countries will have an higher potential degree of internationalization, with less development costs, as the local students will already be able to use them and also adhere to groupwork with other English-speaking foreign students, willing to practice their social skills in a wider context. In the following paragraphs we provide three illustrative examples: an U.S. regional network, a German regional network, and a Brazilian regional network. To finish the section, we refer the U.S. National Collaboratories system [10], which corresponds to one of the largest national networks of remote labs.

— The Interactive Nano-Visualization in Science and Engineering Education (IN-VSEE) project is run by a consortium of institutions belonging to different states in North America [28,29]. IN-VSEE has made available through the Internet a set of Scanning Probe Microscopy experiments, with image broadcasting and control of the instrument on a real-time basis, for supprting the teaching of nano-science and technology concepts in upper-division high school classes and lower-division college lectures. The project was funded by the Applications of Advanced Technologies Programme of the American National Science Foundation. An interesting note about this project is that it makes available, on a remote fashion, a technique that was awarded the 1986 Nobel prize in Physics, on the persons of its co-inventors, Heinrich Rohrer and Gerd Binnig, together with Ernst Ruska. Noticeably, H. Roher is actually a member of the External Advisory Board associated with this project.
— Learnet and Controlnet24 are two German regional networks of remote labs on the subject of control engineering [30,31]. Most of the remote experiments made available inside the consortium were the result of pioneer work and were developed for a closed user community, because of safety issues. The websites of both networks are written in German, and so little information can be extracted from there by those who are not knowledgeable on that language. However, one of the partners, C. Schmid [24] from the Ruhr-Universität Bochum, later integrated a wider European network, named ReLAX (described in more detail in the next section) and thus it was possible to track down his former work at national level, within the Learnet project. This note corroborates the previous assertion that it takes one single remote lab from a certain regional or national network to enter into a continental or intercontinental network to blur the differences between these dimensions, even if that particular remote lab may have initially been built with no internationalization requirements.
— The Remote Experimentation Laboratories (RexLab) of the Federal University of Santa Catarina (UFSC) and of the University of South-

ern Santa Catarina (UNISUL) are two core nodes of a Brazilian regional network of remote labs in the area of microcontroller-based applications [32,33]. Again, the websites of both remote labs are not in English (i.e. they are in Portuguese) but this fact has not prevented the two labs to join, in 2004, a larger, intercontinental network of remote labs named RexNet, which will also be described in more detail in the next section.

The U.S. National Collaboratories system provides the basis for intensive collaborative work among many American IHEs, in many different scientific and engineering areas. Its implementation by the U.S. Department of Energy is one of the best documented ones and includes many success stories, available at the corresponding website [34]. We decided to reproduce here one of those stories just to stress the point of how personal relations may establish unsuspected collaborative directions for a particular remote lab (see 1st footnote).

> *"One of the members of the Materials Microcharacterization Collaboratory (MMC), Edgar Voelkl, visited his hometown of Regensburg, Germany, to attend a conference a couple of years ago. The conference organizer became quite excited when Edgar suggested operating his U.S. based electron microscope remotely during the program. Edgar encountered a lot of skepticism, but he didn't let that influence his plans. The local newspaper announced the remote operation as one of two highlights of the upcoming meeting: 'World premier at the University: A highly sophisticated instrument in the American Oak Ridge (Tennessee) will be operated live through the Internet.' On the night of the session, the lecture hall was almost filled. It was obvious that many came to scoff - but it was all in vain. Toward the end of Edgar's talk, the connection to ORNL was established and the microscope was used remotely to obtain high-resolution images of gold particles. Astigmatism and focus were corrected live, and the final image was downloaded to a laptop in Regensburg. The connection was great - throughput of greater than 1 image per second. The outcome of the session exceeded expectations, and surely converted many skeptics that night."*

## 4. Continental and intercontinental networks of remote labs

An anecdotal observation from the previous story is that the U.S. has progressed more rapidly than Europe in the area of RE. One possible reason may be that the funding mechanisms for joint European projects have been scattered, in the recent past, for many different programmes managed by different EC-DGs, not mentioning bilateral agreements between two or more European countries. This means that it is possible to trace back to the first years of these large funding programmes one same project (or idea around a project with touch-ups on the consortium working on it) being funded by a series of, sometimes overlapping, programmes. It is not our goal to describe the EC research funding structure, neither in the past nor in the present, but nevertheless it is important to have an overall idea to understand how continental and intercontinental networks of remote labs involving European countries have been emerging.

- Education and Training programmes, managed by the EC-DG Education and Culture:
  - SOCRATES I and II (1995-2006).
  - LEONARDO DA VINCI (1995-2006).
- Research programmes, managed by the EC-DG Research, with contributions from other DGs, namely Information Society and Media:
  - 4$^{th}$ Framework Programme (FP) (1994-1998).
  - 5$^{th}$ FP (1998-2002).
  - 6$^{th}$ FP (2002-2006) - IST is one of the 7 key thematic priority areas.
  - 7$^{th}$ FP (2007-2013).
- Co-operation programmes with other world regions, managed by the EuropeAid – Co-operation Office:
  - ALFA – Supports the co-operation between European and Latin-American IHEs.
  - ASI@ITC – Supports the co-operation between European and Asian IHEs.
  - EDULINK – Supports the co-operation between European and ACP IHEs.

Within the projects funded by the 4$^{th}$ FP, namely by the Telematics Application Programme, launched when the Web became freely available to everyone, the RE 1008 – Remote Experiment MOnitoring and conTrol (REMOT) project [35] was one of the first European wide projects to deal with remote access to expensive equipment (i.e. an astronomical telescope and a tokamat). It ran from January 1996 till December 1997, and included institutions from Germany, Italy, Netherlands, and Spain. Project RE 4005 – DYNAmical COnfigurable Remote Experiment Monitoring & Control System (DYNACORE) [36] followed from 1998 to 2000 with further developments in the software architecture used for accessing and controlling the remote equipments. Currently there is a similar accessible network of astronomical telescopes that allow remote access to anyone, through the

Discovery Space (D-SPACE) project, which is co-financed by the EC-DG Information Society and Media within the framework of the eTEN Programme eLearning Action (6th FP) [37]. The project website is accessible through the Xplora – Megalab – Web Experiments portal [38], which also provides remote access to expensive electronic microscopes, a robot in a maze, and an industrial robot, among other apparatus.

The EC-DG Information Society and Media has also financed many other similar projects dealing with remote experiments. The following list was extracted from [39], by searching through all projects dealing with weblabs, remote experiments, or remote experimentation:

— The Collaborative Learning and Distributed Experimentation (COLDEX) project started in June 2002 and ended in May 2005. It involved the use of remote sites, mainly in Chile, for providing real experimental data for a community of learners in Europe. Among those sites were an observatory with a high quality telescope and a seismic measurement station, as Chile is situated in an "active" zone. Again, the remote access to a rather expensive and unique equipment was at the centre of yet another project [40].
— The Collaborative Laboratories for Europe (CO-LAB) project started in April 2001 and lasted for 39 months, with a total budget of 2.12 million euro. It built on the same concepts of the U.S. Collaboratories system, by offering access to remote laboratories [41].
— The Educational Network Structure for Dissemination of Real Laboratory Experiments to support Engineering Education (eMerge) project started in October 2002 and finished in October 2004 [42]. It was funded by the European Socrates programme, through the MINERVA action line, and involved partners from nine different educational institutions, from eight European countries. Cabello *et al*. indicate in [43] that "*the actual work was based on previous experiences like Retwine, the Lab-on-Web and the Socrates RichODL projects, where prototypes of virtual laboratories were realized (…). By using Web technologies and computer controlled instrumentation, students could access to these remote laboratories. The main objective (…)* was *to extend these technologies out of the individual institutions, making the services available to the European students. In the project, the* consortium *emphasized the creation of a variety laboratory experiments, and the development of supporting course material and educational practices*."
— The goal of the UNIVERSAL project (5th FP) was to develop a brokerage platform for distant course units, including remote experiments. It later provided the ground for the EducaNext initiative [44], which is now also supported by PROLEARN [15]. Presently the

EducaNext portal contains hundreds of course units in several different science and engineering areas, many supported by remote experiments, including those developed in the scope of the Workpackage "Online Experiments" of the PROLEARN project.

— The Remote LAboratory eXperimentation trial (ReLAX) project, also funded by the IST programme (5th FP), under the action line "New market mediation systems", ran from October 2000 till June 2002, with a budget contribution from the EC of half million euro. Cyberlab, a Norwegian company, integrated the consortium responsible for this project. It now provides tools and services for web-based sharing and operation of online laboratory resources via a global laboratory network and the accompanying Experiment Service Provider business model, which the company claims to have been tested during ReLAX [45]. An interesting note about ReLAX was the underlying idea of a business model associated with the delivery of remote experiments, able to accommodate different interests ranging from academia to industry, as expressed by Eikaas in [46].
— The Practical Experimentation by Accessible Remote Learning (PEARL) project ran from April 2000 till February 2003 and aimed to develop and share several remote experiments, namely: one visual inspection system for Printed Circuit Boards; one Remote Electronic Workbench; one electronic microscope; and several remote modules for teaching physics and chemistry, e.g. spectrometry [47]. Although it envisaged a unique system for accessing remote experiments, at least two different approaches were used for that purpose: one based in CORBA and XML and another based on LabVIEW. While the first approach proved feasible (a similar approach was used in the previously referred DYNACORE project) it was somewhat discontinued in face of other web technologies (e.g. Java), with the second one being now a commercial-of-the-shelf solution used by many weblabs. The consortium included IHEs from England, Scotland (University of Dundee), Republic of Ireland, Portugal (University of Porto), and a robotics company from Greece.
— Lab@FUTURE and DERIVE were other two IST-funded projects also dealing with remote labs and involving several European partners [48,49]. An interesting note was the participation of the University of Bremen (Germany), through ARTEC, on both projects, which developed a mix of a virtual and remote laboratory in mechatronics, later shared with other European IHEs within the MARVEL project [50], financed by the Leonardo da Vinci programme. The MARVEL project gathered institutions from six European countries, including again the University of Porto, from Portugal.

— The Remote Experimentation Network (RexNet) project ran from January 2005 till December 2006 and was funded by the ALFA programme. It gathered a consortium of 12 IHEs from both Europe and Latin America, including again the University of Dundee, the University of Porto, and the University of Bremen [51]. The project goal was not to discuss the technical, pedagogical, or economical strengths of remote experimentation, but rather to raise and try to answer some questions about the underlying benefits and challenges of establishing a peer-to-peer network of remote labs, and in particular its added value to education. An important aspect of this network was that it built on partners with a vast and rich past experience in the field, with some of them acting as promoters of similar local, regional, or even continental networks of remote labs, as depicted by figure 3. The cases of UFSC and its regional network at Brazil, and the Universities of Porto (Portugal) and of Bremen (Germany) and their continental network established around the MARVEL project are just two illustrative examples within RexNet, among others.

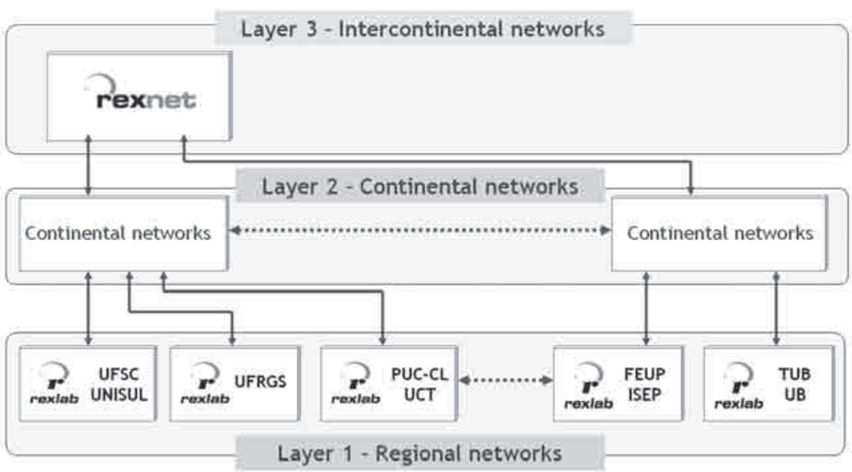


**Figure 3**

Multilevel networks of remote labs: the RexNet experience

To conclude this section we refer the iLab Project at the MIT [52], in which several iLabs for instruction in Electrical Engineering and Computer Science, Civil Engineering and Chemical Engineering were developed.

According to its mentor, del Alamo [19], some of these labs have been shared with students from universities in North America, Europe, Asia, and Africa. Although centred around one single institution, the MIT, this network is probably one of the best well-known cases for the RE community. One of the reasons for its success may come from the fact it is well supported by an IHE, the MIT, that in due time took the decision to promote the dissemination of its courses through the Web [18].

## Conclusion and future directions

The former case is an example of one IHE that is now in the 5th and last stage of development in a progress scale presented by Bates in [53]. Although this progress scale was originally devised for the general e-Learning area, it can also be used for RE, as this is considered to be a subset of e-Learning. Bates establishes the following stages: "(1) *lone rangers, individual people enthused by the technology, working on their own and experimenting*; (2) *lone rangers putting pressure on the university administration to provide help and resources;* (3) *rapid uncoordinated activity, and lots of things happening all over the place and lots of problems as a result;* (4) *focus, policies and priorities, i.e. institutions start thinking strategically;* and (5) *the sustainable and high quality use of e-learning in selected areas or for specific target groups*." It is possible to distinguish situations falling into each one of these stages from the illustrative cases presented in sections 4 and 5. For instance, many of the remote experiments made available through the EducaNext portal [44] were the result of actions undertaken by R&D groups, without the structural support of their Institution Administrations. A fact supporting this idea is that some still struggle with problems related to their Institution policy in relation to firewalls, which is likely to affect the access from the outside to the experiment server, when some particular TCP/IP ports are used.

At this point, we believe that both directions will co-exist, i.e. some IHEs will start to support their groups currently working on RE, as part of an overall e-Learning strategy, giving them the conditions to provide high-quality remote experiments as a sustainable service, while new situations falling into the initial stages will emerge as a result of: (1) adoption of new technologies, like Web 3.0; (2) new combination types between virtual and remote labs being proposed and demonstrated; (3) further developments on the sense of immersion and the collaborative nature associated with RE; (4) the m-Learning area being also considered as appropriated for the introduction of RE (in which case some authors defend the expression "mobile experimentation"); and, finally, (5) unpredicted proposals resulting from human ingenuity.

To conclude, we believe that a new IHE like the European Institute of Technology (EIT), being now proposed by the EC [54], may actually consider e-Learning and RE as key e-services that must be provided to, or shared with, the many IHEs of other world regions that co-operate with Europe. In such case, the EIT may adapt the successful example of the MIT i-Lab, counting on the experience of many other European IHEs already participating on inter-continental networks of remote labs.

## Acknowledgements

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# Collaborative Remote Laboratories in Engineering Education: Challenges and Visions

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**Abstract**

*Remote Laboratories appear to be natural tools for teaching collaborative work skills, because they offer interesting perspectives for social and collaborative learning from multiple and distributed locations. However, remote labs separate users from the real workbench and their traditional tools. Accordingly teleoperating remote lab equipment requires a sufficient degree of interactivity and vividness to give the learner the impression of actually being in the lab. Effective use of collaborative remote labs is based on a feeling of shared space, time and reality, determined by technological and human factors. We will review related concepts and discuss lessons learned from own research and prototype development. New developments involve the use of Mixed Reality techniques and open perspectives for future research.*

## Introduction

Remote laboratories have been an important topic of research during recent years, and it is not difficult to find publications that address this area[1]. The developments in Internet technology, notably the World Wide Web and

[1] For a literature survey see Ma & Nickerson (2006).

its associated technologies (hypertext, web browsers, etc.) provided the basis for the evolution in remote experimentation from the beginning of the 90's, although the basic ideas are much older. Remotely operated apparatuses have long been desired for use in dangerous or inaccessible environments such as radiation sites, marine and space exploration. For example Goertz and Thompson (1952) developed the first telemanipulator in 1945 for the remote safe handling of radioactive isotopes. See Sheridan (1992) for an excellent review of the extensive literature on teleoperating remote systems.

Although remote laboratories have proven valuable for a more efficient exploitation of laboratory resources and can be shared among participants from different places, there has been less research on collaborative applications. We believe that remote laboratories are ideal tools for teaching distributed collaborative work skills, because they offer perspectives of shaping teaching scenarios which are close to real distributed engineering team work. Likewise, remote labs can be shared by many institutions and students worldwide. This may promote the interaction of faculty and students across laboratory-based and technology-oriented subjects in different countries.

It is widely believed that collaborative experiences are powerful drivers of cognitive processes and can significantly enhance learning efficiency. The benefits of collaborative learning are widely researched and advocated throughout literature (Lehtinen 2003). Regardless of the varying theoretical emphasis in different approaches on collaborative learning (e.g. social constructivism), research clearly indicates that in many (not all) cases students learn more effectively through collaborative interaction with others. This motivates us to prepare remote labs for collaborative learning and to use them in distributed teaching scenarios together with simulation tools, hands-on laboratories and practical workshops. Our study suggests that there is a strong demand for research that seeks to create such a *mix*, where collaborative remote labs can play a significant role. This emphasis on collaboration adds new technical requirements to the design of remote laboratories. As a whole, there is a need to improve the usability of collaborative remote laboratory tools because otherwise learners may quickly get frustrated and stop working with it.

In the following sections we describe these issues in depth. We start with an analysis of laboratory environments, using it as an introduction to work out the characteristics of remote labs in comparison to other types of tools, such as hands-on and virtual labs. New results from collaborative work research are presented and we discuss implications for engineering education in general and lab courses in particular. Effective use of collaborative remote labs is based on a feeling of shared space, time and reality (presence), determined by technological and human factors. We will review related concepts and discuss lessons learned from our own research and prototype development. Before concluding, a case study is presented. This recent work involves the use of Mixed Reality (as opposed to 'pure' virtual reality) techniques to support seamless collaborative work between remote sites. We describe this and identify areas for future research.

## 1. **Remote laboratories in engineering education**

In literature, numerous definitions of remote lab environments can be found (e.g. Bencomo 2004, Ma & Nickerson 2006). But nevertheless a universally applicable definition and mutual understanding of what exactly is meant when talking about a remote laboratory does not exist: the terms remote lab, web-lab, virtual lab, tele-lab, collaboratory or online lab are often used synonymously and inconsistently and in some publications there isn't even a clear distinction between those different types of tools. Researchers (e.g. Ma & Nickerson 2006) have convincingly argued that this confusion makes it difficult to evaluate the effectiveness of remote experimentation and its related technologies. The debate is also complex for other reasons. Almost all laboratories in science and engineering are mediated by computers. Accordingly, there are many lab devices nowadays which are operated via a computer based interface anyway. In such cases, the nature of accessing the lab equipment may not differ much, whether the student is collocated with the physical apparatus or is interacting remotely via a virtual interaction panel. Although it might be fruitful talking about the relative extent of remoteness or virtuality, it is also important initially to establish a proper taxonomy for later study. Thus, in order to ascertain what is actually meant by the aforementioned types of labs, we will in the first step differentiate between hands-on and virtual (simulated), local and distributed, and mono-user or multi-user environments. The following criteria allow us to establish a first orientation (see fig 1):

1. The nature of the lab equipment (physical or virtual).
2. The access-mode to perform a task (local or distant access).

As regards these criteria, the general idea behind a *remote laboratory* is the ability to access physical laboratories or workbenches from distant sites by using a suitable communication infrastructure. In a remote laboratory the user (alone or as part of a team) and the laboratory setup are at different locations and participants work through a computer that is connected online to a real device. The typical scenario in education, for example, corresponds to learners that use the web to access the lab from their homes. On most occasions, their objective consists of carrying out a work assignment that is part of their study activities. However, it should be stressed that

| nature of equipment \ user access | local | distant |
|---|---|---|
| physical (real) | **hands-on lab** | **remote lab** |
| virtual (modelled) | **virtual lab** | **distributed virtual lab** |

**Figure 1**

Laboratory environments

remote experimentation is not necessarily an educational activity. In industry, as well as in research centres, the remote control of devices through the Internet represents a unique opportunity to solve engineers' and scientists' needs to access apparatus or machinery from a distance. Another possible scenario consists of an institution that provides remote access to some form of equipment that may be too expensive to be acquired by an individual or even a small company (Eikas *et al*. 2002).

Remote labs can be a useful complementary educational resource to hands-on labs, as they allow monitoring or supervising a running experiment remotely. To get rid of geographic proximity restrictions has far reaching consequences for education. Networked facilities can be shared by students working from distant locations, 24 hours a day. But experimentation in situ with a plant or real object cannot be totally replaced by remote resources.

*Hands-on labs*, where students operate a real plant or manipulate real objects while being directly collocated with the tools and objects in the same room will remain existential in engineering education, because learning experiences in real-life situations are not only a key prerequisite for learning psychomotor skills, but also relevant for understanding theoretical concepts. The psychologist Piaget drew attention to this phenomenon long ago, when he described how cognitive development is generally rooted in the tactile interaction with the objects in their environment (Piaget 1963). Accordingly there is no doubt that hands-on labs and workshops play an important role in engineering education. Nersessian (1991) even goes so far as to claim that "hands-on experience is at the heart of science learning", and Ma & Nickerson (2001) emphasize that hands-on labs are important initially to establish the reality of remote laboratories or the accuracy of simulations for later study. Accordingly, the effectiveness of remote labwork is seen to be correlated to the directness of its link to the real world (Cooper *et al*. 2002).

As remote labs are always networked to physical objects, so called *virtual laboratories* are non-physical tools. Actually, they are simulated labs. Consequently, a virtual laboratory can be defined as a computer-based model of a real-life lab. They can be realized as local or distributed applications. Because a virtual lab consists of a computer program, which can easily be operated simultaneously by more than one user, it is at the same time a multi-user environment ready for collaborative lab work. The most important educational aspect of virtual labs is the reduced risk associated with operator errors, and the opportunity to experiment and practise without being exposed to hazards. That is why the virtual lab very often acts as an antechamber (e.g. for prelab assignment) to the real-world experiment, allowing the application and testing of theoretical knowledge and skills in a safe environment before trying out the same actions on real equipment.

*Distribute*d, or so called shared, laboratories introduce a category that allows sharing lab resources among each other. This kind of infrastructure enables a wide spectrum of scenarios, including the case where different users and lab facilities may be distributed among numerous locations (Ferreira, Müller 2004) (see fig 2).

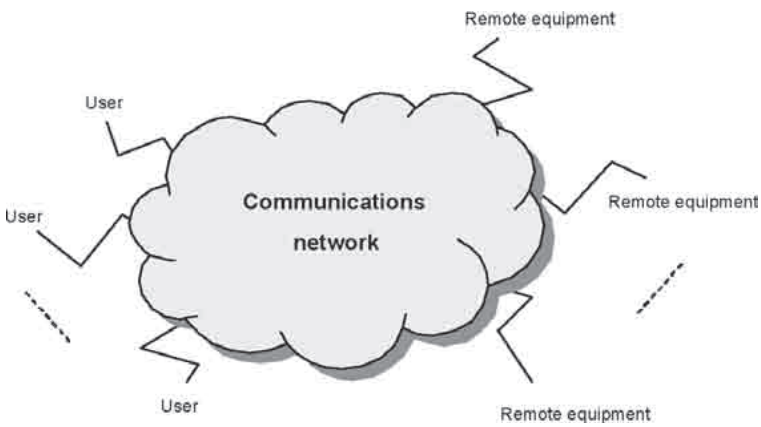


**Figure 2**

Distributed remote lab scenario (Ferreira, Müller 2004)

Notably, the World Wide Web brought new possibilities to the educational community in terms of distributing and sharing lab resources. As regards this aspect, Antsaklis *et al*. (1999) describes the variety of shared labs: "A shared laboratory can mean two or more departments sharing equipment and coordinating the development of experiments. It can mean the development of an integrated network of centralized laboratories…, or it can mean sharing laboratories across campuses and across universities. Shared laboratories within individual colleges or universities, as well as shared laboratories among different universities, make more efficient use of resources, increase exposure of students to the multidisciplinary nature of control, and promote the interaction of faculty and students across disciplines”.

A special and very important category of shared remote laboratory is the one where geographically distributed users can *simultaneously* access and control lab facilities in real time to perform learning or working tasks in a collaborative way. This is actually the category of distributed labs that we focus on in this publication and that we call a *collaborative remote laboratory*. Consequently a collaborative remote lab is a multi-user environment that allows a team to be working on the same lab assignment across distributed and remote sites concurrently. A collaborative remote lab may be consisting of a grid of physical labs facilities distributed among various locations.

## 2. **Perspectives from CSCW research**

Computer Supported Cooperative/Collaborative Work (CSCW) reflects the reality of an increasing number of work situations. CSCW means when two or more people, who are not located at the same place, organize their common work activities by means of computer based tools and services. Many authors agree that it is meaningful to differentiate between cooperation and collaboration. Roschelle & Teasley (1995) give a widely accepted definition of collaborative versus cooperative work: “Cooperative work is accomplished by the division of labour among participants, as an activity where each person is responsible for a portion of the problem solving…”, whereas collaboration involves the “… mutual engagement of participants in a coordinated effort to solve the problem together”. The distinction is based on different ideas of the role and participation of individual members in the activity. Also it makes sense to further distinguish between synchronous (i.e. working together at the same time) and asynchronous activity. Contrary to cooperation, collaboration is “…a coordinated, synchronous activity that is the result of a continued attempt to construct and maintain a shared conception of a problem” (Dillenbourg *et al*. 1995).

Computer supported collaboration introduces a change in scientific and engineering work by divorcing collaboration from physical locations. Usual face-to-face work is going to be replaced, at least partly, if not totally, by computer mediated collaboration. Distributed design and production across remote sites are global trends in industry for saving time and costs. For example, services for remote repair, diagnostics and maintenance (RRDM) is meanwhile widespread, and aid in expanding manufacturing facilities both nationally and internationally (Biehl *et al.* 2004). The integration of technology with physical space will make computing less visible or transparent in future work environments (Fernando *et al.* 2003, Schaffers *et al.* 2005, Collaboration@Work 2006). Ultimately, people will work seamlessly in distributed work spaces with documents, scientific models and virtual prototypes, both alone and collaboratively with distant colleagues as if they were in the same space. Ubiquitous, pervasive and calm technologies will extend human ability beyond limitation of time and physical constraints. Companies are going to implement technologically integrated spaces, housing large embedded displays, networked furniture, wireless devices for tracking people and remote access to supercomputers etc.

A key motivation behind these challenges is to enable continuity of collaborative work, through pervasive access to all kind of information, remote facilities, and groupware services. It is a perspective on collaborative work that has clear benefits for organisations that require individuals to work electronically away from the principal site but still maintain a collaborative link with their colleagues. Researchers (e.g. Bohn *et al.* 2005), who have developed a more critical perspective of this kind of *anyone, at any place, at any moment collaboration* argue that ubiquitous computing or ambient intelligence could leave the users without control. There seems to be a strong need for a balanced view emphasizing how ambient systems need to be visible, how they can be deconstructed, how coherence can be achieved, how they can provide stability and understandability, and in particular how users can stay in control when dealing with a large number of autonomous components (Erbe 2006).

Central to collaborative work as well as collaborative learning are social, motivational, and emotional factors that are difficult to implement in computer applications. In everyday face-to-face communication, social, motivational, and emotional meanings are mediated by using different verbal and non-verbal communication acts (Lehtinen 2003). If information and communication technology is designed to replace these activities completely by computer-mediated communication, it can radically reduce the effectiveness of collaboration because of the limited repertoire of communication modalities. From CSCW research, we know that collaboration tools often require that users carry out activities which do not naturally belong to their tasks, or else the tools foster actions that are rare in normal work and do not support users carrying out their most frequent activities (Lehtinen *et al.* 1998). One of the main challenges for the development of technologies for collaborative work is to create tools which can meet the motivational demands and particularly support the sharing of informal and tacit knowledge. As Hollan and Stornetta (1992) point out, CSCW tools must enable users to go "beyond being there" and enhance the collaborative experience. When this is not the case, users will avoid using the tool.

Nevertheless, and despite all problems we are faced with CSCW, distributed collaborative work is a global trend in industry. Thus, future engineers, technicians and workers are demanded to acquire some kind of competences and professional skills to work effectively in distributed collaborative work settings. In the field of engineering this requires not only competent operating of tools and systems for collaborative design, diagnosis, maintenance, monitoring and repair, but above all the ability to communicate effectively with others (e.g. customers, users, appliers) within computer mediated environments. Moreover, the future work force has to solve the 'mutual knowledge problem', for example by integrating the know-how of others in order to accomplish the work tasks using appropriate methods and tools. Special focus must lie on accessing distributed information from different actors and stakeholders (e.g. suppliers, customers and manufacturers) via global networks.

Although the hierarchy and the division of labour is simpler in educational than in work organisations, we believe that the aforementioned research results in relation to CSCW are applicable to the educational context. There are a reasonable amount of published studies showing positive learning effects when CSCW tools have been applied in educational settings. Generally, it is apparent that students do not only learn from tools and equipment, but from interactions with peers and teachers. There are, however, still many open questions and disagreement why collaborative learning methods affect achievement and even more importantly, under what conditions collaborative learning has these effects (Lehtinen 2003).

## 3. Collaborative learning with remote labs

Reflecting our previous discussion about new demands in collaborative engineering, we could argue that the growth of shared infrastructure in real working live should have implications for pedagogy. For example, students who take up a career in engineering are very likely to participate in computer mediated collaboration at some point. We believe that remote laboratories are ideal tools for teaching distributive collaborative work skills, because they offer perspectives of shaping teaching scenarios which are close to practical engineering team work. This is a motivation to prepare available remote labs for collaborative learning and provide them in distributed teaching scenarios together with other tools and media. Our study suggests that there is a strong need for research that seeks to create such a *mix*, where collaborative remote labs can play a significant role.

If we take a closer look at remote laboratory-based teaching there are a few studies available focused on collaborative learning (e.g. Müller & Steenbock 2001, Tuttas *et al.* 2003, Böhne *et al.* 2005, Gillet *et al.* 2005). Most of this research gives evidence that well constructed group activities used in conjunction with remote labs could generate an added value in regard to team skills, language proficiency, and remote engineering competences. In respect to task time performance, research indicates that remote learners mostly need more time to perform a work assignment or experiment. Of course, this is not surprising at all, because those tasks that require a full multisense perception of the learning object – which is often the case – are effected by reduced perception, and learners need more time or are even not able to accomplish the task remotely. This could be an indicator that the tool is not suitable or that the task itself is not performable at all. But the reason could also be that the learners are not familiar enough with this type of assignment and need more exercise and practice.

If collaboration in shared work spaces is likely to be quite representative of how many engineers will work in the future, collaborative remote labs might be ideal tools to anticipate this in training and education. In conformance with these findings Ma & Nickerson (2006) suggest:

> "… even if remote labs are not as effective as hands-on labs, the experience of working with geographically separated colleagues and specialized equipment may be educationally important enough to compensate for any shortcomings in the technology. It may be that students using remote laboratories will find different ways of collaborating, and the mode of collaboration they choose may affect what they learn from the laboratory experience".

As a result, we should determine that Ma's & Nickerson's observations are essential for the future discussion in our study.

## 4. **Sense of presence and reality within collaborative remote labs**

As mentioned before, the pedagogical effectiveness of lab work is considered to be correlated to the directness of its link to the real world. Accordingly, remote labs are often criticized in that they are not able to provide authentic settings and interactions with real systems (Nejdl & Wolpers 2004). This is evident in single-user applications, but is even more critical in multi-user environments, where participants have to share objects remotely. For example, if students are in an allocated lab seated around an experiment workbench, it is easy for them to look at the experiment set up while simultaneously be aware of the conversational cues of the other participants. But in a distributed and computer mediated work situation, user-interaction related problems, like loss of feedback or social interactivity may occur. Moreover, collaboration within remote lab spaces requires better synchronous communications tools, the possibility of passing the control to other users involved in a session or features for the management of different collaborative schemes and workflows. Consequently, there is a need to improve the usability of remote laboratory tools in this direction. Otherwise learners may quickly get frustrated and stop working with it. As remote labs separate users from their real workbenches and traditional tools the question is how to give learners the impression of being in the real lab working together and influencing reality?

In human-computer interaction (HCI) research, the feeling of being in a place is described as presence. Sheridan (1992) draws a distinction between three types of presence: physical, virtual, and telepresence. Physical presence can be characterized as "physically being there". Virtual presence is "feeling like you are present in the environment generated by the computer".

### 4.1. *Telepresence*

The term telepresence coined by Minsky (1980) in connection with teleoperating systems for remote manipulation of physical objects. Telepresence describes a "feeling like you are actually there at the remote site of operation", and characterizes the situation when someone experiences reality and presence over a distance (p. 120). "Telepresence enables a person to receive live sensory inputs from a distant environment and, under certain conditions, to telemanipulate the objects there" (Zhao 2003). In principle, the sense of telepresence is a feeling of shared space, time, and reality. According to Steuer (1992), telepresence refers to the mediated perception of an environment, which can be either a temporally or a spatially distant 'real' environment. Benford *et al.* (1998) describe classification criteria of shared-space approaches according to the dimensions of transportation and artificiality. They identified four major strands of technology using this classification (see fig. 3), where telepresence combines the remote and physical (Benford *et al.* 1998, p. 193).

Buxton stated that telepresence is a practical term, which describes "… the use of technology to establish a sense of shared *presence* or shared *space* among geographically separated members of a group"

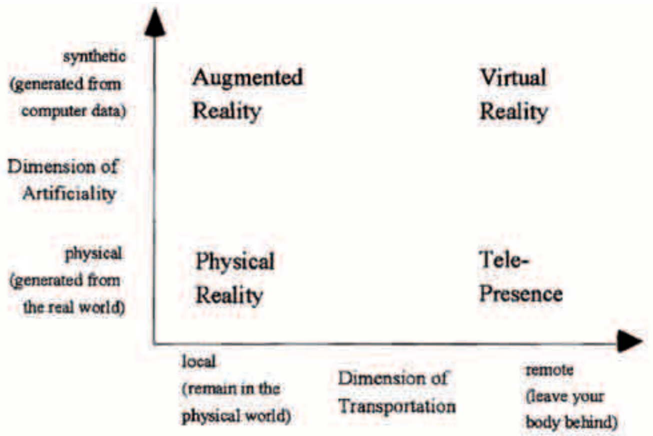


**Figure 3**

Broad classification of shared spaces according to transportation and artificiality (Benford *et al.* 1998)

(Buxton 1993, p. 816). When emphasizing the human aspect, we also have to focus on social and psychological factors of presence and reality, which we will briefly discuss in the following.

### 4.2. *From telepresence to social presence*

As defined by Witmer and Singer (1998), the social and psychological category of presence refers to the feeling of being together, of social interaction in mediated spaces with other persons physically situated in another, perhaps remote, environment. The feeling of being socially present with another person at a remote location is described as social presence. Social presence is an important factor in order to communicate and collaborate efficiently. In distributed work settings social presence is difficult to provide, as humans have to cope with situations in which they cannot perceive all the information they have in face-to-face interaction.

The theory of social presence is originally derived from telecommunication research (Short *et al.* 1976) but met later with response from researchers of the HCI area (e.g. Sallnäs 2004). Short *et al.* (1976) state that social presence represents a synthesis of the following factors: expression, direction of looking, posture, touch, and nonverbal cues. Witmer and Singer (1998) relate the sense of social presence to immersion. Immersion is a mental state characterised by perceiving oneself to be enclosed by, included in, and interacting with an environment that provides a continuous stream of stimuli and experiences. Factors that affect immersion include isolation from the physical environment, perception of self-inclusion in the shared virtual reality space, natural modes of interaction, and perception and control of self-movement. A computer mediated environment that produces a greater sense of immersion increases the level of presence.

Mixed Reality seems to be an approach to support social presence in collaborative remote environments, as it can enable co-located and distributed users to interact in distributed virtual spaces while viewing or even manipulating real world objects at the same time. Mixed Reality interfaces can overlay graphics, video, and audio onto the real world. This allows the creation of shared workspaces that combine the advantages of both virtual environments and seamless collaboration with the real environment. Information overlay may be used by remote collaborators to annotate the user's view, or may enhance face-to-face conversation by producing shared interactive virtual models. In this way, Mixed Reality techniques can produce a shared sense of presence and reality. Thus, Mixed Reality approaches would be ideal for multi-user collaborative lab and work applications. Later on in the next section, we will continue to discuss this aspect.

### 4.3. *Factors creating a sense of presence and reality*

Enlund (2001) introduced a model, which describes the variables that determinate the sense of presence and reality in computer mediated environments (fig 4). The model is based on various theories and empirical findings. The terms "sense of presence" and "sense of reality" are used interchangeably in this concept. The difference is mainly one of subjective involvement: in certain cases users may perceive an environment as being real without having the feeling of being present in it. But the methods and means for stimulating and achieving these feelings are similar. Generally the sense of presence and reality is a feeling of shared space, time, presence, and reality. Enlund suggests to distinguish between the following major factors:

(1) the quality of the sensory environment presented to the recipient of information,
(2) the individual preconditions of the recipient her-/himself, and
(3) the characteristics of the contents of the mediated communication.

In the following, we will reflect on a few of those factors which seem to be especially important within our discussion.

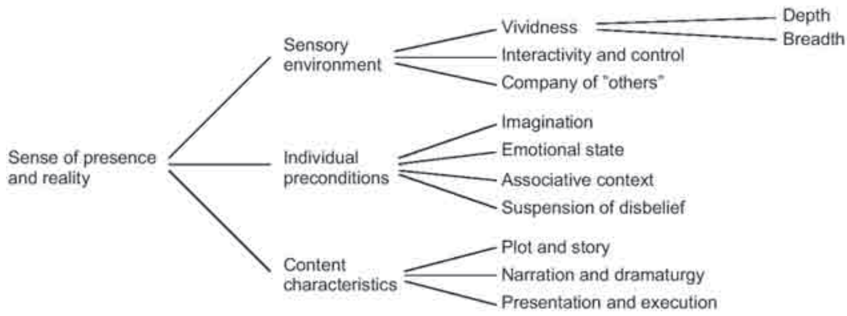


**Figure 4**

Factors creating a sense of presence and reality (Enlund 2001)

### Sensory environment

From HCI research we know that the quality of sensory environment is of paramount importance. Steuer (1992) argues that at least two technological variables are most relevant: vividness and the degree of interactivity. Vividness is a cumulative function of the variety and richness of the sensory information, characterized by the sensory breadth and by the sensory depth. Interactivity is dependent on the extent of control that the user can execute and on the response that the environment offers. Interactivity is, like vividness, stimulus-driven and determined by the technological structure of the environment.

Although the vast majority of work in human-computer interaction often involves only our senses of sight and hearing, with sporadic forays into touch, future remote laboratories will mostly benefit from developments beyond video and sound (Bruns *et al*. 2005). Tangible and embedded interaction, augmented and mixed reality characterize ultimate technologies for further applications in collaborative remote engineering and lab work. Early key work in this area of research may be attributed to Weiser (1993), Fitzmaurice (1996), Ishii & Ullmer (1997), Milgram & Kishino (1994). For an overview see also Ohta, Y. & Tamura (1999).

In particular, and in relation with collaborative presence, there are several studies indicating that vividness and task performance can be positively influenced by the aforementioned techniques. For example, tangible user interfaces (Sallnäs 2004) or touch feedback with shared tangible objects (Griffin *et al*. 2005) improve task performance, making it both faster and more precise. In our own research related to collaborative tangible user interface and haptics we found similar results (Bruns *et al*. 2002, Hornecker 2002). Further work of Yoo & Bruns (2004) describes a mixed

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reality based environment with force feedback to support collaboration in distributed real and virtual tasks. The system is used to get more insight into tangible cooperation between humans, avatars, or in general real and virtual systems. It allows selected teleoperation of objects into reality and their functional connection to a simulation model. Augmented and Mixed Reality used in teleoperation of remote robots or other apparatus help to optimize easy and intuitive use from distant locations. A popular and early application is the MarsMap system demonstrated as part of the Mars Pathfinder mission in 1997 (Blackmon 1998). Friz (1999) developed a telerobot training application based on augmented reality for manipulator programming and control. Åkesson and Simsarian (1999) presented a prototype, called Reality Portal, which provides the ability to interactively explore a remote space inside a virtual environment. Several European projects have addressed the issues of applying augmented and mixed reality techniques as a medium for collaborative training and remote experimentation (Bruns *et al*. 2002, Kaufmann *et al*. 2006, Müller & Ferreira 2004).

Other more advanced technologies, like olfactory displays, could also enhance the sense of presence in next-generation lab environments. As smell can be critical to remote experimentation, for example in relation with a remote digital workbench, smelling smoke from an electronic circuit, can signal the user to interrupt a running experiment in time before the board is destroyed. Several attempts have been made to include olfactory displays in computer-mediated environments (Kaye 2004). Tobias Scheeles' master thesis at artecLab used low-cost technology for an olfactory display to stimulate presence in an artificial CAVE environment (Scheele 2006). Experimental research in computerized scent output reveals that emitting scent on demand, and creating accurate scents are not solved optimally in all cases. However, there are prototypes around (e.g. Yu *et al*. 2003), and even a commercial system from TriSenx (www.trisenx.com) one can use on one's desktop.

Besides visual, auditory, tangible, haptic and olfactory stimuli, another possible source of sensory stimulation is moving air. A few studies already investigate air as a source of feedback and sensation. Noel *et al*. demonstrated that the feeling of presence in a virtual environment could be enhanced by breeze. Similar results were documented by Pratsch (2006) in his diploma work at artecLab. He developed a so called 'Aero-Cave', an interface for a CAVE, which generates airflow caused by every natural movement of the user.

As a result, we should determine that the development of progressively sophisticated technologies can significantly enhance the sense of presence and reality in next-generation lab environments. Some of these concepts and technologies are still in a prototype stage, expensive, or cumbersome in use. However, they open exiting perspectives for new visions for collaborative lab spaces for the future.

### 4.4. *Authenticity and reality*

One other aspect which has to be discussed in relation with remote lab learning is that of authenticity and reality. We must acknowledge that the pedagogical effectiveness of remote labs may be affected by the extent students actually believe in them (is it real or not?). As the reality of the remote hardware is only mediated by distance, users are required to suspend their disbelief to a certain extent. Accordingly, remote labs are sometimes criticized for their inability to provide an authentic link to real systems and apparatuses. However, is it the linkage to the real world that is important, or the belief in it? Thus, it is not amazing that the pedagogical effectiveness of a remote lab might be more or less influenced by the so called 'willing suspension of disbelief'. The phenomenon 'willing suspension of disbelief' is rather known: for example watching a television soap opera or reading a fascinating book often can encourage a kind of emotional realism for the viewer respectively the reader, respectively which only exists at the connotative rather than the denotative level (Enlund 2001). One may have the feeling that it is a true to-life story even when realising that it is completely unrealistic at the denotative level. But in order to fully enjoy the experience, it is most undoubtedly important to willingly suspend disbelief. Ma & Nickerson (2006) argue that "belief may be more important than technology" (p. 11) and moreover "students' preferences, and perhaps their learning performance, cannot be attributed to the technology of the laboratory alone". Consequently it seems to be important to study how students' mental activities are engaged in coping with the laboratory world: "Therefore, an understanding of presence, interaction, and belief may lead to better interfaces. Also, if belief proves important, then hybrid approaches might be contemplated, in which hands-on work is used at an early stage to build confidence in remote or simulated technology used in later teaching"(Ma & Nickerson 2006. p. 14).

When discussing the individual preconditions of learners we should also reflect on their affective experience with a new generation of entertainment technology. As our students play the latest computer games, they are already very familiar with the whole spectrum of immersive 3D environments, namely massively multiplayer online games (MMOs). The affective experience with this kind of environments cannot be matched by traditional e-Learning tools. This phenomenon needs more attention, because there is of course a relationship between presence and enjoyable, playful learning tools. Barfield and Weghorst (1993), for example, report that presence and task performance are strongly influenced by the mediating effect of enjoyment.

A few attempts had been made to integrate elements of immersive 3D environments in collaborative e-Learning tools. In artecLab, we developed a prototype for collaborative and synchronous modelling of pneumatic circuits. The environment provides a 3D interface and couples real artefacts with virtual counterparts. Users are building a physical model while the computer tracks these actions and assembles a corresponding virtual model. The virtual model can be used for further simulation studies. In addition, the system integrates chat, video and audio conferencing tools, plus the possibility to view other user actions as corresponding avatar movements (Ernst *et al.* 1999). Röhring and Bischoff (2003) presented a multiuser remote experimentation system using avatar techniques and 3D chat. Both approaches aim for a similar goal: to stimulate a shared sense of presence and social presence through distributed controlled avatars (tele-actors) in connection with other communication tools and the possibility to interactively access remote hardware and facilities.

Virtual online worlds or MMOs offer the ability for numerous users to simultaneously act in the same shared virtual space. For example the 3D virtual world *Second Life* by Linden Lab (http://secondlife.com) offers considerable options for group work, which makes this environment interesting for collaborative learning. Users, called 'residents', communicate and collaborate on joined complex tasks, while they are able to generate new knowledge and shared expertise. In contrast to many other MMOs, *Second Life* has no predefined goals and users may adapt the environment for their own objectives by constructing and scripting new objects. This open character of *Second Life* has already attracted a number of education projects (Livingstone & Kemp 2006). Accordingly, it seems to be possible to link external lab hardware resources with *Second Life*. The ability to interactively access real labs within *Second Life* opens perspectives at the same time to use the full range of collaboration and groupware facilities provided. Using *Second Life* as a learning portal for accessing digital learning resources is already quite common. Moreover, an active community has started the project SLoodle (www.sloodle.com) to integrate the open source Virtual Learning Environment (VLE) platform Moodle with the 3D world of Second Life. If this project is successful, educators and learners will be able to create new environments for collaborative remote experimentation and work. However, we should not uncritically adapt Second Life and other MMOs for education. The same factors that support collaboration and social presence can promote addictive gaming behaviours that supersede learning activities such as exercise, social interaction, and concept work. Some educators even speculate that excessive involvement in computer games negatively impacts interpersonal relationships, scholarship and family life (Messerly

2004). Up to now, there are no real solid data supporting negative claims about MMOs, though. However, expanding e-Learning into the realms of immersive virtual worlds introduces numerous pedagogical, ethical and legal issues that we will have to confront.

## 5. **A case study: From remote labs to collaborative workspaces**

In a series of case studies and experiments carried out at artecLab, we have investigated factors that determine the quality of presence and reality in collaborative working and learning environments. We have done this using primarily low budget technology. Within this publication we have already briefly reported on some of those experiments and on the indicative results they have produced. In the following we will describe recent work that involves the use of Mixed Reality (as opposed to 'pure' virtual reality) techniques to study how collaborative engineering between remote sites can be supported by Mixed Reality technologies. One of the main problems is to couple seamlessly distributed real and virtual objects which are in the action space of the users. To solve this, Bruns (2001) developed an interface technology for connecting real with virtual components of different kind. The interface, called *Hyperbond*, is a mechanism based on the translation between physical effort/flow phenomena and digital information, like analog/digital and digital/analog conversion. However it aims at a unified application oriented solution connecting the physical world with its virtual representation and continuation. The name *Hyperbond* has been chosen because of its relation to the description of dynamic systems with bond graphs, first introduced by Paynter (1961).

In a current case study we are implementing a prototype of a shared virtual and remote laboratory using the Hyperbond concept. The environment envisaged allows working collaboratively with real and virtual systems, consisting of parts which may be remotely distributed. Accordingly a remote physical laboratory workbench can be coupled with a local virtual workbench and vice versa. The system supports full hardware-in-the-loop functionality, allowing to build up complete electro-pneumatic circuits, which may be consist of distributed mixed physical and virtual electro-pneumatics.

Real and virtual workbenches are located in CAVE-like constructions (Computer Automatic Virtual Environment). We use CAVE's (Cruz-Neira *et al*. 1992) because remote and local participants can immerse into a common workspace for solving a joined task, such us collaborative tele-design or tele-maintenance. Every CAVE consists of a room-sized cube covered with canvases. The different images of other workspaces with the participants working in them are projected onto the canvas walls. The common

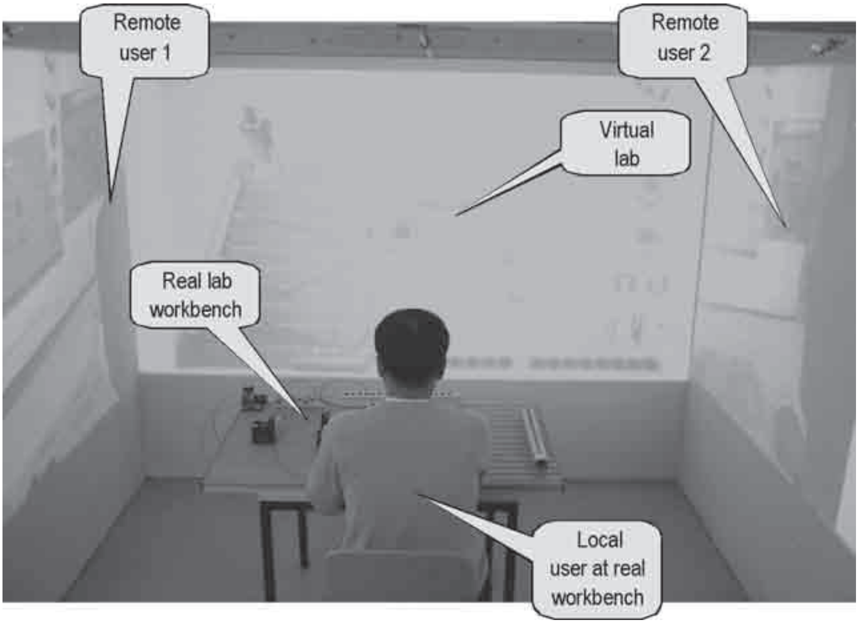


**Figure 5**

Workspace at the real workbench in a CAVE

**Figure 6**

Two distributed users connected to the real workbench from remote

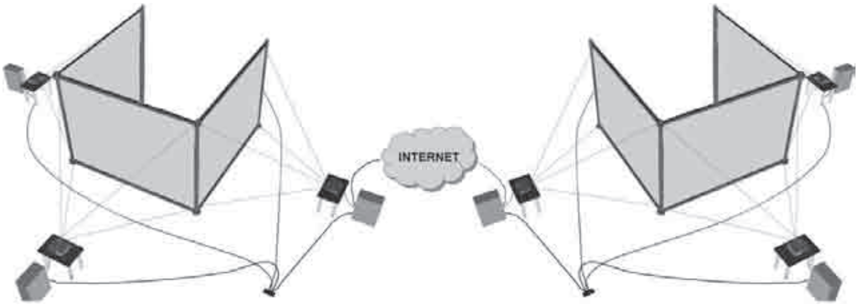


**Figure 7**

Distributed CAVE-based workspaces

virtual workbench and the real physical workbench are accessible via the Internet and also visualized in each CAVE. The projections are controlled by client computers connected to a central media server. As available CAVE's are very expensive, we developed a low budget solution, which consists of wooden scaffoldings, ordinary video projectors and PC's. In comparison to commercial CAVE's our system offers nearly the same performance and provides a sufficient solution for research. The following figures show the arrangements used for the test cases. The basic architecture of the distributed CAVES is illustrated in Fig. 7.

The real and virtual workbenches were implemented as a Web Service to take advantage of web technology (e.g. easy accessibility, platform independence). A central module is the Mixed Reality (MR) Server which realizes this Web Service. The Web Service itself processes HTTP requests and also manages the sessions of all remote users. Relevant data belonging to a certain work session is stored on the server, such as virtual model data, support material and background information. The WWW front end consists of a HTML page including a Virtual Construction Kit (VCK) and a video stream window. The VCK itself is a VRML based tool for assembling virtual worlds: by dragging and dropping objects from a library onto the virtual workbench new objects (e.g. cylinders, valves, and switches) can be added. Each of these objects has connectors which can be linked to other ones. Links can either be tubes (air pressure) or wires (electricity). Connections between real and virtual workbench elements were realized by the aforementioned Hyperbond technology. First experience gained in this case study has already illuminated how future engineering workspaces and laboratories could be structured. Several key features of tomorrow's remote laboratories can be identified, including support for freely exploring a phenomenon and its appearance in various applications and contexts, means for a universal mixing of real and virtual objects, and distributed work on tasks in a multi-modal and multi-user way.

## Conclusion

Our study may provide a starting place for researchers involved in the discussion about the role and value of collaborative remote laboratories in engineering education. A sense of presence and reality can be achieved not only in hands-on, but also in collaborative remote labs. The basic factors of generating feelings of presence and reality in computer-mediated labs are related to the sensory environment, the individual preconditions and other learner's human factors. Perhaps with the proper mix of technologies we can find solutions that meet the requirements of engineering education by using hands-on labs, virtual labs (simulations), and remote labs as complementary educational tools to reinforce conceptual understanding, while at the same time providing enough room for experiential learning and reflection. Our discussion suggests that there is a need for future research that seeks to create hybrid learning spaces, which might be stimulated by more case studies and experimental research. Finally, it is obvious that students do not gain knowledge and skills from technology only. As stated by Ma & Nickerson (2006): "… students learn not only from equipment, but from interactions with peers and teachers. New technologies may call for new forms of coordination to augment or compensate for the potential isolation of students engaged in remote learning".

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# Section II

# Remote labs impact within the learning process

# Competences, Remote Labs and Bologna Process

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## Introduction

There is a clear-cut distinction between learning outcome of learning for social needs and learning outcomes required for academic purposes. The first one implies a dynamic combination of knowledge and understanding skills, while the second is formulated by academic staff on the basis of internal and external criteria. The balance between the above-mentioned requirements is achieved in Bologna Process, which is based on "student-centred learning" concept shifting the emphasis from input to output.

Output orientation means also assessment centred upon competencies. In engineering studies the development of practical skills implies the extended use of experiment during the curricula activities. This paper brings arguments in favour of the remote experiment which is considered to be the keystone in the development of engineering studies. The most important argument is an increase in employment rate among graduate and the creation of premises for lifelong-learning.

The remote experiment, as a tool for improvement in technological education, is the most appropriate way of dealing with the issue of under-equipped laboratories. The remote experiment is conducted by means of e-learning via the Internet. The problem under discussion is that of quality assurance when the system lacks an institutional framework. All the benefits regarding the development of engineering studies may well turn into shortcomings unless we make the difference between quality of design and quality of conformance within the quality of education. There are presented several remarks regarding the peculiarities of quality assurance in the case of WEB-learning.

The e-learning environment is influenced by a series of cycle of changes in both economic and in social-cultural life These in turn bring about major changes in skills and behaviour. The paper outlines the importance of adapting the e-learning environment in order to meet the new requirements in establishing competences.

The concept of "student centred learning" launched in Bologna Process implies the enhancement of engineering education by means of remote experiment. When we design this environment, some peculiarities in quality assurance and new rules in establishing competences have to be considered Therefore, anew tool is presented for the curriculum design, which is called QFD.

## 1. **Current state of the art regarding Bologna Process**

The discussions regarding **competences and their connections with remote labs** must start with a general view on the Bologna process and level of its application.

The main objectives in the Bologna process might be mentioned as being:

- The elaboration of a framework of comparable and compatible qualifications: *workload, level, learning outcomes, competences profile;*
- Defining programmes of study on the notions of: *social needs, available resources, professional and academic profiles, learning outcomes and competences;*
- Developing a model for curricula: *design, implementation, delivering;*
- Fulfilment of the basic conditions:
  - For study programmes:
    - *The social needs* on a regional/national/European level on the basis of a consultation of stakeholders, employers, professional bodies;

—Correlation with the *academic point of view;*
—Necessary *available resources* for the study programme;

- For international degree programmes:

—*Commitment within the institutions* on the basis of agreement;
—*Legally recognition* in the host countries;
—Design of the programme in terms of *ECTS-credits based* on student workload.

—Teaching and learning *methods, techniques and format,* as well as the methods of assessment;
—Development of an *evaluation system for quality assessment*.

This framework must be continued with a synthetic presentation of the content of the learning outcomes and competences. Today we must notice that there is a distinction between learning outcomes in the sense of the social needs and learning outcomes required for award of credit. Required learning outcomes are formulated by the academic staff on the basis of input of internal and external stakeholders. In the mean time competences represent a dynamic combination of: *knowledge, understanding, skills and abilities.* The balance between required learning outcomes and competencies will be formed in various course units and assessed at different stages.

The balance mentioned above has in Bologna process as main tool *student centred concept*. Why? Because today, the majority of the study programmes are *staff centred* (input oriented). It means that curricula reflects a combination of the *fields of interest* of the stakeholders and e*xpertise* of the staff. Student centred, implies two characteristics, related with this material:-shift in emphasis from *input to output* that means changing the role of the teacher (from organizer of knowledge towards an accompanying role) -transparency in the definition of objectives and other dynamics for them and assessment centred on competencies.

Student centred implies also organization of learning as: *more focused* programmes, *shorten* courses, *more flexible* courses, *more flexible delivery* and *teaching*, *more guidance and support*.

Bologna process has crossed in this period a *critical moment* in the Eastern former socialist countries because of: *implementation* of curricula reforms stated in the national laws at *programme level* in the lack of *comprehensive feedback mechanisms at disposal,* in absence of *used information technology* to collect and to analyze feedback, in existed *fragmentation, isolation and lack of dialogue* with social and economic environment [1], [20]. There are also mentioned some tendencies toward*s uniformity (*copy of existed systems) and *overregulation.*

## 2. Enhancing engineering education (EEE) through remote experiment

The educational systems known till now were based on institutional monopoly of the schools. These systems have remained dominant as long as the educational alternatives were weakly developed and do not have the power to become concurrent. Today this concept is obsolete and was replaced by the permanent education concept (life-long learning). The force which has imposed this replacement was the Internet and, as a result of its development, an e-learning market was created [2], [21].

In spite of the development of "free market" in education as a result of Internet facilities, the main discussions, challenges and debates about the adaptation of education at this new cyberspace, are carried preponderantly inside the institutional education system.

In the engineering education case, its enhancement has a special and peculiar aspect due to necessity to add at basic theoretical knowledge the applications for practically skills forming. It explains for what reasons, ODL (ODL stands for?) methodology was applied with success at those specializations which do not need experiment as a part of educational system.

Regarding training in engineering we must to recognize that, for a long time, there are in place two channels of education which depends on the level of experiment as a part of teaching system: against the expected results of internationalization of trade, industry and human resources.

The disfavoured countries will not have in short time the funds to cover this existing gap. As a result, the distance between the mentioned channels will increase. We need a solution because the globalization of work market is based on the concept of "similarity in training" and the argument for this statement is the Bologna Protocol.

What must we do?

Remote experiment together with virtual instrumentation seems to be, at this moment, the best way (cheaper for both types of countries) to cover the differences in laboratory endowment and, as a result of this covering, to erase the actual gap regarding practical knowledge and skills.

What does Enhancing Engineering Education (EEE) mean? In short, all of the partners who are working in this area agreed that EEE consist of:

— Continuous revising of existing programs;
— Creation of new programs;
— Improvement of teaching-learning processes.

Remote experiment and virtual instrumentation (REVI) if adopted at large scale will influence each of above actions (Table 1).

**Table 1**

| EEE actions | REVI response |
|---|---|
| ***Continuous revision of existing programs*** (regarding practical skills, this action means permanent improvement and change of the laboratory endowment, with the goal to be on the line with new technologies) | — For the first channel mentioned above, REVI adopted at large scale presumes cost sharing between partners so that, enlargement of clusters with partners, means lower cost for all of expensive endowments. New device will have a host institution and all cluster partners will have the possibility to do experiments on it.<br>— For the second channel mentioned above, the participation at spends, as a cluster member, will suited with own financial possibilities, and the level of existing programs will be enhanced. |
| ***Creation of new programs*** | — In engineering education new programs creation means investments in laboratory endowment. Many of the countries do not have this capacity in short cycles. REVI offers the flexibility and adaptability in new programs creation because *the key point becomes the content not the costs*. The costs are sharing out between partners. |
| ***Improvement of teaching-learning process*** | — The movement from costs towards content mentioned above, allow the teaching-learning process improvement due to rapid responsiveness at:<br>• New demands of economy;<br>• New possibilities of experiments;<br>• Approach of all new modern areas from didactic level at research level.<br>— As a result of the REVI introduction, the incorporation of ICT and ODL in engineering curricula which presumes:<br>• dramatic changes will occur in the engineering classroom;<br>• the accessibility to education and training of a large number of students will be improved;<br>• Will add to the teacher-student interaction, the student-student interaction |

What is the driving force of REVI-as new component of engineering education? In our opinion there is:

PROMOTING & ENSURING → EMPLOYABILITY OF GRADUATES

Employability is in very tight connection with rapid expansion of knowledge in science, generally speaking, and in engineering in peculiar. Employability is the main request of industry. Many years ago, the knowedge acquired in the faculty was enough for the entire career. But the knowledge expansion in exponential way has conducted to a rapid degradation of employability. REVI environment ensures both good employability after graduation due to the practical skills acquired and re-qualification using life-long learning in ODL manner. The students will not be limited to skills offered by the university endowment. They have the possibility to navigate among a diversity of engineering laboratories approaches, a fact that will create strong supplementary skills. REVI ensures the shift from teaching to a learning centred approach [17], [18], [23].

What is necessary to consider when designing a REVI procedure with large external accessibility? Here, Majewski and Rubinska, in 2002, had offered the following criteria (Table 2):

**Table 2**

| Criterion | 0% Level 100% |
|---|---|
| Technical competence | |
| Practice aptitudes | |
| Solution synthesis ability | |
| Team work capacity | |
| Critical thinking | |
| Communication and behavioural skills | |
| Business acumen | |
| Life time learning capacity | |

REVI positioning according to Tuning Project (www.relint.deusto.es) which made a correlation between generic competencies and which has defined specific competencies for each generic ones, must be appreciated according to the with help in realization of each specific competencies and with its strong influence in acquiring generic and specific competencies (Table 3):

**Table 3**

| Type of generic competencies | List of specific competencies | REVI positioning | |
|---|---|---|---|
| | | In realization | In influence |
| ***Instrumental competencies*** | Capacity of analysis and synthesis | — | * |
| | Capacity of organization and planning | — | * |
| | Basic general knowledge | * | — |
| | Grounding in basic knowledge of the profession | * | — |
| | Oral and written communication in native language | — | * |
| | Knowledge of a second language | — | * |
| | Elementary computing skills | * | — |
| | Information ability skills (ability to retrieve and analyze information from different sources) | — | * |
| | Problem solving | * | — |
| | Decision making | — | * |
| ***Interpersonal competencies*** | Critical and self critical abilities | — | * |
| | Team work | * | — |
| | Interpersonal skills | — | * |
| | Ability to work in an interdisciplinary team | * | — |
| | Ability to communicate with experts in other fields | * | — |
| | Ability to work in an international context | * | — |
| | Ethical commitment | — | * |
| ***Systemic competencies*** | Capacity for applying knowledge in practice | * | — |
| | Research skills | * | — |
| | Capacity to learn | — | * |
| | Capacity to adapt to new situations | — | * |
| | Capacity for generating new ideas (creativity) | * | — |
| | Leadership | — | * |
| | Understanding of cultures and customs of other countries | — | * |
| | Ability to work autonomously | * | — |
| | Project design and management | * | — |
| | Initiative and entrepreneurial spirit | — | * |
| | Concern for quality | — | * |
| | Will to succeed | — | * |

All the above considerations reveal that: REVI is the way to allow e-learning in engineering education and the way to form large clusters of universities with knowledge and also with expenses sharing. The collaborative teaching-learning process will be moved from classroom towards institutional level. REVI will ensure a good employability after graduation and permanent life-long learning environment regarding experiment skills and abilities to handle high-tech devices. It might be a cheapest way of SME's to have access at high technologies for own necessities in measurements, research and validation of new products. REVI might be a solution for quality assurance in teaching/learning for engineering education, due to cluster dimensions and mixture of the rules of quality assessment. At upper limit there is the possibility to create a www.ren.org as the largest World Wide Web with all of remote experiments known in university and research environments, a larger library of practically skills. This network has the capacity to erase the present differences in practice knowledge determined by the different access to funds.

## 3. WEB-learning provides quality of education process?

The education system is, in fact, *a service* delivered for the benefit of society. Consequently, it must respect all the quality assurance principles. As long as the education system belonged to the government and was sustained by public funds, the responsibility for quality assurance has been centralized, being created national authorities, independently or semi-independently with high power in decisions about the quality of education.

Internet has broken this centralization as a result of quite uncontrolled offers in education at all levels. The quality assurance of this global offer and unlimited access means *a new start* in the quality assurance effort. The social system has neither the right nor the power to neglect Internet, and consequently e-learning, as a way to access education.

There is a considerable confusion in our society about the question: **who has the power to apply in WEB-learning the rules which were accepted and verified in face-to-face training in the case in which it is out of institutional frame?** The answer is: **nobody!**

Quality assurance in WEB-learning it is not a problem of power or of authority. It is a problem of understanding, and is addressed both to students and to teachers. What is necessary to be understood? *A parallel between production and education* will offer some solutions.

The shortest definition of quality is: **"fitness for use".** This definition was commented so much in direct connection with production systems that it was remained its label. We try to do a parallelism between quality assurance system from industry and its reflection in education (Table 4).

**Table 4**

| Production | Education |
|---|---|
| **A.<br>PRODUCT LIABILITY<br>IS A MAJOR SOCIAL, MARKET<br>AND ECONOMIC FORCE**<br>The characteristics of strict liability are two:<br>— ***Strong responsibility*** for both manufacturer and merchandiser requiring immediate responsiveness to unsatisfactory quality;<br>— ***Advertising*** and ***promotion*** of the product ***is in connection*** with ***quality and responsibility.*** | **A.<br>GRADUATE LIABILITY<br>IS ALSO A MAJOR SOCIAL<br>AND ECONOMIC FORCE**<br>**BUT**: in the face-to-face teaching/learning<br>— The ***responsibility is diffused*** and many times vague;<br>— The ***responsiveness*** for unsatisfactory quality of graduates ***is too slow***. It takes two or three graduation periods to modify the prestige of an institution on the job market;<br>— Many times the ***aggressive advertising*** and promotion of some education institutions ***cover*** for a period ***the bad quality of delivery***.<br>**BUT**: in theWEB teaching/learning offers:<br>— The ***responsibility is hidden***. Under cover of the computer screen, lack of quality courses might be released on the market;<br>— The ***responsiveness*** for unsatisfactory quality courses ***can be very fast*** if there is an assessment system offered by reliable organizations;<br>— ***Advertising*** and promotion in e-learning and m-learning are ***very aggressive.*** The student, without a selection criteria in hand, may spend a lot of time for nothing. |
| **B.<br>PRESSURE**<br>These two strict product liability principles have as a result a ***strong pressure on the manufacturers, distributors and merchants*** to develop and maintain a high degree of evidence concerning the performance of the products | **B.<br>PRESSURE**<br>The pressure in education has two meanings:<br>— From ***students towards education*** institutions for diversification of the education offer. This diversification will dilute the training products so that quality becomes quite uncontrolled;<br>— From ***job market towards education institutions*** to increase the graduates quality which implies high standards, high costs and many failures before graduation; |

This parallelism, done in the above table, reveals that rules from production are not proper to be applied in education because of conservative character of the face-to-face education and of lack of institutional organization of the WEB-learning offers.

What must be done? First of all to understand some peculiarities of the quality assurance valuable in both systems. There is considerable confusion between *quality of design* and *quality of conformance*. The notion "*quality of education*" is often used without making clear whether it refers to design or to conformance [15], [16].

***Quality of design***. Education is delivered in various grades or levels of quality. These levels are **intentional** so that the requirements and standards applied in teaching are established at the beginning. For students these levels are known as rules of the institution. For teachers, these levels are confined in the course content. The diversity of the rules and the diversity of the contents have produced a broad confusion in quality assurance understanding. This aspect is the **first peculiarity** of the quality design in education system.

In production the workers and the management act upon the products. The product *is not an active part* of this effort. The quality assurance has only the direction towards product. In education *both parts are active*. Top management commitment which is a compulsory condition in the production to ensure quality is not enough in education. As active part of the system the student has his own commitment. So that, design of quality assurance system in education has **a second peculiarity** which must be takes into consideration.

***Quality of conformance***. Is refers to how well the student conforms to the requirements and standards established by the design.

If we are sincere, after this splitting of the quality assurance in design and conformance, we must recognize that 80% of our efforts to build quality system are today directed at design. We speak about quality of courses, quality of teaching, quality of endowment, because these elements are in our hands. For conformance we are satisfied with marks, home-works, projects, tests and so on. The student commitment, the feedback from the job market, the motivation and the prevention are elements which generally speaking we know but we fail to consider permanently as part of the quality of conformance. It is not a mistake it is a reflection of the difficulty to adapt such a conservative system as the educational system to the process of quality assurance. We will try to be more specific in the following considerations.

In production systems, where the direction of the management is only towards the product, the process control must answer questions like:

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— Which inputs affect the output parameters?
— What is the relationship between the input parameters and quality characteristics?
— How can the quality output characteristics be controlled?

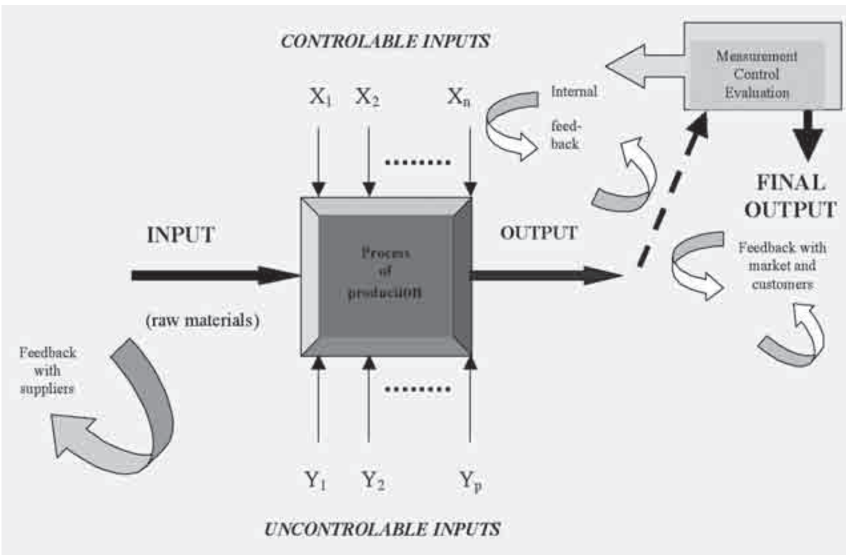


**Figure 1**

Classic scheme of the process control

The main schema of the production process is presented in Fig. 1. We may comment that, internal feedback and external feedback from market and customers, is the manner for the reduction of the variables of the process. The ways used for this purpose were *motivation programs* and *prevention programs*. The motivation programs are addressed to employees and use product exhibits, slogans, contests and other vehicles to stimulate the employees to improve their participation at quality assurance. The prevention program involves a deeper commitment and was concretized in "zero defects" philosophy that means: when a defect is identified, then engineers, managers and employees will devote effort to isolating the source of the defect and to do remedial actions so that this defect does not occur again.

Figure 2 shows the differences between the production process control and the education process. It involves the following remarks:

- In the education process the raw materials are the *inference rules* which are kept in the students mind as intangible assets acquired in the previous schools and the *fundamental reference values* which operate in connection with cultural area of origin (fig. 3). It means that input has not materiality as in the production processes. For this reason a part of the *input is considered uncontrollable*.
- As *controllable inputs* we consider the role of the students with marks, references and awards, the assessment of the pre-existing knowledge, the admittance contest results, etc.
- Outputs in the case of education process are splitting also in two: controllable and uncontrollable. *Controllable* are similarly: role of the student with marks, references, awards, research papers, test, license work, practice and so on. *Uncontrollable* are output inference rules, intangible assets and all operations of knowledge processing and decision taking.

It is obvious that, the above remarks are valuable in the classic education system. In front of the computer and connected to the Internet, the above controllable outputs are in fact uncontrollable. The enrolment of the students in WEB-learning and actions of measurement, evaluation and control are in accordance with the above education process only if this process is organized under an accredited institution authority. And so we return to the initial problem: accredited institution exists when a national authority has the right to confer this title. Under this umbrella we suppose that all the education process delivered under the frame of these institutions has quality and quality assurance system implemented. When e-learning is offered outside this system, the problem of quality assurance begins to be dominated by doubt.

Generally speaking the *primary objective* of quality assessment in WEB-learning, using statistical control, is the **systematic reduction of variability.** As we mentioned above, the variability is introduced by students and by teachers. We work with such a large number and different types of students and teachers that variability is ensured from the start of the education process.

But the student, in today acceptance of the quality assurance process, is the final product and there is not considered a responsible person in this process. The Institution and every teacher has the formal quality assurance responsibility. There is a danger that if we adopt the philosophy according to which "*quality is everybody's job*". If so, quality will become "*nobody's job*".

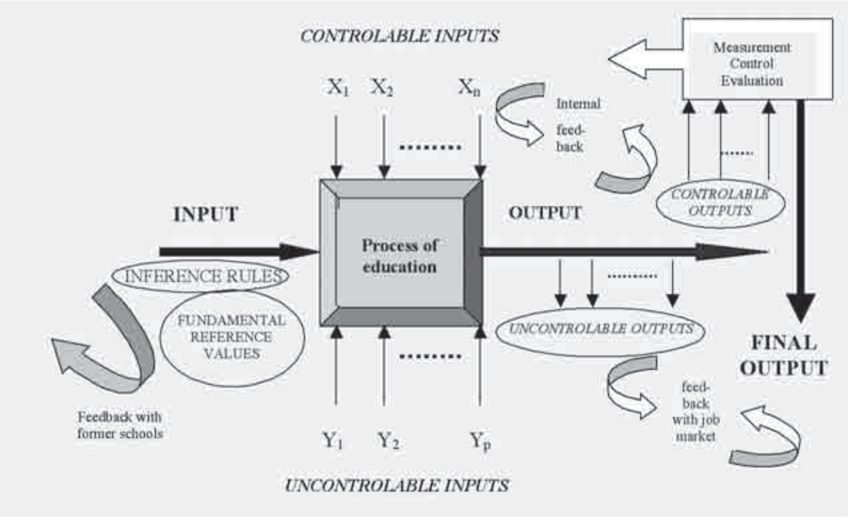


**Figure 2**

Peculiarities in the case of education process

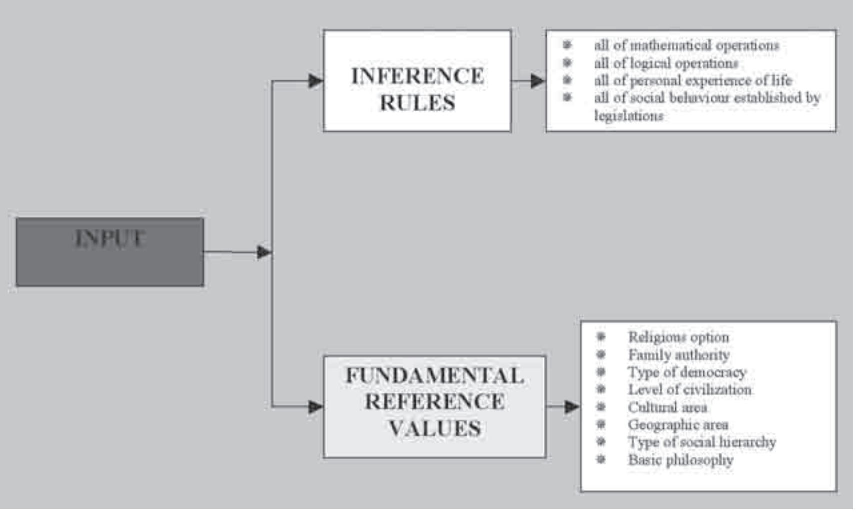


**Figure 3**

The peculiarities of input in the case of education process

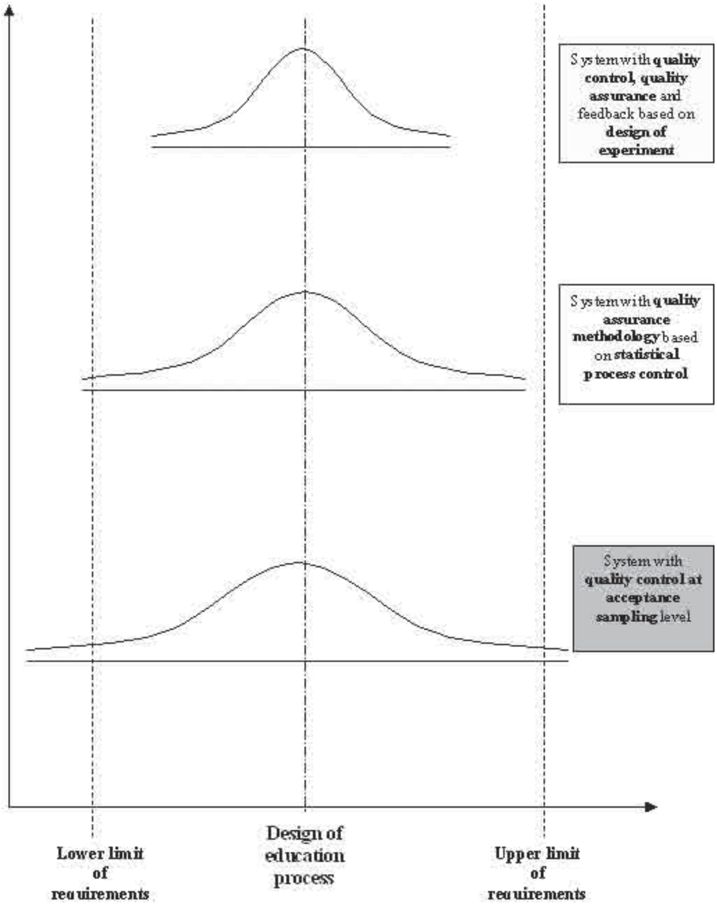


**Figure 4**

The systematic reduction of variability

As in production, to design a realistic usefull quality assurance system it is necessary to have the possibility to **analyze completely the total of the existing learning offers**. It is obvious that in WEB-learning **this is impossible**. In this situation we must appeal to statistics and introduce in the design of quality assurance systems an analysis based on the information contained in a sample from that "population" of learning offers. Depending on the applied statistic methods, we will be in one of the situations described in Fig. 4.

As in production, process acceptance sampling used in quality control will offer the lower level of quality assurance. Better results are obtained with a statistical process control methodology and the best results with design of experiment. We do not have the intention to enter deeply in these methodologies, because they are not the purpose of this paper. We want to mention, for future remarks, that design of experiment is the approach in which systematically varying the controllable input factors and observing the effects that these factors have on the output parameters, offer the key for reduction of the variability in the quality characteristics and determine the levels of the controllable variables that optimize process performances.

We have mentioned the above to emphasize that in statistical control we need to work with controllable input factors. The above analysis stresses that the difference between production process control and education process is just existence of uncontrollable inputs and outputs. IT IS THE FIRST LIMIT OF THE QUALITY ASSURANCE IN EDUCATION PROCESSES.

For the second limit we want to mention the known fact that, in the statistical control, the main problems is the sampling. We will decide about quality drawing conclusions and make decisions about the entire population based on a sample selected from the population. But, in these cases the ***population is known***. In education process control these methods will be limited by the daily increase of the education offer. THE SECOND LIMIT OF THE QUALITY ASSURANCE IN EDUCATION IS THE FACT THAT THE INTERNET DELIVER NEAR UNLIMITED COURSES AND POPULATION IS PERMANENTLY UNKNOWN.

Taking into account the above considerations, with a view to make a step forward in design of the quality assurance system, valuable for WEB-learning education, it is important that: IN PARALLEL WITH THE DESIGN OF A QUALITY WEB-LEARNING METHODOLOGY AT INSTITUTIONAL LEVEL, A QUALITY EVALUATION SYSTEM FOR STUDENTS USE MUST ALSO BE DESIGNED. Being an inseparable and active part of the quality system student must be not only the part which accepted institutional rules as a warranty of quality, but also active parts who operate with own evaluation criteria. Using this proposal, students will be the main tool for selection of the proper education offers from the actual "population" on the WEB.

The dynamic picture described generated by the globalization and WEB-learning lead to set down a set of questions to which an e-audit system must answer for both national and international learning systems. They are presented below classified according to competence fields, [3], [4], [10], [13], [15], [16], [22].

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A) *For the professional-institutional field*

1. Which will be the legal status of the audit organizations accepted both nationally and internationally?
2. How can be commonly assured the jurisdiction for an audit organization that analyses the quality of the teaching and the minimal institutional resources?
3. Will this legal status be a special law, common to all the countries applying it, a ministerial decree supervised by the international organizations that act as guarantors or will there be only bilateral accords?
4. Apart from the task directly connected with the process of learning and teaching will the audit organizations have other tasks (i.e. statistical operations for the governmental level; training of the audit specialists; direct contacts with other national or international audit organizations; research; development in the field)?
5. Depending on a national level acceptance and being created through national laws, will the "autonomy" of the audit organizations exist? Can they be discharged by the same organizations that created them? Can their activity be suspended or modified? Which is the "autonomy" level and where does it define itself so that it would not lose credibility on its actions?
6. Will there be only one audit organization in a country or will it be more that one? How can national systems be audited by external organizations, without infringing the principle of suzerainty?
7. In relation to learning systems and institutions, will the audit process be voluntary – on demand – or obligatory?
8. Will the audit organizations function only for state education or will they act in the benefit of the private or commercial learning institutions?

B) *For the procedural field*

1. Which will be the frequency of the re-audit actions?
2. Will the audit be global, on institutions, on specializations or will it be detailed, focusing on each subjects offered on the Internet?
3. Must the audit candidates be protected for making public unfavourable results or will there be a public announcement regarding the lack of accreditation and the recommendation for suspension?
4. How does an audit finalize? Are there specific signs of accreditation granted? Is there a codifying with inimitable systems or is there a public list of those who are suspended?
5. How will be prevented the abuses and the arrangements?

C) *For the financial field*

1. How will an audit be financed so that the financial independence of the organizations can be assured?
2. Will the audit organizations have the right to establish themselves the level of taxes?
3. Will the audit organizations have the right to lay-off employees so that no connections could be made with the results of the audit actions?
4. Will the audit organizations have permanent employees or will there be limited term contracts with some members of the academic community?

## 4. WEB-learning, is enforced by today shift of skills and changes in social behaviour

Various names are used for our present society: information society, knowledge society, society of services, risk society, post industrial society, prosperity society, post modern society and so on.

The diversity of the above mentioned societies shows that people are living in several societies at the same time, and have the chance to remain in them or change them. In fact one speaks about the same society with many sides. What generates these sides and so many environments? In our opinion ***cycles of change*** determined so many sides. We will present two of these cycles, which we consider have strong influence on the teaching/learning systems in generally and on the WEB-learning methodology in particular.

**The first cycle of change** which we want to present is that of **changes in economy**. It is the cycle which contains two sub-cycles in direct connection with education process. As we observe in fig. 5, there is a sub-cycle of teaching-learning which it put in contact with the new technologies and new content of the education process and will influence economy progress, and a second cycle of training-innovation which represent the progresses made in research under authority of high education institutions or as a result of the work of graduates (human resources) of these institutions.

**Teaching/learning cycle** is located in high-education institutions and has some characteristics:

- It is conservative;
- It has slow adaptation at needs;
- If it is classic face-to-face-till now, it represents the basic production of specialists;

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— If it is long-life learning it is:

- Rapid adaptable at needs;
- Co-operative learning;
- Open at all information from network (broad vision and information);

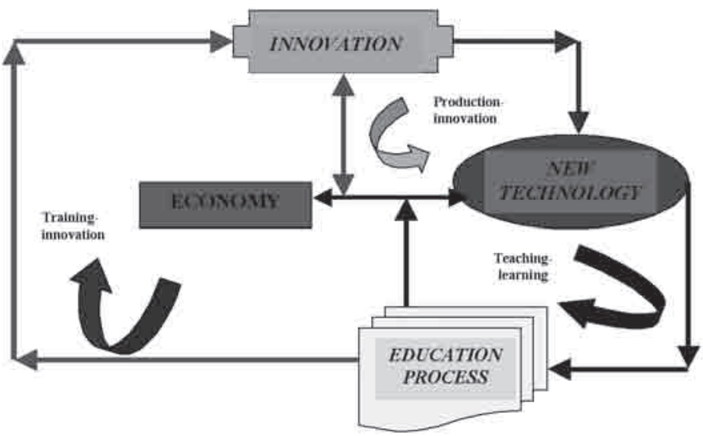


**Figure 5**

Cycle of changes in economy (up to present)

**Training-innovation cycle** has all of above characteristics but has some different locations not only in high education institutions but in research institutes and academies, in engineering companies;

In our opinion, these two cycles which made connections between education process and economy have governed the training improvement. Education was permanently ahead of development so that it is "guilty" of some of the above names of actual society (prosperity, post-modern, risk, services, consumption and so on).

**The second cycle of change** is in connection with social life defined as economy together with socio-cultural environment. What happened in time with this environment? In fig. 6 we try to suggest the sense of changes of it.

In ***"oral culture"*** the base of communication was, is and will be **the voice**. The limits of this culture were DISTANCE and MEMORY. The dissemination of this type of culture was in dependence with memory capacity. The accuracy of the transferred knowledge depended also of memory.

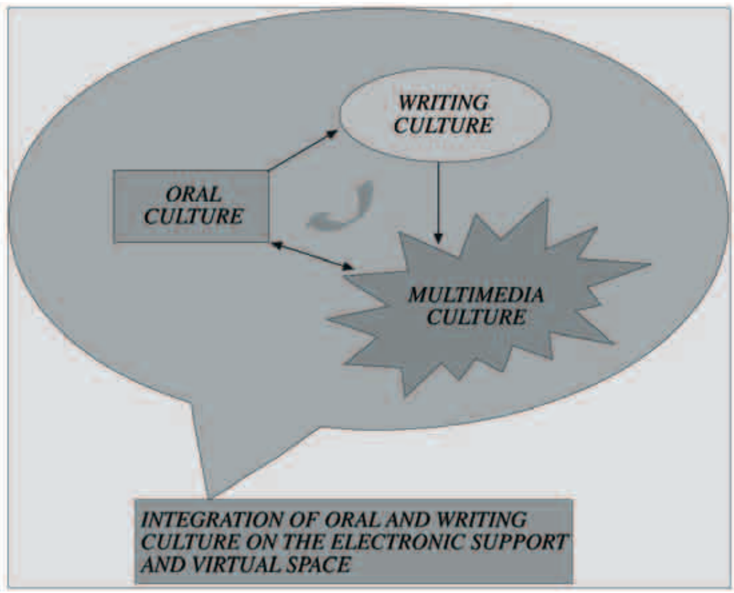


**Figure 6**

Cycle of changes in socio-cultural life

In "***writing culture"*** the **paper support** is the base. The QUANTITY of written materials was the first limit. A single person can not read all of written materials. The second limit was the DISSEMINATION CAPACITY. Even now, existing libraries do not succeed to have on the shelf all printed books do not mention all printed reviews.

In "***multi-media culture"*** proper software's and **electronic support** is the base. NETWORK COMMUNICATION is the first limit. SPEED of TRANSFER is the second limit and ACCESS at software, hardware and network in the third limit.

As we observe in fig. 6 today, all of the cultures were integrated in the virtual space of the multimedia. This statement can be neutral in the first stage. OK is possible to be said, is normal and cheap to transfer all of cultural assets on the electronic environment, [19].

WE WANT TO STRESS THAT THIS NEUTRAL REACTION NEGLECTS ALL CHANGES PRODUCE IN THE SHIFT OF SKILLS AND IN SOCIAL BEHAVIOR.

We will mention briefly some aspects in connection with these changes produced in skills and in behaviour (Table 5).

**Table 5**

| Skill of behavior | Description of the change |
|---|---|
| MANAGER | Is “**typist”** at own laptop and the secretary has other tasks and assumed further duties |
| SERVANTS | **Become technicians** with advanced skills in driving complex washing machines, cleaners, kitchen, interphones etc. |
| TEACHERS | Do not prepare lessons and figures. They prepare powerpoint, multimedia lessons, video-conferences. The **pencil was replace** by software and computer. |
| CORRESPONDENCE | Writing was replaced by **talking correspondence** with or without images. |
| PAYMENT | Instead of pay-office at bank desk we sit in the front of the computer and know to use **e-banking, e-payment, and e-shopping**. |
| DREAMS | We replace the reverie moments after a good book of poetry with **virtual reality** with more power to create different worlds, different cultures, different scales of value, according to reader imagination. |
| LIVING | We stop living at home, town region, we start to live in a **communication system**, we living in a **program segments**. |
| HOMELESS | At classic homeless categories, the new evolution has added new homeless: **“digital homeless”.** I. e. the people who do not accept new media and are not able to handle them |
| PAPERLESS | More and more people prefer to read information’s directly from the screen. Others prefer to printing and after to working on it. The **quantity of paper** used for printing is now an important indicator of evolution and an important **indicator of evolution** in electronic culture. |
| FAMILIES | Before, the sense of development was from the individuals towards the family. Society is developing now from the **family towards individuals**. Men and women work together. Women are marrying later. Every third child is born illegitimate. |
| SCREENAGER | He has two stages: **active** in front of the computer as worker and **passive** in front of the television as consumer |

*Table 5 (Continued)*

| Skill of behavior | Description of the change |
|---|---|
| PARTNERSHIP | The stabie partnership given by the family or working team has change. Now, partnership is determined by **common interests**. If interests are changed, partnership will be cancelled. The parents-in the past-could "order" something to children. Now they must justify it before asking not to order. |
| THE GROUP | In the past-working group was essential both in economy and in education. The new e-learning environment stresses also the group work importance, BUT this is new ones-it is the **virtual group.** These groups are formed under rules of interest not as geographic location. The Internet brought together people from different countries, under the rule of same objective, preoccupation or hobby. They do not know each other in the classic manner. They are a picture, a name a small digital movie. The **new kind of "friendship"** has emerged. |
| VIRTUAL NEIGHBORHOODS | The old importance of **the "place"** which was in the past the base in the neighbourhood definition was change. The new virtual neighbourhoods share the **same "time"** not the same place. |
| INDIVIDUALISATION | Is concentrated in four words: **now (**nobody wants to wait); **here** (capacity to access in network every place and information); **for me (**individualist mentality of the new environment **"computer and I ")** |

WEB-learning is defined as a new methodology in teaching/learning. It has been developed by persons who gain their basic knowledge in the classic education system. For this reason the majority of teaching/learning rules and approaches are transferred from face-to-face learning to the WEB-learning. BUT, the creators do not take into account the above considerations (tab. 5). The WEB-learning methodology must adapt its rules at the above described new environment. We will offer some new rules in accordance with the above emphasized shifts in skills and behaviour with the main goal to be used in the correlation between education process and ***competences establishment***:

- *Teacher does not address his lesson to the class. He speaks with a virtual community.*
- *Teacher as model for the student has disappeared. The models for young generation are from sport, movie, politics or from virtual reality.*

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— *The family help in education has moved to the collaborative teams and tutors.*
— *The selection of students moves from regions to the world.*
— *The courses content is compared with others so that increases the danger to assist at rejection of teachers or even of universities after these comparisons.*
— *The class is not the same during the study years. It can change in content after every course depending on student's objectives.*
— *The tutoring methods become more important than value of the courses. Students are not prepared to develop themselves for a specific goal. So that tutoring, collaborative learning, blended learning has become of real importance.*
— *In four years-the classic period for learning in high education-because of "intensive communication"- the value of the course content is relative. In the mean time the job-which can be defined as final goal of the student-is in danger of becoming obsolete. Which will be the future needs in society-ask the young student? Telecommunications, information technology and tourism-is the answer. So that a lot of students "knock" on these doors in spite of the facts that without food and materials, for example, there is nothing to be done.*

WEB-learning must move from actual definition towards the new ideas which stress a new mentality. The "teaching market" is a notion with expansion throughout the world. In this situation globalization of the "teaching market" imposes the adaptation at different cultures. Globalization of the "teaching market" will stress the individualization of learning. WEB-learning must be developed from certain geographical locations towards a certain "interest's location". WEB-learning must emphasize multimedia culture with integration of new "oral culture" in communications and new "writing culture" in information exchanges.

## 5. A tool for the curriculum design which take into consideration competencies.

If the environment of WEB-learning is so dynamic, it is necessary to have a special tool for curricula design. Each evolution in teaching/learning has started with curriculum design. The starting point of this action are declared needs and requirements, but the practice proved that old curricula had influenced strongly from the new ones. The explanation of this situation consists in the conservative character of classical education and in reserves of the teachers regarding change, who augmented the conservative character mentioned above.

The new tool, which we want to present, is in fact the application of Quality Function Deployment (QFD) for curriculum design and evaluation for restructuring a degree program. This is an analytical tool that allows the curriculum developer to see the entire program with each interaction between different variables and prerequisites. The final result can perform easily benchmarking against similar programs. QFD tool can also be used as a planning tool for dynamic changes of an existing curriculum [6], [7], [8], [9], [11], [12].

Quality Function Deployment started as a set of matrices in Japan in the '60s, evolved quickly into what we know today as QFD. It is a pictorial representation of complex variables, their interactions and translation into details. It works very well in product design where it captures the qualitative needs of customer and converts them into quantitative specifications, and it details these into workable design parameters. The picture allows also introducing weights to all the above and it becomes a complete image of the design process.

Although there are many ways for designing curriculum, two main approaches are used:

— The syllabus approach, which simply considers the course content in terms of topics, subtopics, etc.;
— Another one is the objective approach which considers the learning objectives or what the students will be able to perform/do after delivering to them the course content.

Intensive consultations are carried out within the educational institution (experts, educators, administrators) and outside (surveys, advisory committees, professional societies, etc) in order to cover all requirements for an optimum package.

— The method described in this package uses a combined approach and makes use of QFD as a tool to organize and evaluate the curriculum design variables.

The general model for curriculum design requires three matrices (Fig. 7). A fourth matrix can be used for delivery mode, if required.

The first matrix called NEEDS, lists the customer' needs for which the new program is developed. In order to satisfy those needs, a set of required skills should be developed and, the relationship between the two sets, is evaluated in this matrix. Once validated, the skills can be carried into the second matrix, called SKILLS, to match a set of primary topics. On the next level of deployment, TOPICS matrix, primary topics are broken down into secondary topics, and these now create courses for which instructional hours are assigned.

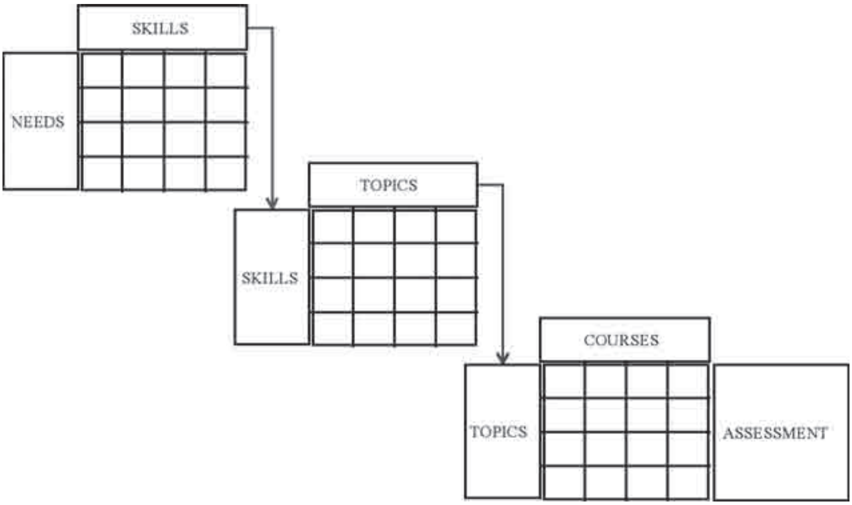


**Figure 7**

General QFD model for curriculum design

The order of entry in the needs matrix is not important; each one is being treated separately. Major sources to identify these needs are strategic economic plans, industry surveys and analyses, trends and think-tanks.

The next step is to generate a list of "skills" (competencies) which are required to meet the needs. The best way to generate this list is using brainstorming. The question to ask is: "what skills are required to satisfy the needs?" There is no need to limit the number of skills because unrelated skills can be removed during the matrix analysis phase. The analysis will reveal what relationship exists between each particular need and skill.

The NEEDS matrix is shown in Fig. 8. The needs were taken from a national paper produced by Ministry of Education and other official sources. As shown, the relationships between needs and skills are complex but very useful for the design process. Different relationship levels (strong & moderate or strong & moderate & weak) can help to map this complexity more easily.

Unrelated skills without any relationship will be removed from the matrix. More skills should be added if there is any need not "covered' by at least two skills. Applying consistently the rule of minimum two skills for each need will generate skills which usually overlap and are related with more need than one.

**INDUSTRY NEEDS**

Relationships

■ moderate

● strong

| INDUSTRY NEEDS / REQUIRED SKILLS | Math ans statistical skills | Applied engineering competence | Practical problem solving skills | Use statistical quality tools | Understand business concepts | Interpersonal relation / communication skills | Understand quality management systems | Use / intepret standards and codes | Use testing / measuring equipment | Innovate / entrepreneurship / regional outlook |
|---|---|---|---|---|---|---|---|---|---|---|
| Develop new product/process/service | ■ | ● | ● | | ● | | ■ | ■ | ● | ● |
| Develop adequate manpower for quality engineering | ■ | ● | ● | ● | | ■ | | ■ | ■ | |
| Support convergence of technology/service | ● | ● | ● | | ● | ● | ■ | ■ | ■ | ■ |
| Create/update national infrastructure (satandards, certification, testing) | | | | | | | ■ | ● | ● | |
| Adopt TQM/ISO 9000 or other quality management systems | | | | | | ■ | ● | | | ■ |
| Develop mindset for higher productivity | | | | ● | ■ | | ■ | | ■ | ● |

**Figure 8**

NEEDS matrix for a Quality Engineering program,
Temasek Polytechnic, Singapore

To generate the primary topics it is necessary to list topics that are required to be taught in order to create the skills from the previous matrix. The list of topics is complete only when each skill is covered by at least two topics ensuring that all the skills are properly addressed. Assigning relationship levels to primary topics has a special meaning and must be done carefully.

The SKILLS matrix shown in Fig. 9 will introduce numerical values to the primary topics based on the relationship level in terms of hours. The hours refered here are instructional hours, such as lectures, tutorial, projects, workshops, laboratory sessions, or any other form of contact hours with students. Again, brainstorming can define the primary topics, which can be large fields of knowledge, such as Mathematics, Mechanical design, etc.

■ **STRONG = 80 hrs**
● **MODERATE = 40 hrs**
▲ **WEAK = 20 hrs**

| **REQUIRED SKILLS** | Mathematics | Special Maths $ Statistics | Statistical quality control | Design of Experiments | Design & Drafting | Metrology | Computers & Programming | Mfg. processes & materials | Electrical & Electronics | Applied mechanics | Instrumentation & Automation | Reliability Failure analysis | Communication skills | Food and Chemical | Business Organization | Human Relations | Quality systems | Industry project |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **PRIMARY TOPICS** | | | | | | | | | | | | | | | | | |
| Total hours: 2500 Estimated hours | 100 | 140 | 160 | 80 | 80 | 120 | 200 | 200 | 180 | 80 | 100 | 100 | 100 | 180 | 220 | 60 | 280 | 120 |
| Mathematical & statistical skills | ■ | ■ | ● | ● | | | ● | | | ▲ | | ▲ | | | | | | |
| Applied engineering competence | ▲ | ▲ | | | ■ | | ■ | ■ | ■ | ▲ | ● | ● | | ■ | | | | |
| Practical problem solving skills | | | ● | | | | ■ | ● | ● | ● | | | ▲ | ▲ | ▲ | | ▲ | ● |
| Use statistical quality tools | | ● | ■ | ● | | | | | | | | | | ■ | ■ | | ● | |
| Understand business concepts | | | | | | | | | | | | | | | ■ | | ● | |
| Interpersonal relation / communication skills | | | | | | | | | | | | | ■ | | ▲ | ● | ▲ | ● |
| Understand quality mgmt systems | | | | | | | | | | | | | | | ▲ | | ■ | |
| Use / intepret standards / codes | | | | | | ● | | | ● | | ▲ | ▲ | | | | | ■ | |
| Use testing / measuring equipment | | | | | | ■ | | ■ | ▲ | | ● | ▲ | | | | | | ▲ |
| Innovate / entrepreneur / regional outlook | | | | | | | | | | | | | | | | ▲ | | ▲ |

| Competences / Needs | Basic Knowledge | Informatics | Network and Grid Technologies | Simulations Technologies | Virtual and Remote Applications | Systems Control and Automatic Control | Remote Control | Remote Sensing | Telerobotics Teleoperation of Mechanic Systems | Human Computer Interfaces Usability Reusability | Online Lab Administration Tools of Remote Works Standards |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Extension of Internet possibilities in learning-teaching for overtake<br>• geographical limits<br>• high costs of face to face teaching | ■ | ▲ | ■ | | ■ | | | ■ | ■ | ▲ | ■ |
| To launch new methods for face at the growing complexity of engineering tasks | | ▲ | | ■ | ■ | ■ | ■ | ▲ | ■ | ▲ | |
| Application of high technology equipments also in SME's | | ▲ | ▲ | | ▲ | ■ | | ■ | | ▲ | ▲ |
| Demands of globalization and division of labor | ▲ | | ■ | ▲ | ▲ | | ▲ | ▲ | ▲ | ■ | ▲ |
| Cover the increasing expensive equipment need for high-tech research | ▲ | | | ▲ | ■ | | | | ■ | | ▲ |
| Need of high qualifies staff to control recent equipments | | ▲ | | ■ | ▲ | ■ | ■ | ■ | | ▲ | ▲ |
| Management and quality assurance | ▲ | ▲ | ■ | ▲ | | | ▲ | ▲ | ▲ | ■ | ■ |

| | Basic Knowledge | Informatics | Network and Grid Technologies |
|---|---|---|---|
| Basics of computer serial and parallel communications | x | | |
| Basics of Internet Communications | x | | x |
| Basics of microcomputer systems | x | | |
| Client server communications | x | | x |
| Virtual reality language and communications | x | x | |
| Programming language for Internet (Java, XML, ...) | x | x | x |
| Internet technologies (software) | x | x | x |
| IP management licensing and legal issues | x | x | x |
| Wireless technologies | | | x |
| Matlab / Simulink | x | | |
| Maple | x | | |
| LabVIEW | x | | |
| Design of Remote Experiment | | | |
| Prototyping experiment | | | |
| Design of analog and digital systems | | | |
| Control system theory | | | |
| Computer aided control system | | | |
| Sensors | | | |
| Multiple sensors systems | | | |
| Digital image processing systems | | | |
| Digital image capture and control | | | |
| Remote control software | | | |
| Control of selected hardware | | | |
| Remote control systems | | | |
| Human factors Knowledge and mental models | | | |
| Ergonomics in remote engineering | | | |
| Project remote experiments managements | | | |
| Standards of tools for Remote work | | | |
| CISCO-basics | | x | |
| LEGO Mindstorm system | | | |
| Lejos system | | | |

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Simulations Technologies | | | | | | | | | | x | x | x | | | | | | | | | | | | | | | | | | | |
| Virtual and Remote Applications | x | | | | | | | | | | | | x | x | x | | | | | | | | | | | | | | | | |
| Systems Control and Automatic Control | | | | | | | | | | | | | | | | x | x | | | | | | | | | | x | | | | |
| Remote Control | x | | | x | | | | | | | | x | x | | | | | | | | | | | | | | | x | | | |
| Remote Sensing | | | | | | | | | | | | x | x | | | | | x | x | x | x | | | | | | | x | | | |
| Telerobotics Teleoperation of Mechanic Systems | x | x | x | x | x | | | | | | | x | | x | | | | | | | | | | | | | x | | | x | x |
| Human Computer Interfaces Usability Reusability | x | x | | | | | x | x | | | | | | | | | | | | x | x | | | | x | x | x | | | | |
| Online Lab Administration Tools, Standards | | x | | | | | x | x | x | | | | | | x | | | | | x | x | | | | | | | x | x | | |

**Figure 9**

SKILLS matrix for a Quality Engineering program, Temasek Polytechnic, Singapore

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Usually, the relationship levels are in a ratio of weak/moderate/strong=1/2/4. Based on the number of hours available for such a program, the relationship levels can receive a numerical value, in this case weak=20 hrs, moderate=40 hrs, strong=80 hrs. The total in each column will define the estimated hours to deliver each primary topic as shown in the column heading.

The TOPICS matrix is used to identify courses by combining topics and to benchmark the proposed program against similar programs. Course constraints are in terms of delivery (semester, term, number of hours) and their content must be related, and in proper sequence to facilitate the learning process.

At this stage curriculum design is like building a house where smaller blocks are better and more flexible. Primary topics can be detailed in secondary topics for an easier analysis and course construction. At the same time, secondary topics will allow a fair and more accurate comparison with other curricula, which otherwise would be difficult and very subjective. Realistic benchmarking should be done using identical or similar components and these are usually not courses but more likely secondary topics.

Following a number of drafts the final product of five Math courses is shown in Fig. 10. Each secondary topic is defined in number of hours of delivery, and the course outlines are detailed in terms of unit and evaluation instrument with weights for the final grade. On the assessment side a comparison with a similar program B is made. The benchmarking offers opportunities for modification and improvement, and allows for incorporating good features from similar curriculum into your own.

In the concrete case of "MARE" Project, made together with CTI-Austria, Limerick University-Ireland, Ilmenau University-Germany and Maribor University-Slovenia, Transilvania University had proposed an application for joint European master curricula design in the field of Remote Engineering and Virtual Instrumentation. It is shown in the above two matrix-NEEDS and SKILLS. It is only a point of view, because as in all curricula only the practice will indicate the correlations between needs-skills and courses. As we will know, without feed back from working market, it is impossible to correlate these two matrixes.

QFD matrices technology can be used for a number of objectives:

— develop a program for the first cycle (Bachelor degree) and a structured second cycle (Master degree) and also a program of continuing education (part-time and distance education) geared for lifelong learning in conjunction with industry needs. The continuing education program can be connected to the mandatory probation job period of a junior engineer.

| PRIMARY AND SECONDARY TOPICS | A AM | B AM | C AM | D AM | E AM |
|---|---|---|---|---|---|
| | 59 | 47 | 75 | 45 | 60 |
| number systems | 4 | | | | |
| methods to solve equations | 6 | | | | |
| methods of solving systems of linear equations | 5 | | | | |
| linear transformations and matrix algebra, systems of linear equations | 6 | | | | |
| identities, inequalities for algebraic and trigonometric expressions | 5 | | | | |
| vector, geometric representations, force, velocity and acceleration | 7 | | | | |
| MS Excel software for graphing expressions and solving complex equations | 5 | | | | |
| word problems into mathematical expressions for solving problems | 5 | | | | |
| transcendental functions and solve related engineering applications | 9 | | | | |
| sequences and series to solve technical applications | 7 | | | | |
| coordinate systems, correspondence between geometry and algebra | | 2 | | | |
| conic sections and quadratic curves | | 4 | | | |
| plane curves representations, calculus in engineering applications | | 6 | | | |
| vectors applications both in plane and in space | | 6 | | | |
| cylindrical and quadric surfaces | | 6 | | | |
| vector-valued functions and space curves | | 8 | | | |
| integration techniques in vector fields | | 12 | | | |
| limits series and functions | | | 2 | | |
| criteria for function continuity in its domain | | | 2 | | |
| differentiation formulae | | | 3 | | |
| function derivative ,tangent and inflexion points, minima and maxima | | | 2 | | |
| applications by applying differentiation calculations | | | 3 | | |
| anti-derivative and rules for indefinite and definite integrals | | | 8 | | |
| integral calculations for a range of applications | | | 8 | | |
| differentiation of transcendental functions | | | 8 | | |
| methods for integration | | | 9 | | |
| problems of multiple integrals | | | 12 | | |
| expansion of functions in series | | | 8 | | |
| solutions of ordinary differential equations engineering applications | | | 10 | | |
| Mathematical models, analytical and numerical solutions, physical systems | | | | 3 | |
| Approximations and errors in numerical methos | | | | 6 | |
| roots of equations, simultaneous linear equations | | | | 12 | |
| processing data , curve fitting techniques, regression | | | | 12 | |
| numerical differentiation and integration | | | | 12 | |
| structure of physical relations, | | | | | 4 |
| dimensionless products and variables | | | | | 8 |
| techniques for dimensional modeling | | | | | 8 |
| constraints and limits of mathematical modeling | | | | | 6 |
| case studies for typical applications of modeling | | | | | 7 |
| descriptive statistics methods | | | | | 6 |
| hypothesis testing for sample with known and unknown variances | | | | | 9 |
| reliability concepts | | | | | 7 |
| predicted life of parts and assemblies | | | | | 7 |

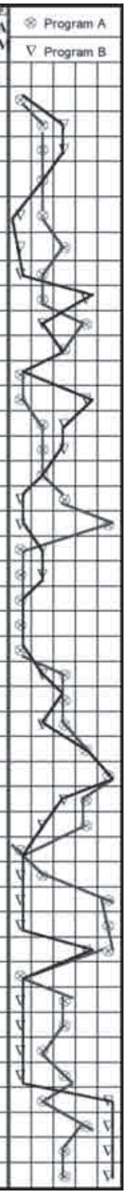


**Figure 10**

Primary and secondary TOPICS matrix for Mathematics, IAMT bachelor program at Conestoga Institute of Technology, Canada

— Benchmarking of different local and national programs, European and other international programs, especially North American programs, become possible in short time.
— An easy way to follow prerequisites not only for entire courses but for primary and secondary topics that are required for two courses running in the same semester preventing delivery duplication.
— A visible and accurate outline of textbooks which may integrate knowledge from more than one discipline.

## Conclusions

1. Bologna Process shifts in emphasis from input to output; it changes the teacher's role from that of an organizer to that of a learning facilitator;
2. The remote experiment is a tool for developing engineering studies providing facilities for a continuous revision of the existing programmes, as well as the creation of new programmes and the improvement in teaching-learning process;
3. The remote experiment increases the employment rate among graduates as a result of shifting the focus from teaching towardsw learning process;
4. The remote experiment has a great influence in acquiring both generic and specific competencies and in coping with the problem of under-equipped laboratories;
5. WEB-learning environment, and the remote experiment in particular, will generate a special design methodology of quality assessment, with an emphasis on the quality of design and the quality of conformance;
6. The main objective of quality assessment in WEB-learning using statistical control is the systematic reduction of variability;
7. The existence of uncontrollable inputs and outputs is the first limit of the quality assurance in e-learning education;
8. The second limit of the quality assurance in WEB-learning is that the Internet delivers nearly unlimited courses and "population" in terms of statistics is constantly unknown/indefinite;
9. The influence of a series of changes triggers major shifts in skills and in behaviour, which further entails new rules in establishing competences;
10. These new rules require new tools/techniques. The QFD methodology for curriculum design is presented, since a correlation is needed between social needs, skills and competences.

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# Assessing e-learning in web labs

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**Abstract**

*Remote Labs (also called WebLabs) allow remote access to expensive equipment, and allow for many different people, from different countries and time zones, to share the same facilities at different times, through the Internet. A second aim of web labs is to to develop low-cost variants of web labs for education facilities in developing countries. But one of the main problems that researchers face when trying to develop a web lab, is that of trying to convince institutional and research boards that web labs are useful, efficient, attractive, and, in sum, worth of financial support. There seems to be no doubt that web labs are cheaper than traditional ones; if they were shown to be at least as efficient, research funds will certainly be available for them. Although researchers have often conducted survey studies to assess the users' opinions and attitudes towards web labs, these studies fail to provide scientific and unambiguous support. In this chapter we provide some suggestions on how to use the scientific method to assess the effectiveness of web labs.*

## 1. **Teaching vs. research labs**

Before we start, let us first clarify that web labs can be understood, and classified, in two main groups: those dedicated to research and those dedicated to e-learning. Nowadays, most engineering web labs are of the second type, but in other disciplines, such as psychology, web labs are equally used for research purposes (see [1] [2]). In the case of research labs, there are obviously many problems in using web labs instead of traditional labs, but there are also many advantages. We have discussed these matters, as applied to psychology web labs, in other publications (see, e.g. [3] [4]; for reviews, see also [5], [6], [7]). Although the differences between engineering and psychology labs are obvious, some of the problems that we encountered and some of the solutions that we proposed could perhaps be of use in the engineering domain as well. As an example, we are finding that using the web to replicate classical, well-known, experimental results in psychology is a critical first step that should be conducted before trusting the web lab as a tool to generate new (and reliable) knowledge. It is possible that readers interested in research engineering web labs may find that some of the ideas developed when implementing a psychological research web lab can be of use to them as well. In the present chapter, however, we will focus on how to assess e-learning in a web lab. That is, we will address the learning issue in the engineering web lab from the point of view of research on the psychology of learning. Indeed, the method used to assess that learning is taking place should not differ as a function of whether the learner (or student or user) is learning grammar or psychology or engineering; The learning process is a general mental process that does not change as a function of what the content of this learning is. It is a mental process that works the same way regardless of whether it is taking place in the web or in a classroom or in the forest. Thus, the important question for our present purposes is simply how to assess that learning has occurred.

Of course, once we are certain that learning has taken place in the web lab, we will also need to perform some additional tests in a real lab in order to make sure that students are able to transfer their competencies to a real lab. Practical lab work is an essential part of engineering education and one argument stressed against web labs is that the students do not learn to use the real instruments, but only web interfaces. Performing some of the tests we will mention below in a real lab will be necessary if we would like to address this concern as well.

## 2. Measuring the learning process vs. measuring the learning outcomes

Most often in the educational system, satisfaction and attractiveness are being assessed instead of learning. Appreciate, however, that students may find extremely attractive an easy going class in which they do not need to work much, and this, of course, does not necessarily mean that they are learning what they are supposed to learn. At best, subjective evaluations on how much students *believe* they have learned are sometimes used. This can be quite misleading. It is not satisfaction or personal opinions, but learning itself (i.e., knowledge and competency acquisition) what we are supposed to assess. Moreover, another problem is that when effectiveness rather than attractiveness is assessed, most often learning is assessed only after the training period is over (e.g., end-of-semester exams). In that case, what we assess is the product of learning, but not the way in which it occurs. In other words, we can assess at that time whether learning has taken place, but not whether it proceeded slowly, continuously, gradually, and so on. It is also true, most often this is the best we can do: we usually have no resources to record the students' progress at all times. But when we design experiments to assess learning in a psychology laboratory we usually need to assess, in addition to the final product of learning, the way in which it occurs; or, in other words, the variables that conform the learning curve. That is, we need to assess those variables that allow us to see the progress of learning (how does learning proceed in one task or another). These variables are those that should show improvement as learning progresses. Certainly, one of the main advantages of web labs is that they allow the teacher to automatically record the students' performance as they learn. This provides an extraordinary advantage over traditional systems, as we can construct a learning curve, which can be most informative of the details of the acquisition process.

Figures 1 and 2 show two examples of learning curves. Figure 1 shows the mean time that students require to complete Task A as a function of the number of training sessions. As they learn more, the time they require to complete the task is reduced. Figure 2 shows the same students performing the same fictitious task, but the dependent variable in this case is the number of problems solved per session, again as a function of the number of training sessions. Note that, although opposite in shape, both the slope and the height of these two curves are highly informative of the learning process and can certainly be used to compare how students learn in one or another situation. Of course, the easiness with which a learning curve can be recorded in a web lab, as compared to more traditional labs or classes is a key advantage that can certainly be used as a strong argument in favor of web labs. Traditional teaching techniques provide very few opportunities to assess the learners' performance while training takes place, whereas in web labs each student's activities can be recorded automatically. However, this is not enough. Even if we can argue that in this way we can assess the whole learning process as it occurs, which is great, we will still need to offer a comparison showing that, at the end, our web-lab students learn more. The next section focuses on this point.

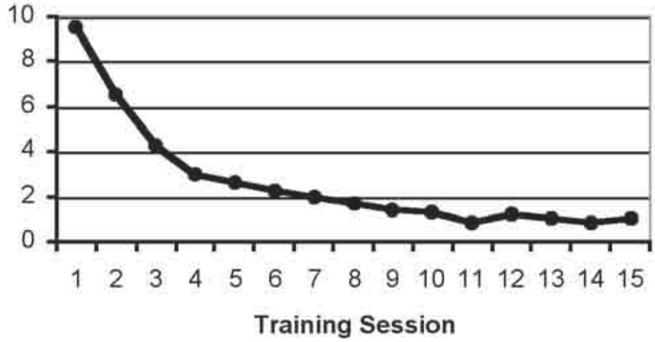


**Figure 1**

Time to complete a given task is one of the most widely used dependent variables to assess that learning is taking place. As learning proceeds time decreases

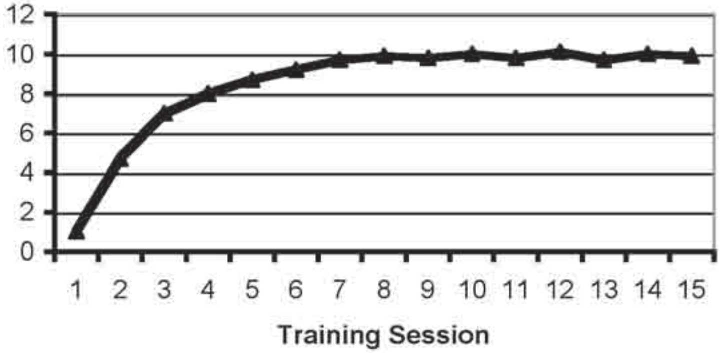


**Figure 2**

Another dependent variable that is widely used to assess the process of learning is the number of problems that the student is able to solve per session (or per unit of time). In this case the curve increases as learning proceeds

## 3. How to design an experimental study

Below we suggest some additional ideas also borrowed from the way in which we usually design learning experiments in the field of the psychology of learning. We believe that this can probably be helpful when assessing e-learning in engineering web labs as well. In brief, the problem of assessing the effectiveness of any specific learning (or e-learning) technique is not different from that of using the scientific method to test whether the probability of a given outcome (in this case, learning) is higher or lower when we use that technique as compared to when we do not use it (all other things being equal). As a very first and very general step, any textbook on scientific methods should be of much help in suggesting many ideas and experiments in addition to (or instead of) the ones we propose here (e.g., see [8]). Nevertheless, it might be helpful to highlight some of the most critical points.

### 3.1. *Defining the dependent variable*

The first thing we will need to do is to clearly define what we want to teach and what we want to assess. Thus, we need to know exactly what we mean when we refer to the "effectiveness" of a web lab (or any other learning tool). Does "effectiveness" mean that students are able to solve this or the other exam after spending x hours in the lab? Or does effectiveness mean being able to make less than x number of errors in a certain task? Or is it being able to develop a complex and independent project in a certain amount of time? Does effectiveness mean for us attractiveness, so that students will report that they are happy with the lab and the professor when they participate in those opinion surveys that all universities run at the end of each semester?… Whatever our dependent variable means for us, we should be able to define very, very clearly. We should be able to spell it out in the form of: "By the end of this course, students should be able to…" Moreover, we should be able to specify how exactly we are going to assess that the students have met those criteria: What type of exam and/or projects do the students need to pass so that we can agree that they have met the objectives we set for the course? This is not something special for the case of web lab's assessment; it is just something very general that should be specified even if we use a traditional lab (or no lab at all) and would like to know how efficient this technique is. There is nothing new so far.

But there are more things, in addition to this one, that we are supposed to test when we introduce a new, innovative method, such as a web lab. Once we know that our students have learned something, the next questions are: How much did our teaching technique contribute this outcome? Was it better than alternative methods? Thus, once we have clearly defined our dependent variable or variables, we will probably want to decide what our comparison (i.e., control) condition or conditions should be. As an example, we may want to assess the same variables both in the remote lab and in the traditional lab in order to be able to compare their effectiveness;

otherwise we will have no comparison to offer, and convincing institutional boards that our method is better (or at least similar) to the old one will be impossible.

### 3.2. *Control groups… or how to discard alternative explanations*

One of the very first things we need to keep in mind when assessing a certain technique (our experimental condition) is that we will always need to assess its effectiveness against a control (or comparison) condition. Our control group must be identical to our experimental group in all variables except for the one we are trying to assess (in this case, the teaching method). This is important because otherwise we will not be able to know which variable is responsible for the results that we observe. Ideally, a single class of students from the same country and university and sharing the same teacher can be divided into two homogeneous groups of students (as similar as possible in factors such as I.Q., academic performance, and all other variables that could affect the results); then each of those groups can be exposed to two different teaching strategies: one using a web lab, the other one, the control group, using a different teaching strategy. Among the many teaching strategies that we could use with the control group, we will quite probably prefer a traditional lab, so that we can provide identical problems for both groups to solve and we can then compare the time they need to solve them, the number of problems they solve per session and so on. In principle, this could do.

There are three possible outcomes for this experiment, and the one that is most frequent and easy to get, like in any other experiment, is the null result. That is, the result that shows that there is no difference between groups. In our case, designing an experiment in which we just test Lab A against Lab B and we observe that there is no difference between them will be just too easy. The problem with showing that there is no difference (i.e., that both types of labs are equally effective) is that this result can be attributed to too many different variables. It can be due, for instance, to a lack of sensitivity in the variables we chose as dependent variables. It can also be due to lack of statistical power in that we used a sample that was too small for the type of effect that we were expecting to show. Or there could be a ceiling effect. In sum, null results are not informative. The best thing to do would be to add a few other groups to this study so that we are sure we will avoid the null result. But of course, there is always the possibility that even if we decide to start by running this simple, two-groups, study, we do not get a null result and we can, instead, show that our web lab is better (not equal) to our traditional lab. Again, this could do, at least in principle.

But we should be aware that even if we are able to show that our web lab is more efficient that our traditional lab our critics will still have some arguments against our study. Perhaps the only thing we are showing when we show that our web lab works better than our local lab is that we have a very poor local lab. This design does not provide evidence that our local lab is effective. The possibility exists that our traditional lab is so bad that students learn nothing in it. In sum, a third group will almost always be needed in which students not exposed to any type of lab (but equivalent in all other respects and receiving all other classes) are being assessed on the same problems. This would allow us to test whether the use of any type of lab in our university (whether remote or local) has any beneficial effect on our students and also whether one type of lab training is better or worse than the other.

Finally, there is at least one more alternative explanation that we will possibly need to discard. No matter how nice the results of the above experiment turn out to be, there is always the possibility that providing students with a computer program in which the experiments can be simulated results as effective (and certainly cheaper) than the web lab. We will not be able to discard this critique with the above study alone. If we also want to discard the idea that simulations are equally effective, a fourth group of students using the best possible existing virtual laboratory (simulation) software will be needed in our study… It might happen that learning through simulations is slower, or it might prove to be equally effective. However, the results of real world experiments (remote or local) differ sometimes very much from the results of simulation experiments (whether local or web-based). As some have argued, for engineers, which use both in their daily work, it is necessary to know these differences. Thus, even if they were equally effective, a web lab could be shown to be quite efficient if it proved superior than a local lab in making students understand the differences between simulations and real world experiments.

### 3.3. *Generality*

It should also be taken into account that assessing the effectiveness of a particular web lab against a particular traditional lab and against a particular group of students exposed to no lab condition but in the same university might be something too specific and with little ecological validity (poorly generalizable). If we wanted to use the results of the study to impress research committees and to advance the future of web labs, then several experiments from several different laboratories should converge on the same results. Alternatively, several researchers from different universities and countries could agree on a common experiment to jointly test the effectiveness of web labs in general. This ideal experimental study should include a large sample of web labs, local labs, no lab conditions, and virtual (simulated) labs (though in this later case, and assuming there is enough consensus among researchers as to which one is the best possible simulated lab software, it might make sense to use just the best one, instead of a large collection of simulation programs This would certainly be a critical piece of research for the future of web labs. Figure 3 shows a fictitious outcome of this ideal experiment.

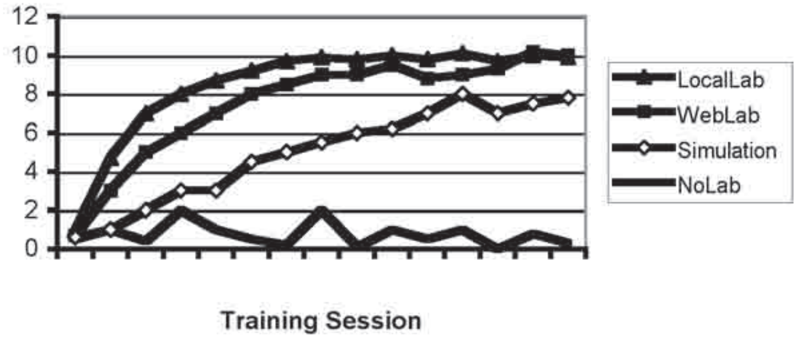


**Figure 3**

Fictitious outcome of an ideal experiment in which the number of problems solved per session in each of ten participating web labs is averaged and compared to the mean number of problems solved in the corresponding control groups (local lab, no lab, and simulated lab condition) in each of the participating universities. In this example, learning in the averaged web lab is slightly slower than learning in the averaged local lab, but equally efficient after a certain number of training sessions. Moreover, statistical analyses should show that the average web lab is significantly better than the averaged no lab condition and the averaged simulated lab condition.

## 4. **Ethics**

There is a matter of ethical concern which we have not yet mentioned but which is closely related to the type of experimental design we have proposed in this paper to assess learning. It is not a trivial matter, as it is something often rose by reviewers of grant proposals. Imagine, for example, that we have developed a new drug that improves people's memory. In order to test the effectiveness of the drug we need to conduct an experiment, giving the drug only to half of the participants and then looking for differences between the memory of those who took the drug and the memory of those who did not. The problem is that some would regard this experiment unethical because it implies giving access to our drug only to half of the volunteers of the study, instead of directly giving it to everybody, so that they all can benefit from the potentially good effects of the drug. Similarly, if we have a web lab that we suspect that will provide enormous educational advantages over older methods, wouldn't it be much more ethical to offer access to it to all our students? Many reviewers will say our proposal is unacceptable!

Our response to this criticism, however, should be clear. If you decide not to run the experiment just because you are sure that the new method *has to* work, then it is trial-and-error what you are doing with your subjects. Every new generation of students (or patients) will suffer the consequences of potential errors in your method. Testing your innovative methods in just one part of your population in order to know, by the end of the experiment, which method is best, is certainly a lot more ethical practice than testing it in the whole population and not even caring about scientifically demonstrating its effectiveness. This being said, however, applying it to the whole population is what you should pursue by all means once you finish your study… *if* you have been able to demonstrate that your method is better than the one at use. You are ethically obliged to do this once you know your method works. Behaving this way is certainly much more ethical that applying the untested method to all possible participants without even caring to run a controlled, experimental test of its consequences.

In addition to this specific problem concerning the use of control groups, there are also many other ethical issues that need to be considered when designing research with humans. Very strict and clear ethical regulations apply in most countries concerning human research. These codes are quite similar to each other and their only purpose is to protect those people that serve as subjects in our experiments (e.g., see [9], [10]). Moreover, there is an increasing international consensus that, in addition to the rules concerning human research in general, research conducted through the Internet presents some peculiarities and should also be subject to additional ethical recommendations (see [11]). These recommendations include things such as how to treat the data of Internet research subjects, which should be absolutely anonymous and voluntary, and how to make sure that the participant has read and understood the information regarding the purpose and method of the study before accepting to send his or her data to the experimenter. It is important to take this into account because it means that we cannot use any type of software to get personal or other type of data from the students without their consent. This means that some type of data which are often collected just because it is customary to do so (e.g., gender, age, name…)

should simply not be included in the design of our study (unless they are very important with respect to the study we need to perform, and, in this case, we will need to ask the students directly to please provide these data –and be aware that their response is not necessarily true).

## Concluding comments

We hope to have shown that there are no fixed rules on how the scientific assessment of web labs should look like. The number of groups that will be needed for the study should be carefully discussed beforehand, and the variables clearly defined. The experiments will always need to be designed as a function of what our question is, what we would like to conclude from the study, and as a function of the type of alternative explanations that we would like to discard. As shown in one of the examples above, if we want to show that both web labs and local labs are effective as compared to no labs, but we want to also be able to discard the critique that a good simulated lab computer program would have done as well as our web and local labs, then we need to include such simulated lab condition in our study. In other words, the most important point when deciding how to design the experiment is to make sure that we are using the right groups as a function of what we want to conclude from the experiment and the critiques that we would like to discard.

The other thing that should have become quite apparent in the preceding paragraphs is that one experiment will probably not be enough. For each study that a scientist might publish to demonstrate that Treatment A is better than Treatment B, critics of this idea will be able to publish several other studies in which, looking at other variables, or including different controls, they could reach different conclusions. Thus, it is important to make sure that our experimental study addresses, beforehand, as many of those possible critiques and alternative explanations as possible. If this requires using so many control groups that the experiment will become unviable, then we should consider the option of running several concatenated, smaller studies. When reported together, they should be able to tell a whole, consistent, solid story about the effectiveness of web labs.

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# SECTION III

# Remote labs development issues

# Issues in WebLab development: security, accessibility, collaboration and multilinguality

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**Abstract**

*WebLabs are novel eLearning applications with a promising future. Once a WebLab reaches the state of stable prototype, there are still many issues that have to be taken care of before the system can be considered a first quality web based application. In the following pages some of these issues are addressed, and pointers are given so as to take the first steps in dealing with WebLab security, accessibility, collaborative development and multilinguality.*

## 1. WebLab security

For years WebLabs have been developed and maintained by professionals working in laboratories. These professionals, mainly electronic and control engineers, are experts in hardware or microelectronics, but not necessarily in system administration and security issues.

Supported by the new European Higher Education Space influenced by the Bologna Declaration, WebLabs are growing in importance [1]. In a near future, they should be able to leave the restricted laboratory scope to be included in the infrastructure of the University and be considered as an important part of e-Learning for certain subjects. Of course, to reach this point the WebLabs should meet some requirements including the fulfilment of the security policies that already apply to the rest of the IT services offered by the University.

In most cases, the collaboration of the IT Department of the University will be a must to be able to apply the existing knowledge of system administration and security to the WebLab servers. Of course, lecturers and laboratory technicians will still be responsible for the contents and the hardware side of the system.

Experts agree: Absolute security does not exist. It is not difficult to find peculiar phrases supporting this affirmation like "The only truly secure system is one that is powered off, cast in a block of concrete and sealed in a lead-lined room with armed guards - and even then I have my doubts." [2]

However, we should always keep in mind some good practices and recommendations related to network and both server and client-side security.

### 1.1. *Server-side security*

Once WebLab servers fulfil the security policies defined by the IT Department of the University, we should not have to face unpleasant situations like servers which are not up to date with missing security patches/hotfixes or old packages installed, servers with unnecessary services running or servers with unconfigured or badly configured services.

Of course, a secure operating system is an important and necessary piece of the total system security puzzle, but it is not the only one. A highly secure operating system would be insufficient without application-specific security built upon it [3]. To achieve this objective, security should be considered an essential matter during the design stage of the WebLab.

Another important aspect of security WebLab developers should work in is the integration of the user authentication system with existing Lightweight Directory Access Protocol (LDAP) or RADIUS servers. We can find good examples of this integration in the Virtual Internet and Telecommunications Laboratory of Switzerland (VITELS) [4].

This practice would help not only to avoid situations like the use of weak passwords as the complexity requirements established by the IT Service for the LDAP server apply, but also to prevent attacks against the usually less secure local database keeping usernames and passwords.

Finally, we should not forget about physical security of the servers supporting the WebLab. If possible, servers should always be physically located in an access-controlled environment to prevent locally performed attacks.

### 1.2. *Client-side security*

A large number of the analyzed WebLabs require the use of Java applets, ActiveX controls or a Flash player on the client side. This necessity could be considered a drawback for different reasons.

First of all, some of this plug-ins may not available on every platform. Secondly, any plug-in might require administrative privileges for its installation. In some scenarios a student may fail when trying to access a WebLab using a computer of the University because of a lack of privileges.

Even though Java Virtual Machine or ActiveX controls are claimed to be secure having their own security models like Java sandbox or digital signatures, malicious or flaw executable code may exploit security breaches [5].

It's not easy to find WebLabs working without any plug-in installation required. WebLab-Deusto, a pure HTML/JavaScript system programmed with AJAX [6], is a good example of these so called thin clients. In the thin client model, all the code is executed by the server side of the system while the client only performs simple display functions.

### 1.3. *Network security*

The TCP/IP protocol has been criticized as having been designed with no thought of security. There are a number of serious security flaws inherent in the protocol suite. In spite of this, we can always use mechanisms that ensure confidentiality and integrity of data transmitted over the network and allow us to establish secure and encrypted connections between the clients and servers.

We have some examples of the use of Virtual Private Networking (VPN) mechanisms to encrypt network communications between the client and the server in off-campus accesses [7] [8]. VPNs are used to create an encrypted tunnel for the traffic sent between the student's computer and the VPN server, allowing students to make secure connections to Campus Lab environments.

More extended is the use of secure HTTP (HTTPS) which includes the Secure Socket Layer (SSL). SSL is used to provide secure channels and its use is mainly recommended. This is specially important in pages that work with sensitive information like the login pages that perform the authentication of the username and password.

Firewall technology has become the most popular defense to prevent illegitimate traffic inside the corporate network. Configuration of firewalls is a formidable and error prone task. This emphasizes the need to restrict or reduce complexity at the firewalls [5]. The use of not well-known ports in addition to http (80/tcp) and http-ssl (443/tcp) ports is quite usual in existing WebLabs and could be considered a security flaw because it adds complexity to the management of the firewalls.

Taking all this into account, it seems clear that security is should be considered an essential matter during the design stage of the WebLab, and that the installation, administration and maintenance of the servers which support the WebLab should be left to the IT Service of the University. It is advisable to locate the servers supporting the WebLab in a restricted access area and to integrate the authentication of the web server with existing LDAP servers in the organization. One should minimize the number of not well-known open ports required to allow communication between the server and the clients, and try to use thin clients, leaving the code execution work to the server side of the system.

## 2. **WebLab accessibility and usability**

Web applications have changed the lives of many people nowadays. Communication, access to information, learning, commercial transactions and entertaining, among others, have changed dramatically with the introduction of the Internet and Web based applications. These technologies are specially promising for disabled people, who can now perform for the first time many of the above activities. For example, until now a blind person could not access the information in a daily newspaper, except by having someone reading it out loud. Today the combination of Web versions of newspapers, and screen reading software allow blind people to read the news, assuming that the newspaper has designed its Web version without accessibility barriers [9].

Accessibility barriers that WebLabs and other Web based applications should avoid include graphical information without a textual description, mouse only interaction, or multimedia content without adequate captioning. The Internet has the potential to increase the access of disabled people to all kinds of learning tools, but accessibility barriers reduce or completely eliminate this potential, leaving disabled people as helpless and discouraged as before.

Developers should take into account that disability is a relatively common condition. As many as 10% of the population suffer some kind of disability, and we could add to these certain temporary situations in which the ability to carry out certain tasks is decreased: medication, noisy work environment, use of old technology (slow devices, small screens), etc. It should also be mentioned that optimizing the access to Web applications for the disabled often improves the use of the system for all users.

Other reasons to consider this issue seriously are, in the case of commercial applications, the fact that a company can hardly ignore 10% of their potential customers, and for many other developers, legal issues that might make conformance to certain accessibility guidelines mandatory.

### 2.1. *Laws and regulations*

Accessibility of information technologies has not been regulated until recently. In the case of Spanish legislation, we can mention the "LEY 34/2002, de 11 de julio, de Servicios de la Sociedad de la Información y de Comercio Electrónico" (LSSICE), in which the issue of accessibility of the elderly and the disabled to information delivered through electronic media is addressed. The LSSICE states that Public Administrations should ensure that information they offer in their Web pages is accessible for disabled and elderly users by the end of the year 2005. Public Administrations should also require that all new Web pages they finance, fulfill that accessibility requirements mentioned above. This law also recommends to promote the adoption of accessibility guidelines in the case of service providers and hardware and software vendors [10].

More recently, the "LEY 51/2003, de 2 de diciembre, de Igualdad de Oportunidades, no Discriminación y Accesibilidad Universal de las personas con discapacidad" (LIONDAU), enforces universal accessibility and no discrimination. This law makes it compulsory to gradually make all products and services accessible for all, and gives deadlines to carry out all necessary adaptations. In the case of computer products and services -WebLabs included- there is a 4 to 6 year deadline for new developments (8 to 10 years for existing products) to fully apply all accessibility requirements. The National Government assumes the responsibility to study the accessibility of products and services of major impact in the population, and to develop a curriculum in Universal Design for the education of future professional in various fields, including information technology [11].

Many other countries around the word are also regulating accessibility of information technology products and services, and this could apply to WebLabs developed in those countries. New laws and regulations appear frequently, so the interested reader is advised to consult legislation of his home country. The following are just a few examples:

- Germany: "Gesetz zur Gleichstellung behinderter Menschen und zur Änderung anderer Gesetze vom 27. April 2002".

— Italy: "Legge Stanca - "Disposizioni per favorire l'accesso dei soggetti disabili agli strumenti informatici 2004".
— Portugal: "Resolution of the Council of Ministers Concerning the Accessibility of Public Administration Web Sites for Citizens with Special Needs".
— USA: "Section 508". It is part of the Rehabilitation Act of 1973 and it has been one of the most influential legislations in developing awareness in accessibility issues. It states that all computer applications used by the US Federal Government should be accessible to disabled people "unless it would pose an undue burden to do so".

### 2.2. *Web Accessibility Initiative*

The World Wide Web Consortium (W3C) stresses the importance of accessible Web content, and promotes the Web Accessibility Initiative (WAI) to develop resources to make Web applications, including WebLabs, accessible to people with different disabilities.

The WAI has developed guidelines which are considered the standard reference for Web content accessibility and can provide different materials and resources to help in the motivation of developers and the development of accessible sites. Guidelines and materials are developed by working groups formed by companies, governments, disability organizations, research institutions, etc. so that a high degree of independence is achieved [12].

Web accessibility includes not only Web sites and applications that people with disabilities can interact with but also Web clients that can be used with screen readers and other assistive technologies and Web authoring tools that promote production of accessible Web pages.

### 2.3. *A first evaluation of Web accessibility*

One of the resources that the Web Accessibility Initiative offers is a list of actions to take if one wants to verify for the first time the accessibility of a WebLab or any other Web based application. These steps are not intended to fully check the conformance to any set of accessibility guidelines, but to get a general picture of the accessibility status of the application. The steps combine manual checks with the use of semiautomatic tools, and can be easily performed:

1. Selection of a representative sample of pages of the site. One should select the most probable entry pages of the site together with some

pages rich in graphics and tables, or having complex functionality and interaction.

2. Check the selected pages with different browsers, carrying out the following actions:

   — Do not show graphical content and verify that a descriptive text for each image is available
   — Do not activate sound and verify that all audio information has a text equivalent.
   — Modify text size and verify that all changes are properly shown on the screen, and that the applications are still usable at larger font sizes.
   — Test the application with different screen resolutions and window sizes.
   — Change the video equipment to monochrome mode and verify that the contrast among different colors is acceptable.
   — Try to access all the functions in the application through keyboard interaction only.

3. Check the selected pages with special browsers [13] such as a voice browser or a text browser. Verify that the information available using this special browsers is equivalent to that obtained through a conventional graphical user interface. It is specially important that information scanned sequentially is meaningful, because that is the way many of the adaptive technology tools work.
4. Use two or three automatic accessibility evaluation tools [14] and check the results. Web accessibility evaluation tools can be a useful resource and reduce the effort of carrying out evaluations. They can help prevent and eliminate accessibility barriers in Web applications, but they cannot detect or eliminate all accessibility problems, and some checks and verifications should be done manually. These tools cannot judge by themselves the degree of accessibility of a Web application, but can greatly help a human operator in performing this task.

### 2.4. *WebLab usability*

The design of any interactive information system involves achieving a high degree of usability. This general term includes different aspects such as effectiveness, ease of use, efficiency, learnability and safety.

How can we increase the usability of our WebLabs? The only way is to develop the system with the final user in mind from the very beginning

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of the process, approach that has been termed *user centered design*. A good place to start getting used to the terminology and techniques of usability is the collection of papers available at [15]. This author puts forward an interesting method, from the practical point of view, which he calls *discount usability*: it is basically a set of low cost techniques that can be applied to any software project. He argues, not without reason, that if one wants to do things very thoroughly, one might not do them at all, and so, it is better to do some simple usability engineering than none.

One of these simple techniques is called heuristic evaluation, and it consists of performing a systematic inspection of a user interface design checking its conformance to recognized usability principles [16]. With just three or four evaluators, the benefits to cost ratio is maximum, and many of the areas of improvement of the user interface can be detected at an early design stage. Normally, evaluators do not communicate until the inspection has been carried out, and only afterwards they combine their findings.

Although the *think aloud* method has traditionally been executed by psychologists and human factors experts, a simplified version can be done by any of the members of the development team of a Web based application. Just get some representative real users, and select some typical tasks to be done with the system. Observe user interaction carefully and insist that the user speaks out all his thoughts. Any difficulty that a user encounters is a hint to a possible design flaw. Accessibility and usability of WebLabs are important factors that must be considered from the first stages in development. Solidarity, economical and legal issues should lead developers to take these factors into account in order to develop better WebLabs for an even wider audience.

## 3. **Collaborative development models and WebLabs**

There are different development methodologies in the so-called Collaborative Development Model such as Agile Methods, Pair Programming (Extreme Programming) or Community Based Development models. The following section will be focused in the relationship between WebLabs and Community Based Development model comparing it against the traditional Closed-Source Software model.

### 3.1. *Why should WebLab development model be collaborative?*

Several successful Open-Source projects are based on a Collaborative Development model that keeps them alive and prevents from reaching a level of complexity which could be difficult to manage. Many analyses can be found in literature, [17] [18] [19] [20], describing it and summarizing Community Based models' characteristics: growth speed, creativity, simplicity, fewer defects and extensibility/modularity. Nevertheless, there are also some limitations of Collaborative models [21] and tensions between Community Based model and Corporate Culture or Agile Methods could arise [22].

#### 3.1.1. Community-based models' strengths

*Faster system growth*. Analyses of big Open-Source projects such as Mozilla or Apache [18] [19] (Mockus *et al*., 2000, 2002) confirm their strong growth ratio, corroborated later by [17] Paulson *et al*. (Paulson *et al*., 2004) by calculating a percentage of growth in each release.

*Creativity*. It is not easy to measure creativity but [23], [24] and [17] agree that is a typical characteristic of Community Based Development model and it can be estimated by examining the number of features or functions added by release.

*Simplicity*. Both modularity and simplicity help a project to be extensible and that is a main prerequisite for a successful Open-Source project [23]. Code complexity can be measured using well-known metrics, but as Paulson *et al*. noticed, the complexity of some systems may be found in its data structures rather than in its code.

*Fewer defects*. This characteristic is very controversial and there are several studies defending each point of view: [19] and [22] state that Open-Source community is more responsive in identifying and fixing defects; in the other hand, [25] argues that high quality only applies to some projects, those with good code review and those with good authors, Open-Source is not inherently better or safer. It may be related with software project's lifecycle and amount of developers. As commented by [17], Open-Source projects need to be in a fairly developed state to be successful [23] [26] [22].

*Extensibility/Modularity*. All successful Open-Source projects have been designed allowing to be extended easily without having to change core functionality. [23] shows successful examples such as Linus Torvalds' Linux and Larry Wall's Perl, where their feature-set have been evolved in response to the needs of their users.

These characteristics may be merged: by making the users of a product into code developers, you speed debugging, improve quality and gain specialized new features that may eventually turn out to be important to a wider audience [23].

#### 3.1.2. Limitations of the Community Based Development model

Community Based Development model's characteristics are not present in every stage of a project's lifecycle. Both Open-Source and Closed-Source approaches begin in a similar manner: [23], [26] and [22] suggest that it must be something that can be run and tested by developers and contributors, otherwise commented characteristics will not arise.

Besides, Community Based Development process is usually radically different from Corporate Culture: volunteer and non-volunteer work mixed, work is not assigned, no explicit system-level design, no project plan, schedule, list of deliverables, etc. [19].

Other Collaborative Development Models can also conflict with Community Based ones mainly in communication issues [27]):

- Adapting to remote communication: instead of face-to-face verbal communication rigorously controlled, informal communication using e-mail, IRC, Instant Messaging, etc.
- Managing internal and external communication: many contributors may be in other countries speaking other languages.
- Relinquishing control: instead of controlling the direction and development style of the project, share the control with other members of the community.
- Delivery schedules: instead of using fixed time cycles, deliver when the deliverables are useful and stable.
- Good citizenship: there are underlying, sometimes unwritten, rules when participating in the Open-Source Community that must be understood.

Tensions not only come from one side, Open-Source developers are usually not comfortable with Corporate Culture [27]:

- Monitoring of developers: due to voluntary nature of the collaboration, Open-Source developers are not used to be monitored.
- Fixed time schedules: Return-On-Investment and cash flow cycles instead of typically ad-hoc cycles of Open-Source projects ("It is done when it is done").
- Quality Assurance Processes: in spite of the "Linus's Law" ("Given enough eyeballs, all bugs are shallow"), there are no formal Open-Source code review processes normally, and code reviews may be shown by Open-Source developers as an extension of the "monitoring of developers" requirement.

All these arguments may be analyzed and discussed in order to decide if it is a good moment to release a software project as Open-Source or

Free Software. According to this section, it is very reasonable to release as Open-Source a working WebLab that can be run and tested in order to speed up its growth, increase its creativity and extensibility and ease bug fixing, but not before having adapted WebLab's development into a Community Based Development model.

### 3.2. *Common tools used in Community Based Development models*

When the number of developers involved in a project increases, having a source code managing systems becomes mandatory. Big Open-Source projects like Apache or Mozilla have their own source *"forges"* typically implemented using a Concurrent Version System (CVS) or a SVN [19]. Not so big projects have their source code forges hosted in SourceForge.net or savannah.gnu.org. Designers of SourceForge.net [28] started the portal with the Community Based Development model in mind:

— Minimize administrative work.
— Maximize communications and collaboration.
— Preserve project knowledge.
— Make it easy to establish projects and recruit experts.
— Find and leverage existing code.
— Do all of this on a global scale.

Nearly as important as managing project's source code is managing its bugs. Big projects like Apache use Problem Reporting Databases and Mozilla developed its own problem tracking system called Bugzilla [19]. Smaller projects manage them using communication services of their source forges or by email.

TODO lists are widely used in Open-Source projects, sometimes related with bug tracking and fixing, but mostly to provide a rough idea about what to do next [29], serving as a "map" rather than a "script" which coercively determine actions in a fixed order.

Documentation and communication are the base of collaboration. Project's extensibility depends on a good developers' documentation and fast and easy communication channels. Community Based projects use wiki-pages for collaborative documentation and translation to many languages, blogs of developers (usually syndicated in a "planet", like planetkde.org), mailing lists where decisions are taken, IRC or IM (Gtalk, Jabber, etc.) meetings, or even MUD (Multi-User Dungeon) systems (Globus Toolkit developers use it, really) to decide which will be the next common step.

### 3.3. *Common features in a WebLab that can be reused*

When developing a WebLab it is obvious that *"one size doesn't fits all"*, but there are some common features which are difficult to develop, need much time to be fine-tuned, or can be developed easily by a distributed group (i.e. internationalization). Those ones are perfect candidates to be implemented collaboratively.

Analyzing several WebLabs [1] we have found some examples of typical features that could be considered:

— Authentication module: nearly every WebLab needs an Authentication module and It is not easy to develop a good one, there are security issues (i.e., SQL Injection attacks), interoperability problems, etc.
— Reservation module: usually a WebLab is a valuated resource that must be well assigned and scheduled.
— Traffic Shapping module: network access speed is often a problem for IT staff and professors (both sides).
— Web Controls module: in each WebLab there are similar hardware (i.e. webcams, oscilloscopes, etc.) that must be controlled by a web application. Browsers' compatibility issues can be fixed in a clean and centralized way, and AJAX can be used in order to minimize network traffic.
— Multilingual Support module: it may be difficult to develop a portable multilingual support module, but at least having a common glossary is a good idea in order to avoid confusing terms and misconceptions.

### 3.4. *Is my WebLab using a Community Based Development model?*

Developing a software project using a development model is not a binary question, there are many degrees between a community driven project and a totally closed one. These questions may help to analyze if your remote lab is using a Community Based Development model or not:

— Has my WebLab been developed by many people working together?
— Has my WebLab been developed using code of other projects?
— Is my WebLab's code managed using a CVS (Concurrent Versions System) such as subversion (SVN)?
— Do I use a Open Source/Free Software License in my WebLab?
— Is our WebLab's code downloadable freely from Internet by anyone (i.e: at sourceforge.net)?

- Is our WebLab's code is in other organizations / universities / companies and that brings us synergy?
- Do we use a mailing list to manage contributions, installation issues, problems about our WebLab?
- Do we use a wiki-page to manage internationalization ("i18n"), contributions, installation issues, problems about our WebLab?
- Does our WebLab's development team contribute with patches for projects used to develop the WebLab (i.e: contributions to Apache project if WebLab is based on Apache)?
- Every time I need a new feature in our WebLab, do I develop it on my own?

If you have answered most of these questions affirmatively, your WebLab may have been developed under a Community Based Development model, and some typical characteristics of the model can be assumed.

## 4. **Multilinguality in WebLabs**

Internationalization and localization [30] [36] are complementary processes aimed to adapt a product (mainly software, but also web content as a specific case) to users of any nation or culture. Internationalization, also known as "i18n" (due to the 18 letters omitted), may be seen as the first stage of the process, seeking to prepare the product to serve any user worldwide, or at least users of several nations and/or cultures, but in the way less dependent on these. Localization (known as "l10n" for a similar reason) is the second stage, in which the product is prepared specifically for users of concrete countries, regions and/or cultures [37].

Most of the efforts of internationalization and localization lay in the user interface, but their development is pervasive, that is, it has strong relations with other parts of a software application. This is dramatically true for the specific case of web content, due to its nature, purpose, and universality, so today it is mandatory to consider i18n and l10n as key factors from the very first stages of the overall design of a complex web site.

Internationalization and localization originates from the language point of view, i.e. the need to offer a product in a (widely) known language or in the user native language, but it is important not to think that internationalization is merely "translating a content to English" and that localization is only "translating that content to other languages as Dutch, French, Spanish or Japanese". Now, i18n and l10n involve, apart of the language, many other social, economic, and cultural aspects: date/time calendar and format (including time zone), currency and numbers formatting, measure units, names and titles of people and organizations, addresses and telephone numbers, government assigned identities (such as personal ID, passport, or Social Security numbers), legal issues, and so on.

The key question today is to understand that "language translation" (or better, "multilingualization" or "m17n") is only one of the efforts to be carried out in the process of making available a product to a wide range of users, probably the most expensive of the efforts, but one that must be embedded in the overall design of a product verifying i18n and l10n guidelines [31] [38].

### 4.1. *Multilingualization*

Thinking specifically of a web site, it is true that the multilingualization task has some particularities. The key issue of a web site (as distinctive of a classical software application, for example) is its typical dynamic behavior: a web site changes more or less continuously, indeed "very" continuously, with frequent addition of new contents/functionalities and/or modification of existing ones. So, it is necessary not only to make a good design of the site, but also to plan carefully the strategy that will cope with the site's dynamic behavior along its life-cycle.

Designing the web site with internationalization and localization issues in mind allows to fulfill most of the requirements at the development stage, and there should not exist significant efforts to be done during the life-cycle of the web site.

But content translation, as the main subtask of multilingualization, extends not only to the development stage, but also to the whole life-cycle stage, and indeed with a significant stress: every new content or either every content change have to be translated to the site's languages. For this reason, and given the expensiveness of the translation efforts, former assertions become almost a law: it is necessary an integrated good design, and it is necessary a site's administration tool supporting, among others, translation task.

### 4.2. *Standards, platforms, tools*

Given the requirements above mentioned, design and development of a web site should take into account several key technologies. First of all, the use of international standards is almost mandatory, not only for content mark-up, visualization, or dynamic behavior, but also for character sets (UNICODE, ISO 8859, etc.), content encoding (UTF, etc.), languages and locales (ISO 639, ISO 3166, RFC 3066) and so on.

Second, the selection of the web development platform is a key factor from the practical point of view. Obviously, this selection must take into account the main purpose of the web site to be developed, but the fact is that there are web platforms that integrate some or all of the internationalization, localization, and multilingualization issues, and that, in that case, they normally provide support to make easier the administration task to cope with the life-cycle evolution of the web site.

Third, specifically for the multilingualization objective, there are several tools, most notably "gettext" (GNU Project, Free Software Foundation) [32], oriented to the multilingual content management, that allow not only to store and classify texts in several languages, but also to reuse and to obtain little variations of existing ones.

## 4.3. *The translation task*

Content translation task has specific needs, as it has been said before, because it extends normally to the whole life-cycle of the web site, but also due to the fact that it is a complex task that frequently (if not always) involves the work of "different" people with "different" purposes. Obviously, the grade in which this imposes strong requirements on the web design depends on the nature and purpose of the web site, but it may be interesting to look at the most complex case (a big text-centered multilingual web site, for example, an enterprise or institution) to see the solution.

In a medium or big organization, (web) contents development follows a certain workflow from the stage of writing to the stage of final publication. This workflow is indeed more complex when the contents have to be multilingual. Managing this complexity involves three (almost) orthogonal aspects.

First, it is necessary a basic mechanism of "version control" that keeps track of the different steps of content development, and not only in the original language, but also in the other languages versions.

Second, there are different "roles", or functions, of the people involved: writers who develop original content, translators who do the translation, proofreaders who must validate it, managers who must approve publication.

Third, the contents themselves should be assigned several "properties" informing of their "state", that, on the first hand, take into account the stage of development/translation (with values as draft, translated, revised, approved), but on the other hand, that could reflect different kinds of relations, as publicability (confidential, shared, public) and others. It is important not to confuse state with version control, although there are obviously several similarities: version control should be seen as a low-level mechanism, whereas state is a high-level property.

Given that, the workflow should define the procedures to be carried out for the development of the (multilingual) contents, making the processes to be done explicit for the different agents involved (roles), the conditions and subsequent changes of the contents state, and the mechanisms of communication needed for the tasks.

For that reason, extending that said in former sections, depending on the textual nature of the web site, it may be convenient to select a web development platform that allows for text content development and translation management, or else, at least to have a minimal support tool and a set of procedures that could cope with the complexity of the translation task. As an example for the last, among others, wikis are means of collaborative work that implicitly have some of the functionalities explained, and that can be used with a little control in a structured way to implement the processes involved.

### 4.4. *The multilinguality test*

The Multilinguality test consists of a list of features that a software should fulfill to support services and resources in more than one language or locale on the Web. See also localizability testing [33] [34] [35] [39] [40].

Basic check list:

1. Was your website planned to be multilingual before it was designed and implemented? Y N
2. Did you analyzed and selected the developing platform bearing in mind localizability? Y N
3. Is it sensitive to user preferences set on the Language-Options menu? Y N
4. Do language symbols follow international standards (ISO 639, etc.)? Y N
5. Does it support input of texts in any language via UNICODE? Y N
6. Does it have a multilingual content management tool (eg. gettext or similar)? Y N
7. Can it cope with date, currency and other language or locale sensitive issues? Y N
8. Does it support version control? Y N
9. Does it allow for different content management roles (writer, translator, proofreader)? Y N

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10. Does it account for publicability issues (draft, private, approved, revised, translated, etc.)? Y N

The last 3 requirements refer to workflow.

## Conclusion

A WebLab, and any other web based application, has to deal with various issues in order to move up from the state of stable prototype to that of a high quality application. Among these issues we can mention security, accessibility, collaborative development and multilinguality

The security of the WebLab should be taken care of by the IT Service of the University, and it should be considered an essential matter during the design stage of the project. It is important to minimize the number of open ports required to allow communication between the server and the clients, and try to leave the code execution work to the server side of the system.

Accessibility and usability of WebLabs are basic factors that must be taken into account from the first stages in development. Legal, economical and solidarity reasons should lead developers to consider accessibility and usability in order to develop better WebLabs for an even wider audience.

WebLabs, can benefit from collaborative development by having many people working together in the project, and using code of other projects. The potential audience of the system can be increased by using Open Source/Free Software License and by making it downloadable freely from Internet by anyone (i.e: at sourceforge.net). Different technologies like mailing lists or wikis can help with the management of contributions, installation issues, etc.

In today's globalized world, multilinguality is increasingly important, and this issue should be considered from the very first stages of development. Developing platform should be selected bearing in mind localizability. Standard technologies should be used when possible (for example, ISO 639 for language symbols or text input via UNICODE). Other problems to be solved include date, currency and other language or locale sensitive issues.

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# Remote Laboratories from the Software Engineering point of view

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**Abstract**

*Remote Laboratories or WebLabs constitute a first order didactic resource in engineering faculties. However, in many cases they lack a proper software design, both in the client and server side, which degrades their quality and academic usefulness. This work analyzes and selects the best software technologies to implement the client and server sides in a WebLab.*

## Introduction

This chapter is going to focus on the software part of Remote Laboratories, avoiding other issues of WebLabs, such as hardware, academic, and so on. The software of Remote Labs is often underestimated by the designers of the Remote Laboratory, resulting many times in poor quality software with many drawbacks in availability, security, scalability, maintainability, and so on. This chapter selects the best strategy to design a Remote Lab taking into account all the parameters that, in our opinion, best qualify a WebLab.

Section 2 shows why it is important for the development of Remote Labs to pay attention to the software side of the project requirements. Section 3 describes the experience of the University of Deusto in developing WebLabs, which will be the basis for in sections 4 and 5 to review some interesting technologies that can be applied to Remote Laboratories, both in the client (section 4) and in the server (section 5) sides.

## 1. Experts needed from the beginning

Imagine that a faculty is interested on building a Remote Lab. The designers may simply start building such small Remote Laboratory with a couple of students using only one platform, only one hardware experiment, and no security consideration. As "it already works" they can think that they can then move this WebLab to different subjects with hundreds of students accessing maybe dozens of experiments of different types, probably designed by different designers. However, this would not be possible. To achieve such deployment scenario, the Remote Lab should have been well designed and developed from the beginning in order to allow for easy deployment and good maintenance. In essence, the system should be modular enough to be used in different experiments and platforms.

On the other hand, the system will inherently be exposed to the Internet, with all the security implications; possible vulnerabilities in the system could allow attackers not only to gather sensitive information, but also to damage the experiment itself. Unfortunately, the experiments often impose platform restrictions to the student (a experiment which needs some software that will only be available under one platform, for instance). Obviously, whenever possible the system should not impose any restriction, or, in the worst case, the fewer restrictions the better. However, WebLabs are usually promoted and designed by Electronic or Control Engineers who naturally tend to place more attention on the hardware side than on the software side. The problem is that when the designers realize that software experts are needed in the project, it may be too late, because maybe the problems found in the design are so severe that a redesign of the system from scratch is required.

## 2. WebLab-Deusto Experience

The University of Deusto has been working on the WebLab-Deusto Remote Laboratory since 2001. Initially, it was focused on programmable electronic devices, but today it is being used in four subjects and it supports experiments based on CPLD, FPGA, PIC microcontrollers and GPIB instrumentation for hundreds of students. The main point of this section is not to describe WebLab-Deusto but to briefly show the accumulated experience in Software Design applied to Remote Laboratories [1] [2].

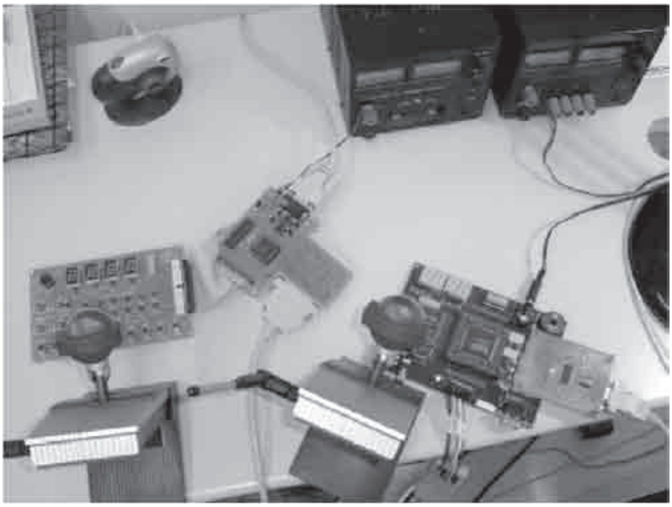

**Figure 1**

WebLab-Deusto

Historically, WebLab-Deusto has followed a parallel evolution to the one experienced in software. Figure 2 shows the evolution experienced by the architectures of WebLab-Deusto.

The rich experience of the University of Deusto in terms of Remote Laboratories software development is summarized in Fig. 3 and in the following two sections describing the client and server side.

## 3. **Client side**

The client-side in a Remote Laboratory is the software that the user of such laboratory employs. Depending on the experiment, this client may need to send a file to the Remote Laboratory server, view a real-time video of what is happening in the Laboratory, return to the user a file with the

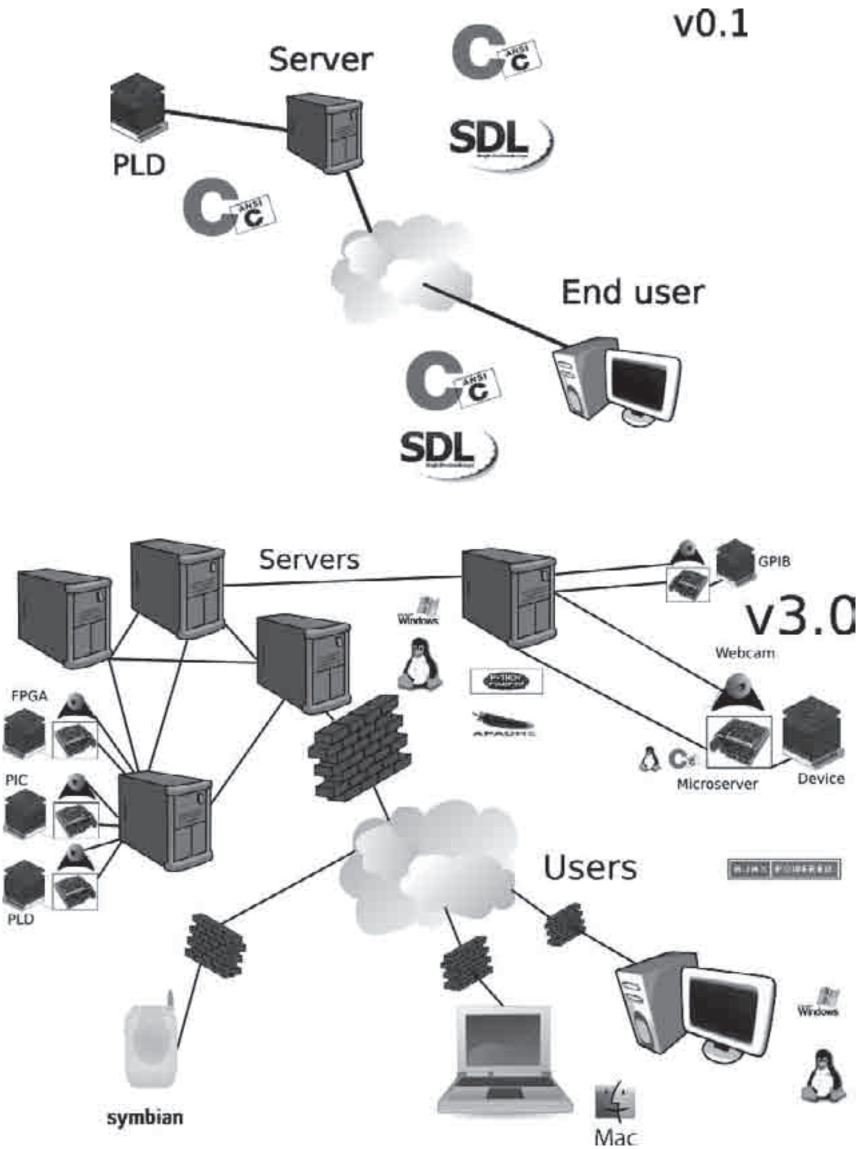


**Figure 2**

WebLab-Deusto Software Architecture Evolution from v 0.1 to v 3.0

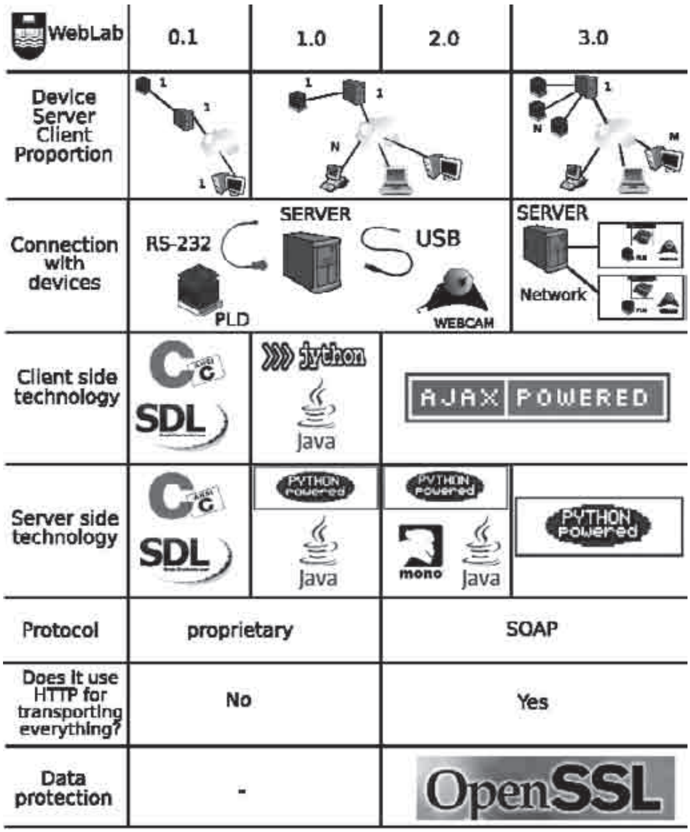


**Figure 3**

WebLab-Deusto Technology evolution

results of the experiment, interact with the experiment, or to provide other functionalities.

The client should avoid unnecessary restrictions on the user. On one hand, if all the functionalities are provided through an accessible web, it might be a much better option than providing an application which requires a lot of software: any user through a web browser will be able to see the accessible web page, while in desktop application case, it will only work in some platforms (only on Microsoft Windows, or only in Java Environments, for example) and only if the supporting software has been previously installed.

### 3.1. *List of technologies*

A wide range of technologies can be applied to the development of Remote Laboratories clients, from the thinnest accessible web page to the heaviest application. The applications could be classified into two main groups:

- Desktop applications: those run in the user's desktop computer.
- Web based applications: those accessed by a browser in the user's desktop computer.

A desktop application can be almost anything, it can be developed in many languages (C, C++, Java, .NET, Delphi, Python…) and over different platforms, and it may have few restrictions. However, those applications are less portable and more intrusive than the web based applications, because they usually have access to the system just as regular applications that the user launches, and many of them are programmed for one concrete operating system, and usually requiring an installation process. Anyway the quality of a desktop application depends on itself. The most interesting point of desktop applications is the flexibility they provide: they usually can do many more things than a web application can do. Since, in principle, they do not usually have restrictions, the designer can explore some possibilities, such as making use of 3D graphics or getting integrated in the user's desktop. This is something web applications usually do not provide, or they did not until very recently with the arrival of the Web 2.0 approach.

The present work will focus mostly on web applications since they provide other interesting features that desktop applications do not provide, like maximizing portability or ensuring that they are not going to be intrusive. Under this point of view the technologies can be classified into two categories:

- Intrusive applications. Regular desktop applications and some forms of web-based applications are intrusive, since they require the same access privileges as the user launching the application on a machine. They are usually call intrusive because they can access the client's hard disk, read any file in the computer (as user of client's computer), read, write any file the user (as user of user's computer) can write, or open as many connections to the outside world as a user can, for instance.
- Non-intrusive applications are those which warranty the user that the application is not going to access any system resouces which may damage the hosting host. This way, the user can safely run the

application without worrying about security or privacy, because the application will not be able to read the information from any file of the hard disk that the user does not explicitly choose, the application will not be able to introduce any kind of virus in the system, and so forth.

The main problem with intrusive applications is security. Applied to a Remote Laboratory developed by a University, the students will download the desktop application from the server of the Remote Laboratory, and they will have to trust not only the Remote Laboratory development team, but also they have to trust that nobody has broken into the desktop of these developers where the code of the application is, they have to trust that nobody has broken into the server where the application is, and they have to trust that the network they are using to download the application is secure enough. If any of these asserts fail, someone will in fact be breaking into the students' computers and perhaps the University will have some responsibility. Non-intrusive applications are obviously clearly preferred in security terms.

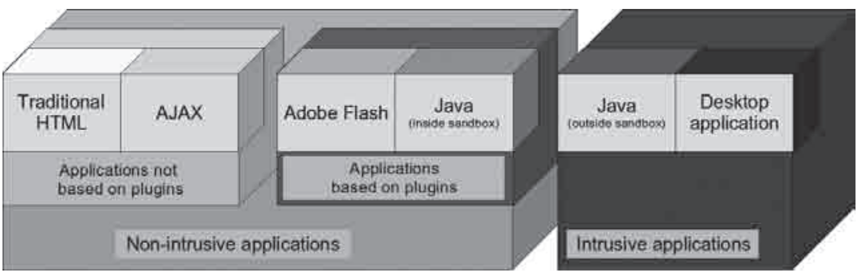


**Figure 4**

Technologies classification in the client side

According to Fig. 4 it can be said that the more powerful a technology is, the less universal it becomes. From this point of view, the best strategy is the one that makes a WebLab universal. This chapter analyses the different technologies to select one of them. Previously it can be said that the discussion in the client side for WebLab-Deusto was between AJAX and Adobe Flash, and AJAX was finally selected because it allows WebLab-Deusto to be used for "all students" and not only for some of them who have previously installed the Flash player.

### Desktop applications

Desktop applications are mostly intrusive applications. Non-intrusive desktop applications can be built in Java or .NET environments, where the user can change the security policy of the application in order to avoid the application to access the hard disk, for example [3] [4]. Anyway, the security of a desktop application depends on the quality of the developing team. Thus, these applications can not be analysed in general and they will not be taken into account in the next sections.

### ActiveX

Java and ActiveX are probably the most powerful systems in terms of flexibility among the web applications technologies, but ActiveX only runs under Microsoft Internet Explorer and its applications are intrusive applications (although they ask the client to confirm that he allows them to execute the application as intrusive applications). These facts make ActiveX applications closer to desktop applications than to pure web applications.

### Java applets

Java, on the other hand, is a powerful platform to develop Rich Internet Applications. In order to use Java, the client needs to have the Java Runtime Environment (JRE) installed [5].

The good point of the JRE is that it can be installed in many Operating Systems, and it can be embedded in multiple web browsers. The bad point of the JRE is its availability: there are different versions, and if the designer develops the Java client (known as Java applets) for JRE 1.5, it will not run in the client's machine if it has JRE 1.4 installed.

The problems derived from JRE versions increases when using different platforms: Sun Microsystems, creator and designer of Java, supports some popular platforms (Microsoft Windows for x86 and x86-64 architectures, Linux for x86 and x86-64, and Solaris for x86, x86-64 and SPARC architectures), but neither Mac OS or Linux on Power PC architecture (the architecture that Macintosh computers used to have) are supported [6]. So if the client bought a Macintosh, using Mac OS or Linux he would not be able of installing Sun Microsystems' JRE. The client could use Apple's JRE implementation in Mac OS, and IBM's JRE implementation in Linux over Power PC, anyway. The problem here was that these implementations took more time to be released. Thus, whenever Sun Microsystems released a new version of Java, many developers would move to the new version, and, until these implementations would support the new version, the software developed by these developers would not be able to be used from a Power PC computer. This is changing anyway, due to the fact that Apple does not sell any Power PC anymore (they moved to x86 architecture [7]), and that Sun Microsystems' Java implementation is now Open Source Software [8], so the availability in other platforms might change in the near future.

Another availability problem is that, since Java applets are not a popular technology anymore (it used to be years ago), people tend not to have the JRE installed, so the user of the application will have to download the JRE and install it before running the application. This can be a real problem if the client is in a restricted computer (such as a cybercafé, or probably the computers of the University, where he does not have an administrator account). Also there are compatibility problems between Virtual Machines of Sun and Microsoft

An interesting point of Java is that when an applet is running, it runs in a *sandbox*: it is not, by default, an intrusive application. It does not have access to the hard disk, it can not establish connections to other computers (except for the server which provided the applet), and so on. The problem is that when the experiment requires the user to send or download a file, the sandbox becomes the problem. The designer has to choose between sending the file in other technology (like basic HTML), or avoiding the sandbox (turning the applet into an intrusive application). Another solution is to develop a mixed application (using both technologies), but, although it is possible to call Java applets' methods from Javascript and Javascript functions from Java it is not usual. It is better to choose another technology, or, if there are key reasons to use Java, then just escape from the sandbox or sign the Java applet. However, signing an applet requires that the signing organization pays for a third party certification authority.

### Adobe Flash

Adobe Flash (formerly called Macromedia Flash until December 2005 [9]) is now the leading technology for RIAs (Rich Internet Applications). The user of an Adobe Flash has to install the Adobe Flash Player, which will interpret byte-code found in files in the SWF format. Once the Adobe Flash Player is installed, the applications made in Adobe Flash will be non-intrusive cross-platform applications with many capabilities: video, real time video, audio, development in ActionScript, access to web services, and even access to files in a non-intrusive way (when accessing a file, the user chooses the file). The potential Adobe Flash has for graphics and animations, as well as to access web services, providing a non-intrusive approach makes it suitable for developing Remote Laboratories.

The use of Adobe Flash is widely spread, and it is available under many platforms (Microsoft Windows, Linux, Mac OS [10]). Anyway, this availability is relative, because today no platform is supported under 64 bit architectures, which is quite a big drawback. Also, version 7 has been the only one supported under Linux (while in Microsoft Windows version 9 was already supported) by mid-January 2007 [11]. The other problem with this version is that there is only one big provider, Adobe, and their only implementation is proprietary software. For example, in December 2006, a security bug was found in the Adobe Acrobat Reader, which is extremely widely used in the Microsoft Windows world, so every web site which had a *pdf* file had a potential security problem in terms of someone stealing the session of a client of that website [12]. This kind of problem might also happen if a security bug is found in the Adobe Flash Player.

### AJAX

The big star of the last two years in Rich Internet Applications is AJAX [13]. AJAX is the combination of several existing web technologies (XHTML, Javascript, CSS, DOM…) with a new component: XMLHttpRequest. This component allows calling asynchronously XML Web Services from Javascript. This is why AJAX is actually the acronym of Asynchronous Javascript And XML.

The big point of AJAX is that all the components, except for XMLHttpRequest, are standards that the web browsers already support. So, if any web browser implements this new component, AJAX applications will automatically work in that web browser. AJAX is a new technology based in current standards.

This is a very interesting issue, since this makes AJAX the most portable platform of the ones explained up to this point that supports interactivity with the server. There are many implementations of this set of technologies, under most platform and architectures since wherever there is a web browser, AJAX applications are going to run. This way, even web browsers for Mobile Devices, such as the Opera mobile web browser in many mobile devices [14], latest versions of Microsoft Internet Explorer for Windows CE, or the new Open Source Web browser that Nokia includes in many of their devices support AJAX. So, with no extra effort at all, AJAX applications will run even in mobile devices.

Big companies as Google or Yahoo started releasing their new advanced web applications in AJAX, like Google Maps, Google Mail or Flickr. Since then, many platforms for AJAX development were released, so AJAX now is being used in many web applications. The new Google Docs and Spreadsheets [15] are especially remarkable, since Google is exploiting the user experience capabilities of AJAX to provide users a new way to write documents in an web based Office Suite, in a collaborative way (two users can be writing the same document at the same time, and the changes made by the other user will automatically appear in the screen).

AJAX itself does not provide video or audio capabilities. For small videos with no sound where a slow frame rate may do the job, refreshing an image could be enough, and this way, many Remote Laboratories could be completely based on AJAX, but if the Remote Lab needs high video and audio capabilities the application must integrate a specific function based in Adobe Flash, for example.

#### Traditional HTML applications

Traditional HTML applications are web applications which only use the classic well known web standards such as XHTML, HTML, CSS, etc. It does not have by default any capability of interaction with the server, video, or audio. Anyway, if the web page follows web standards, it will work under any standard compliant web browser.

Furthermore, there is much work placed on web accessibility (based on web standards), making possible to develop an accessible web application that will allow disabled people to use the web page. This is something quite difficult to do with all the technologies mentioned above, except for Adobe Flash which provides, since Flash Player version 6, accessibility functions for developers to use [16].

### 3.2. *Choosing a technology for the client*

The question after explaining these technologies is: Which technology should be used for a concrete Remote Laboratory? The answer to this question is to explore the technologies, starting with traditional HTML applications, and to ask oneself: can the Remote Laboratory be used with this technology? One should consider using a traditional HTML application better than an AJAX application, and using an AJAX application better than an Adobe Flash application, and an Adobe Flash application better than a Java applet, and so forth. In each case, while the latter might have more capabilities and might even provide a better user experience, it is going to lose in terms of availability, portability or accessibility in comparison with the former.

Table 1 summarizes the possibilities of the technologies for designing the client. The characteristics analyzed in the table are:

— *Paradigm:* Is the technology used the current paradigm for new rich applications?
— *Cross platform:* Does the application run under different Operating Systems?
— *Intrusivity:* Are permissions asked to the user for accessing the hard disk, establishing connections, and so on?
— *Providers:* Is it possible to use tools developed by different providers?
— *Installation required:* Does the application require software installation such as virtual machines or players?
— *Price:* Can the tool be used for free?
— *Mobile devices:* Will the application work on mobile devices?
— *Flexibility:* Have the technologies capabilities for developing applications under different contexts?
— *Accessibility:* Can the application be used by disabled people?
— *Developers communities:* Is there a big community of developers behind the technology?
— *Available network protocols:* Network capabilities of the technology.
— *Development tools:* Are there powerful tools for working with this technology?
— *Standarization:* Is the technology based on standards?
— *Bandwidth:* How much bandwidth does the application need?
— *Audio and video:* Can audio and video be used with this technology?
— *Acceptance by Web Browsers:* Is the technology part of the Web Browser?

Analising numerically the results of Table 1:

— AJAX is numerically the most valued technology.
— Looking at the most important aspects, AJAX is also more valued (see Table 2).
— If the application needs audio or high quality video, at least Adobe Flash is required.
— If interaction is required, as usual in Remote Labs, traditional HTML must be discarded.
— Java Applets are similar to Adobe Flash in most of the issues, but they lose in terms of availability.
— ActiveX is not recommendable for Remote Laboratories development because it does not provide anything useful that the other technologies can not provide, and it presents problems in terms of availability in different platforms.

**Table 1**

Analysis of the client side technologies

| | Java Applets | Adobe Flash | AJAX | HTML | Active X |
|---|---|---|---|---|---|
| Paradigm | *** | **** | ***** | **** | * |
| Cross-platform | ** (1) | **** (2) | ***** (3) | ***** (3) | * (4) |
| Intrusivity | *****/* (5) | ***** | ***** | ***** | * |
| Providers | *** | * | ***** | ***** | * |
| Installation required | ** | *** | ***** | ***** | * |
| Price | ***** | *****/** (6) | ***** | ***** | *** (7) |
| Mobile devices | ** (8) | ** (8) | **** (9) | **** | ** (8) |
| Flexibility | **** | **** | *** | * | ***** |
| Accessibility | ** | **** | ** | ***** | ** |
| Developers communities | ***** | ***** | ***** | ***** | ***** |
| Available network protocols | ***** | ***** | **** | ** | ***** |
| Development tools | ***** | *** | ***** | ***** | *** |
| Standarization | **** | *** | **** | ***** | ** |
| Bandwidth | ***** | ***** | *** | ** | ***** |
| Audio and video | *** | ***** | ** | * | ***** |
| Acceptance by Web Browsers | * | * | ***** | ***** | *** (10) |
| Grading | 56 | 57 | **65** | 64 | 45 |

1. While the Java Virtual Machine is available under several Operating Systems, it is not possible to assume that every user has installed it, even less if the developers of the Remote Laboratory are using a modern version of Java.
2. It is common to find Adobe Flash Player installed. Anyway, today it is still not possible to find it in 64-bit architectures.
3. It is possible to assume the user will have a web browser installed.
4. It only works under one web browser, available only under one Operating System.
5. Depending on if the developer tries to work out of the sandbox or not.
6. The user does not need to pay for the Adobe Flash player. Developers will have to pay if using the editor provided by Adobe to create the Remote Laboratory, although there are free alternatives.
7. ActiveX requires having Microsoft Windows, which is not free.
8. With restrictions and depending on the device.
9. It may work out of the box if using some AJAX enabled browsers, like the Opera web browser, Nokia OSS Web Browser or Internet Explorer.
10. ActiveX is only part of the browser in Microsoft Internet Explorer.

For a specific WebLab, the designers can select the requirements of the WebLab in the Table 1 and analyse them, or even the designers can add new characteristics to the Table. For instance, the Table 2 shows the comparison between Adobe Flash and AJAX for the development of WebLab-Deusto. The most suitable technologie for the WebLab-Deusto requirements is AJAX

**Table 2**

Analysis of the client side technologies for WebLab-Deusto

| | Adobe Flash | AJAX |
|---|---|---|
| Paradigm | **** | ***** |
| Cross-platform | **** | ***** |
| Intrusivity | ***** | ***** |
| Installation required | *** | ***** |
| Mobile devices | ** | **** |
| Development tools | *** | ***** |
| Audio and video | ***** | ** |
| Acceptance by Web Browsers | * | ***** |
| Grading | 27 | **36** |

Anyway, among all the treated technologies, the approach that is experiencing a faster growth is, by far, the AJAX approach. More and more, especially inside the so called Web 2.0, new Internet applications are using AJAX as the technical engine of the client software. The advantages it provides in terms of availability, independence from a unique provider, fast load speed and integration inside traditional web pages, make it very suitable to be seen as the first technology to use when interaction in a web page is needed. The main drawback of AJAX for Remote Laboratories development is that it does not directly provide audio or high quality video capabilities, which can be provided by adding an Adobe Flash application or Java applet which supports this. Since both Adobe Flash and Java applets are interoperable with AJAX, the integration of these technologies in an AJAX application can become trivial. Google Mail, for instance, is a complete AJAX application which supports online conversations, and it uses a little Adobe Flash application for playing sounds each time someone sends a message [17]. Everything in Google Mail, except for these sounds, will work on a web browser without Adobe Flash.

### 3.3. *Developing the client*

Each of the approaches explained in the previous section has, at least, a couple of tools. For example, the traditional HTML applications and the desktop applications can be built on every general purpose programming language. There are also many tools that are helpful in applet development. In the case of Adobe Flash, there is, of course, Adobe Flash. There are also dozens of Javascript libraries available for AJAX development, and many toolkits for integrating AJAX in different existing web development platforms. So, the designers can choose among a lot of developments tools: Google Web Toolkit, OpenLazslo, AJAX.NET, AJAX for PHP, etc. The first two are going to be described in detail.

The recently open sourced Google Web Toolkit [18] [19] provides the developer an Application Programming Interface with several widgets and controls written in Java, and the developer writes the whole web application in Java. Then, the Google Web Toolkit will compile the client of all this application to an AJAX enabled client.

Anyway, a very interesting platform for Rich Internet Applications development is OpenLaszlo [20]. OpenLaszlo is an Open Source platform that provides the designer an Application Programming Interface available from the LZX programming language (the OpenLaszlo programming language, which is an XML dialect, can define the user interface, beeing the accept and callbacks methods written in Javascript). Once the designer writes an application in this language, he will compile it to Adobe Flash so users will be able to access the application with the Adobe Flash Player installed, just as any other Adobe Flash application. The most interesting point of OpenLaszlo is that, since version 4, they will support multiple runtimes. So, in the same way he can compile the code written in LZX to Adobe Flash, he can compile the same LZX code to an AJAX application. And, in the same way, the designer will be able to compile the same code to Java ME (Java 2 Micro Edition; applications written in Java for mobile devices). And he will be able to compile the same code to other runtimes that someone may develop the in future [21].

Right now, this is not possible because version 4 has not been released yet. But the AJAX compiler is already supported in the beta versions they have released. And Sun Microsystems (the creators of Java) is working together with Laszlo Systems (the creators of OpenLaszlo) in the Orbit project, which is the codename of the project that will allow LZX to generate J2ME code [22].

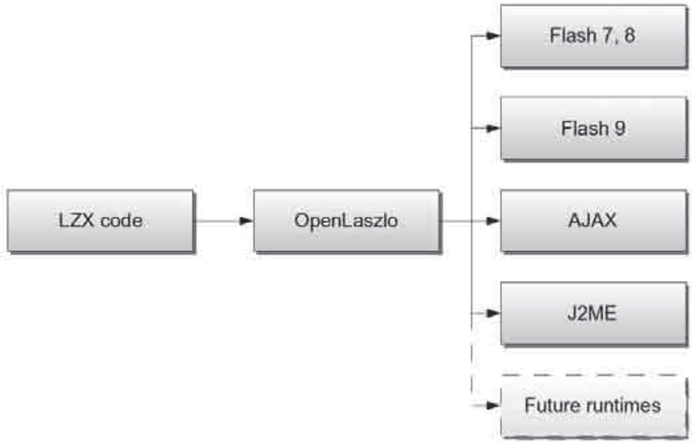


**Figure 5**

OpenLazslo platform

So, whenever this software is available, the designer can write the code in one unique language (LZX), and he will get the advantages of the AJAX and Adobe Flash approaches by having a client for both platforms with no extra effort. He can even choose which version of Adobe Flash he needs (version 7 might be more interesting than version 8 if the designer wants to support most Linux users right now, for instance). And he will actually have support for Java enabled mobile devices also with no extra effort.

## 4. **Server side**

Although a very important part of the Remote Laboratory is the client and the technologies associated to it, the biggest part of the project is for sure, the server side. If the server is good but the client application is poor, the whole system will be poor, but if the server is poor, it does not matter the quality of the client, because the whole system will be poor.

The problem is that the decision of the technologies used in one place can make the technologies used in the other more or less suitable, and depending on what characteristics needed in the client, some characteristics will be imposed in the server. In the beginning of the project, the overall architecture must be designed. For instance, if using Google Web Toolkit or OpenLaszlo, the designer will need Java in at least one part of the server, and it would be recommendable to continue using Java in the rest of the server for integration.

These dependencies on the server side are not such a big problem. Demanding a dependency in the client side forces every single user to install that dependency, but demanding a dependency in the server only forces the system administrators to install these dependencies on deployment, and to maintain that software. Anyway, some dependencies should not be taken lightly, especially if these dependencies are highly coupled to the server software and they are not cross-platform. If the designer develops the Remote Laboratory server under the Microsoft .NET Framework, and this software can not run under Mono (an Open Source Multi-platform Development Framework that is partially compatible with .NET [21]), then the Remote Laboratory will depend on Microsoft Windows (although the clients may use other Operating Systems). If the designer needs to deploy his servers under Linux at some point in the future, even in a punctual situation (a laboratory that runs under Linux, for example), it will be a problem. Loosely coupled systems may not be such a problem, because, depending on the concrete case, it might be possible to find software that does the job in other platforms. For example, if the Remote Laboratory has a piece of software that retrieves the video from a Webcam and places it somewhere in the hard disk, and this software has nothing to do with the rest of the system, it can perfectly be Microsoft Windows dependent and then use other piece of software that does the job under Mac OS, and another piece of software that does it under Linux, if no cross platform software is found.

Anyway, good design does not depend on the technology used. And there are just too many technologies available for server development, so it just does not make sense to analyse the technologies in the same way some client technologies were analysed in the previous section (see Table 3). A technology can make it easier to develop a secure, scalable, maintainable server, but this will only happen if the developer uses the advantages of the technology and if the designers of the application work enough on the design. Python, Java and .NET are three of the most used technologies for this kind of developments.

The chosen technology for the WebLab-Deusto development is Python [24], because it is a very powerful dynamically typed programming language, which has a strong open source community in its background. It was chosen because it allows very fast development, being very suitable for rapid prototyping. It is being used internally in Google, Yahoo, Industrial Light & Magic, NASA, and others [25]. Even Microsoft has developed a Python interpreter for their .NET Framework called IronPython [26], and there is also a Python interpreter written in Java, called Jython [27].

**Table 3**

Analysis on technologies for the server side

| | Python | .NET | Java |
|---|---|---|---|
| Cross-platform | ***** | * (1) | **** |
| Price | ***** | ** (1) | **** (2) |
| Developers Communities | ***** | ***** | ***** |
| Development tools | *** | ***** | ***** |
| Development speed | ***** | *** | *** |
| Web Services libraries | ** | ***** | ***** |
| Language features | ***** | *** | ** |
| Robustness | *** | **** | **** |
| Dynamism | ***** | **** | **** |
| **Marks** | **38** | **32** | **36** |

1. There is a popular Free and Open Source cross platform development framework led by Novell called Mono, which is in many ways compatible with Microsoft .NET Framework. If the Remote Laboratory works under Mono, license costs will be decremented and it will be able to be used under different platforms.
2. It depends on the tools and framework used.

## Conclusion

Using the experience obtained developing WebLab-Deusto since 2001, the paper has analysed different strategies to develop a WebLab from the software point of view -server and client sides- avoiding specifically the hardware side.

The client technologies can be classified in terms of power and universality. It can be said that the more powerful a technology is, the less universal it becomes. From our point of view, the universality of a WebLab client is more important than its power. Using the results of Table 1, the technology that seems most ideal for Remote Lab client development is AJAX.

The scenario and the criteria in order to select the technology for developing the server side is not like those used in the client side. From our point of view, the best option is Python because of its rapid prototyping cycle and open source nature.

## Acknowledgements

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# Graphical Programming and Remote Controlled Laboratories

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**Abstract**

*Engineering education necessitates the use of laboratories for measurement, data collection, analysis and design activities as well as for hands on experience of equipment, physical devices and for empirical evaluation.*

*In the educational field, new teaching methods have appeared allowing the teachers to find innovative techniques to enhance the students' motivation and improve their education: multimedia tools, hypertext systems, interactive systems, graphical programming, information exchange between teacher and student through internet, information access from any part of the world without temporal constraints.*

*The main idea behind establishing Remote Controlled Laboratory (RCL) is to enable students or learners to conduct laboratory experiments at a distance from the actual experimental setup. Access could be from anywhere where web (remote) access is possible. An additional objective is to free experimentation from fixed time limits and allow repetition.*

*Remote Controlled Laboratories are becoming widely accepted in universities for providing distance education and for augmenting traditional laboratories. There is a lot of interest in remote controlled laboratories from pedagogical point of view.*

*Fast processors, advanced computer graphics and visual programming technology have made computer simulation and visualization a reality on desktop machines.*

*The main idea of the present paper is to put together – in the same place – and to describe the new graphical programming technologies and how easy can be the development of Remote Controlled Laboratories using one of these technologies (for example like LabVIEW from National Instruments and VEE-Pro from Agilent Technologies).*

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# 1. **Graphical Programming**

## 1.1. *Introduction*

National Instruments LabVIEW, a premier virtual instrumentation graphical development environment, uses symbolic or graphical representations to speed up development. The software symbolically represents functions. Consolidating functions within rapidly deployed graphical blocks, like first virtual instrumentation component, further speeds development.

Second virtual instrumentation component is modular I/O, designed to be rapidly combined in any order or quantity to ensure that virtual instrumentation can both monitor and control any development aspect. Using well-designed software drivers for modular I/O, engineers and scientists can quickly access functions during concurrent operation.

The third virtual instrumentation element – using commercial platforms, often enhanced with accurate synchronization – ensures that virtual instrumentation takes advantage of the very latest computer capabilities and data transfer technologies. This element delivers virtual instrumentation on a long-term technology base that scales with the high investments made in processors, buses, and more.

With virtual instrumentation, software based on user requirements defines general-purpose measurement and control hardware functionality. Virtual instrumentation combines mainstream commercial technologies, such as the PC, with flexible software and a wide variety of measurement and control hardware, so engineers and scientists can create user-defined systems that meet their exact application needs. With virtual instrumentation, engineers and scientists reduce development time, design higher quality products, and lower the design costs.

National Instruments introduced virtual instrumentation 30 years ago, changing the way engineers and scientists measure and automate the world around them. Today, virtual instrumentation has reached mainstream acceptance and is used in thousands of applications around the world in industries from automotive, to consumer electronics, to oil and gas and especially in university normal teaching and eLearning environment.

Virtual instrumentation is necessary because it delivers instrumentation with the rapid adaptability required for today's concept, product, and process design, development and delivery. Only with virtual instrumentation can engineers and scientists create the user-defined instruments required to keep up with the world's demands. To meet the ever-increasing demand to innovate and deliver ideas and products faster, scientists and engineers are turning to advanced electronics, processors and software. Consider a modern cell phone. Most of them contain the latest features of the last generation, including audio, a phone book and text messaging capabilities. New versions include a camera, MP3 player, and Bluetooth networking and Internet browsing.

The increased functionality of advanced electronics is possible because devices have become more **software centered**. Engineers and scientists can add new functions to the device without changing the hardware, resulting in improved concepts and products without costly hardware redevelopment. This extends product life and usefulness and reduces product delivery times. Engineers and scientists can improve functionality through software instead of developing further specific electronics to do a particular job.

Virtual instrumentation achieved mainstream adoption by providing a new model for building measurement and automation systems. Key of its success includes rapid PC advancement; explosive low-cost, high-performance data converter (semiconductor) development; and system design software emergence. These factors make virtual instrumentation systems accessible to a very broad base of users. PC performance, in particular, has increased more than 10,000X over the past 20 years. Virtual instruments takes advantage of this PC performance increase by analyzing measurements and solving new application challenges with each new-generation PC processor, hard drive, display, and I/O bus. These rapid advancements combined with the general trend that technical and computer literacy starts early in school, contribute to successful computer-based virtual instrumentation adoption.

Another virtual instrumentation driver is the proliferation of high-performance, low-cost analog-to-digital (ADC) and digital-to-analog (DAC) converters.

Applications such as wireless communication and high-definition video impact these technologies relentlessly. While traditional proprietary converter technology tends to move slowly, commercial semiconductor technologies tend to follow Moore's law – doubling performance every 18 months. Virtual instrumentation hardware uses these widely available semiconductors to deliver high-performance measurement front ends.

Finally, system design software's, which provides an intuitive interface for designing custom instrumentation systems, furthers virtual instrumentation. LabVIEW and VEE-Pro are examples of such software. The LabVIEW and VEE-Pro like graphical development environments offer the performance and flexibility of a programming language, as well as high-level functionality and configuration utilities designed specifically for measurement and automation applications.

## 1.2. *Software's*

### 1.2.1. Introduction

We can use for the Remote Laboratories many software solutions but from these solutions we selected two well known and powerful "Graphical Programming" tools:

— LabVIEW from National Instruments.
— VEE-Pro from Agilent Technologies.

Now LabVIEW in his great development arrived at a recognized maturity with the actual 20 years anniversary release. In the same time the developers from Agilent released new VEE-Pro versions, good software products that make you more productive, so you can focus on solving engineering problems, not on programming. Agilent VEE Pro is a powerful, intuitive graphical programming environment, that provides you the fastest path to measurement analysis.

With every new release for this powerful Graphical Programming tools, we expect to have an increased flexibility and many new facilities.

### 1.2.2. LabVIEW

LabVIEW is a graphic object-oriented computer language developed in order to facilitate hardware and software communication [1]. LabVIEW is a complete computer language that can be used like Basic, FORTRAN, or C. In LabVIEW we can create Virtual Instruments (VI's) that aesthetically look like real instruments but are controlled by sophisticated computer programs. There are several levels of data acquisition Vls that make it easy to control data flow, and many signal processing and analysis algorithms come with the software as premade Vls. In the classroom, the similarity between virtual and real instruments helps students understand how information is passed between the computer and attached instruments. The software may be used in the absence of hardware so that students can work at home as well as in the classroom. LabVIEW can be used to control data flow between computer and instruments, have many important features for signal processing and analysis, and help students to easy and fast understand how virtual instruments may be used in place of physical instrumentation.

The development of powerful personal computers and workstations has transformed the way physicists, engineers and other scientists work. Increased processing speed and available memory have led to the development of highly sophisticated programs that perform intricate calculations and handle large data sets. Electronic signal processing can now often be replaced by digital computer processing.

Windows and graphical user interfaces have made it possible for computers to perform multiple tasks simultaneously and have made it easier for scientists to analyze and display data as well as to write papers, manage references, and so on.

Although computer interfacing software has taken advantage of faster processing, development of user-friendly languages for integrating machines and computers has been slow. Integration of computer interfacing software into the curriculum has been slower still. LabVIEW offer a powerful, widely applicable approach to interfacing that uses object-oriented programming and the concept of "virtual instruments" (VIs) and by this approach can be used in the classroom and the research laboratory.

This discussion focuses on LabVIEW, a computer language developed by National Instruments - for computer interfacing through their data acquisition boards, which can be purchased separately. National Instruments is not the only company to take this route, but LabVIEW is probably the most commonly used software of this type, is available for a wide variety of computer systems, is a complete language, and is user friendly.

In the specific discipline of electrical and electronics engineering, one approach for delivering electronics laboratories on the Internet has been to use simulation software with virtual instruments such as MultiSim to conduct the experiments [2]. Gurocak conducted several assessment studies comparing students who performed the labs using Electronics Workbench vs. students who completed the lab course in the hardware lab and found that there were no statistical or practical differences between the two groups [3]. Campbell conducted a similar study [4]. The results of his study showed that students who completed the courses using labs based on simulation software (like Multisim from Fig. 1) performed as well as those who completed the physical labs on a final test conducted on the physical lab. Specifically, he found no statistical significant difference between the groups in the time required to complete a physical lab at the conclusion of the course. The

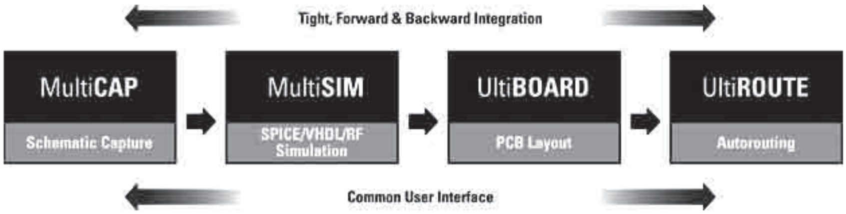


**Figure 1**

Multisim product flow

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simulation software approach is especially well suited for working professionals such as engineering technicians who are completing an engineering degree. These professionals are often already well trained using electronics test equipment such as oscilloscopes, function generators, power supplies and digital multimeters, and don't need further instruction using these devices.

Another approach has been to develop courses that combine the use of simulation software and a personal lab kit to conduct the experiments (Fig. 2). A personal lab kit that includes all the required lab functions necessary to perform electronics circuit design and test (i.e. DC supplies, signal generators, oscilloscope) may be built on a board to plug directly into the PC at a relatively low-cost (less than 200 Euro). This solution may be more adequate for students without prior lab experience (e.g. freshman students taking DC and AC circuit analysis courses).

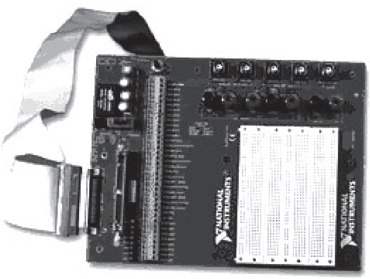
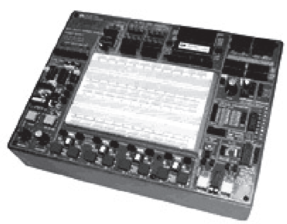



**Figure 2**

National Instruments (www.ni.com)
and INEX (www.inexglobal.com) personal lab kits

A third possible solution is to develop web-based labs using virtual instruments connected to real test equipment and real devices. In this scenario, the instructor, lab technician, or on-campus lab partner must set-up the circuit or device under test on-campus and connect it to the test equipment. The remote student can then use the web interface to take all the required measurements and perform the lab online. This solution can be used in combination with any of the previously described approaches. For instance, a student can use the online virtual instruments to characterize a specific electronic device (op-amp, diode, FET, MOSFET, BJT…), model the real device based on the characterization, perform simulations using the modeled device, and complete the experiment using their personal lab kit.

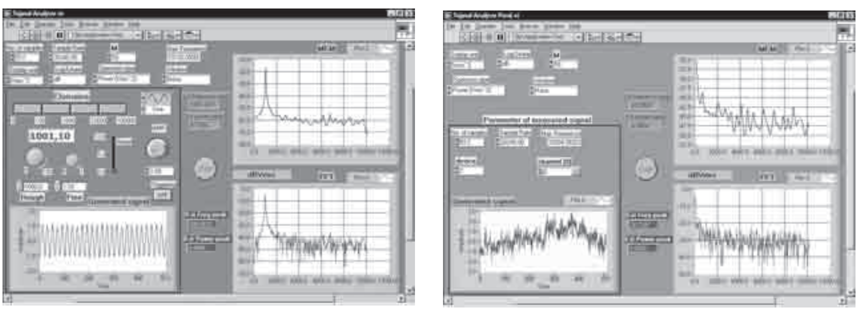
In our paper [5] we demonstrate the high efficiency of using the LabVIEW in the teaching-learning process (for example in Signal Analyze).

One of the most known methods for signal investigation consists in estimation of Power Spectral Density (PSD), signal's power distribution function of frequency. PSD can be estimated by the classical FFT analyze and by the new Maximum Entropy Method MEM. FFT analyze algorithm can be easy implemented, need a small computation time, can be applied at a large signal classes, but in order to minimize the errors you need to apply a high number of spectrum mediation and this multiplies the acquisition time.

For signals like seismic signals, corrosion electrochemical noise, phenomena whose measurement time is shorter, due to the inability to make the necessary averages in order to apply the FFT algorithm, the MEM algorithm was developed [6].

In Fig. 3 we present the interfaces of the applications that are running on a single computer. In Fig. 3 (a) it is presented the case of signal analyze using the two methods: MEM and FFT, the signal generation being simulated in LabVIEW, while in Fig. 3 (b) the analyzed signal proceeds from an analog generator and it is being measured with the aid of a data acquisition board.

For these applications we developed a LabVIEW Client-Server interface and now were integrated in our Remote controlled laboratory with simulated and/or real signals.



(a) Simulated application (b) Real application

**Figure 3**

Interface of application for MEM analyzer

### 1.2.3. VEE-Pro

Agilent VEE Pro is a Visual Engineering Environment that allows you to program by creating an intuitive "block diagram." You select and edit objects from pull-down menus and connect them to each other by wires to specify the program's flow, mimicking the order of tasks you want to perform [7].

Users can quickly create, test, and update code because programs can be run and debugged on-the-fly by using VEE Pro's Start, Stop and Pause buttons.

Programs also are self-documenting; Agilent VEE Pro illustrates the connections between individual objects, so programs are easily understood by others. Plus, with its built-in tutorials and numerous sample programs, demos and context-sensitive help, beginning and veteran programmers alike can get started quickly and stay productive. If you ever get stuck, you have the confidence that comes with included technical support. There is also an active user's forum that shares best practices and helps other users with common questions.

The Agilent VEE software family offers an easy graphical programming environment that ensures fast measurement analysis results. Agilent VEE Pro is intended for large programs with more than one development engineer. It handles day-to-day programming tasks in instrument control, measurement processing, and test reporting. It simplifies test development with enhancements for system integration, debugging, structured program design, and documentation. VEE automates instrument configuration, accelerates the creation of operator interfaces, streamlines test sequencing, and simplifies application development and program enablement across the Internet.

This product provides access to MATLAB Script and functions from the Signal Processing Toolbox, giving users a wide selection of numeric computation tools, engineering graphics, and signal processing functions. MATLAB Script is a runtime version of MATLAB, deployed using the MATLAB Runtime Server, that provides access to the MATLAB language and to analysis and visualization functionality. End users of VEE have access to MATLAB functions, but do not have access to the MATLAB command line, or editor/debugger, or the ability to save M-files. This product also provides seamless interoperability with full MATLAB.

Agilent VEE Pro is designed for engineers and scientists who need to quickly create and automate measurements and tests. It can talk to any device from any vendor using GPIB, LAN, USB, RS-232, VXI and other interfaces or buses, including PXI and SCXI data acquisition and modular instrumentation devices from National Instruments.

Agilent VEE Pro can control any standard instrument and many vendor's PC plug-in cards with an instrument driver, a vendor-supplied DLL, or via Agilent VEE Pro's easy and powerful Direct IO capability. Instrument addresses and other parameters can be verified at runtime and changed on the fly, without reconfiguring programs. Agilent VEE Pro automatically handles different data types, providing automatic conversion and giving you powerful data handling capabilities with a minimum of complex programming.

Agilent VEE Pro's compiler generates optimized code that can be further enhanced with its built-in Profiler. The Profiler allows you to quickly analyze critical sections of code to save development time when fine-tuning your programs.

Agilent VEE Pro comes standard with a RunTime execution engine that provides the ability to distribute run-only Agilent VEE Pro applications at no extra charge.

In VEE Pro new releases, National Instruments' data-acquisition products appear as devices in VEE's Instrument Manager. They can be accessed easily through an interface much like a standard VXI plug&play driver, with function panels to simplify programming. VEE Pro includes now seamless, menu-driven communications with Microsoft Excel, enabling quick creation of spreadsheets for presenting measurement data and test results. In addition, allows users to incorporate Microsoft .NET controls into graphical user interfaces and provides wizard-like tools to simplify using the .NET Framework as well as Interchangeable Virtual Instruments (IVI) drivers. VEE Pro supports instruments and devices from all vendors, and offer sample programs for 150 top Agilent instruments to enable users to set up and take measurements then analyze, display and store data, very fast.

Agilent VEE Pro supports industry standard instrument drivers, including IVI-COM and VXI plug&play as well as a variety of legacy drivers. In addition to GPIB connectivity, Agilent VEE Pro allows you to connect directly to LAN and USB enabled instruments using industry standard protocols.

The open development environment of Agilent VEE Pro allows you to easily use other applications and tools. With access to .NET classes and assemblies, this software can programmatically perform everyday tasks and interact with other applications. The .NET Framework (Common Language Runtime and Framework Class Libraries) is installed with VEE Pro so it is instantly available. Support of ActiveX, DLLs, and other tools ensure access to the capabilities you need.

Agilent VEE Pro includes the most requested enhancements:

- — Easy, menu-driven control of Microsoft Excel for saving and retrieving data as well as automating reports.
- — Integrated support of National Instruments data acquisition and modular instrumentation hardware.
- — New, built-in sample programs and Instrument Manager auto-detect functionality for a fast onramp to using Agilent instruments.
- — Support for Microsoft .NET controls (widgets) for building richer user interfaces.

— Quick access to the powerful .NET framework for adding email capability to programs, accessing databases, etc.
— Simplified integration of industry-standard IVI-COM instrument drivers, and more…

## 2. **Communications Technologies**

### 2.1. *Protocols*

ASDL…TCP/IP…Novell…Web…Intranet…Ethernet…DNS…

Because there are so many acronyms and technologies related to the Internet today, it helps to put things in perspective by starting with a very basic idea: the term **network**.

One basic definition of a network is "two or more electronic devices linked in some way to permit the exchange of information". In information technology, a network is a series of points or nodes interconnected by communications pats. Networks can interconnect with other networks and can contain sub-networks. Often when we use term "network", we are thinking of a certain classification, such as LAN (local area network) or WAN (wide area network), TCP/IP or IPX (data transmission technology), voice or data, public or private, dial-up or dedicated (type of connections), Internet or intranet (access type).

The Internet Protocol (IP) mainly specifies that every computer or device (called a **host**) on the network can have its own unique address, known as the "IP address". The IP address is a little like your telephone number: no one else can (or at least no one else should!) have the same telephone number you do.

While IP specifies how to address data to a specific destination and can move packets of data between computers, TCP works with IP to do several important things. Because different IP packs from the same message may be sent along different routes and arrive at the same destination at different times and out of order, TCP reassembles the packs to put the message back together as a whole. TCP also checks to make sure that all of the IP packs actually arrive at the destination. If for some reasons there are missing packets, TCP can send a message back to the sending machine and request the missing IP packets to be resent.

The nice thing about TCP/IP working together is that you don't need to worry about "how" your data is transmitted from one IP address to another; the protocol takes care of that for you. Data packs from e-mail you send get lost and retransmitted all the time on the Internet without you noticing, because TCP handles the reliability of the transmission.

Another feature of the TCP/IP is that it is a **connection-based** protocol. This means that a connection between the origin and destination computers is opened, kept "alive" while data is being sent, and then closed. The term **socket connection** is used to describe this connection between two IP hosts. The normal procedure is for one host to request a socket connection to the remote host. If the remote host accepts the request, a socket is opened. Only while this socket connection exists can data be transmitted from one IP address to another. Once either host disconnects or closes the socket connection, no more data can be transmitted.

When a host makes a socket connection over TCP/IP to another host, it must connect to not only a specific IP address, but also to specific **port** on the remote computer (machine). A port is a dedicated listening address, referenced by a number between o and 65535, that can be reserved for specific services in TCP/IP.

Data Socket, according to the National Instruments, is "a single, unified, end user API (Application Programming Interface) based on URLs for connecting to measurement and automation data located anywhere, be it on a local computer or anywhere on the Internet. It is protocol independent, language independent, and OS-independent API designed to simplify binary data publishing".

Essentially, Data Socket is a technology that allows you to send and receive data over a network from a variety of software platforms (including LabVIEW) without worrying about low-level implementation details.

### 2.2. *TCP-IP Applications*

TCP allows the developer to setup data communication between virtual instruments on a network using internet protocol addresses and port numbers. TCP sets up an end to end connection between the two communicating parties over which the data is sent. For each message sent, the receiver has to know the length of the package sent in order to use the correct number of bytes in determining the message that was sent. With the ability to send and receive messages of varying lengths, one can develop various complicated methods for the transfer of data with the use of state machines. TCP can be used with any protocol that is built with TCP as its base like http, ftp etc. It enables the developer to set up communications between clients where the clients can "negotiate" on the data to be transferred and how it will be transferred [8].

**The Advantage:**

— Variable length messages allows clients to negotiate the transfer of information.

— Data that is transferred is buffered by receiver.
— Servers can be built where desired.

**The Disadvantage:**

— Can be complicated to setup.
— This method of data transfer can be used for most kinds of data. With a little extra knowledge one can be able to set up interesting communication models between applications.
— Implementation.

A typical sender-receiver implementation is shown in the Fig. 4.

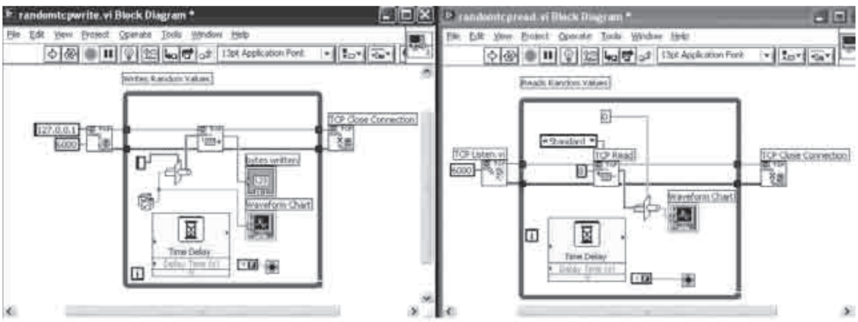


**Figure 4**

LabVIEW TCP/IP Application

Protocol (IP), User Datagram Protocol (UDP), and Transmission Control Protocol (TCP) are the basic tools for network communication.

TCP/IP communication provides a simple user interface that conceals the complexities of ensuring reliable network communications. One can use the TCP/IP functions located on the Functions»Communication»TCP palette for TCP communication in LabVIEW. As with DAQ, instrument, and File I/O communication, the process involves opening the connection, reading and writing the information, and closing the connection.

With most I/O communication, the processor is always the client that initiates a connection to the disk drive server, the external instrument server, or the DAQ board server. With TCP/IP connections, a computer can function either as the client or the server. The following block diagram represents a client application that initiates a connection to a remote server with TCP Open Connection. The server, or daemon, listens for remote connections and responds appropriately.

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LabVIEW users can develop custom applications for TCP/IP communication. The programmer is responsible for developing both the client (Fig.5) and the server.

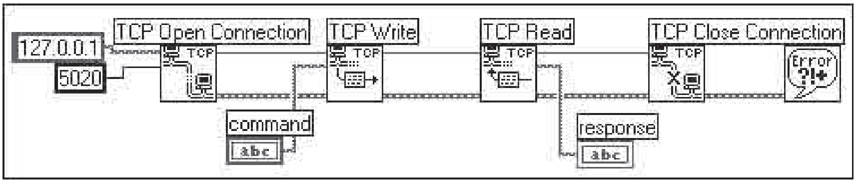



**Figure 5**

TCP/IP LabVIEW Client

Because anyone can initiate a connection to a server, you might want a server access control. The following block diagram shows how the server uses the remote address output value of the TCP Listen VI to determine whether a remote client has permission to access the server (Fig. 6).

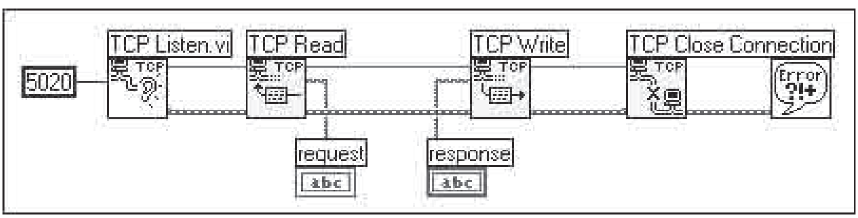


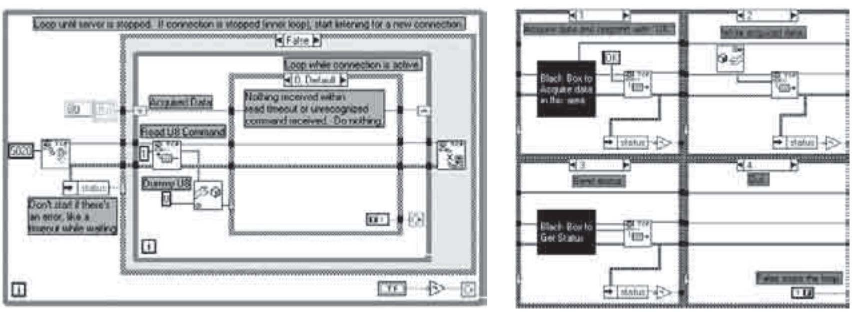

**Figure 6**

Permission to access the server

Most applications do more than write and read one value. Communication is an ongoing process that involves protocol. For example, suppose a client sends the following four commands by 8-bit integer to the server: ***acquire data and confirm***, ***send data***, ***get status*** and ***close connection***.

In the following block diagram (Fig.7 (a)) a While Loop surrounds the rest of the VI. This allows the VI to handle multiple sequential connections without having to restart after each connection closes. The VI cannot handle multiple simultaneous connections. The outer Case structure determines whether a valid connection occurred. If not, nothing happens. If a valid connection occurs, the VI enters a While Loop that reads one byte from the TCP/IP port. This byte holds commands 1 through 4 from the client. If no command is received within the read timeout period, the default case of the inner Case structure sends a TRUE value to the continuation terminal of the inner While Loop to keep the connection active.

The following block diagram shows the other four cases of the inner case statement (Fig.7 (b)). Each case handles a specific command that the server can send. Each case sends information to the continuation terminal, which determines whether or not to continue the loop. In particular, the Quit case always returns a value of FALSE. After leaving the loop, the server closes the connection with the client.



(a) (b)

**Figure 7**

TCP/IP Server architecture

This type of server architecture allows you to develop flexible servers for more complex network communication procedures. The protocols you develop might be more complex than the previous example.

## 2.3. *Data Socket*

Data Socket, according to National Instruments, is “a single, unified, end user API (Application Programming Interface) based on URLs for connecting to measurement and automation data located anywhere, be it on a local computer or anywhere on the Internet. It is protocol independent, language independent, and OS-independent API designed to simplify binary data publishing”.

Essentially, Data Socket is a technology that allows you to send and receive data over a network from a variety of software platforms (including LabVIEW) without worrying about low-level implementation details.

With Data Socket, for examples, you can send formatted data back and forth between two LabVIEW machines on a network, a LabVIEW and a LabWINDOWS-CVI program, or even between several Web browser clients and LabVIEW (see Fig. 8).

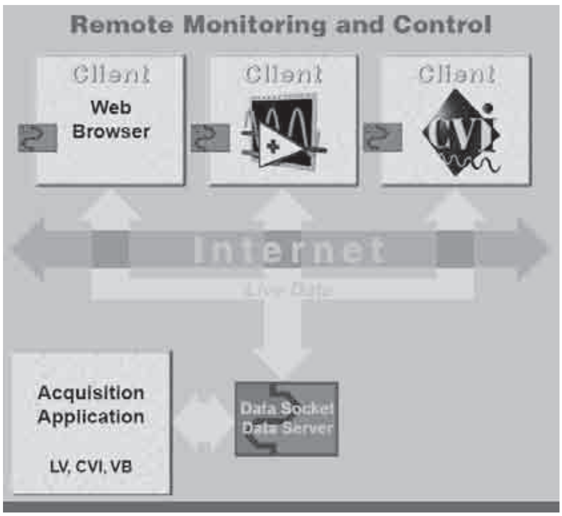



**Figure 8**

Data Socket can connect a variety of software environments

Because one of the key components of the Data Socket is the Data Socket Server, a small application that is external to the programming environment, your programs don't have to worry about how to manage TCP/IP connections, nor does performance in your specific application vary with the number of clients connected. In addition, Data Socket can handle several data types, including integers, floats, strings, and Booleans, as well as arrays of these. By letting Data Socket handle typecasting and conversions internally, you don't have to worry about sending header information or formatting your data in a special way to be transmitted over the network.

The Data Socket Server is a standalone application (available for Windows only) that runs on a computer and will handle client connections. The client connections may write data to the server (know as Data Socket publishers), or read data from the server (Data Socket subscribers) from any one of the publishers. The Data Socket Server automatically handles the underlying network connections and the data packet transmission, making it transparent to the clients. We will examine the Data Socket Server in a more detail shortly.

The Data Socket clients implement the Data Socket API to talk to the server. This API is available in the following implementations: LabVIEW VI's, LabWINDOWS-CVI C library, ActiveX control, JavaBeans.

The ActiveX implementation can be used with Windows development environments like Visual Basic and ComponentWorks, and can be embedded into a Web page. The JavaBeans implementation is good news to fans of platform independence because it makes Data Socket API available to any platform that can run Java (JavaBeans are reusable pieces of code that your custom Java programs can run). In addition, you can embed Java applets in Web pages that use Data Socket.

### 2.4. *VI Servers*

By using LabVIEW's built-in TCP/IP functions, we could build a custom client VI and server VI to pass data back and forth. You also have another easy way to build a networked LabVIEW application over TCP/IP using feature called the **VI Server**.

The VI Server gives you the capability to access features programmatically in LabVIEW either using VI Server functions in a block diagram or through an ActiveX control. Don't let name confuse you: "VI Server" is much more than just some type of networking server built into LabVIEW (although it is that as well). The VI Server functionality is really a way of introducing "object-oriented programming" into LabVIEW. For example, with VI Server you can programmatically [9]:

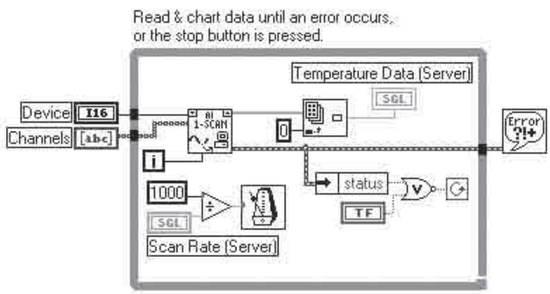
- Load a VI into the memory, run it, and then unload the VI without having it statically linked as a subVI in your block diagram.
- Dynamically run a subVI that get called at run-time, by only knowing its name and connector pane structure(that is known a calling a VI by reference).
- Change properties of a particular VI, such as the size and position of the front panel windows, whether it is editable, etc.
- Make LabVIEW windows move to the front of screen.
- Call a subVI from the block diagram, without waiting for it to finish executing (one of the few places you can get away with not obeying the normal dataflow paradigm!).

A property is some characteristic of the object that may be either read, written, or both, depending on the property. An example of a virtual instrument class property is VI Type. This property informs us whether the VI is: a standard VI, a global variable VI or a custom control VI.

Fig. 9(a) shows the front panel of a VI monitoring temperature on one channel. This is our server side VI, which we call AcquireTemp.vi. We have controls for the DAQ device number, channel, and scan rate. Here we have configured a channel called Temp1 using the DAQ Channel Wizard. We have a thermometer indicator that displays the temperature. This VI runs on the computer with the DAQ hardware.

Fig. 9(b) below shows the block diagram of this VI. We use the AI Read One Scan VI to configure the hardware on the first iteration of the while loop and read one scan from the DAQ device for each subsequent reiteration. Note that the loop is software-timed.


(a)




(b)

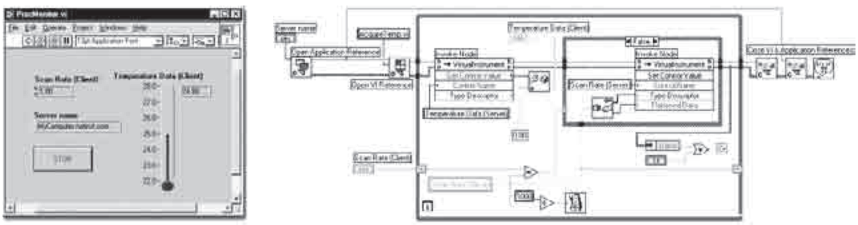
**Figure 9**

Process Monitor Example (a) and Process Monitor diagram (b) (VI Server)

In some situations we would like to monitor the temperature from another location. In this case, we want a simple client interface that displays the temperature and perhaps varies the scan rate. Fig. 10(a) below shows the front panel of this client VI, which we call ProcMonitor.vi.

We also provide a control that specifies the network name of the server computer. In this case, the stop button stops only the client-side VI, but we could also program the VI to stop the server side VI.

Fig. 10(b) shows the block diagram of ProcMonitor.vi, the client VI. The first thing we must do is open references to both the server side LabVIEW and AcquireTemp.vi using the Open Application Reference and Open VI Reference functions. Several operations take place in the while loop. The while loop is timed using the client-side scan rate. The default value of this scan rate should match that of the server side so that one VI is not looping much faster than the other. During each iteration of the while loop, we use the Get Control Value method on our VI reference to retrieve the value of the indicator labeled Temperature Data (Server) on the server. Recall that this is the name of the thermometer indicator on the server. Control values are passed as flat binary strings, so we use the Unflatten from String function to convert the data to a single-precision floating-point value. We then pass this value to the Temperature Data (Client) indicator, which is the client's thermometer indicator.



(a) (b)

**Figure 10**

Process Monitor Example (Client VI) (a) and Process Monitor Diagram (b)

We also monitor the client's desired scan rate. If it changes, we invoke the Set Control Value method in order to change the value of the control labeled Scan Rate (Server) on the server. In effect, this changes the acquisition rate on the server. We use the Flatten to String function to pass our scan rate into the parameters of the Invoke Node.

When the user on the client-side presses the Stop Button, we stop the while loops and closes the open references to the VI and the server's LabVIEW. At this point, we could also stop the server VI using the Abort VI method or some other programmatic method (preferred). A nice feature of this VI is that it can be used on more than one client, so multiple users can monitor the process simultaneously.

## 3. **Remote Control**

Tools for interactive instrument and laboratory control fall into three broad categories:

— Web-based,
— Remote computer control,
— Client-server.

Each of the three approaches has advantages (and disadvantages) for different applications. Web-based tools show great promise for wide distribution of basic instrument operation, but not all instrument functionality can be easily provided in the confines of a browser. Commercial remote control software can easily control an existing instrument's computer rather than the instrument itself, but remote control software uses proprietary protocols, and there are concerns about security and network efficiency. Client-server distributed computing is efficient and scaleable but requires a complete redesign of an instrument's data acquisition system if it is applied to an existing instrument.

### 3.1. *Web-based Remote Operation*

The World Wide Web is experiencing explosive growth in both its distribution and its capabilities. While originally used for the display of multimedia information, the Web has now become a mechanism for interactive applications. The advantages of a web-based solution are numerous. Web communication is (nearly) platform independent, browsers are ubiquitous and everyone knows how to use them, web traffic is usually allowed to pass through firewalls, and strong security can be implemented. The requirements for remote operation of beam line facilities have many aspects in common with other types of facilities.

Like a good example we use the Neutron Residual Stress Facility (NRSF) at ORNL's High Flux Isotope Reactor (HFIR) [10]. They developed platform independent interfaces for motion axes and instrument accessories, web or Internet based control, equipment collision protection and safeguards, video image feedback on system condition, and security for instruments and data. Likewise, the requirements for remote collaboration among experimenters at beam line facilities are common. Researchers need shared data processing and analysis, video conferencing, security for proprietary information and the ability to share use of licensed databases and software.

LabVIEW allow the front panel of any open LabVIEW VI (subroutine) to be converted to a JPEG image that is visible through a web browser. The web server automatically updates these images at a selectable interval, 10 seconds being appropriate for this instrument. These frames show the status of the data acquisition system but do not provide control. For navigation and selection of display of different VI panels, we overlay the images with an image map that allows the user to appear to push the buttons that call and exit the various VI's in the overall system.

### 3.2. *Remote Computer Control*

Essentially all modern scientific instrumentation is controlled by a computer and increasingly, these computers are commodity PCs running a version of Windows. In many cases, the controlling software for the instrument is "closed" with no documented ability to externally script or control of the application.

Remote control software bypasses this limitation by controlling the remote computer rather than the remote instrument. The screen, keyboard, and mouse of the local computer are duplicated at the remote site. This software is commercially available at low cost. Most of works at the NRSF has been done using Timbuktu Pro6 (proprietary system) because it supports all Windows versions as well as Macintoshes. A computer running any of these operating systems can control a computer running that same operating system or any of the others.

Performance on high-speed (>10 Mb/s) local networks is excellent with only a slight sluggishness in the perceived responsiveness of the computer. Performance on a wide area network will, of course, depend on the network performance but is useable even at ISDN speeds. One reason that performance is better than might be expected is that Timbuktu Pro does not simply send bitmap images of the local screen; when possible, it sends the system commands that cause elements of the screen to be redrawn. These commands can require much less bandwidth to transmit than the resulting bitmaps would require.

One key aspect of Timbuktu Pro is that it provides access to the complete remote computer system not just the instrument. This is an advantage for the system owner who can use this feature to restart programs, copy files and perform other functions on the remote computer. However, this same feature is less desirable for remote users who are intended to have only control of the instrument but not have access to the computer's other software and network privileges.

### 3.3. *Client-Server Remote Operation*

When writing a new data acquisition system, or when sufficient access is provided to an existing one, a client-server approach has many advantages. It can be a very efficient user of network bandwidth and strong security can be readily implemented. The LabVIEW-based data acquisition can be rewrite easy to allow a client-server mode of operation. Communication is over an IP socket. Recent versions of LabVIEW provide the ability for LabVIEW applications running on different computers to interact with each other with very little programming required. However, NRSF researchers did not make use of this capability and instead did everything “by hand”. One reason is that they want to be able to use clients based on languages other than LabVIEW.

In general terms, we can argue that both the server and the client application exchange information and commands over the network. The server application directly controls the instrumentation and collects data. It accepts commands from either a local operator or a client that it has granted permission to perform control. The server, in the case of NRSF systems, also broadcasts to all connected clients the status of the application, the values of changed variables, and the diffraction spectrum. The client application duplicates the screen information of the server and updates its display with data received from the server [10]. The client application relies on its own routines to display images identical to the server. If allowed to control, the client can send most of the commands available to the local operator at the server; otherwise it operates in observer mode. The Server must be started first and must have reached its steady state mode, i.e.: must have passed the initialization phase. Then a client can start its version of the application and communicates with the server-based application. The Server keeps a log of the connections and control activity received from the clients.

When the Server application is started, it performs some initial steps and then waits for a user command, either local or from a remote connection. The main program listens to the commands from the controlling computer. When started, the Client tries to establish a connection with the Server. If it is not successful, whether because the Server is not running or the network is down, the client terminates.

## 4. **Remote and Virtual Laboratories**

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 (Fig. 11).

| | EXPERIMENTER LOCAL | EXPERIMENTER REMOTE |
|---|---|---|
| EXPERIMENT REAL | Traditional Laboratory | Remote Laboratory |
| EXPERIMENT VIRTUAL | Local Simulation | Virtual Laboratory |

**Figure 11**

Characterization of labs

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.

Online labs are typically organized in a Client-Server-Architecture [11]. 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.

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 need to point out where we are facing any 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 these situations, depend on the situation, but in [11], [12] and [13] 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.

### 4.1. *NI ELVIS and Virtual Instrumentation*

Virtual instrumentation is defined as the combination of measurement and control hardware and application software with industry-standard computer technology to create user-defined instrumentation systems. Virtual instrumentation provides an ideal platform for developing instructional curriculum and conducting scientific research. In an instructional laboratory course, students perform various experiments that combine measurements, automation, and control. Tools or systems used in these situations must be flexible and adaptable. In research environments, virtual instrumentation provides the flexibility that a researcher must have to modify the system to meet unpredictable needs. Research and instructional efforts also require that their systems be economical. Because you can reuse components in a virtual instrumentation system (without purchasing additional hardware or software), virtual instrumentation is an economical choice. Finally, measurement systems must be scalable to meet future expansion needs. The modular nature of virtual instrumentation makes it easy for you to add new functionality.

NI ELVIS (National Instruments Educational Laboratory Virtual Instrumentation Suite) uses LabVIEW-based software instruments, a multi-function DAQ device, and a custom-designed bench top workstation and prototyping board to provide the functionality of a suite of common laboratory instruments [14]. The NI ELVIS hardware provides a function generator and variable power supplies from the bench top workstation. The NI ELVIS LabVIEW Soft Front Panel (SFP) instruments combined with the functionality of the DAQ device and the NI ELVIS workstation provide the functionality of the following SFP instruments:

— Arbitrary Waveform Generator (ARB).
— Bode Analyzer.
— Digital Bus Reader and Digital Bus Writer.
— Digital Multimeter (DMM).
— Dynamic Signal Analyzer (DSA).
— Function Generator (FGEN).
— Impedance Analyzer.
— Oscilloscope (Scope).
— Two-Wire Current Voltage Analyzer.
— Three-Wire Current Voltage Analyzer.
— Variable Power Supplies.

In addition to the SFP instruments, NI ELVIS has a set of high-level LabVIEW functions, which you can use to customize your display and experiments, to control the NI ELVIS workstation from LabVIEW. With NI ELVIS software, you can control the NI ELVIS instruments in a nonprogramming environment with SignalExpress. In addition to the NI ELVIS instruments, you can also use the general AI, AO, DIO, and CTR functionality available on the NI ELVIS hardware (Fig. 12) in SignalExpress.

**Figure 12**

Desktop NI ELVIS System

The NI ELVIS software, created in LabVIEW, takes advantage of the capabilities of virtual instrumentation. The software includes SFP instruments, the LabVIEW API, and SignalExpress blocks for programming the NI ELVIS hardware. NI ELVIS ships with the SFP instruments, created in LabVIEW, and the source code for the instruments. You cannot directly modify the executable files, but you can modify or enhance the functionality of these instruments by modifying the LabVIEW code. The instruments are virtual instruments (VIs) that are necessary in typical laboratory applications.

### 4.2. *AppletVIEW in Remote Labs*

AppletVIEW is a framework and enabling technology for building interactive, distributed event-based software applications. It is a very flexible technology which can be either built upon as a core technology or added to existing software infrastructures.

The AppletVIEW software is installed on the computer which will be the server. The web browsers used as clients do not need anything installed on them.

Before installing AppletVIEW, you must have a Java JRE version 1.4 or higher installed on your server. AppletVIEW will not work without it.

The AppletVIEW Server supports two multi-user modes:

- **"Many to One"** - if multiple remote users connect to your system and they all share a single VI, this is the "Many to One" mode.
- **"Many to Many"** - if multiple remote users connect to your system and they all interact with their own copy of your VI, this is the "Many to Many" mode.

**"Many to One"** is the default mode in the AppletVIEW Server. When you create an applet which references a VI, when the remote applet connects to your system, it will look for the VI to already be in memory. This means it must be open and running along with the AppletVIEW VI. Each client will be able to connect to this one VI and see changes from all other clients using the same VI.

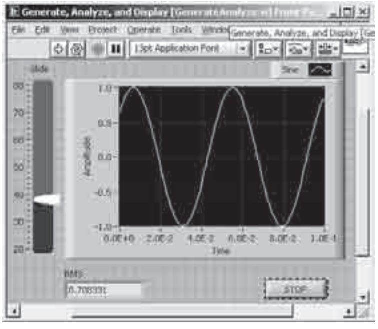
**"Many to Many"** mode is supported by the use of VI Templates. If you have an existing VI for which you want each client to operate their own copy, you should save a copy of your VI as a template in the web root directory. The remote applet will reference this template file (instead of the original VI file), and every time a client connects a new version will be loaded into memory for the client.

When you exit LabVIEW, it will ask you whether you want to save the run time versions created from the template. It is not necessary to do so.

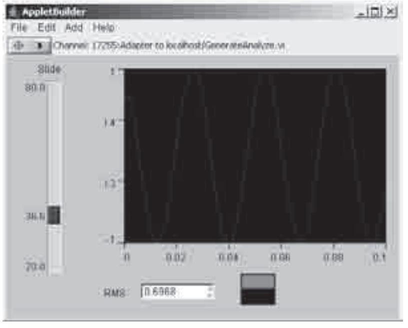
You do not need to recreate your instrument “by hand” in AppletBuilder. When you use AppletBuilder, you can connect to the AppletVIEW Application Adapter VI running in your local instrumentation system and “collect” or “pull in” the interface for any of your VIs.

To “pull in” the configuration of an instrument, first run the AppletVIEW Application Adapter in LabVIEW, and then run the instrument you want to “pull in”. Then, in AppletBuilder, choose the Read Server option from the File menu. AppletBuilder will ask you to locate the Application Adapter on your network (normally this will be LOCALHOST since AppletVIEW is normally run on the same machine as your LabVIEW system). AppletBuilder connects to the AppletVIEW application server and creates a list of running VIs. When you choose which VI you want to “pull in” to AppletBuilder, it will collect the configuration from the Application Adapter and build the front panel of your instrument.

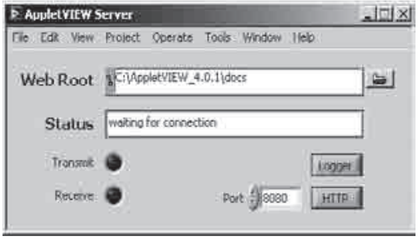
In the Fig. 13 you can see one LabVIEW simple application and how to develop his front panel using AppletBuilder.



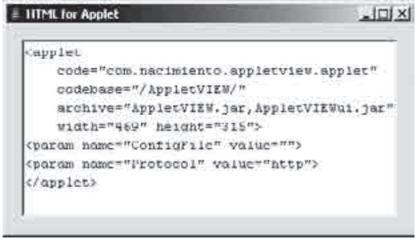

LabVIEW Application




AppletBuilder Front Panel




AppletVIEW Server




Applet build by AppletBuilder

**Figure 13**

Build one LabVIEW Application and his Applet

Once you collect an interface, you can modify it in AppletBuilder. You can change the arrangement, color, size, position, etc. of the elements. When satisfied with this new configuration of your instrument, save it as a configuration file, a Java Virtual Instrument (.jvi file).

At this point the process of recreation of your instrument is almost complete. If you prefer, you can rebuild your instrument “from scratch” in AppletBuilder by using the Add menu to add the components you want. Then you can resize, arrange, and configure them as you want.

When you are finished creating your applet in AppletBuilder, it is important to save it. When you choose Save from the File menu, you will be prompted with a dialog to save your applet. You can choose either to save your applet as JVI or VIML. JVI is a compact binary format, while VIML is an easier read XML format. You normally should save your applets into your web path so you can view them with your web browser (Fig. 14).

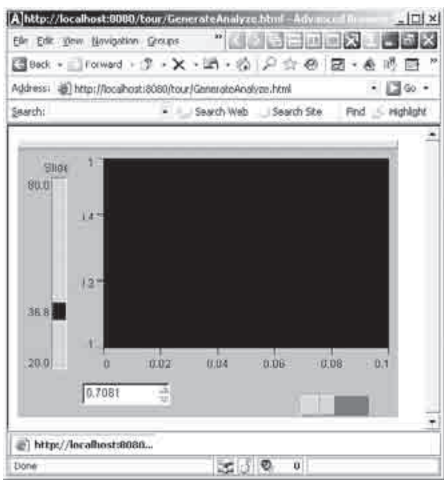



**Figure 14**

Web page running the Application Applet

Your web path is the root directory of the AppletVIEW HTTP server. This directory is normally the /www folder in your AppletVIEW installation directory. It’s important to note that the AppletVIEW server uses this directory by default.

The .jvi file is a binary file that contains all the configuration information for your applet. It can only be read and modified by AppletBuilder, or loaded with AppletVIEW's Java classes through a web browser. Note that this file is not a Java .class file; that is, no Java compilation has occurred. Instead, the Java class files ("AppletVIEW.jar") dynamically build your applet at run-time based on the .jvi file. This is why sometimes the .jvi file is called a configuration file. This gives the client browser a big advantage when browsing different applets, because the Java class files are only loaded once. The applet configuration files load very quickly because they are usually very small.

For a web browser to load an applet, it must load an HTML file that references your applet. This reference is created with an <APPLET> tag inside an HTML page. When you browse to this HTML page on a web server, the server sends both the Java class files and the .jvi configuration file and to create your instrument in the web page.

AppletBuilder writes the <APPLET> tag for you. If you save your applet and then choose the HTML option from the File menu, a window opens containing the applet tag for your applet. Copy and paste this tag into your own HTML file, save your HTML with your .jvi file, and your applet instrument is ready.

You can also add some optional parameter tags inside the applet tag to modify the applet's default behavior.

## 5. Multichannel Self-Growing Laboratories

In the last few years, focused on the collaboration with a team from Carinthia Tech Institute Villach -Austria, we have tried to develop a remote controlled laboratory in the Electronic Engineering field at the "Transylvania" University of Brasov. The work at Brasov was concentrated to develop an interface for our server which provides the possibility to simultaneously connect for many users to many applications?

A new task for our work was to develop possibility for clients to make a scheduler for access the applications. Another direction of research was to create a possibility to adding on-line at our laboratory, any new developed application. If it is started, the server detects it and shares it for the client [15].

Open and Distance Learning has known an accentuated development, being taking over and recognized by more and more counties and universities as an alternative way of learning and perfecting. There are companies that have well organized structures of perfecting based on the ODL system in their field of activity, such as CISCO, Microsoft etc. These companies give the possibility of perfecting by offering the study materials on-line, such as: courses and seminaries, tests for verifying the attained level, exams for courses graduation etc. Many universities have developed departments dedicated to ODL. Still, all of these studies are oriented towards the fields that do not require laboratories that might need the maneuverability of certain devices or studies of real phenomena. The necessity of a laboratory brings big organizing problems: the space, available qualified personnel, high costs etc. In certain fields of ODL where the laboratories are necessary, has been taken over the idea of joining the ODL with the standard learning by creating some local academies where the students could achieve the necessary preparation in laboratories. So, in applied fields such as the engineering one, the accomplishing of the ODL system would require some compromising that in the most of the cases would lead to the fact of not taking into consideration this modality of study.

In order to avoid these local laboratories, there is an ascendant flow of creating the so-called virtual laboratories, though them the troubles of the ODL in the applied fields are overcame.

In our paper “Self Growing Remote Controlled Laboratory” [15] we wish to present a simple possibility of creating real laboratories remote controlled that would allow the continuing growing number of new applications.

A team of Carinthia Tech Institute Villach - Austria, stated this direction of research and this has been developed in collaboration with our team from CVTC, Transylvania University of Brasov.

Together with Carinthia Tech Institute and other universities from Europe it was started the first European Master in the field of Remote Engineering (Project “MARE”). In the future, our applications will be used in a virtual laboratory for the students of this master.

The creation of laboratories like these can be oriented on two directions of approaching:

- The creation of some applications that allow the study of some physical, chemical etc. phenomena or of the behavior of the investigated systems, by selecting the available parameters without having the possibility of step by step controlling these devices in the system. This approach allows the understanding of the phenomenon and not of the maneuverability of the devices in the system;
- The creation of some interfaces for effective step by step control of the devices in the system thus allowing the learning of physic devices maneuverability.

By joining the two directions of approaching it is allowed the creation of some complex laboratories of study. By making these laboratories functional, the area of covering of the ODL system could be extended. A very important sector is the engineering one. The chosen applications for our laboratory are taking over the field of Electronic Engineering.

RELBV Data Socket Sever is a LabVIEW application that plays the part of a server. The purpose of the application is to allow the connecting of several clients to many applications spread on different workstations. This concept assumes that at one moment of time one client can control one or more applications and another client can control other applications.

The used communication protocol is data socket transfer protocol (dstp). In order that this application should function, the data socket server given by the National Instruments in the LabVIEW package having the afferent rights for writing and reading, must be started on a station that is visible on the Internet.

Due to the fact that the communication with this server is being done on the 3015 port, this port must be opened on that particular station. Using this technology we improved the security for our applications, because we have only the NI-Data Socket Server in a demilitarized zone and the rest of our applications: the server application and the applications can be wherever on the network without the knowledge of the client.

RELBV_DSS (Fig. 15) has as purpose the clients' login, verification of sever-client connections, client's access to the application, testing of applications' status (functional or not), and client's scheduled programming to different applications.

In order to accomplish these functions, the RELBV_DSS application memorizes the information in a database called "Baza_de_Date_Users".

In this database are registered the accounts and passwords of these clients, the data regarding the connecting of a client (history: date and hour of connecting and disconnecting), the state of each connected client: new entered, busy, busy-scheduler (status dedicated to the clients for making the schedule), or in the state of exit (Time Out or Lost Connection). In this database are also registered the status of the applications: available (0), busy (1), reset (2) or unavailable (3).

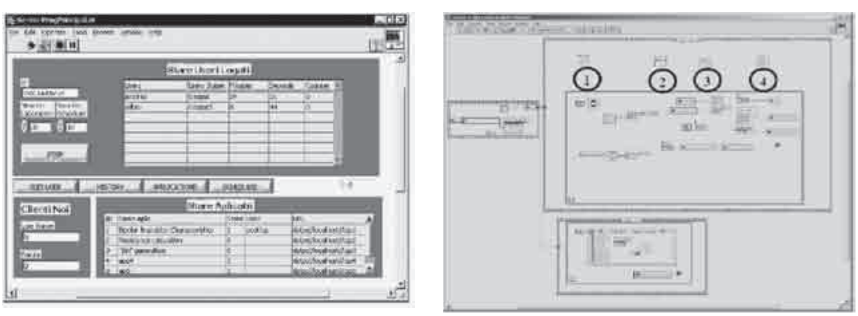


**Figure 15**

User Interface and Diagram for RELBV_DSS Application

The used database has been created in Microsoft Access. The communication from LabVIEW with the database is using the Data Connectivity Tools Add-on.

The application is being built on 4 main modules (Fig. 16): **ServerUser.vi, Nucleu2.vi, NucleuAccessType.vi** and **ServerApplications.vi.**

**ServerUser1.vi (1)** is waiting the request for access from a client, verifies and allows the right of access for this client (in the case of access, the client is being registered in the database, receiving the status "enter" and the information about the name of the applications registered in the database).

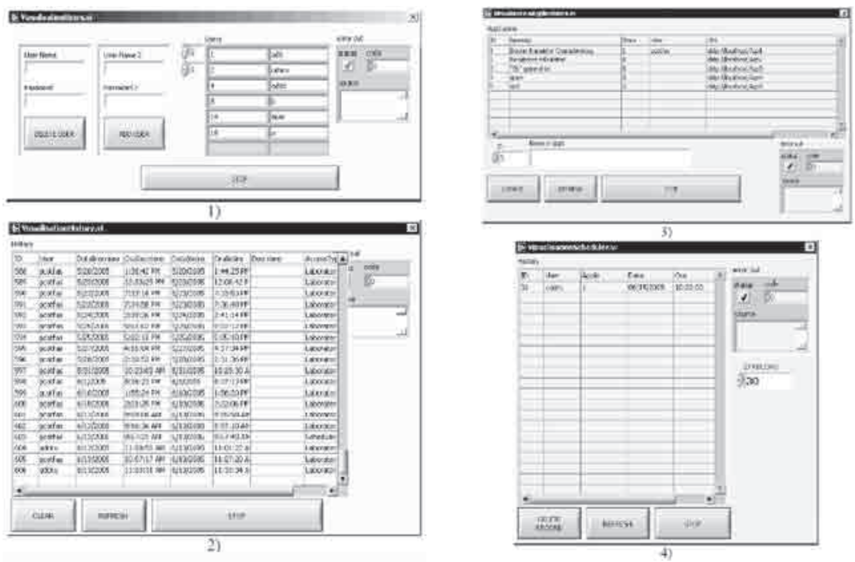


**Figure 16**

Interfaces for Server Management

**Nucleu2.vi (2)** and NucleuAccessType.vi are applications that play the part of starting a new instance of the InstanceUser.vi and Instance UserAT.vi applications for every new user connected to the server.

**InstanceUser.vi** controls the state of each user logged to the applications server, while **InstanceUserAT.vi** controls the state of each user connected to the scheduler area. So, for each user a new instance is created, that runs independent of the other instances of the other users.

At the starting of the instances for the two applications, the users are being put in the "Busy" and "BusyS" state. Here, the existence of the connection with the clients and the status of the access time are verified. In the case of lost connection, the user is being deleted from the list of logged uses after 5 verifications of the connection.

All of the clients receive a settled access time, at whose expiration they shall be automatically disconnected. From here it is also being sent to each client the information about the applications' status (available or not).

ServerApplications.vi. is starting one instance of the ApplicationControl.vi application for each application that is registered in the database.

ApplicationControl.vi makes the connection between the server and the applications registered in the database. ApplicationControl.vi is checking the applications' status (running or not) and it writes it in the database. If a client is connecting to one of the applications, ApplicationControl.vi puts this application as being "Busy" (and no other client cannot connect to this application) and warns it about the existence of a client that is connecting to it and so the application shall enter in the control behavior.

Many facilities for controlling the application have been introduced for the management of the server (Fig. 16) such as:

1. The module for editing clients' accounts. The allowed operations are the deleting of a client or introduction of a new client;
2. The module for visualizing the history of server's activity (connected clients, date, hour of the connection, the activities accomplished in the laboratory);
3. The module for editing and visualization of applications' status (the name of the positioning application etc.);
4. The module for scheduler that allows the visualization and deletion of clients' schedule.

The interface of the application allows setting and visualizing of the next parameters:

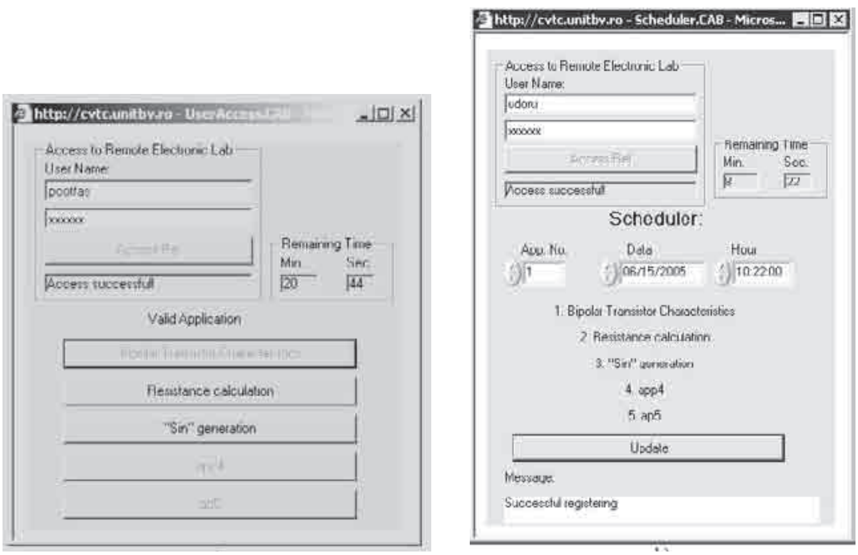
**Controls:**

1. IP (URL address or the IP of the station on which runs the Data Socket Server);
2. 2. Allowed Time – the value of the time allowed to the clients for a work session (for example: 30 min for the lab, 10 min for scheduler). The time can be ulterior changed.
3. Edit User – calls the application for editing the clients' accounts;
4. History – calls the application for visualizing the history;
5. Applications – allows editing the applications;
6. Scheduler – allows editing and visualizing the schedule for clients;
7. Stop – Stops the application.

**Indicators:**

1. Logged User Status – allows the visualization of the working clients:
   - — The name of the clients;
   - — The remained time for working: minutes and seconds;
   - — The connection counter (>5 the client will be automatically disconnected)
2. New clients - allows the visualization of the clients that try to connect (the information remain active only during the communication with the potential client);
3. Applications' status – presents the number, the name and the status of the application (0-available, 1-busy, 2-reset, 3-not connected to the server). If a client has been connected to an application, his name will also appear.

In the Fig. 17 you can see the ActiveX for Login in the Remote Laboratory.




(a) (b)

**Figure 17**

ActiveX for Login

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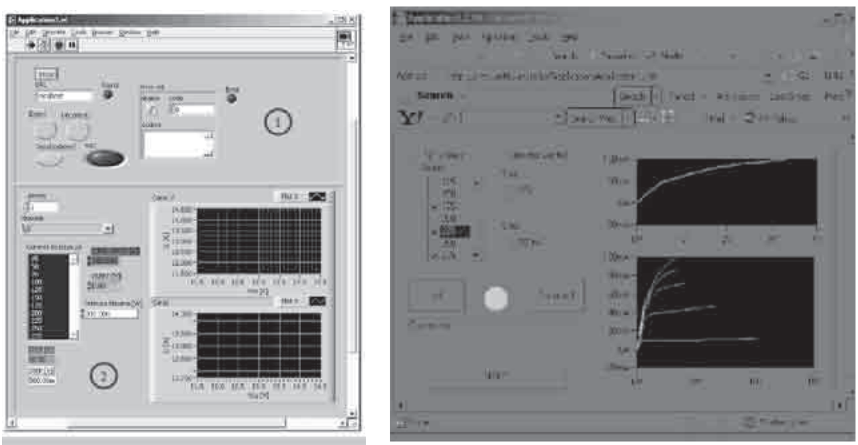
This first ActiveX allows the registering of the client and if successful, allows the connection to the available applications. Each ActiveX is opened in a new window.

From this interface any student can to select one of the free applications.

In the Fig. 18 you can see the Application 1 (one of the possible application at the student login) interface and the corresponding ActiveX.



(a) (b)

**Figure 18**

Application 1 Interface (a) and ActiveX for this Application 1

The creation of some virtual laboratories [16-19] that allow accomplishing real experiments remote controlled allow the growing of the covering area for ODL in the field of Engineering and Applied Sciences. In addition to this, there could be made shared experiments in which researchers situated in different locations can share the data and the results.

The partnership between different institutions that participate with this kind of virtual laboratories could lead to an increased quality in the teaching - learning process by using the different kind of devices, instruments and experiments that otherwise would be unavailable. So, instead of the existence of an identical system in every institution, each participant will participate with different systems and so, a wider area of equipments and experiments studied by the students could be covered.

The using of the ActiveX technology for remote control, via web, also brings some trouble due to dependence of the used platform. In order to overcome this trouble, in the future it will be attempted to implement some technologies that are independent of the used platform (for example: using techniques based on Java).

The creation of some self-growing laboratories, in which the number of applications can grow together with their accomplishing leads to a flexible for administrating structure and by using the databases in controlling the laboratory, its management performances can grow.

## Instead of Conclusions

We must connect and introduce here the idea of Personal Learning Environment PLE connected in the last years with the not so new idea of Long Life Learning LLL.

The idea of a Personal Learning Environment recognizes that learning is continuing and seeks to provide tools to support that learning. It also recognizes the role of the individual in organizing their own learning (in any place at any moment). Moreover, the pressures for a PLE are based on the idea that learning will take place in different contexts and situations and will not be provided by a single learning provider. Linked to this is an increasing recognition of the importance of informal learning.

Informal learning is something of a conundrum. Fairly obviously, we learn throughout our lives, in all kinds of different setting and contexts. Most of this learning does not come from formal educational programmers. According to the Institute for Research on Learning, at most, formal training only accounts for 20 percent of how people learn their jobs. Most workers learn their jobs from observing others, asking questions, trial and error, calling the help desk and other unscheduled, largely independent activities [20].

I think we must work together and to try to provide Personal Learning type environments PLEs (for all our learners: undergraduates, graduates and LLL) linked to institutional Learning Management Systems and this can be a real good "Remote Integrated Solution" RIS.

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# SECTION IV

# Remote labs in use

# Teaching, Learning, and Remote Laboratories

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**Abstract**

*Very often, the concepts of learning and teaching appear somehow mixed together although their use emphasizes who is considered to be at the center of the process. At European level, Bologna Declaration has put the emphasis on the "What students do?" paradigm, shifting the center of the process to the student. Such paradigm also supports life long learning objectives. The remote laboratory concept provides a tool to sustain this shift towards a student-centric teaching approach. However, within engineering education, this means an additional stress on laboratories, as a result from the pressure to increase experimentation, and raises the question: how to handle overcrowded laboratories? Remote labs present a solution to this problem, allowing students to access experiments without time and location restrictions. In this chapter, two typical types of experiments were presented: on one hand, the one associated with expensive set-ups experiments and representing the "one-of-a-kind" experiment type, (common in process control), and on the other hand the one associated with low-cost experiments that can be replicated (common in embedded systems and basic electronics experimentation).*

## 1. **Introduction**

Remote laboratories are receiving increasing interest from a number of "society players". In the first row of supporters we can find academia and educational-related players, which integrate remote laboratories in the broader area of e-learning and e-teaching. Also, industry and service providers are aware on the usage of remote laboratories, making use e-learning technologies to support life-long learning activities. In this area a synergistic collaboration with academia can be very fruitful for both partners. In addition industry uses remote laboratories' technologies to support several activities at their own core business. That is the case of remote-operation, remote-monitoring and remote-control.

However, different players manage access and availability in a completely different way. While academia tends to favor open access and open technologies (like the MIT initiative, just to mention a single case), on the other hand industry and service providers tend to favor proprietary solutions and restricted access (as far as they intend to protect their core business, and see proprietary solutions and restricted access as the best way to accomplished their goals).

In this sense, a first problem associated with remote laboratories usage can be identified:

Open source/free of charge versus Proprietary solutions

As a matter of fact, this problem seems to be intrinsic to the nature of academia and industry, as the "driving force of industry" goes towards profit generation, while the "driving force at academia" is focused on dissemination and the contribution to mankind knowledge development. Also from an individual point of view, the same main dichotomy between industry and academia can be identified: while the entrepreneur tends to valorize "profit", the researchers tend to valorize "the beauty of new discoveries".

Nevertheless, it is possible to pinpoint a good set of new opportunities to explore in both areas. At the academic side, several workshops, symposiums, conferences and special sessions on e-learning and e-labs have been launched during the last few years (for instance [1]). Also new journals or special issues on established journals have been devoted to related subjects.

At the technology transfer level, where academia, industry and service providers can interact in order to increase citizen quality of life, several EU sponsored R&D programs for projects & networks are ready for funding (namely Leonardo da Vinci, Socrates, and Minerva, among others), offering good opportunities for innovative R&D collaborative works.

As a conclusion, we may say that the current situation of remote laboratories usage relies on the area of e-learning and e-teaching environments.

## 2. **Learning and Teaching**

Sometimes the concepts of learning and teaching appear somehow mixed. However, their use tends to emphasize who is at the center of the process.

Taking the excellent piece of "edutainment" (a contraction of EDU(cation) and (enter)TAINMENT), available with the film "Teaching teaching and understanding understanding" [3], according with John Biggs [2], before the 80's the emphasis was on "What students are?" (and the answers could classify the students into "good students" or "bad students"), while some time afterward the paradigm shifted (due to the number of "bad students" in comparison with the number of "good students") and the emphasis became on "What teachers do?" … to handle so many "bad students" in University. During this stage, the teacher acting as an entertainer becomes more common, in order to assure the grabbing of students' attention. Regrettably, being a better entertainer does not assure at all that the students will get better results…

Currently, the new paradigm emphasizes "What students do?" shifting the center of the process to the student, instead of the teacher.

This new paradigm is in line with Bologna Declaration, and supports life long learning as well.

At this point, we must recall once again the works from John Biggs [2] and what is classified as the "three levels of thinking about teaching". Roughly, these three levels for teachers are related with the referred three phases. In this sense, level one teachers are associated with "good student - bad student" perspective, found when we follow the "what students are?" attitude, also known as the "blame the students" approach to teaching.

In a similar way, if we consider the question "what teachers do?" one will find the "good teacher – bad teacher" perspective, also known as the "blame the teachers" perspective. The level two teacher can emphasize the entertainer aspect with different strengths, but at the end, this usually results on passive students.

In order to actively involve students in the learning process, one needs to emphasize the "what students do?" question. The level three teacher is more concerned with the learning outcome of the teaching process, through systematic observation of what the student does before, during, and after teaching.

This shifting of paradigms can also be seen as the shifting from a "faculty-centric" to a "student-centric" teaching approach.

What is important to stress in the context of this chapter is that the remote laboratory concept provides a tool to support the referred shift of paradigms towards a student-centric teaching approach.

## 3. **Which role for remote laboratories?**

The remote laboratory concept as received some criticism, as some people claim that the pedagogical benefit over the traditional laboratory is not clear. In the sequel, we will emphasize some of the benefits.

It should be noticed that constructivists' theories highlight the importance of practical work, shifting the focus to the "learning by doing" paradigm. In case of engineering education, this means that additional stress is shifted towards laboratories, as some "social pressure" – mostly from employers – tends also to increase experimentation.

This increase in lab activity raises one important question: how to handle overcrowded laboratories?

The question is not new, and was answered in different ways in the past, according to specific additional constraints (within different teaching areas).

A first line of action is to shift experimentation into simulation. This may be a good solution for some subjects within engineering education, namely for introductory experiments, but as a general solution it is completely inadequate.

A second tentative to circumvent the problem is to enlarge the period of availability of the laboratory (open laboratories). Once again, this may be a reasonable way out for many areas on engineering education, but it is not possible to apply whenever bad usage can originate injuries or damages.

A third solution to accommodate increasing experimentation is to replicate the experimentation set-ups and give them to students. Unfortunately, for most of the engineering areas this is not viable.

Finally, relying on a remote lab could accommodate the benefits of the above solutions, without the referred problems. Figure 1 summarizes the referred solutions.

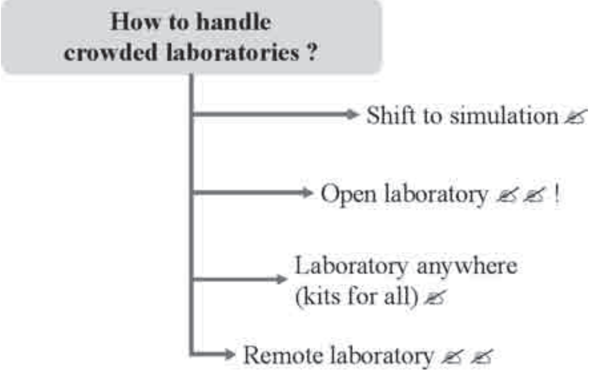


**Figure 1**

How to handle crowded laboratories? Most common answers

Within this framework, our proposal for a laboratory experimentation strategy may be summarized as follows:

> Laboratory experiments? Anytime, anywhere, as much as the student wants!

In general terms, we like to consider three levels of exercising around a specific experiment:

- First level is related with physical instrumentation using a physical set-up;
- Second level is related with emulation; where the physical instrumentation is replaced by a set of input and output signals that can be manipulated by the student, allowing him/her to mimic the physical environment;
- Third level is associated with simulation.

Although first and third levels have their own role in the teaching process (as well as in the development process), the second level (emulation) is the traditional level for lab experiments at several engineering areas.

The "emulation goal" can be accomplished through different solutions. We identify the following three approaches:

- The physical workbench type solution is associated with using a set of switches, push-buttons and other types of inputs to produce the excitation for the experiment, and leds, displays and other output devices as a way to visualize the experiment output status;
- The virtual workbench solution is the "computer aided version" of the previous one, where the student can use a software application (complemented with a piece of hardware to make the physical connection to the system) to generate inputs to exercise the system and some windows to present the output status; several solutions are ready to be used, being LabView the most well known of them;
- The third solution – the remote workbench – is the "internet version" of the previous one.

First and second solutions are local, in the sense that the student and the experiment are located in the same area; the third solution is remote, in the sense that the student operates the experiment remotely.

The first and second solutions may be accomplished by lending to the students the necessary modules to perform the tests; the third solution is carried out by means of a set of servers that can offer remote access to experiments.

A feature that must be taken into account when taking an emulation approach are the time constraints associated with the operation and reaction of the experiment.

In broad sense, according to the nature of the time constraints, three groups of experiments are to be considered:

- Batch input/output: the experiment is divided into three stages – the set-up stage, where test values and operations are defined; the execution stage, where the test is actually performed; and the output stage, when results are provided to the student. This is usually the case for the computational intensive applications.
- Simple input/output: this group covers control systems with simple input-output relationships. This is the case for some automation systems, where the control is managed through a state machine, which imposes a behavior evolution based on the received inputs.
- Real-time input/output: this group includes control systems with complex input-output dependencies and with real-time constraints. This is the case for systems where it is necessary an accurate timing associated with the inputs or the outputs.

Table 1 summarizes the dependencies between the different experiment's classifications. It is clear that, excluding projects with real-time constraints (where direct physical interaction between the experiment and the environment is mandatory), the remaining categories can be adequately supported by the proposed remote laboratory, without loss of testing capabilities.

**Table 1**

Experimentation associated with the different types of projects

| Input-output type | Operation type | Workshop type for adequate emulation support |
|---|---|---|
| Batch i/o | Simulation, or Emulation, or Physical | Physical, or Virtual, or Remote |
| Simple i/o | Simulation, or Emulation, or Physical | Physical, or Virtual, or Remote |
| Real-time i/o | Physical | Not applicable |

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## 4. **Typical case studies**

In the following sections, we will emphasize general characteristics of two types of experiments, common within engineering education.

The first group of experiments covers the case where the experiment is not replicable. This is the situation in most process control examples where automatic control has been used.

The second group of experiments is associated with replicable experiments. This is the typical situation for experimentation on electronics, digital systems and embedded systems.

### 4.1. *Process control experimentation*

Automatic control is a major field in almost every engineering subject and is an important part of the respective engineering curricula [10]. Automatic control applications range from chemical processes, through mechanics, electronics up to communications and economics. Although simulation does occupy an important role in the learn in process, practical education needs to be based on real aspects that occur in mechanical, electrical, or chemical systems. However, due to their cost, size and other restrictions, the number of laboratory experiments available is small when compared to the high number of students enrolled on the subjects. Besides, work in a real laboratory imposes time and physical boundaries both for students and for academic staff. It requires significant scheduling effort and financial investments. Lately, universities are strongly advocating for the introduction of modern education technologies, and the option of online delivery of courses both for internal and external students.

Remote control comes as a solution to these problems, allowing students to gain control of experiments, without leaving their workplace. Experiments may be located on the same room or on a different location. Taking advantage of the internet and the development of related technologies, an increasing number of remote access solutions are being developed [5-9]. We will present a tool called SMCRVI, developed as a response to the need of remote access to lab experiments on Control related classes [9].

This tool provides an environment for remote control implemented based on the LabView platform and builds a client-server architecture for real and virtual laboratories. A real physical system or a process model can be remotely controlled from a personal computer (PC) via the Internet using virtual instruments. The system allows experimental data to be collect and transfer to the remote user for further analysis. A distinguishing feature of this tool is the possibility for several students to share simultaneously the online data from an experiment, although only one may be in actual control of the experiment.

Up till now, only a LabView based remote client application was developed, but other remote control interfaces can be built using technologies such as Common Gateway Interface, JavaScript or Active Server Pages, allowing the use of a HTML browser as an interface.

A characteristic feature of dynamic systems study is that a long time is spent on data analysis, model and controller development, and on simulation. Only a relatively small amount of time is used in direct contact with the plant. Thus, an experiment may be shared by several students without loss of efficiency. Also, for model development purposes, students may share the data available from a running test, without actually performing the test themselves.

In order to comply with both on-lab and remote constraints, SMCRVI was developed according to the following set of specifications:

- The experiment must be able to run standalone (without any student connected to it). It must have a demonstration mode, where tests are performed by an operator (ex: a teacher) and all the students have online access to the test data.
- Students should connect to running experiments. There are two levels of interaction with the experiment:
  - Full control of the experiment.
  - Online access to the test data.
- At each time only one student can control the experiment. However, at the same time, there may be a large number of other students accessing the data from the test he is conducing.
- Test data is to be available to the students analysis environment in an easy way.
- A degree of automatic supervision has to be included allowing to:
  - Automatically limit the access time of students in full control mode.
  - Automatic access both in full control mode and data access mode.
  - Avoid undesired and/or unsafe operations.
- A degree of operator supervision has to be included allowing to:
  - Monitor the tests performed by students.
  - Perform tests for demonstration purposes.
  - Restrict access to the experiment.
- Remote access to the experiments is to be done over the local area network available in the laboratories.

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SMCRVI uses a client-server architecture where the server is a PC type computer connected to a data acquisition system. It is to be located close to the experimental setup. The client stations are PC type computers, with no special requirements. The communication between client stations and the server is supported by some Ethernet network. The server station must be able to run Matlab and LabView. The only Client software yet developed requires also the client station to be running LabView, but this restriction is supposed to be raised in the future.

SMCRVI is composed by two software packages: the Central Command Tool and the Client Station Tool. The Central Command Tool is located on the Server. Figure 2 shows its structure. This tool performs data acquisition and experiment control; it handles Client communication, commands and data transfer; it also provides a graphical interface for the operator. It is entirely programmed in Labview. It uses the Labview Matlab Script feature to allow Clients to implement their controllers and to handle Matlab data.

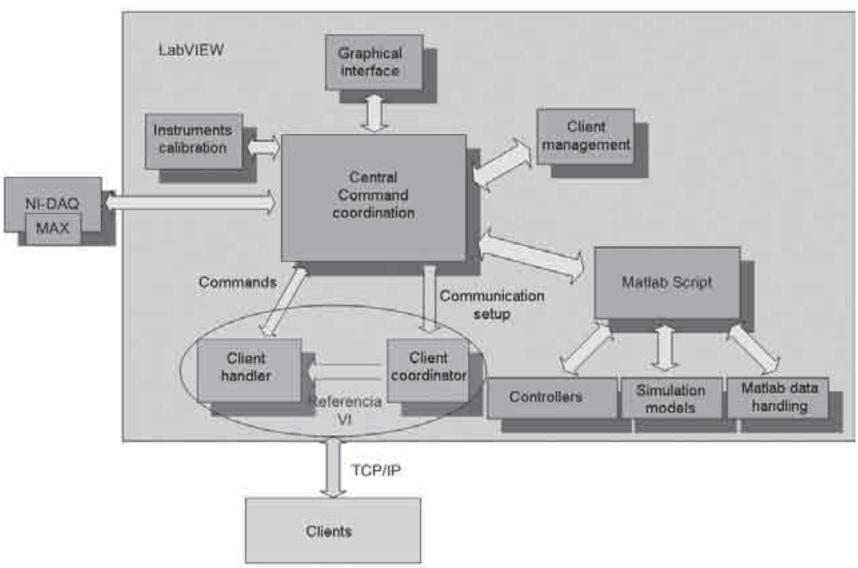


**Figure 2**

Central Command structure

The Client Station Tool is located on the Client computers. It is designed to provide a graphical interface to connect with remotely located experiments. If the client station is also running Matlab, SMCRVI may be called from within the Matlab environment and, at the end of the test, the results are collected directly as Matlab environment variables.

Labview software handles the communication with the Server and provides the user a graphical interface with the experiment. The user may chose between monitoring a test conducted by another user or to perform a test himself - both in open and closed-loop. No prior knowledge on Labview programming is required.

Once SMCRVI is called the graphical interface appears (Figure 3). The interface is divided in two sections. In the right half there is a graphic window showing online the experiment data – both commands and plant output signals. The user can select the signals to be shown and the scale (auto-scale is default). All the experiment signals are transferred to the user even if they aren't shown on the screen.

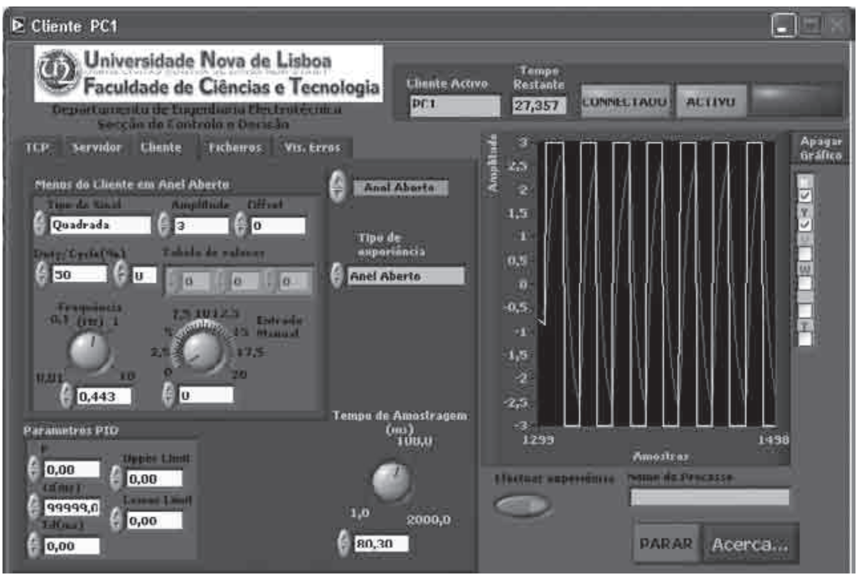


**Figure 3**

SMCRVI graphical interface

In the left half the user controls the experiment (if allowed). The interface's main tag (as shown in Figure 3) is composed by two panels: the signal generator panel and the controller panel.

The function generator produces signals to be applied to the plant. The user may switch between open and closed-loop tests. In closed-loop mode

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the user may chose between a pre-programmed PID controller and a user defined controller. In the latter option the user may select from the set of user controllers available on the Server, or he may upload his own controller onto the server. User defined controllers are implemented using the Labview's Matlab Script feature.

The controller panel allows the online tuning of the controller.

#### 4.1.1. Remote control

Performing remote control over a computer network is a dangerous matter. Delays on data transfer and losses of communication are the main reasons to avoid this solution. Thus, al of SMCRVI's control signals are computed locally at the Server. The Server's control parameters mirror the parameter values from the Client which is controlling the test.

When there are no communication problems over the network this feature is transparent to the user. Whenever there is a communication loss, the Server continuous to ensure the experiment control and the user recovers the I/O data when the communication is reestablished.

#### 4.1.2. Experimental setups

SMCRVI has been used to control the two-tank level control process from Figure 4. The water flows from a reservoir into a set of two connectable tanks. Available measures are water level and flow. Water flow is controlled by means of an electrical driven motorized valve. According to the teachers request the process dynamics may be manually changed by connecting the two tanks together or by changing the section of the connection.

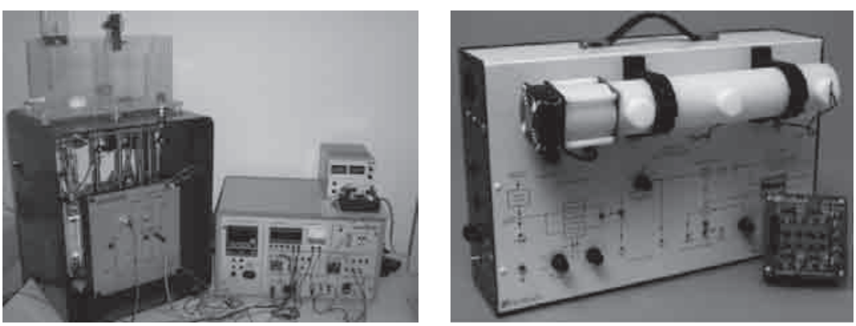

**Figure 4**

a) Two-tank level control process. b) Temperature-air flow process

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A number of experiments may be performed with this unit, ranging from a simple level control loop to cascade control and non-linear control.

SMCRVI has also been used together with a Temperature-air flow process. The process consists of a ventilation unit coupled with an electrical heating element. The power to the heater is controlled through an electrical voltage sign and temperature measurement is available. The process dynamics changes with the selected air flow or by placing the temperature sensor at different distances from the heating element.

Other equipment can also be connected. To setup a new experiment, the local operator needs only to, interactively, select the set of I/O channels to be used.

#### 4.1.3. Discussion

SMCRVI addresses the needs from the courses on Control Systems, Computer Control and Intelligent Control. The applications range from experiments using the simple PID controller through applications of state space control and adaptive control.

Hands-on practice is very important for students. Although students may have captured the core of the concepts and its application within a simulation environment, the ability to "make things work" with a real process provides them a significant increase in their degree of confidence. However, control hands-on classes are not always easy to manage.

In a typical Control Systems hands-on class, each group of students must leave its workplace and go to the process workbench (possibly in another room) where a teacher explains how to interact with the equipment. The students perform their tests and collect the test data which will be analyzed at their usual workplace. They are then replaced by the next group of students and the "process" repeats itself. In these classes there is always some degree of disorder.

With SMCRVI this disorder is averted. In the classroom it avoids the need for students to leave their usual workplace thus preventing disorder. It also saves time by allowing a fast switch on the group which is performing the test and also by the sharing of real-time test data. By granting off-class access to the experiment it takes off the pressure on students allowing them to conclude and repeat tasks which they were not able to finish during class.

### 4.2. *Embedded systems experimentation*

As referred, the second type of experiments considered has as common characteristics its relatively low-cost and the possibility to be replicated.

Experiments associated with embedded systems, reconfigurable devices or basic electronics fall within this characterization. Several examples on remote laboratories for embedded systems experimentation can be found in the literature [11 - 15].

At Universidade Nova de Lisboa, we are considering a remote laboratory based on a four level structure (see Fig. 5):

- Student, remotely connected to the local server using a browser through the internet;
- Local server, enabling virtual workbench to be used remotely;
- Virtual workbench adaptor, which interacts with the local server in order to produce inputs to the system under test and get current status of the outputs;
- Microcontroller system under test (which is a 8031 microcontroller based micro-system in the illustrated case).

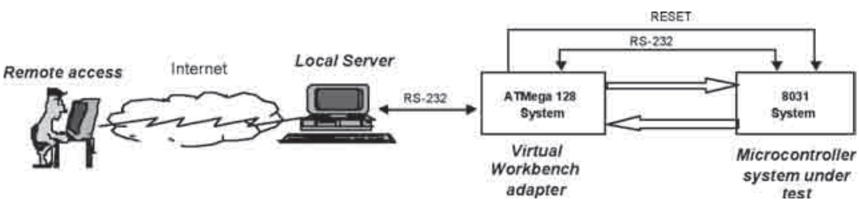


**Figure 5**

Remote laboratory structure

The current implementation of the local server is based on LabView, which can assure adequate connectivity to lower levels, while taking care of the internet connectivity.

Fig. 6 presents two snapshots of the LabView VI, the first one to allow remote reset of the system under test, followed by the download of the program and its launching; the second snapshot is activated afterwards and it's used to impose inputs and get output status from the system under test.

In this sense, the usage of the virtual workbench is very close to the procedures one has to comply when interacting directly with the 8031 microcontroller system.

For the virtual workbench adaptor, a simple system based on an ATmega128 microcontroller was considered. General features include:

- Two RS-232 links; one devoted to the connection with the local server, in order to receive commands from the user and return responses; the other is targeted to connect with the system under test;

**Figure 6**

Snapshots of the virtual workbench:
download of a program and monitoring of the system under test

— A set of inputs to acquire actual outputs of the system under test;
— A set of outputs to impose values at the inputs of the system under test;
— A reset output to assert reset pin of the system under test (and get control back to the monitor program).

From the point of view of connection between the local server and the workbench adaptor, a simple protocol was defined, including the following set of commands:

— Reset of the system under test;
— Download a file to the system under test;
— Download commands and binary sequences to the system under test (command at the upper serial link will be echoed at the lower serial link);
— Get actual status of system under test outputs;
— Impose specific values at the system under test inputs;
— A command to enable further use as a terminal (from local server to the system under test, being the workbench adaptor "transparent").

This workbench adaptor can also be used for general virtual and remote laboratory experiments.

The proposed architecture for the remote laboratory based on four layers is to be used within embedded systems courses, covering from introductory and intermediate courses including advanced ones, as well. Although, the emphasis of this presentation was on the support for microcontroller experiments, the same environment can be used for introductory digital systems courses (where combinatorial functions implemented through discrete logic and modules, and sequential circuits are taught), or even to intermediate courses on digital system design (where programmable logic devices, like CPLDs and FPGAs are used).

However, for introductory and intermediate courses, the possibility of having replicas of the laboratory environment with every group of students is something that can be achieved at reasonable prices (the estimated price for a complete experimentation kit is below 100 euro). As a matter of fact, for those introductory and intermediate courses, current solutions at Universidade Nova de Lisboa emphasize this possibility, in opposition to remote labs support, which means that the students receive an experimentation kit at the beginning of the semester and give it back at the end. In this sense, the validation of the presented proposals using a course with a large number of students enrolled was not yet fully performed. The full usage of the presented framework is foreseen to be included in the support to a new course (on co-design and reconfigurable platforms), to be launched next academic year, where expensive FPGA platforms will be used. For that course, the proposed remote lab architecture will have a key contribution to support experimentation "every time, every where".

## Conclusions and future needs

In this chapter, general characteristics associated with remote experimentation were presented. Two types of experiments emphasizing extreme situations were considered: the first one associated with experiments of "one-of-a-kind" type, normally associated with expensive set-ups (common in process control), and the second one associated with low-cost experiments that can be replicated (common in electronics and embedded systems).

Finally, as a very important open issue, we may identify the current lack of standardization for remote labs which has to be solved in order to allow interoperability between different experiments and integration of experiments available at one location with others available at different locations.

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# Proposal of equipment for practical teaching in control engineering: Extension to Remote Laboratories

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**Abstract**

*The main objective of this chapter is to present an innovative equipment specifically designed for practical training in industrial instrumentation, control engineering, and automation. The role of the control and automation issues applied to this prototype is discussed. Its conceptualisation to be integrate in a remote laboratory and its possibilities will be introduced.*

## Introduction

Laboratory equipment plays and will certainly play an important role in control engineering education [1]. Generally, laboratory equipment for control engineering teaching is designed with few industrial hardware resources. In their design, many manufacturers pay more attention to the immediate check of the basic theoretical topics of the control theory and do not take care of the practical aspects of industrial control [2].

Due to this situation:

— Many control engineering students finish their studies without having a real practical overview of how control theory fundamentals are applied in industry. They either do not have a true image of the industrial hardware used in process control or they lack the practice to use it properly [3].

— There is a gap between the theoretical and the technical-practical training of the graduates, which facilitates the deep-rooted lack of trust that industrial enterprises have in universities because the practical education in these centres does not satisfy the industrial requirements [4].

Therefore, one vital aspect of control engineering education is the laboratory and practical work need to provide engineering students a taste of real industrial situations, measurement and instrumentation. Another important tendency in the field of control practice is the increasing employment of information technologies for the learning process. A natural extension is to make students able to perform real experiments, in real time, on real equipments, but over the Internet, i.e. the use of this equipment as a remote laboratory. In order to reduce this gap and offer control engineering students a technical-practical and professional education, the Faculty of Engineering-ESIDE, University of Deusto and Miesa Engineering (Spain) have together conceived, designed, and manufactured an innovative prototype with industrial equipment [5, 6, 7].

In order to describe the scope of this equipment, this chapter is organised as follows: Section 2 describes the conceptualisation of the innovative equipment that has been taken into account in the design process of the prototype; Section 3 describes briefly the process and its equipment; Section 4 presents the control issues applied in the design of the different control systems for the prototype; Section 5 makes a study about the automation system requirements to integrate this prototype in a remote laboratory. Finally, as a conclusion, the prototype's potential for theoretical-practical training is analyzed.

## 1. Conceptualisation of the innovative prototype

As mentioned in the previous section, one of the main difficulties that a Faculty of Engineering finds in the practical training of students in the field of automation, control systems, and instrumentation is the lack of proper equipment with industrial focus that brings the student closer to the industrial reality. From the equipment's innovation point of view, the prototype conceptualisation has to be made paying special attention to the following aspects: conventional technologies for control and supervision and emergent technologies in industry, and all these ones should be able to be integrated in a Distributed Control System (DCS).

This kind of equipment has been designed taking into account the following basic topics of conventional control and supervision technologies used in industry:

— Practical knowledge of a multiloop control structure, multiloop controller tuning, and process supervision: programming and configuration of the communications for a Supervisory Control And Data Acquisition (SCADA) system, and conceptualisation of a hierarchical alarm system.

Related to emergent technologies in industry, topics considered should be:

— Control through Programmable Logic Controller (PLC), PID programming in a PLC, Pofibus DP periphery, Profibus PA instrumentation, and communications (Serial communications, Profibus DP and PA fieldbuses, and Ethernet TCP/IP). These technologies allow this prototype to be integrated in a remote-accessible laboratory, as will be described in section 5.

## 2. **Process description**

This prototype has been conceived for the control engineering student's training and for investigation in the fields of industrial instrumentation, continuous process control and industrial computer science [7].

This section is divided into the following parts: First physical elements and instrumentation that make up the plant are described. Next the different technological elements of control installed in the prototype are presented, and lastly the equipment's possibilities in the field of communication technologies and use as a remote laboratory are described.

### 2.1. *Plant description*

The equipment brings about a thermodynamic process of heat exchange. The prototype provides the appropriate control loops and instrumentation needed for industrial processes [8]. The process consists of heating a process fluid using steam as a control agent. The control objective is to maintain the heated water temperature, $T_O$, at a set value, $T_O^{SET}$, $T_O = T_O^{SET}$, whatever perturbations may take part in the process. A continuous service of hot and cold water is necessary, which represent the steam and process fluids respectively.

For this reason, this prototype consists of a hot water closed circuit and a cold one:

— **Hot water circuit**. It is formed by the dump D-002 that contains an electric resistance, an impulsion pump B-002 downstream installed, a control valve FV-002, a flow transmitter FT-002, and auxiliary instrumentation. The water is heated to 60ºC.

— **Cold water circuit**. It is composed of the dump D-001, an impulsion pump B-001 and an air cooler E-001 installed downstream and upstream of the dump, respectively; a cold water feed valve FV-001, a flow transmitter FT-001, and auxiliary instrumentation.

PT-100 temperature transmitters (TT-001, TT-002, TT-003, and TT-004) measure the inlet and outlet temperature to the heat exchanger E-002. TT-005 measures the temperature inside the hot water dump.

The schematic diagram in Figure 1 shows the location of the different components and the instrumentation in the plant.

## 2.2. *Control technologies*

Currently, industrial processes are controlled by computer or micro-controller based systems. These systems include controllers and PLCs. In order to investigate the possibilities of these different kinds of technologies for industrial plant control, this prototype is equipped with a multiloop industrial regulator, a high/medium performance PLC, and a PC in its frontal part, as shown in Figure 2. There is an external selector for connecting one or another kind of controller [8].

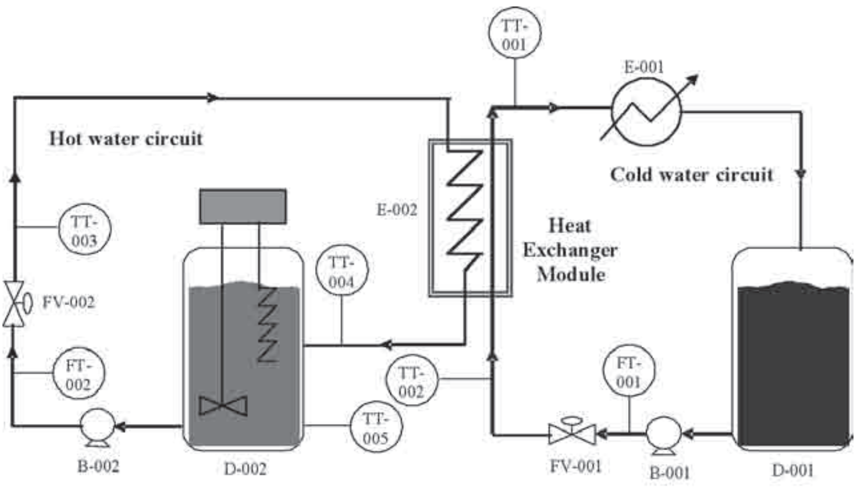


**Figure 1**

Scheme of the plant with its different components and instrumentation

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## 2.3. *Communication technologies*

Actually, main technologies related to computer sciences used in the process industry are data acquisition cards, fieldbuses and industrial communications, processes supervision, and real-time application development.

For this reason, the prototype is equipped with data acquisition cards for communication between equipment's instrumentation and the PC, cards for communication between the PLC and the local PC and/or the remote PC. Industrial commercial software packages for process supervision are installed. This prototype presents all the necessary communication technologies to be integrate in a DCS and to be a part of a remote laboratory.

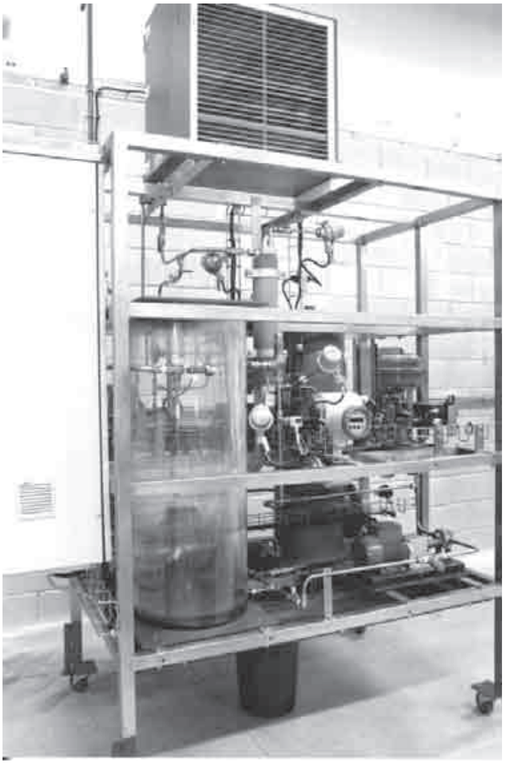

**Figure 2**

Real picture of the Heat exchanger prototype with its industrial equipment

## 3. **Control issues**

### 3.1. *Process modelling of the process*

First of all, it is important to consider that a counter-current heat exchanger is used in our prototype. Figure 3 represents the evolution of hot and cold fluid temperature along the exchanger in the thermodynamic process of heat exchange.

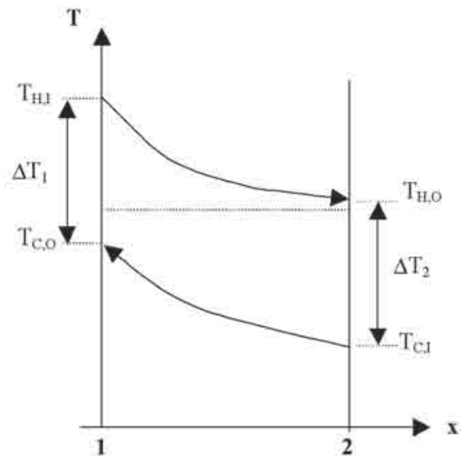


**Figure 3**

Profile of the hot and cold fluid temperatures along the heat exchanger

In order to develop the mathematical model, the transfer function, and the block diagram for this process [9, 10], we firstly start with a heat energy balance for the cold (1) and the hot fluid (2), assuming negligible heat losses and constant volume and physical properties. It results in the following equations expressed in global variables:

$$m_C c_{PC} \frac{dT_{C,O}}{dt} = \rho c_{PC} Q_C \left(T_{C,I} - T_{C,O}\right) + UA\left(T_H - T_{C,O}\right) \tag{1}$$

$$m_H c_{PH} \frac{dT_H}{dt} = \rho c_{PH} Q_H \left(T_{H,I} - T_{H,O}\right) - UA\left(T_H - T_{C,O}\right) \tag{2}$$

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where $m_H$ (kg) and $c_{PH}$ (J/kg·K) are the hot fluid mass and specific heat, respectively, contained in the coil; $m_C$ (kg) and $c_{PC}$ (J/kg·K) are the mass and specific heat, respectively, of cold fluid contained in the exchanger and dipping the coil; $T_H$ (K) is the hot fluid temperature contained in the coil, $T_{C,I}$, $T_{C,O}$, $T_{H,I}$, and $T_{H,O}$ (K) the cold and hot fluid inlet and outlet temperature, respectively, $\rho$ (kg/m$^3$) is the fluid density, $Q_C$ and $Q_H$ (m$^3$/s) the cold and the hot fluid flow, $U$ (W/m$^2$·K) is the overall heat transfer coefficient and $A$ is exchanger transmission area. For the liquid contents of the exchanger, the specific heat at constant volume is considered to be equal to that one at constant pressure.

From these equations, in the case that main variables in the process are constant, the steady-state model can be obtained, see equation (3). From this model, the value of the cold fluid temperature outlet the exchanger ($T_{C,O}$) for a steady-state situation can be estimated.

$$c_{PC}\bar{Q}_C\left(\bar{T}_{C,I}-\bar{T}_{C,O}\right)=c_{PH}\bar{Q}_H\left(\bar{T}_{H,O}-\bar{T}_{H,I}\right) \tag{3}$$

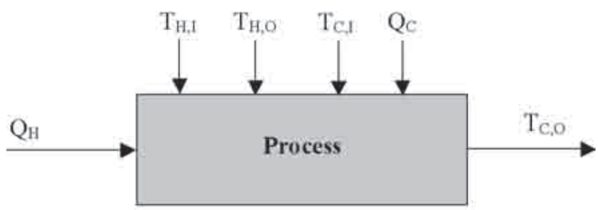


**Figure 4**

Main variables of the process

Main process variables of the process are represented in Figure 4. All perturbations affecting the evolution of the output variable have been identified, being considered the cold fluid flow as the most important perturbation in the process.

From this point, deviation variables will be represented by lower-case letters, absolute variables by capital letters, and steady-state values of the different variables by capital letters with a hyphen on top, as defined below:

$$\begin{array}{ll} Q_H=\bar{Q}_H+q_H & Q_C=\bar{Q}_C+q_C \\ T_{H,I}=\bar{T}_{H,I}+t_{H,I} & T_{C,I}=\bar{T}_{C,I}+t_{C,I} \\ T_{H,O}=\bar{T}_{H,O}+t_{H,O} & T_{C,O}=\bar{T}_{C,O}+t_{C,O} \\ \Delta T_1=T_{H,I}-T_{C,O} & \Delta T_2=T_{H,O}-T_{C,I} \end{array}$$

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### 3.2. *Dynamic model*

Developing the equations of the heat energy balance (see equations 1 and 2) in terms of deviation variables and taking into account the steady-state model (see equation 3), the following linear dynamic model is obtained:

$$\left.\begin{aligned} m_C c_{PC}\frac{dt_{C,O}}{dt} &= \rho c_{PC}\left(\bar{T}_{C,I}-\bar{T}_{C,O}\right)q_C+\rho c_{PC}\bar{Q}_C\left(t_{C,I}-t_{C,O}\right)+UA\left(t_H-t_{C,O}\right) \\ m_H c_{PH}\frac{dt_H}{dt} &= \rho c_{PH}\left(\bar{T}_{H,I}-\bar{T}_{H,O}\right)q_H+\rho c_{PH}\bar{Q}_H\left(t_{H,I}-t_{H,O}\right)-UA\left(t_H-t_{C,O}\right) \end{aligned}\right\} \quad (4)$$

Grouping the terms in $T_{C,O}$ and $T_H$:

$$\left.\begin{aligned} m_C c_{PC}\frac{dt_{C,O}}{dt}+\left(\rho c_{PC}\bar{Q}_C+UA\right)t_{C,O} &= \rho c_{PC}\left(\bar{T}_{C,I}-\bar{T}_{C,O}\right)q_C+\rho c_{PC}\bar{Q}_C t_{C,I}+UAt_H \\ m_H c_{PH}\frac{dt_H}{dt}+UAt_H &= \rho c_{PH}\left(\bar{T}_{H,I}-\bar{T}_{H,O}\right)q_H+\rho c_{PH}\bar{Q}_H\left(t_{H,I}-t_{H,O}\right)+UAt_{C,O} \end{aligned}\right\} \quad (5)$$

Where the following new magnitudes can be defined:

$$\left.\tau_C=\frac{m_C c_{PC}}{\rho c_{PC}\bar{Q}_C+UA}[\sec] \quad \tau_H=\frac{m_H c_{PH}}{UA}[\sec]\right\} \quad (6)$$

$$\left.\begin{aligned} K_1 &= \frac{\rho c_{PC}\left(\bar{T}_{C,I}-\bar{T}_{C,O}\right)}{\rho c_{PC}\bar{Q}_C+UA}\left[K\cdot m^{-3}\cdot\sec\right] & K_4 &= \frac{\rho c_{PH}\left(\bar{T}_{H,I}-\bar{T}_{H,O}\right)}{UA}\left[K\cdot m^{-3}\cdot\sec\right] \\ K_2 &= \frac{\rho c_{PC}\bar{Q}_C}{\rho c_{PC}\bar{Q}_C+UA} & K_5 &= \frac{\rho c_{PC}\bar{Q}_H}{UA} \\ K_3 &= \frac{UA}{\rho c_{PC}\bar{Q}_C+UA} \end{aligned}\right\} \quad (7)$$

Finally, introducing these magnitudes into the linear dynamic model, the following equations are obtained:

$$\left.\begin{aligned} \tau_C\frac{dt_{C,O}}{dt}+t_{C,O} &= K_1 q_C+K_2 t_{C,I}+K_3 t_H \\ \tau_H\frac{dt_H}{dt}+t_H &= K_4 q_H+K_5\left(t_{H,I}-t_{H,O}\right)+t_{C,O} \end{aligned}\right\} \quad (8)$$

Taking the Laplace transform from equation (8), the model included into the simple feedback loop showed in Figure 5 can be obtained:

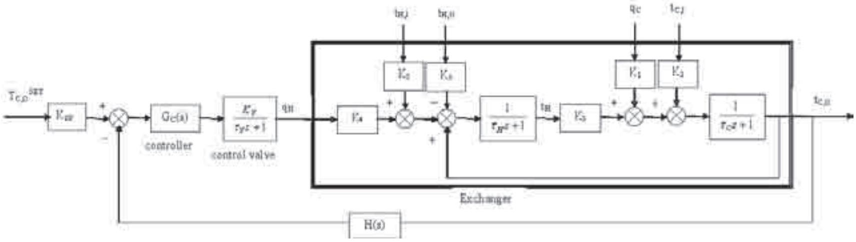

**Figure 5**

Process block diagram with a simple feedback loop

3.3. *Control loop structure: Multiloop control system*

A multiloop structure is determined considering the effects of the perturbations over the controlled variable [9, 11]. Main process variables are:

- **Controlled variable**: cold fluid temperature $T_{C,O}$ outlet to the exchanger. Control objective is achieving $T_{C,O} = T_{C,O}^{SET}$.
- **Perturbations**: Cold fluid flow $Q_C$ and its temperature $T_{C,I}$ inlet to the exchanger, and eventually $T_{H,I}$.
- **Manipulated variable**: Hot fluid flow $Q_H$.

If it is supposed that physical properties do not vary and if heat losses do not exist, we have to analyse only the effects of perturbations and flow changes in the hot fluid. The effect of flow changes in the cold fluid over $T_{C,O}$ is fast, and that of $T_{C,I}$ is delayed because of the own transport delay in the exchanger shell. On the other hand, the flow changes in the hot fluid are also delayed due to the dynamic performance of the control valve.

Multiloop control system's configuration implemented in the prototype consists of a three-element control [11]: feedback, cascade and static feedforward control. However, the different control configurations shown in Figure 6 are available in the prototype [12, 13].

In Figure 6, $m_T$ is the temperature controller output, $PV_T$ is the output temperature process variable, $PV_{Q_H}$ is the hot fluid flow, $Q_H^{RSET}$ is the hot fluid flow remote set point, $Q_H^{LSET}$ is the hot fluid flow local set point, TIC and FIC are the temperature and flow controller, respectively, and $m_V$ is the flow controller output.

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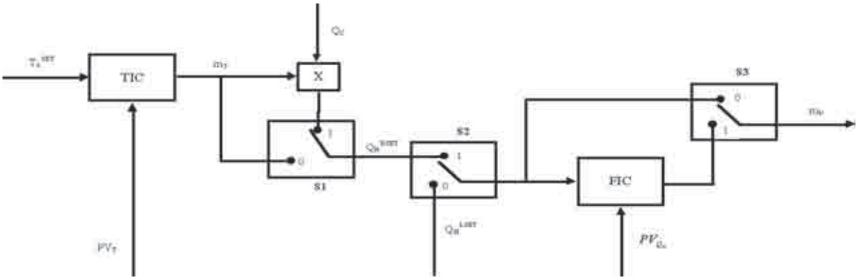


**Figure 6**

Process block diagram

This prototype can operate with the different possible loops indicated by the configuration shown in Table 1.

**Table 1**

Configuration of the different possible loops implemented in the prototype.

| S1 | S2 | S3 | CONFIGURATION |
|---|---|---|---|
| 0 | 1 | 0 | Simple feedback loop (temperature) |
| X | 0 | 1 | Simple feedback loop (hot fluid flow) |
| 0 | 1 | 1 | Cascade loop (temperature and hot fluid flow) |
| 1 | 1 | 1 | Cascade and feedforward loop |

## 3.4. *Experimental results*

As mentioned in section 1, the particular interest of this work is to present an equipment designed for training students in the practice of control loop implementation and for familiarizing themselves with the handle of industrial regulators.

Nearly of the 90% of the industrial applications can be controlled by a PID controller and the main difficulties consist in tuning correctly its parameters [13], so that our effort is centered in achieving that our students learn PID tuning methods [15, 16]. In the specialized literature several PID tuning methods are described [9, 11, 13, 14]

For the basic education, we consider that it is enough if our students learn to apply the open and closed loop Ziegler-Nichols method [17] and to implement a three-element control: feedback, cascade and feedforward control.

On the other hand, it is important that they can be able to apply directly Ziegler-Nichols formulae and later to make a readjustment of the PID parameters in order to improve the system performance [18].

In tables 2, 3, 4, and 5 the open and closed loop Ziegler-Nichols parameters and their readjustment by trial and error, respectively, are showed.

**Table 2**

Parameters of the PID controller obtained using the open loop Ziegler-Nichols method

| Controller | $K_C$ | $T_I$ (seconds) | $T_D$ (seconds) |
|---|---|---|---|
| P | 42 | — | — |
| PI | 37.9 | 50 | — |
| PID | 50.5 | 30 | 7.5 |

**Table 3**

Initial parameters from Table 2 modified by trial and error method

| Controller | $K_C$ | $T_I$ (seconds) | $T_D$ (seconds) |
|---|---|---|---|
| P | 30 | — | — |
| PI | 25 | 60 | — |
| PID | 40 | 40 | 10 |

**Table 4**

Parameters of the PID controller obtained using the closed loop Ziegler-Nichols method

| Controller | $K_C$ | $T_I$ (seconds) | $T_D$ (seconds) |
|---|---|---|---|
| P | 27.5 | — | — |
| PI | 24.75 | 86.32 | — |
| PID | 33 | 52 | 13 |

**Table 5**

Initial parameters from Table 4 modified by trial and error method

| Controller | $K_C$ | $T_I$ (seconds) | $T_D$ (seconds) |
|---|---|---|---|
| P | 25 | — | — |
| PI | 20 | 90 | — |
| PID | 30 | 60 | 15 |

The following figures represent the system response for the previous adjustments.

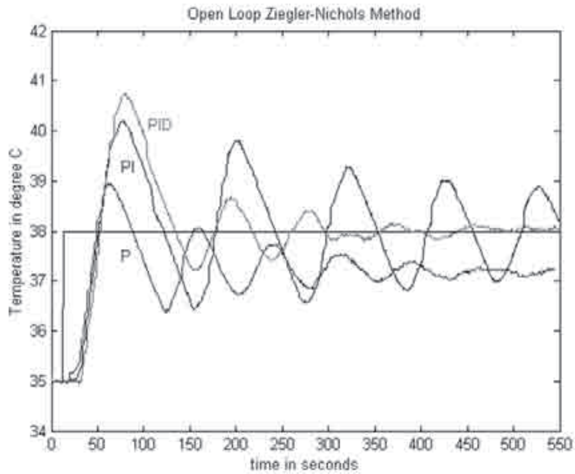


**Figure 7**

Results for Table 2

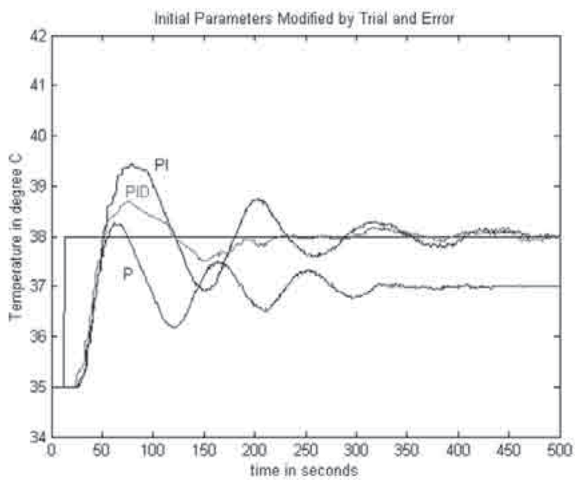


**Figure 8**

Results for Table 3

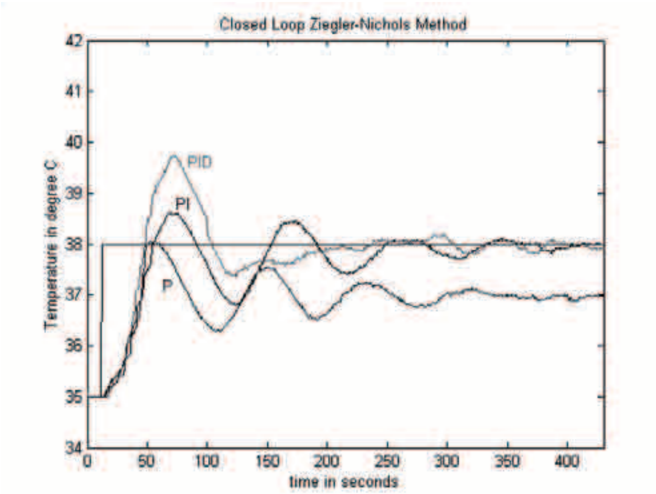


**Figure 9**

Results for Table 4

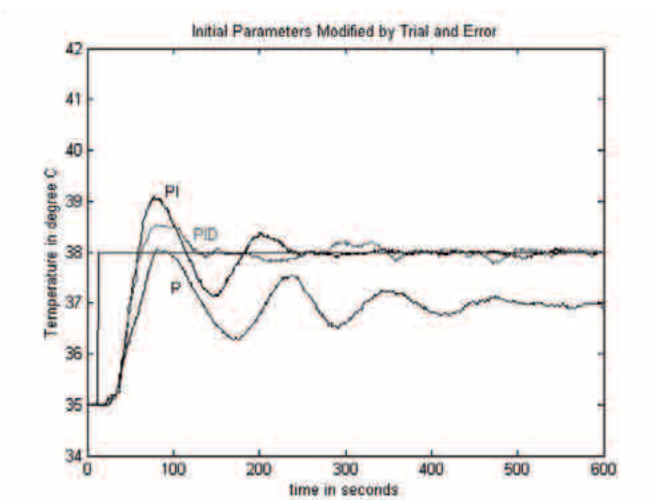


**Figure 10**

Results for Table 5

From the education point of view, the most important thing is to check the relationship between the gains of the different controllers and the one between the derivative and the integral time in the PID case, instead of applying formulae.

In the case of the PI controller, the integral mode introduces a delay that causes a 10% reduction of the P controller gain. This causes a decrease in the loop controllability, so the system response with a PI controller results more oscillating than with a P one (see figures 7, 8, 9, and 10).

When we use a PID controller the gain increases 20%, while the relationship between the derivative time and the integral one is 1:4. The increase of $K_C$ for the PID, compared to $K_C$ for the P controller justifies the increase of the loop controllability. System response is faster and less oscillating compared to PI response [14].

The relationship between integral and derivative time is very usual when PID controllers are tuned by trial and error method. It is important to say that these observations are useful including for making fine readjustments starting with closed loop Ziegler-Nichols formulae.

Referring to the readjustments obtained applying the open loop Ziegler-Nichols formulae, it is checked that they complete the previous observations [17].

Other aspects that must be sited are:

- Controller gain is proportionally inversed to the process gain. In the practice, this means that the controller gain must be readjusted when the open loop gain of any element changes.
- The fewer ratio between the loop delay and the time constant of the system will be the more easy to control.

In our prototype $P_\mu = \dfrac{\tau_D}{\tau} = \dfrac{15s}{35.8s} = 0.419$, which indicates that this process is not difficult to control.

In figures 7, 8, 9, and 10 different responses for the different controllers and adjustments are shown.

## 4. **Integration in a remote laboratory**

This prototype supports four independent control modes using different technologies for industrial plant control, communications, and supervision, as shown in Figure 11.

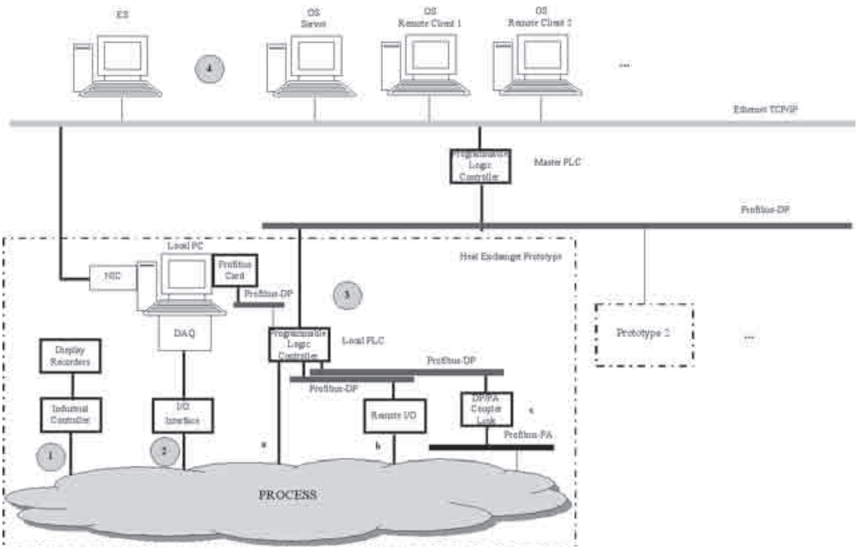


**Figure 11**

Diagram of the automation system specifications

1. **Autonomous mode**: In this mode, a multiloop industrial regulator based on a micro-controller is used. The prototype has display recorders to visualize the different variables of the process.

2. **PC mode**: Data acquisition cards are the interface for the communication between process and the computer. Although control algorithms actually are implemented and developed using MatLab, another software can be used. A graphic user interface has been developed with a commercial SCADA.

3. **PLC mode**: The aforementioned control algorithms have been implemented in the local PLC. The PC is directly connected to the local PLC through Profibus-DP fieldbus. In the local PC, a graphic user interface has been developed using a commercial SCADA. There exist three different possible configurations used as the interface for the communication between the process and the local PLC [19]:

a) Direct connection between the process and the local PLC.
b) Decentralized periphery using I/O remote modules, which are connected to the controller through Profibus-DP fieldbus. In this configuration the local PLC is used as DP master.

c) PA Instrumentation. This is the option if PA devices are available in the process. The DP/PA link and the DP/PA coupler allow a transition between Profibus-PA and DP fieldbuses, working as DP slave and PA master.

4. **DCS mode**: In this mode, a high performance PLC is used as DP master. Therefore, the possibility of connection to more prototypes controlled by its own local PLC is added. The connection between the different local PLCs is made through Profibus-DP fieldbus.

The local PLC works as DP slave, taking into account that this mode allows the three different options of connection between the local PLC and field devices.

Related to the visualization, the configuration of the system is made in the engineering station (ES). On the other hand, there exist operator stations (OS), where the process is supervised and a server-client structure is used.

## Conclusion

In this paper an innovative heat exchanger prototype has been described and its potential for theoretical-practical training has been analysed.

The prototype is a replica of a real industrial process so that it allows the familiarisation and the ability to manage a plant with industrial equipment, the conceptualisation of instrumentation loops, the interpretation and realization of piping and instrumentation diagrams (P&ID's), calibration of industrial instrumentation, and the selection and sizing of instrumentation. From the training in process control point of view, with this equipment the following basic topics of control theory may be considered: process modelling, control loops conceptualisation (multiloop control), industrial regulators tuning, and advanced control.

Related to training in communications and process supervision, the practical training in this field is focused in the study and development of SCADA systems, and application development for serial and Profibus fieldbus communications, as mentioned in previous sections. Its integration in a DCS for its use as a remote laboratory is considered.

Actually, 1, 2, and 3a technologies are implemented in this prototype. At the present, the prototype presented in this paper is being integrated in a distributed control system together with an ion exchanger, a steam boiler, and a pH control prototype, forming a part of the *Laboratory of Measurement Systems and Regulation* in the University of Deusto. A similar prototype designed by the Department of Automatic Control, University of Deusto and manufactured by Miesa Engineering (Spain) using 3 and 4 technologies of control with b and c options, together with an ion exchanger and a steam boiler prototype comprise the *Automation and Process Control Laboratory of the Integrated Centre for Education in Renewable Energies CENIFER* in Navarre (Spain). This adds the assembly, the configuration, and connection of DP periphery and PA instrumentation. The design and manufacture of the prototypes for this laboratory was supported by the Government of Navarre and the Ministry of industry, Tourism and Trade of the Central Government.

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# The electronic laboratory: traditional, simulated or remote?

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**Abstract**

*Laboratory activities are essential components of electronic engineering pedagogy. The introduction of complex solid state components and the development of software simulation and design techniques has deeply affected the organisation and use of educational laboratories. In particular, for digital design, traditional hardware laboratories are replaced by "virtual" environments, where simulated components are used instead of real ones. The diffusion of the Internet has further modified the education environment, with the introduction of remotely-controlled laboratories.*

*The chapter explores the issues relevant for the pedagogical use of virtual and remote labs in the field of electronic engineering, using as examples two projects developed in our institution and used in our courses. Deeds is a learning environment for digital electronics based on a set of simulators and web resources. It enables integrated simulation of combinational and sequential logic networks, finite state machine and microcomputer boards. The Deeds has capabilities of guiding student's activities by delivering learning materials through specialized browsers and it has been specifically designed to support distance education. ISILab is an environment currently used to deliver remote access to experiments of electronics. Students can practice with electronic instruments and measurement methods to execute real experiments on analogue and digital circuits. The experiments deal with basic electronic measurements, such as the delays in digital circuits or the gain and the distortion of amplifiers, and let to use devices such as waveform generators and oscilloscopes.*

## Introduction

Laboratory activities are essential components of any engineering pedagogy. In our field, electronics, they accompany and support the learning activities of many courses. The evolution of electronic and computer technologies of the last decades has had a profound effect in the organisation and use of educational laboratories. We could identify the two major driving forces as the introduction of complex solid state components and the development of software simulation and design techniques. As a result, traditional hardware laboratories have lost their central place, being replaced by “virtual” environments where simulated components are used instead of real ones. This is especially true for digital electronics, where CAD applications have completely replaced traditional design and prototyping techniques, for students and professional alike.

The diffusion of the Internet has definitely accelerated the pace of innovation in our field. Nowadays, Internet-controlled remote laboratories are available in many educational institutions and, more and more often, targeted to replace traditional laboratories. In fact, the possibility of replacing traditional laboratories with facilities available without time and space limitations is too attractive to be overlooked. This new scenario offers the potential for a deeper integration of practice with traditional lectures, and for a much wider and more efficient use of laboratories. Furthermore, it opens the road for the integration of laboratories into distance learning activities [1].

The process of replacing traditional with remote laboratories has, obviously, two faces. The first one consist in the development of the lab itself, the second one in a serious reflection on the pedagogical targets that must justify the technical effort. Remote labs, in fact, do not replicate the same experience as a traditional lab and do not develop exactly the same skills. The chapter aims to explore the issues relevant for the pedagogical use of virtual and remote labs in the field of electronic engineering, with an obvious reference to the two projects developed in our institution, i.e. the Deeds virtual lab for digital design and the remote, general purpose lab ISILab.

## 1. The electronic laboratory

A short history of electronics transports us, in a very short time span, from vacuum tubes to transistors to systems on a chip, composed of hundred of millions of active components. The pace of development of electronics is unprecedented in the human history and not replicated by any other engineering technology. While a car or a ship or a train are, basically, the same machines, exploiting the same principles of more than a century ago, with only a slight improvement in performances, today's electronic devices represent a total revolution, and not only in technology terms. The increase of several orders of magnitude in performances, coupled with the comparable decrease of cost has made possible a huge variety of applications, unthinkable of only a couple of decades earlier. Today's sophisticated software technologies are made possible and significant only by the availability of supporting electronics. It is not easy to assess, in this complex framework, the role of the electronic educational laboratory.

### 1.1. *The traditional electronic laboratory*

Until a few years ago it was a common practice to perform traditional laboratory activities within the context of courses of electronics. They were often based on the construction and testing of circuit prototypes. Laboratory served many purposes, from demonstrations of principles to practice of measurements, from design and prototyping to testing and troubleshooting. The underlying assumption was always to establish a bridge between theory and practice.

Academic lab activities tend to use the mainstream industrial technology of the moment, but often with a few years delay. In the case of digital systems, the circuits were usually assembled out of TTL integrated circuits with the support of a solder-less breadboard. The integration of a solder-less breadboard with driving and test logic (Fig. 1) makes a simple but complete digital lab. This has been the state of the art for many years.

We refer here to the experience made in many years of teaching an introductory course of digital design. The laboratory activities accompanied the lectures all year long, with an intense use of the facilities, given the large number of attending students. Most of the laboratory session time was needed for the construction of the circuits, often critical because of second-order effects, such as faulty components or, more often, bad electrical contacts within the breadboard, due to excessive wear and/or careless use. Circuit testing followed, executed with a traditional electronic laboratory instrument bench (power supplies, oscilloscope, waveform generators, and logical testers). When dealing with systems, whose design had been developed in the lectures, performing functions in a realistic way, the wiring could become (see Fig. 2) very complicated, time consuming and conductive to connection mistakes. Therefore, most of the student efforts went into circuit assembly, a

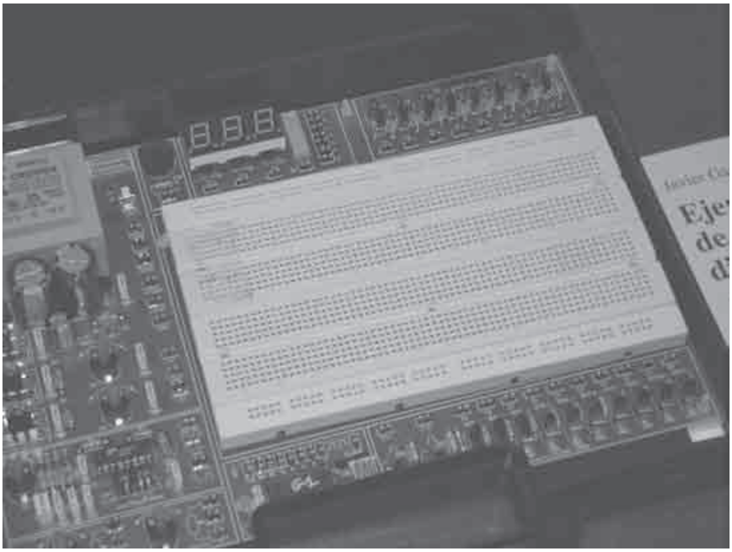

**Figure 1**

A solder-less breadboard with test circuitry

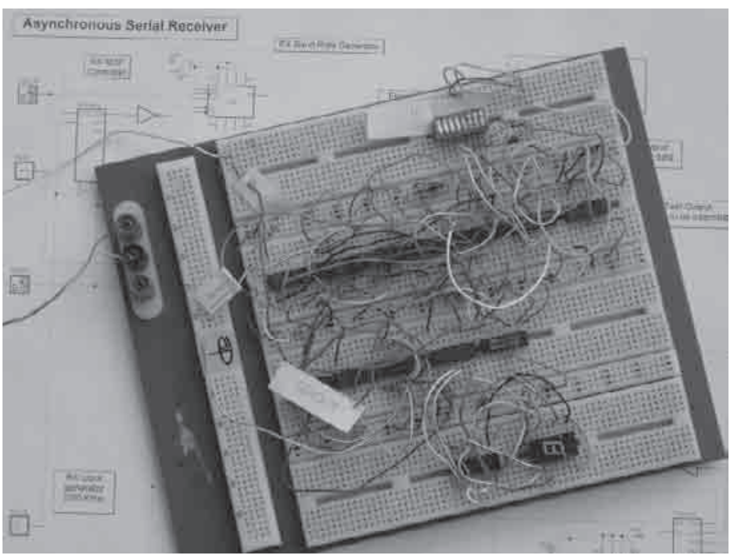


**Figure 2**

The complex wiring of a simple digital system controlled by a FSM practice that has a limited value for acquiring digital design skills and, with technological advances in digital components, is not anymore representative of the techniques used in the professional practice.

### 1.2. *Simulation-based laboratory*

The explosive development of digital electronic techniques of the last two decades has changed not only the component fabrication but also the design practices, with the consequent demand of a new approach in the preparation of the new digital designers.

Nowadays, Computer Aided Design (CAD) techniques are an essential part of the design process, while prototype fabrications with procedures that are mimicked by the former bread-boarding are less and less important. The evolution of digital technologies, therefore, has suggested the replacement of the former experimental setup by a set of software tools, that constitute what we can call the simulation-based (or “virtual”) digital laboratory.

Available software tools include both professional applications, developed for commercial families of PLD (Programmable Logic Devices), often offered for free by the manufacturers of the PLD, and simulation tools designed for educational applications. A partial list of commercial products targeting the educational field includes: XilinX [2], Altera [3], OrCAD [4], NI MultiSim (formerly Electronics Workbench) [5], Tina Design Suite [6], Digital Works [7], MacroSim [8], Proteus [9].

Many others have been developed inside universities in a no-profit perspective. This scenario is more difficult to describe, since it is more various and, somewhat, dispersed. While the commercial packages tend to cover the whole set of digital devices and techniques, it is common to find, in this category, tools dedicated only to specific topics. Furthermore, an Internet search finds, side by side, projects that are “alive” and evolving with new releases, and others that do not show recent updates. A far from complete list could include: Circuit Shop [10], Digital Simulator [11], EasySim [12], Logisim [13], Digital WorkShop [14].

Software simulation tools may be associated with hyper-textual and interactive multimedia materials to embody a “learning environment”, providing a variety of resources to support understanding and practice. An example is the “Distance Learning on Digital Systems” project [15], developed at Tallinn University of Technology and Technical University of Ilmenau. The web pages contain theoretical, hyperlinked text parts and interactive, action based parts for practical experiments, tools for examinations, self-testing, and practical training [16].

The authors have explored at length the potentialities of highly interactive learning tools [17], reaching the decision of using a general purpose simulator to replace a multitude of specific tools. The possibility of adopting a professional tool in an introductory course has been discarded, since students do not have the skills and the frame of mind of the accomplished digital designer, whom the professional tools are made for. Hence, the decision of developing an environment that, while providing professional simulation performances, would preserve the main advantage of the learning tools quoted above, i.e. the possibility to logically link simulator operations with tutorial material. The result is the "Digital Electronics Education and Design Suite" (Deeds) [18,19], a project developed at our institution.

### 1.2.1. The Deeds: overview

Deeds is a learning environment for digital electronics that provides an innovative set of tools and resources for teachers and students (Fig. 3). It is extensively used by the students of the first and second year of electronic

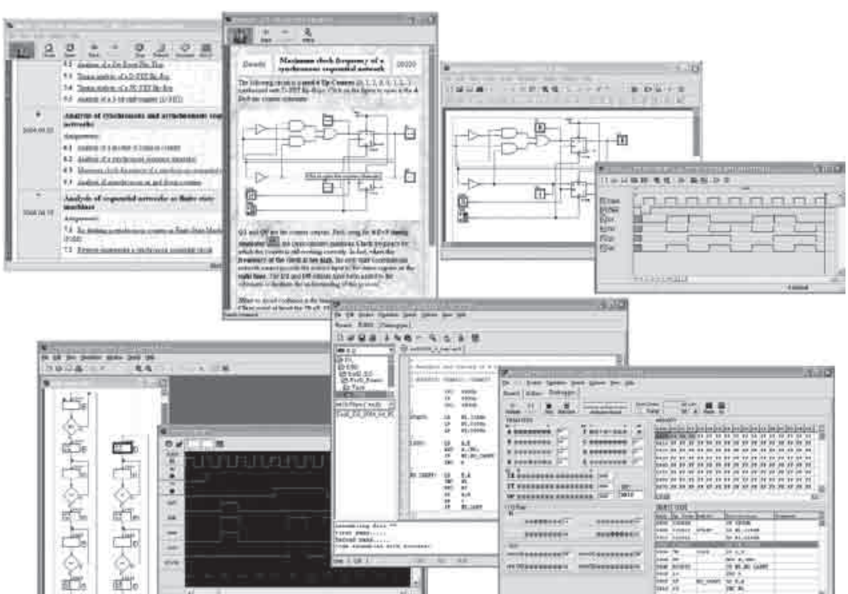

**Figure 3**

An overall view of the Deeds suite

and information engineering and as a support for project-bases courses. Deeds is composed of three simulators that cover combinational and sequential logic networks, finite state machine design, microcomputer interfacing and programming at assembly level. They are characterised by a "learning-by-doing" approach, and, being fully integrated together, they allow design and simulation of complex networks including standard logic, state machines and microcomputers.

The simulators are integrated within an HTML browser, enabling Internet navigation to find pages with lessons, exercises and laboratory assignments. Deeds includes an Assistant browser that provides step-by-step guidance to students in their work. The environment is designed to help students in acquiring the theoretical foundations of digital design, together with analysis and problem-solving capabilities and practical synthesis and design skills. Deeds can be adapted to different formats of instruction (lectures, exercises, lab assignments, etc.) and can be delivered at different student levels. To do so, teachers can combine together and personalize the available simulation tools to suit their pedagogical needs by contributing to the lecture space their own learning materials (the lecture space can be composed with any HTML editor). The simulation tools themselves may adapt to different student level and provide a subset of their features when used with beginners.

### 1.2.2. The Deeds simulators

The simulators included in the Deeds package are the Digital Circuit Simulator (d-DcS), the Finite State Machine Simulator (d-FsM) and the Microcomputer Emulator (d-McE).

The Digital Circuit Simulator (d-DcS) appears to the student as a graphical schematic editor (Fig. 4), with a library of simplified logic components, specialised toward pedagogical needs and not describing specific commercial products. The library includes user-definable components, that the user can design as Finite State Machines (FSM) and build with the Finite State Machine Simulator.

The library includes also a 8-bit microcomputer board, accessible through standard input-output parallel ports, besides other inputs as clock, reset and interrupt request. The firmware of the board can be programmed at assembly language level. Using standard logic ad/or FSM, the schematic editor allows building specialized input/output devices that can be connected to the microcomputer board.

Simulation can be interactive or in timing-mode. In the first mode, the student can "animate" the digital system in the editor, controlling its inputs and observing the results. This is the simplest mode to examine a digital network, and this way of operation can be useful for the beginners. In the timing mode, the behaviour of the circuit can be analysed by a timing diagram window, in which the user can define graphically an input signal sequence and observe the simulation results. This is the mode closest to one adopted by the professional simulators.

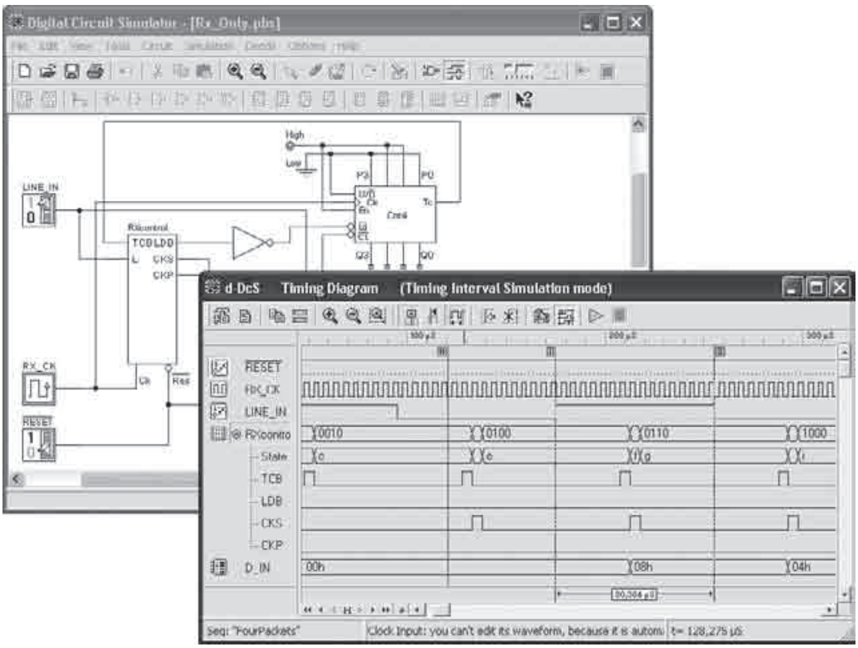


**Figure 4**

Timing analysis with the Deeds Digital Circuit Simulator

The Finite State Machine Simulator (d-FsM) allows graphical editing and simulation of finite state machines components, using the ASM (Algorithmic State Machine) paradigm. The tool allows the local functional simulation of the finite state machines designed by the user, with runtime display of the relations between state and timing evolution (Fig. 5). The components that the d-FsM produces can be directly used in the d-DcS and inserted into the digital circuit schematic. Also, FSM components can be exported as VHDL processes.

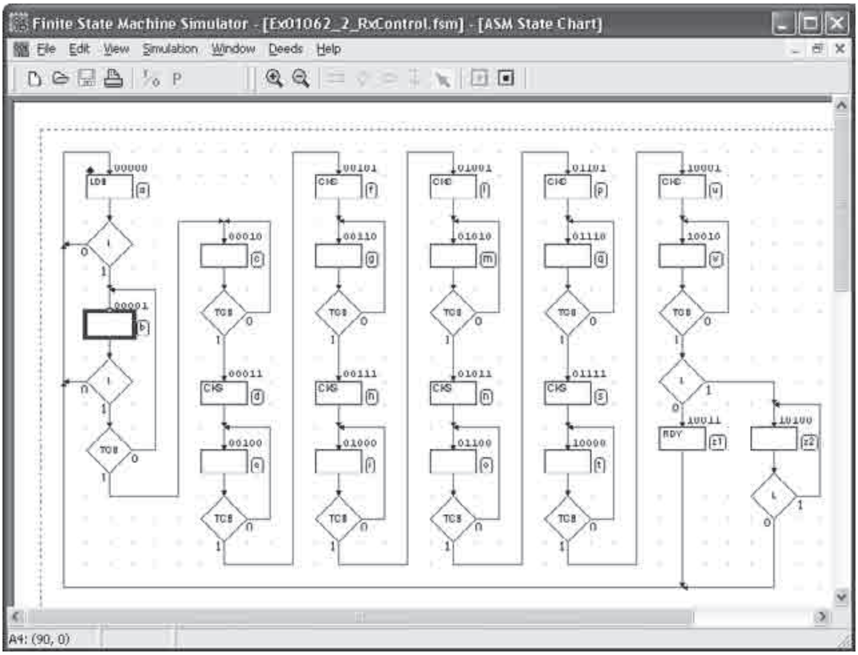


**Figure 5**

ASM chart edited in the Deeds Finite State Machine Simulator

With the Microcomputer Emulator (d-McE) the user can practice programming at assembly language level (Fig. 6). The emulated board include a CPU, ROM and RAM memory, parallel I/O ports, reset circuitry and a simple interrupt logic. The custom 8-bit CPU, named DMC8, has been designed to suite our educational needs, and it is based on a simplified version of the well-known 'Z80' processor. We have ruled out the possibility of emulating a state-of-the-art processor because we believe that the complex architecture is an obstacle to understanding the basic principles of machine-level programming.

The integrated source code editor enables user to enter assembly programs, and a simple command permits to assemble, link and load them in the emulated system memory. The execution of the programs can be run step by step in the interactive debugger, where the user can observe all the structures involved in the hardware/software system: ROM and RAM memory contents, I/O port state, CPU registers and the assembly code in execution.

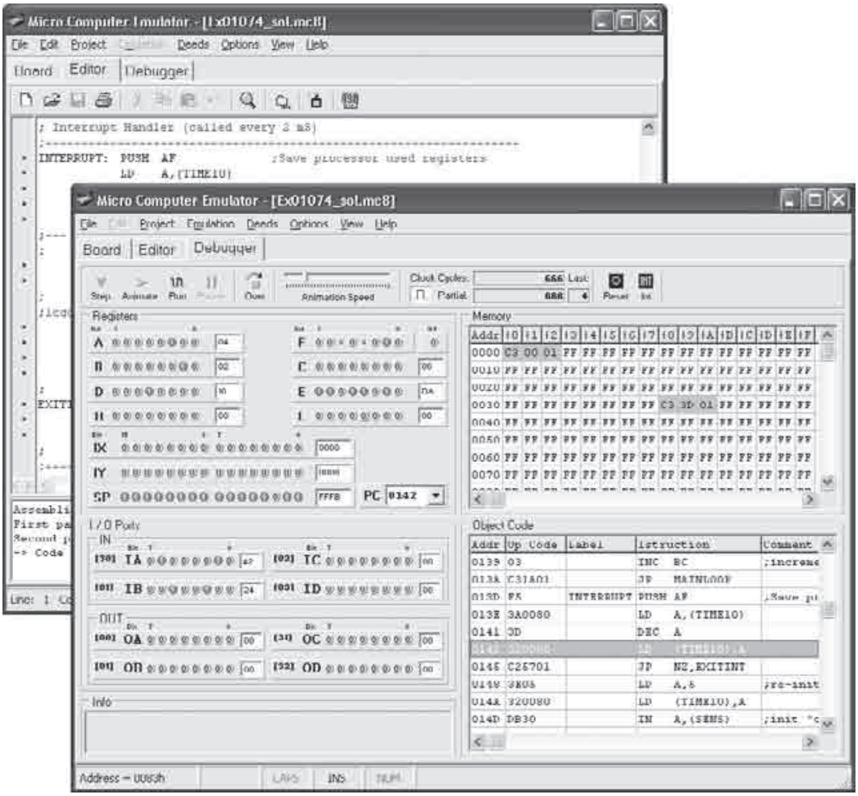


**Figure 6**

The interactive debugger of the Deeds Micro Computer Emulator

### 1.2.3. Learning and designing electronic systems with the Deeds

A lecture based on Deeds appears as an HTML document with text and figures. Text, figures and visual objects can be active, because they are 'connected' by the browser to the editing and simulation tools of Deeds. For example, let's suppose that the theory presents a digital circuit, and displays its schematic. When the user clicks on the schematic, Deeds launches the corresponding simulator, and opens that schematic in it. As necessary, the Deeds open another browser (the Assistant) that can contain step-by-step instructions on how to design, explore or test the circuit itself. Such procedure is equally useful to convey concepts both on simple components and on more complex networks. The target of traditional exercises is to help understanding theory, applying it to simple cases and providing a feedback to the teacher through the delivery of the solutions. In our system exercises are presented as HTML pages, containing text and figures of the assignments (Fig. 7).

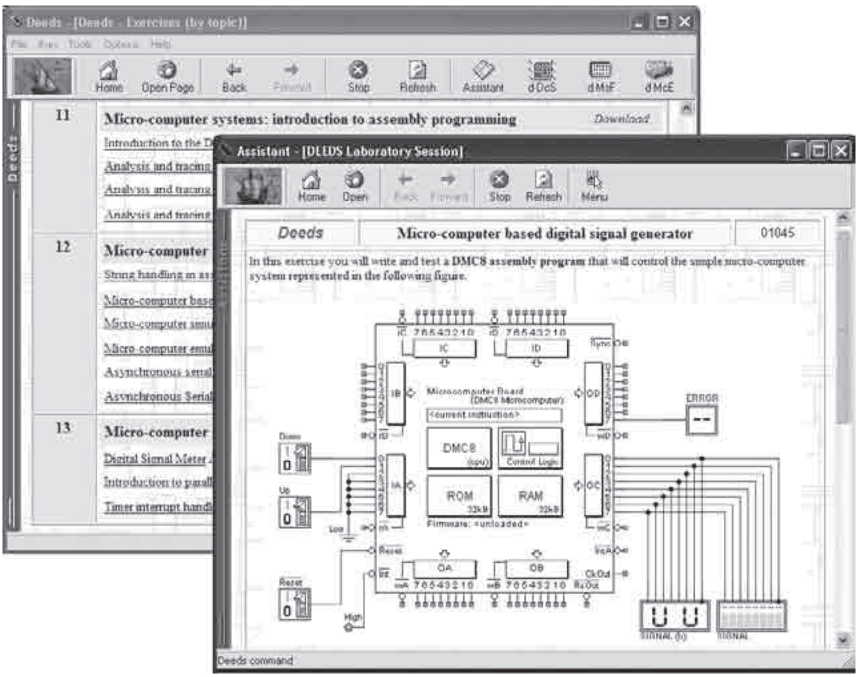


**Figure 7**

A laboratory assignment proposed by the main and assistant browsers of the Deeds

Project development phases are guided by help and instructions supplied through the Assistant browser, even if such instructions, in this case, are at higher level and the use of the simulation tools is less guided and left more to the user initiative.

The Deeds approach is meant to replicate the features of a professional environment, within the guidelines suggested by the educational purpose of the project. The role of Deeds is to allow students to work out a solution, or to check its correctness, when obtained manually, and to provide graphical tools for editing the web page containing their reports. When learners are satisfied with their work they use Deeds to deliver the reports through the Internet (Fig. 8).

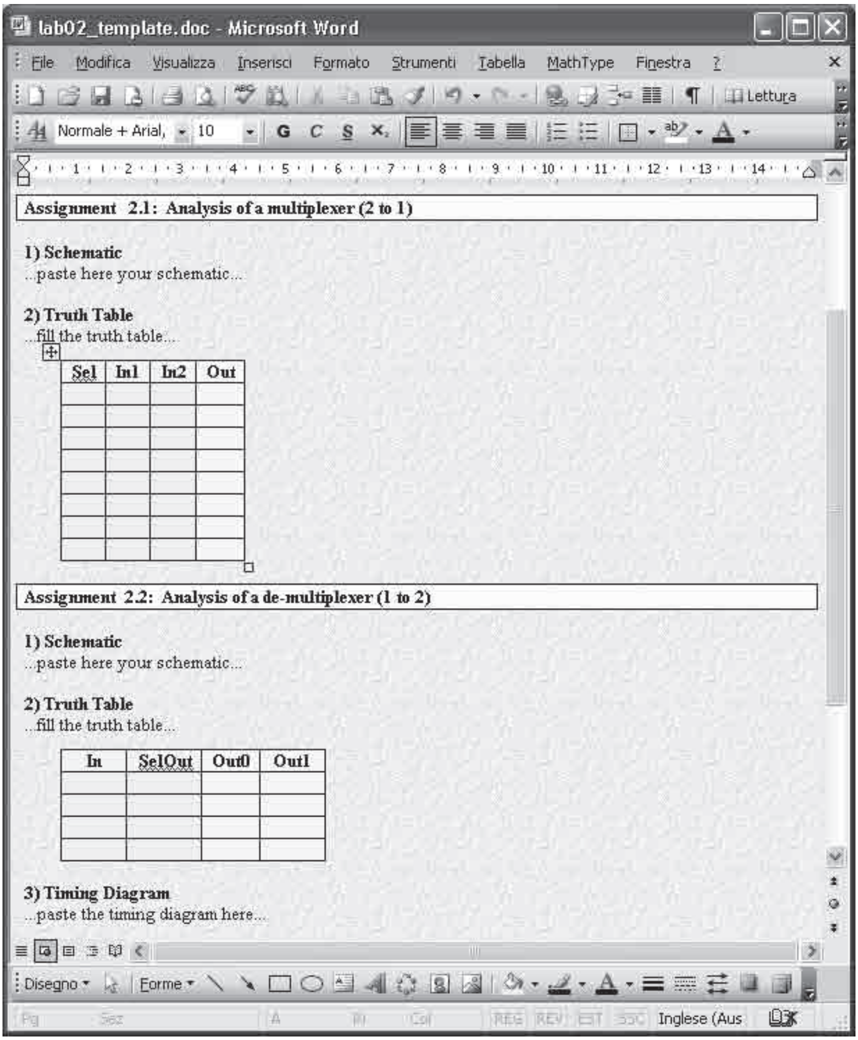


**Figure 8**

An example of a simple Deeds laboratory report template

The use of Deeds implies also a different approach to the structure of the exercises. In fact, with the simulator, students are naturally tempted to skip manual analysis. Exercises, therefore, must be targeted more to the real understanding of the issues than to the execution of repetitive tasks, such as paper-and-pencil construction of timing diagrams.

Another important feature of the Deeds is the ability to deliver to the students a suitable trace of the solution (i.e. a partial schematic of the solution). Using this approach, teachers can direct students towards tasks aimed to the real understanding of the key concepts of a particular problem, without using their time for repetitive and less-meaningful operations.

On the same line, the d-DcS allows the saving of input signal sequences, for testing purposes (Fig. 9). Teachers can take advantage of this feature in several ways. A digital circuit analysis, for instance, can be proposed together with one or more meaningful sets of input sequences, to facilitate understanding of the proper behaviour of the circuit under test. Another use of the saved input sequences, useful to learn circuit design, could be to provide to the students, in addition to system specifications expressed by text, predefined sets of input signal against which testing their implementations. Last but not least, when delivering a solution to the teacher, students can demonstrate their awareness of the circuit functionality by proposing reasonable input test sequences.

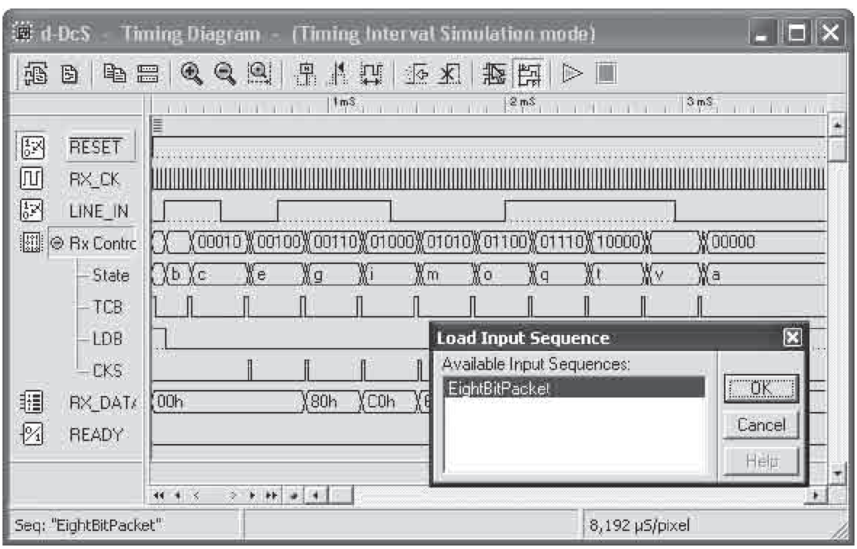


**Figure 9**

An example of timing analysis using a saved input signal sequence

The development of a digital design project is the field where Deeds can fully be exploited. In fact, the interactive logic simulator, the finite state machine module and the microcomputer board emulator can work simultaneously in the simulation of a system where standard digital components can be controlled by state machines and/or a microcomputer board, as it is the case in contemporary digital design. Obviously, the modules can be used independently, to test separately the system parts. Finally, we stress the fact that Deeds has been specifically designed to support distance education and collaborative project work within an inter-institutional and international context. Deeds has been used as a support of the activities of the NetPro project, a European project of the Leonardo DaVinci program, that has developed project-based learning through Internet [20,21].

### 1.2.4. The advantages of simulation over traditional laboratory activity

The experience of several years of use of a Deeds based simulation laboratory has confirmed the assumption that we made in the design phase. Simulation of digital circuits, indeed, has proved much more effective than the previous bread-boarding activity, under several points of view. The "construction" of the network is easier and faster, as are changes and modifications. The "animated" simulation lends itself very well to understanding, step by step, the behaviour of circuits and providing an effective connection with theoretical concepts. The availability of a pedagogical support allows the students to work unsupervised. With Deeds, most of the student time in the lab is spent in a pedagogical effective way and the need for tutoring and scheduling laboratory session is made easier.

Because Deeds has been developed in house, we provide it free of charge to students for their personal use. Last but not least, the availability of a common simulator and the delivery of assignments through Internet has made possible the remotisation of laboratory activities and their integration within distance learning courses.

In conclusion, the advantages outnumber by far the disadvantages, all of which can be summarised by the obvious statement that the contact with the physical reality of a digital system is lost. This means that circuit assembly, connection with instrumentation and measurements are no more objects of the laboratory practice. We believe, though, that in the case of an introductory course of digital design, such features are of lesser importance and a traditional lab can be replaced with a simulation based (virtual) one with a definitive gain under the pedagogical point of view.

## 1.3. *Remote laboratory*

### 1.3.1. Remote laboratories and ISILab

Internet-controlled educational remote laboratories for electronics are already available from many educational institutions [22,23]. In the following, we will make reference to the pedagogical experience made with the early use of ISILab, the on-line laboratory developed by our institution and described in another chapter of the book.

Our first approach with the pedagogical use of remote laboratories took place several years ago. The experiments carried out by our team were targeted to the students of the introductory digital design course already described. Given the large number of attending students and the close monitoring activities, the experiments have provided a large amount of data to drive the technical development of ISILab and orient its pedagogical use.

To facilitate the introduction of the remote experiments, and to gather data for the evaluation of the test, the activity took place initially inside the laboratory, with supervision and tutoring. In successive runs, the remote lab has been available from a PC classroom (with tutors, for students requesting assistance) and from home.

### 1.3.2. The remote experiment

The choice of a suitable experiment takes into account the previous knowledge of students in the field of electronics and the aims and methodology of the course and its laboratory. The latter, based on Deeds, uses the simulation as the main tool for the design, analysis and understanding of digital networks. We decided that it would make little sense to replicate with a real circuit a previously simulated (or a new one), since the results would have been hardly distinguishable, when gathered with a very simple set of instruments. We went, therefore, for the measurement of the propagation time of a logic gate. Such experiment represents a new point of view by respect to simulation, presenting logical signal in their physical aspect.

Fig. 10 shows the HTML page describing the experiment, in terms of educational objectives and operational steps. The workbench appears as it was presented to students during the experiment itself. The picture of the traditional breadboard is included, to give an idea of the physical aspect of the circuit under test. The instruments controlled by ISILab (clock generator, analogue oscilloscope, and a digital oscilloscope) are accessible by way of very simplified user interfaces. The choice of creating simplified

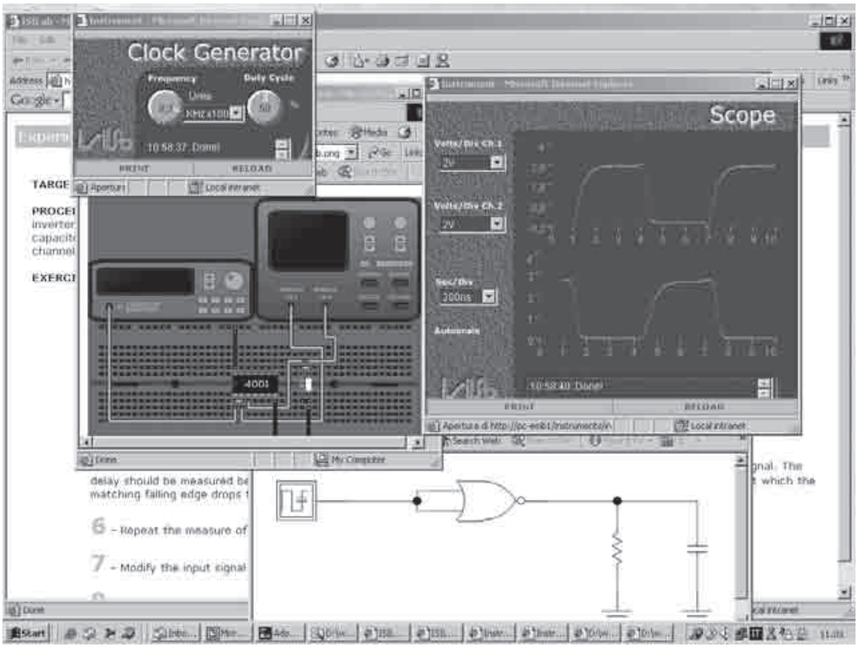


**Figure 10**

ISILab measuring the propagation delay of a logic gate

control panels was driven by the need of avoiding the complexity of the traditional instrument panels, since students were not trained yet on the use of laboratory instruments.

In the execution phase students interact with instruments' control panels in order to perform the required measurements. A written report describing the execution of the experiment and its results was requested from each group of two students.

### 1.3.3. Evaluation of the results

The evaluation of the results from the first experiments with the remote lab provided a large amount of data that we try here to summarise.

Students typically access remote lab experiences alone (sometimes in small groups), without tutoring. At the first year, the students' technical background is so limited and diverse that only very simple, if any, experiments can be performed autonomously by the totality of the attendants. Furthermore, we cannot count on any familiarity with measuring instruments and circuit breadboards. In spite of the presence of written instruction on the ISILab site, many students missed the tutorial support that used to have in traditional labs. At the same time it became almost impossible providing feedback to the experimenters and, even more important, get feedback from them. This is a sensitive point especially for first year courses but not a serious drawback in more advanced ones. It is obvious that it is not possible to remotise lab activity without implementing pedagogical changes.

The reduced interaction with the objects under test represents another sensitive point. In fact, our remote lab does not offer a realistic laboratory environment. At a low level of technical competence, it is difficult to see the difference between a remote experiment and its software simulation. Furthermore, when exposed to electronic instrumentation they are not familiar with, students tend to lose their interest for the experiment itself, accepting in a passive way any data provided by the instrumentation.

From the evaluation questionnaires we learned that the majority of students would prefer to work in a real laboratory and to be able to construct the circuit themselves.

All these problems have an adverse effect on the usefulness of the remote lab when applied to this educational situation, where the main target is to stimulate interest in the issues experimented. On the other side, the experiment also showed a few remote lab advantages, like the possibility of repeating an experiment many times and from anywhere. From the organisational point of view, the fact that a single laboratory workbench could be shared, unsupervised, among several users, provided logistical and economical advantages.

### 1.3.4. The evolution of the remote laboratory

The evaluation of the first experiment has provided the background for an improvement of the remote laboratory, with special care of its educational aspects. An on-line experiment, under the new approach, is not an isolated event, but part of a strategy, which we divide in three phases: (a) Pre-lab, (b) Lab, and (c) Post-lab.

The Pre-lab phase consists of a set of activities that must be performed by users before each experiment. They include tutorials to train students on the use of instrumentation and to provide the background necessary for understanding each experiment and interpreting the results. The access to the experiment is allowed only upon a positive individual test on the issues explained in the tutorials. Such pedagogical actions are conveniently served by a Learning Management System (LMS), as explained in the following section.

The central phase, named Lab, consists in the experiment execution. In comparison with the early experiments, it has been improved the interaction of the user with the experimental set-up. The possibility of moving the oscilloscope probe among several test points in the circuit enhances the "reality" of testing. As far as the choice of the on line experiments is concerned, we design experiments that allow a clear distinction between physical measurements and their software simulation and cannot be approached by simulation alone.

The last phase, the Post-lab, is designed to stabilize and confirm students' learning with assessment activities. A report on the experiment asks for a critical view of steps and results, and a comparison with results obtained with simulation.

### 1.3.5. Integration with a Learning Management System

With the pedagogical approach just described, an on-line experiment is no more an isolated event but becomes a component of a learning path. The match between the experiment and its tutorials is best served by a Learning Management System (LMS). We choose to integrate ISILab with the Moodle LMS, [24] an Open Source software package that can count on a growing community of users and developers, and allows the addition of new modules or SCORM objects. The integration of ISILab into the Moodle environment means, by the way, the immediate availability of a large number of tools, such as identification and profiling, discussion forums, etc. In particular, we created the Pre-lab activities using the tools provided by Moodle itself, by inserting the educational contents and defining the policies for accessing them. We split the topics as reusable parts, and chained them to create a learning path.

Students must review the theoretical foundation of an experiment before executing it. For this reason the system evaluate the acquired theoretical knowledge before granting the access to the further steps. The assessment is done using a quiz session. The questions are strongly oriented to the specific topic and a minimal score threshold is defined for each experiment.

Passing the Prelab phase allows students to execute the experiment. Moodle supports the preparation of the students' report on the experiment, too.

A specific module of Moodle has been customized in order to use it for collecting the users' feedbacks about the effectiveness of the new release of ISILab.

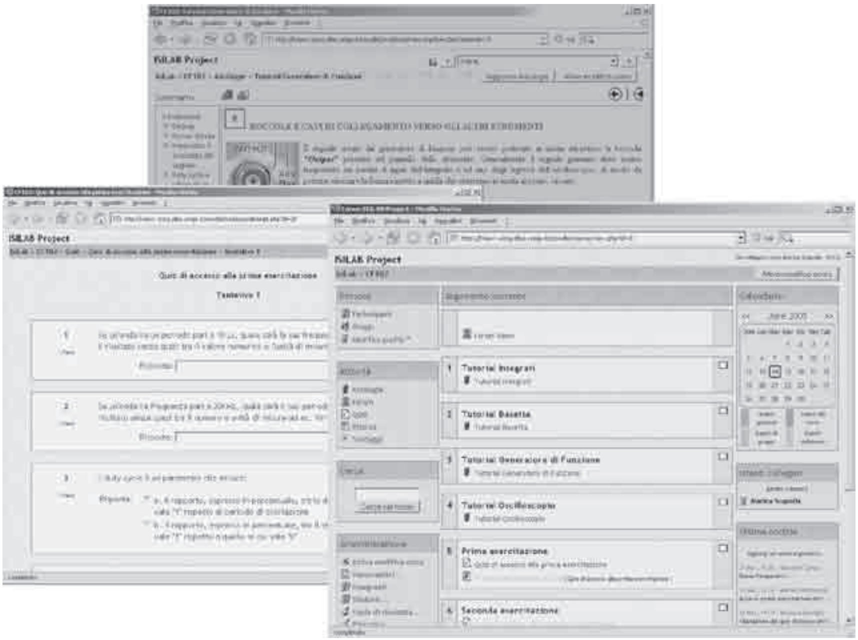


**Figure 11**

Snapshots of Moodle pages

## 2. Reflections

To have a view on the roles and future perspectives of the three types of electronic laboratories we should, first of all, try to assess the state of current electronic technologies and foresee their expected future trends.

### 2.1. *Trends in electronic technologies and their effects on education*

A trend already established and very likely to continue is the digitalisation of electronic circuitry. This is not the place to explain the reasons, which are obvious to the practitioners of the fields. Analogue electronics is becoming more and more a niche for the applications involving very high frequencies, weak signals, interfaces with transducers (sensors and actuators) and the like. In many cases, analogue electronics is relegated to serve as interface between an analogue world and all-digital systems.

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In such situation, learning the design of single-stage transistor amplifiers and other basic analogue building blocks has, to our opinion, the same role that, a while ago, was typical of semiconductor physics: fascinating subject, culturally very relevant, but not mandatory for the curriculum of a circuit designer. We must keep in mind that we have to train engineers, who must work with state-of-the-art technologies. That's the inescapable target. As a consequence, given the limitations intrinsic to any curriculum, we can go back toward fundamentals only to a limit. Nowadays, the distance between the final target and the basic, traditional issues, is such that an information engineer can hardly afford a deep learning of analogue electronics. The same is true, maybe to a lesser extent, for the circuital issues pertaining digital electronics. In a world where system design is largely a matter of software, digital components must be treated as blocks, whose dimensions and functions increase in parallel with system's complexity.

Programmable logic devices (PLD), very large arrays of standard logical components, are configured as final devices by programming their connections. Embedded computers take away from standard logic most of the functions it used to perform. Reconfigurable circuits can morph themselves into different systems by a proper software.

### 2.2. *Virtual or remote laboratories?*

In this framework, we must be careful in assessing the needs and purpose of the laboratory. It is quite obvious that software tools are the main avenue to design today's and tomorrow's digital systems. The same tools find a proper application in the education field, in courses dedicated to PLD, micro and embedded computers, signal processing and the like.

Digital simulation tools, especially when developed with educational applications in mind, are, to our judgement, the elective choice even for courses targeting the basic issues of digital electronics. We think we have demonstrated, in the section of the chapter dealing with simulation, that dedicated tools, like Deeds, are an excellent support for learning digital electronics.

Which is, therefore, the role of remote labs in the field of digital systems?

Our experience has highlighted the convenience of adopting simulation and the difficulty of using a remote lab (and even a traditional lab). The role of the latter should be restricted to the cases where a real experiments is providing information not available by software simulation.

As an example, the observation of digital signals with an analogue oscilloscope and the measurement of propagation delays in gates and elementary sequential networks put the students in touch with the physical reality of a circuit, usually hidden when using a digital simulator.

With this approach, remote experiments in digital electronics are targeted to investigate electrical phenomena that involve the "analogue" aspect of digital systems and, therefore, they could be associated with analogue electronics and treated with the same methodology.

## 2.3. *The PLD remote lab*

A serious attempt to implement a remote lab for digital electronics that allows to interact with relatively complex digital systems, matching the educational effectiveness of simulation, is represented by the use of PLD-based boards [25, 26].

These very large arrays of standard logical cells can be configured into complex and meaningful systems by a proper software, establishing the connections among cells.

PLD's manufacturers make available, together with the simulation and configuration programs, for a very low price, boards that can be easily connected to a PC. They present a certain number of I/O lines, displays and interfaces. The cumbersome initial phase of circuit wiring is replaced by the download of the configuration file that, obviously, can be performed remotely, via the Internet. In synthesis, students develop a system using local tools and then test it by downloading a file in the remote laboratory.

Currently available PLD-based remote labs offer very limited testing options, with simple input switches and LED output displays, visible through a webcam. We expect them to evolve toward a more professional set of stimulus generation and logic state analysis of the outputs. Without the above, the local simulation is the real pedagogically meaningful phase and the remote hardware test plays only the marginal role of making available the test board and familiarising with downloading procedures. On the contrary, a proper interface with signal generators and oscilloscope or logic analyser would produce a universal digital workbench, useful for introductory labs in digital electronics. In that case, the remote lab would integrate the simulation, adding the motivating effect of seeing things work in the real world.

## 2.4. *Remote simulators*

Currently available networking technologies allows the remote operation not only of a lab but, of course, of simulation software. Replacing a local simulator with a network-based one would provide several advantages, among which the instant updating of software, the statistical tracking of learners' activities, the possibility of charging users for the access and all the other features of a server based application.

## Conclusion

A good understanding of the pedagogical aspects is essential for an efficient use of electronic labs. We cannot assume that, by the fact that remote labs can be built, they are necessarily useful. We must keep in mind that remote labs cannot replicate, as a whole, the experience of a traditional lab and do not develop exactly the same skills. A thorough investigation on pedagogical applications of remote labs, and their results, is in order, as it has been done in the past, for example in [27], that examines the simulator approach versus conventional courses. There is no simple answer to the question "which laboratory is the best for electronics?". All types of laboratories offer unique advantages. At the moment, we believe that engineering students should be offered a balanced mixture of real, virtual and remote labs.

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# A New Concept for Distributed Laboratories Based on Open Source Technologies

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**Abstract**

*This chapter discusses the general principles of remote laboratories. It focuses on the experimental and hardware aspects of the innovation. Access methods, protocols, and new web technologies such as Web 2.0 have been covered elsewhere. A remote laboratory project was started in 1999 at Blekinge Institute of Technology (hereafter referred to as BTH) in Sweden to ascertain if it is feasible to design a remote electronics laboratory which could function as a supplement to local instructional laboratories and provide students with free access to experimental equipment. Today, there are two laboratories online, one for electronics and one for signal processing. These are used as examples in the ensuing discussion. The BTH Open Laboratory concept evolved over a number of years. Its object is to add a remote operation option to traditional instructional laboratories thereby making the latter more accessible. This option is equipped with a unique interface enabling students to recognize on their own computer screen the instruments and other equipment which most of them have used in the local laboratory. The research is focused on what is considered to be the greatest challenge in engineering education today, i.e. to give students a laboratory experience that is as genuine as possible without direct contact with the actual lab hardware while at the same time allowing teachers to use standard equipment and readily available learning material. The winners are not only students and teachers, but also universities, which will be able to share distributed laboratories. Finally, the chapter presents some ideas about standards for primarily distributed electronics laboratories based on IVI (Interchangeable Virtual Instruments).*

## Introduction

Laboratory science courses can be described as necessary for engineering students in terms of seeing how science is made. The overall goal of engineering education is to prepare students for practising engineering and, in particular, to deal with natural forces and materials. Thus, from the earliest days of engineering education, instructional laboratories have been a vital part of undergraduate programs [1]. Physical experiments allow learners to see that mathematical models correspond with nature and to study the limitations of these models. Experiments also provide the framework for students to learn to cope with real-world problems and gain hands-on experience, e.g. sound and vibration analysis involves acoustics and structural dynamics, etc. Sound and vibration are measured on three-dimensional acoustic and/or on three-dimensional structural systems. Such measurements require understanding of the dynamic properties of the systems, appropriate dynamic models, microphones and vibration sensors as well as an understanding of how sensors affect measurement. Analysis of acoustic signals and vibration signals is generally carried out using sophisticated signal processing systems called “estimators”, whereby information from the measured signal is extracted and interpreted, and frequent non-linear and non-stationary behaviour is observed.

However, during recent decades there has been a decline in the number of instructional laboratories in engineering education. The prime cause is clearly the task of coping with greatly increased student numbers, while staff and funding resources have scarcely changed. Contributory factors include the seductive appeal of simulating experiments on computers, where there are no unexpected or unpleasant clashes between theory and simulation [2]. However, new technologies, e.g. the Internet, offer new possibilities including increasing the number of physical experiments in undergraduate education without incurring any significant increase in cost per student.

When performing experiments in an instructional laboratory learners use instruments to measure what they cannot perceive directly with the human senses and use their fingers to set the instruments as well as create and manipulate the experimental setup. Today, many academic institutions offer a variety of web-based experimentation environments that support remotely operated physical experiments [3]-[6]. Such remote experiments entail remote operation of “distant” physical equipment. There are two main methods of remote operation and control of distant lab equipment. The most obvious is the remote desktop technology. A computer controlling an experimental setup is remotely operated using some type of VNC (Virtual Network Computing) software [7]. The other method comprises a laboratory consisting of at least one server, often called the "lab server," and a number of client computers. The main difference lies in how users access the experimental equipment controller. Access methods, protocols, and new web technologies such as Web 2.0 have been covered elsewhere [8]. This paper focuses on instructional laboratories for undergraduate education. The following definitions are used in the text. A *remote laboratory* consists of at least one server and a number of client computers which can be scattered all over the globe. An *open laboratory* is a traditional laboratory with a remote control option. Like other authors, we use the term *local laboratory* to denote a traditional instructional laboratory without remote control. The term "on-campus laboratory" is ambiguous because students can sit somewhere on campus conducting experiments on a server in a room which is close by. A *virtual laboratory* is based on simulation software. A comparative review of the literature on these types of laboratories has been made elsewhere [9].

General principles for remote laboratories are discussed in section I. The BTH open laboratory concept presented in section II can be described as a structured approach which increases undergraduate students' access to experimental resources with the aid of the Internet. The concept relates to the opening of local instructional laboratories for remote operation and control as described in section III. These laboratories are now ready for dissemination; BTH is currently creating a hub for this purpose. The source code is released under GPL (General Public License) [10]. The BTH concept covers the sharing of laboratory equipment among universities and other teaching establishments. However, the current laboratory software is to be further developed to enable sharing of equipment. Organization of open laboratories ready for equipment sharing is outlined in section IV. An open standard for distributed electronics laboratories is discussed in section V.

## 1. **Remote laboratory elements**

Most remote laboratories are accessible independent of space or time using a computer with an Internet connection and a web browser. Video and sound transmission can be used for remote observations but human senses other than sight and sound are more difficult to convey. Most instruments have a remote control option, and human fingers can often be replaced by a remotely controlled manipulator, a so-called "telemanipulator", the level of sophistication of which may vary. The Internet is used as communication infrastructure. Each user's instrument settings and other data required to set up a desired experiment are sent from the user's computer to the lab server. The server sets up and performs the experiment and returns the result to the user's computer. A block diagram of such a laboratory is shown in Fig. 1. The number of client computers that can be connected and perform physical experiments simultaneously varies from laboratory to laboratory.

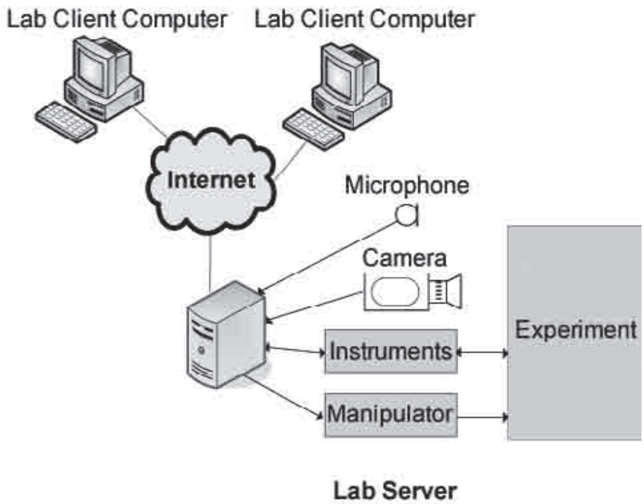


**Figure 1**

Block diagram of a Remote Laboratory.
The microphone and video camera are optional

Most desk top instruments have a remote control connector for GPIB (General Purpose Interface Bus), for example; this is placed in the rear panel. In other cases, the instrument can be connected directly to the Internet through an Ethernet port. Computer-based measuring instruments consisting of a plug-in board, fitted with a tiny physical panel containing connectors and a software module in the host computer are frequently seen in laboratories today. There are instrument boards on the market that can be plugged into the mother board of a standard desk top PC. However, the normal PC chassis is a disturbing environment for an instrument board. The instrument platform used in the open electronics lab is PXI (PCI eXtensions for Instrumentation) [11]. Another platform which was introduced in 2005 is the LXI (LAN eXtensions for Instrumentation) which may become a LAN-based successor to GPIB [12]. The software module displays a virtual front panel containing control knobs and buttons on the host computer screen. The user can turn the knobs and adjust the instrument settings with the mouse. The fact that the virtual front panel is separate from the plug-in board enables us to install this piece of hardware in the lab server and to display the virtual front panel on the screens of the client computers. An example is shown in Fig. 2, where the virtual front panel is a photograph of the front panel of a desk top oscilloscope manufactured by Agilent Technologies, and the plug-in board is a high-speed digitizer from National Instruments. It is possible to combine a virtual front panel representing an instrument from one manufacturer with hardware from another as long as the performance of the hardware matches that of the depicted instrument. The graphics routines of the front panel in Fig. 2 are written in Adobe FLASH. Another convenient alternative requiring only modest programming experience is to write these routines using LabVIEW, which is a graphical software development environment for measurement and automation produced by National Instruments [13].

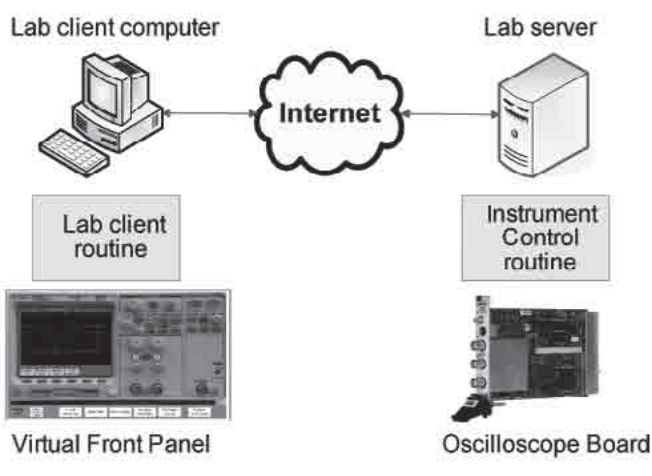


**Figure 2**

Remote- controlled instrument

The manipulator component is often the most complicated in a remote laboratory and very few, if any, such devices are commercially available. The manipulator must be designed for each type of laboratory using various remote-controlled actuators, i.e. transducers that transform an input signal into motion. Examples of actuators are electrical motors, relays, hydraulic pistons, electroactive polymers etc. An example of a manipulator is shown in Fig. 3. A number of relays arranged in a matrix pattern together with instrument connectors and component sockets on stacked printed circuit boards are used in an electronics laboratory for the purposes of remote circuit wiring. The relay switches are embedded in the circuit under test to confine the length of the wires and gain bandwidth. The corresponding virtual panel is a breadboard. Photographs of components mounted in the sockets of the matrix are displayed in a component box at the top of the breadboard. In this way, the circuit the learner creates on the virtual breadboard is transformed into a physical circuit in the matrix.

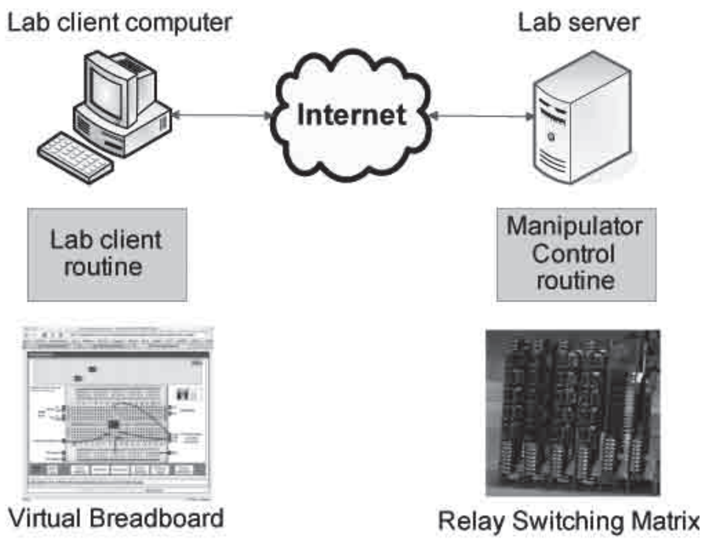


**Figure 3**

Example of remote-controlled manipulator

## 2. The BTH open laboratory concept

Research at BTH is focused on what is perceived to be the greatest challenge, i.e. to provide students with a laboratory experience that is as genuine as possible despite the lack of direct contact with the actual lab hardware. At the same time, the open laboratory system allows teachers

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to use existing equipment and learning material. The BTH Open Laboratory concept is about providing new possibilities for students to do laboratory work and become experimenters without increasing the cost per student. The plan is to add a remote operation option to traditional instructional laboratories to make them more accessible for students, irrespective of whether they are on campus or mainly off campus. This option is equipped with a unique interface enabling students to recognize on their own computer screen the instruments and other equipment most of them have previously used in the local laboratory. The objectives are as follows:

- To provide learners with free access to experimental equipment. On-campus students can perform experiments remotely as a supplement to or replacement of locally supervised lab sessions. They can perform lab sessions at home or elsewhere outside the laboratory in preparation for face-to-face sessions or repeating experiments. This is an attractive option for students requiring more time than is normally available in a regular face-to-face session or for students wanting, for example, to practise how to handle the instruments more competently. Off-campus students can perform lab sessions with or without the assistance of a "remote" teacher.
- To create distributed laboratories. Universities around the world should be able to share remote laboratories equipped with expensive equipment. This would require a time reservation and accounting system. It would be possible for students to perform a great variety of experiments.
- To keep written course material separate from the laboratories (lab servers) and stored in the LMS (Learning Management System) of the university. The students should start each remote lab session from the LMS, e.g. Moodle.
- To implement cost-effective methods for assessment of laboratory work.

While there seems to be a general agreement that laboratories are necessary, little has been said about what they are expected to accomplish. However, learning objectives for laboratory work are currently being defined [1]. It is possible to use open laboratories for assessment of laboratory work. A practical laboratory-work examination could be arranged much like a normal written one in a room with an invigilator and, where each student sits in front of a lab client computer.

A remote laboratory project was started in 1999 at BTH to ascertain if it is feasible to design a remote electronics laboratory to supplement local instructional laboratories and provide free access to the experimental equipment in the local laboratory to students enrolled in circuit analysis and electronics courses. A number of ideas have been tested in regular courses in subsequent years.

It was necessary to provide a virtual breadboard environment combined with a relay switching matrix to enable students to wire circuits remotely. The complexity of such a matrix increases rapidly with the number of circuit nodes to be created. If a desired circuit has N nodes and if the user wishes to add, for example, one resistor, there are N•(N-1)/2 branches into which it can be introduced, e.g. 120 possibilities for 16 nodes. However, the circuits formed in lab sessions contain only a small number of nodes and are not particularly complex. It is also necessary to exclude some combinations for safety reasons. On the other hand, it is important that the space for unexpected solutions or harmless mistakes is as great as possible. In more advanced courses, the circuits are more complex, and the students do not want to wire the circuits. The virtual breadboard is still useful because a pre-wired breadboard showing an already wired circuit can be loaded. The wiring cannot be modified but the student can connect test wires from the instruments to certain nodes. The corresponding fixed physical circuit could take the form of a printed circuit board added to the card stack in Fig. 3.

In a local laboratory session an instructor checks each circuit formed to avoid possible damage to components or instruments. If the circuit is safe, the student or the student team is allowed to continue by activating the power source. However, in the open laboratory, unknown users are allowed to start lab sessions and perform experiments in private. Inexperienced users could conduct harmful experiments, e.g. overload a resistor. Since the equipment is normally left unattended, the resistor could burn and users would in all probability encounter strange results in subsequent experiments where the destroyed component is included. It is thus essential in an open laboratory to include a virtual instructor i.e. a software algorithm which checks the desired circuits before the power source is activated.

Would it be possible to accommodate more than one user per server at the same time? Yes, each user spends most of the time wiring and setting the instruments; these measures are carried out locally in each client computer. Only when the user wants to perform a measurement is a message sent to the server. A time-sharing scheme is easy to adopt but it imposes restrictions on the time period allowed for each measurement. In electronics, the teacher can easily choose an appropriate time scale for the experiments by selecting proper values for the components to be provided thereby ensuring a reasonable server response time providing only a single sweep mode is supported for the oscilloscope.

Is it feasible to use the concept in other domains? To find the answer to this question a remote laboratory for mechanical vibrations experiments was built. The switching matrix was replaced by a mechanical structure with some transducers attached and the instruments were replaced by a signal analyzer. This laboratory can be used from undergraduate level to advanced research level within academia or industry. In the mechanical domain it is often easier to perform experiments than to find a sufficiently accurate simulator. The best way to acquire experience is to spend many hours in the laboratory supervised by an expert teacher. Sound and vibration measurements and subsequent analysis of acquired data generally require considerable experience if reliable results are to be achieved. An open laboratory with or without a remote instructor is an excellent supplement.

## 3. **Current open laboratories at bth**

BTH has opened two local instructional laboratories for remote operation and control, one for electronics and one for signal processing – more precisely, mechanical vibration analysis. The laboratories are used in regular education. They are equipped with a unique virtual interface enabling students to recognize on their own computer screen the desktop instruments they have previously used in the local laboratory. In the electronics laboratory, the physical breadboard has been replaced by a circuit-wiring manipulator. The switching relay matrix is shown in Fig. 3. In the signal processing laboratory, the device being tested is a mechanical structure. Each laboratory is organized as in Fig. 1, but a common web server is used for lab management and storing learning material.

The local electronics laboratory has eight traditional lab stations enabling a corresponding number of students to perform experiments simultaneously, all supervised by an instructor. At each station there is a lab box with a white solderless breadboard and some instruments as in Fig. 4. The lab station which is accessible remotely looks different. The instruments and the host computer are installed in a PXI chassis as in Fig. 5. This equipment is manufactured by National Instruments. The desk top instrument to the left is the power supply manufactured by Agilent Technologies. The corresponding virtual front panels are photographs of the front panels of the instruments in Fig. 4. As an example, a screen dump displaying the DMM is shown in Fig. 6.

The card stack located on top of the PXI chassis in Fig. 5 is the switching matrix. It is a stack of PC/104-sized printed circuit boards. "PC/104" is the name of a common standard for embedded systems [14]. The two boards to the right in Fig. 5 are instrument connection boards used to connect

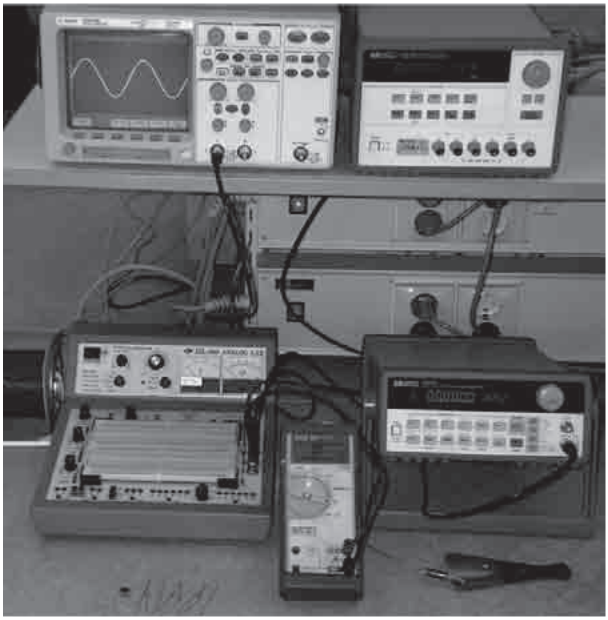

**Figure 4**

Lab station in a local electronics laboratory at BTH

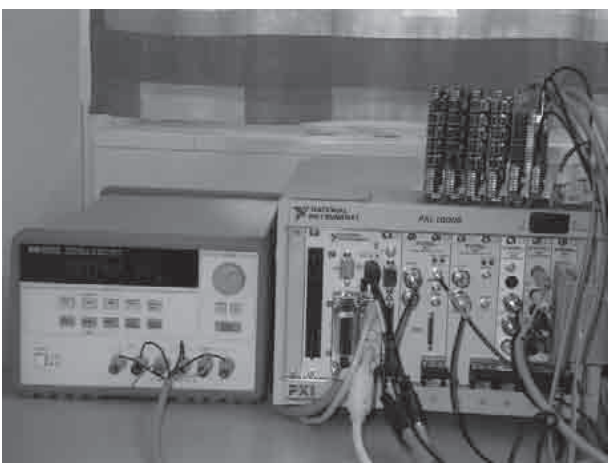

**Figure 5**

Lab server

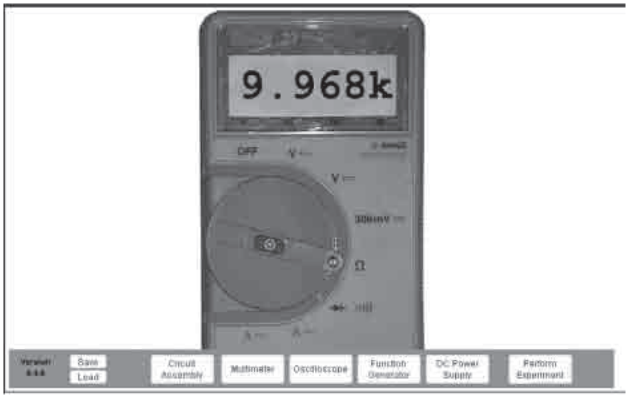


**Figure 6**

Screen dump showing the DMM

instruments to test points. The other four boards are component boards on which the online components are installed in sockets. The boards are stacked using two connectors; one sixteen-pin connector located in the center of each board, and one forty-pin connector. The former connector makes a bus, i.e. sixteen potential nodes that via relay switches can be connected to components installed in the sockets of all component boards forming the stack. It is possible to use seven of the potential nodes denoted A – F and 0 as test points via single pole relays on the instrument connection boards. All relays are controlled from an I/O board in the PXI chassis via the forty-pin connectors.

The lab client software written in Adobe FLASH is automatically downloaded into the user's computer when s/he is allowed to enter the laboratory. The user wires a circuit, connects the instruments, sets the instruments and finally presses the *Perform Experiment* button to send an XML-coded message containing the instrument settings and a netlist of the desired circuit to the server. The lab server decodes the message and transfers it to the instrument and switching matrix control modules which are created using LabVIEW. However, circuit-data processing is somewhat more complicated, as shown in Fig. 7. In the client computer, the wiring is converted to a netlist. The Setup List is a list of the components displayed in the component box above the breadboard. The Check List describes all circuits considered safe by the teacher to create. The Master List lists all the online components and how they are located in the matrix. An example of a routine written in LabVIEW is to be found in Fig. 8 which shows a DMM

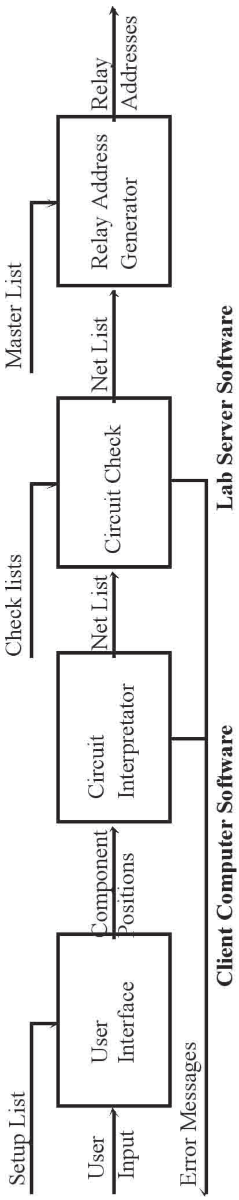


**Figure 7**
Circuit data processing

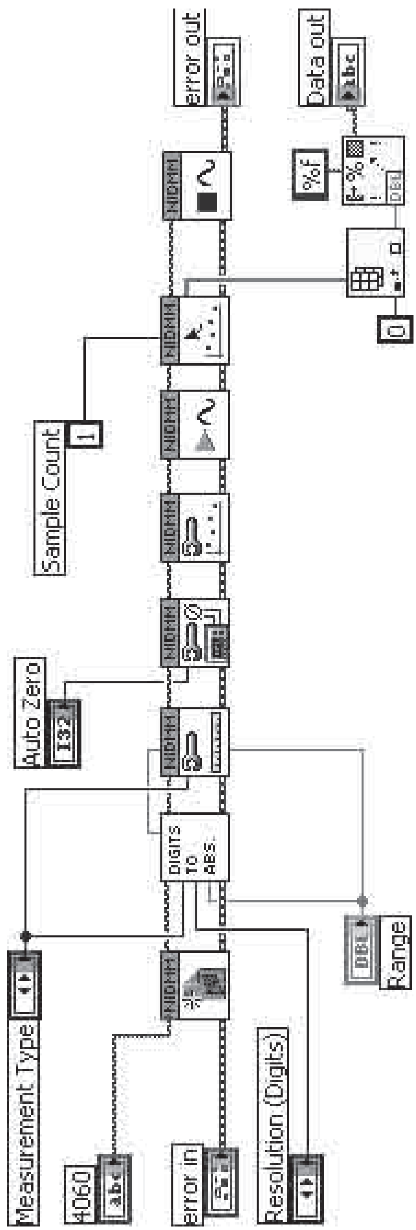


**Figure 8**
DMM control module

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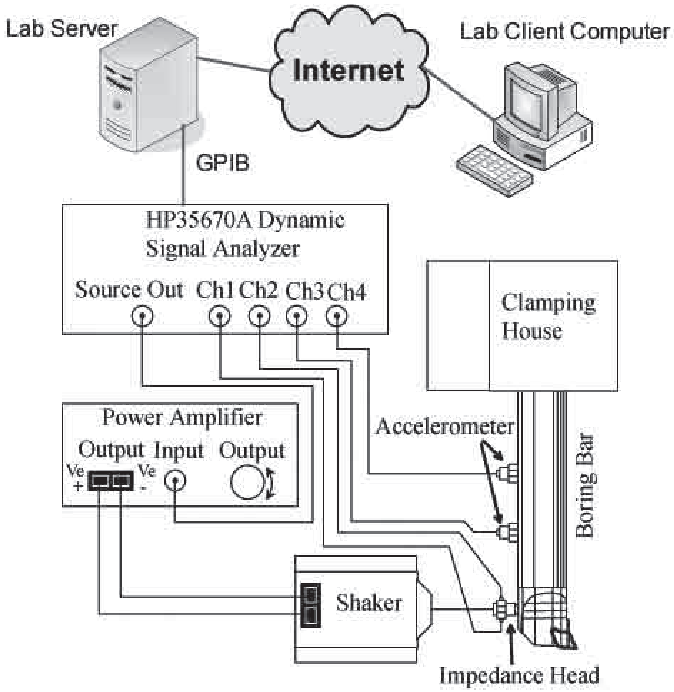


**Figure 9**

Block diagram of the server with a clamped boring bar
as an example of an experiment object structure

software module based on the NI-DMM driver. The standard LabVIEW programming style has been used. The data flow is from left to right and is controlled by the error line wired to all sub Vis. First the DMM is initialized and set up as desired by the user. Then a measurement is made and sent to the lab server. The current laboratory hardware and software have been described in more detail earlier [15]–[17].

The server in the remotely controlled signal processing laboratory for mechanical vibration analysis consists of a number of different components (see Figs 9 and 10). The HP35670A dynamic signal analyzer is the main component in the server. It produces the excitation signal and collects and analyses the sampled version of the signals connected to the four inputs of the analyzer. The test probes are accelerometers and force transducers connected to the signal analyzer's inputs. The electrical circuit is replaced by a mechanical structure, e.g. a boring bar. The structure is connected to an electro-dynamic shaker which converts the electric signal from a signal analyzer signal source to a mechanical, one-dimensional motion. Thus, the shaker applies a force forming an input signal to the mechanical structure. The virtual front panel of the signal analyzer is shown in Fig. 11 [18].

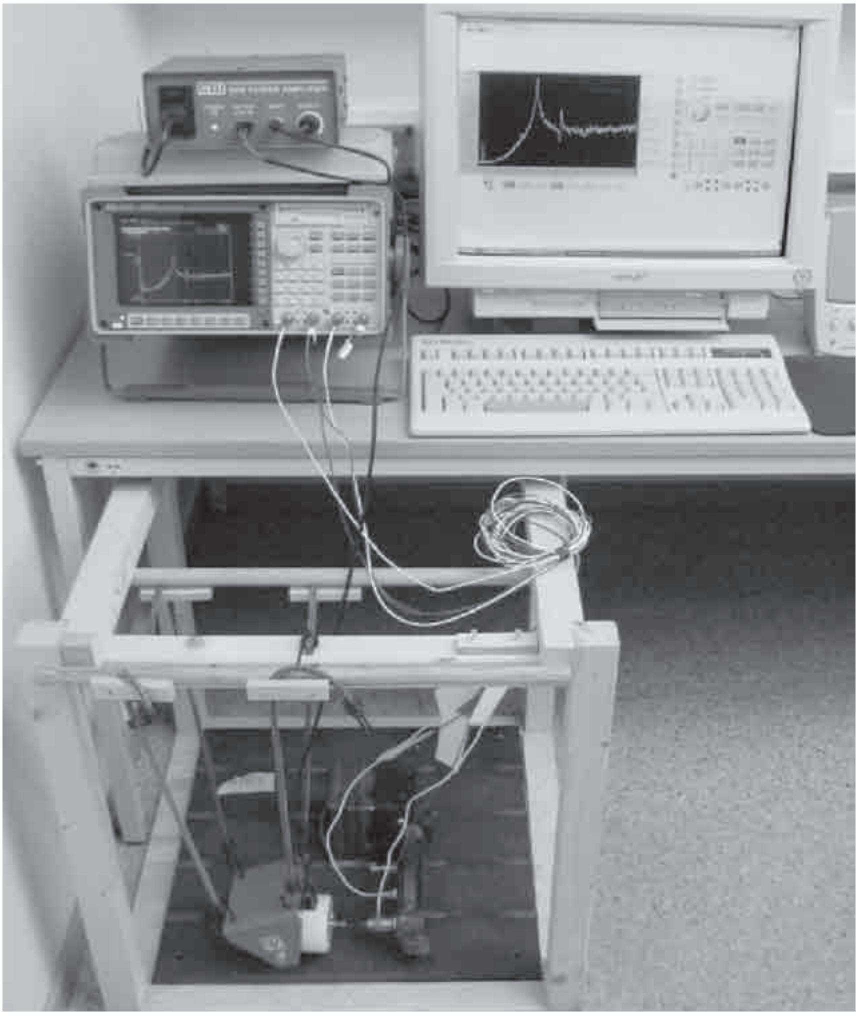

**Figure 10**

Photograph of the server with a clamped boring bar as an example of an experiment object structure

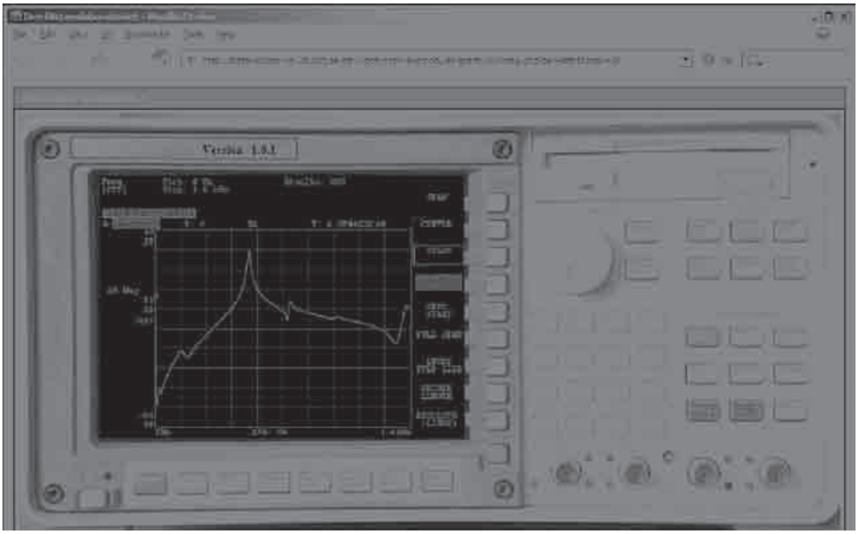

**Figure 11**

The virtual front panel of the signal analyzer as displayed in a web-browser on a lab client PC

## 4. The Future: A Lab version allowing equipment sharing

A distributed open laboratory which allows equipment sharing could consist of one lab server where a register of all lab resources is stored in a database, and a number of equipment servers controlling the instruments and manipulators. The lab server controls the equipment servers, which can be scattered all over the globe. As an example, a tentative block diagram of the coming version of the laboratories at BTH is shown in Fig. 12. There will be two equipment servers for electronics experiments, one for vibration experiments and one common lab client software module.

Authorized teachers can log on to the lab server and book times for supervised lab sessions via a web interface. They also set the number of seats in each session, the start and end dates of the course, list the email addresses of the enrolled students, and specify the identification of the LMS (Learning Management System) of the university or department. To perform experiments, students log on to their courses in the LMS and select a lab session. The LMS sends the student's e-mail address and the list of equipment to be used in the session to the lab server, which selects the most appropriate equipment server for the session. The address of this server,

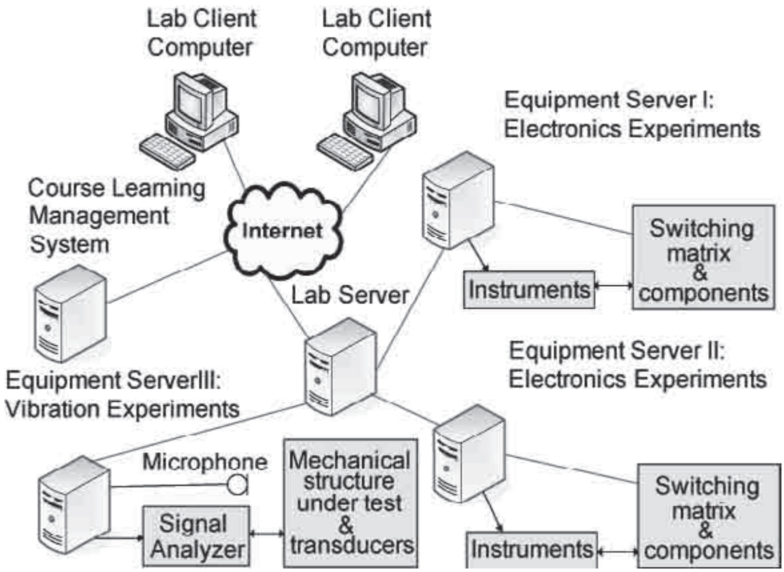


**Figure 12**

A new version of the open laboratories at BTH

the virtual panels of the instruments, manipulator, and other devices are entered into the lab client software module; the lab client software module is then downloaded to the student's computer. The student can now start experimenting.

A new equipment server for electronic experiments will be set up as in Fig. 13. The embedded controller in the PXI chassis will be replaced by a PCI Express desktop host. The PXI chassis will contain a function generator NI PXI-5402, an oscilloscope NI PXI-5112, a DC power supply NI PXI-4110, and a digital multi-meter NI PXI-4060 or NI PXI-4072. The current instrument and switching matrix control modules will be rewritten using LabVIEW 8.2.

A new version of the BTH switching matrix for circuit wiring is currently being designed. The number of potential circuit nodes will be the same as previously but now it will be possible to connect nine of the potential nodes (A – H and 0) to the oscilloscope or DMM. The oscilloscope ground terminal is still connected to node 0. The other 7 nodes (X1 – X7) will be connected to screw terminals via single pole relays. These are primarily intended for connecting power supplies. The matrix will no longer be controlled via a digital I/O board in the PXI chassis. The I/O board will

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**Figure 13**

New PXI chassis without embedded controller

be replaced by a control board in the card stack connected directly to the host computer via a USB. The layout of the instrument connection board and component board are the same, with a center connector feeding potential circuit nodes to the next board in the stack; the relays are now controlled, however, by an on-board microprocessor. Two connectors feed an $I^2C$ control bus and two eight-bit buses to all boards in the stack. The two eight-bit buses are used for transferring data to and from mixed components such as AD converters, digital potentiometers etc. which may be installed on the component boards.

A new equipment server for the sound and vibration experiments in the signal processing laboratory will also be set up. The plan is to replace the HP35670A dynamic signal analyzer as well as expand the dynamic signal analyzer capacity in stage 1, by using two NI PXI-4461 (24-Bit, 204.8 kS/s, 2-channel data acquisition and 2-channel analog output modules) and four NI PXI-4462 (24-Bit, 204.8 kS/s, 4-channel data acquisition modules). A NI PXIe-1062Q PXI Express Chassis will carry these dynamic signal analyzer modules.

Also, new mechanical and acoustic systems will be introduced as well as suitable methods for remote modification of the same. The task of acquiring and subsequently analysing sound and vibration data to produce accurate and reliable information is complex. One obstacle is the user interface of the software used to acquire and analyse the sound and vibration data. It has thus been decided to develop a user-friendly interface for the remote-controlled signal processing laboratory for sound and vibration analysis. Furthermore, new accurate estimators for sound and vibration quantities will be developed and implemented.

## 5. Standardization ideas

Most instructional electronics laboratories for engineering education at universities around the world contain the same equipment, (oscilloscopes, waveform generators, multi-meters, power supplies, and solderless breadboards) although models and manufacturers may vary. Such laboratories are already in a way a de facto standard. It could thus be a good idea to start defining common concepts which can be used to enable sharing of equipment and learning material for undergraduate education courses in electronics.

The IVI Foundation is a group of end-user companies, system integrators, and instrument vendors, working together to define standard instrument programming APIs [19]. The IVI standards define open driver architecture, a set of instrument classes, and shared software components. To enable interchangeability, the foundation creates IVI class specifications that define the base class capabilities and class extension capabilities. There are currently eight instrument classes, defined as:

— DC power supply.
— Digital multimeter (DMM).
— Function generator.
— Oscilloscope.
— Power meter.
— RF signal generator.
— Spectrum analyzer.
— Switch.

Base class capabilities are the functions of an instrument class that are common to most of the instruments available in the class. For an oscilloscope, for example, this means edge triggering only. Other triggering methods are defined as extension capabilities. The goal of the IVI Foundation is to support 95% of the instruments in a particular class.

One idea is that the instruments should comprise functions defined by IVI base capabilities. Classes are defined for all the instruments mentioned in the previous paragraph. The drivers NI-SCOPE, NI-FGEN, NI-DMM, and NI-DCPower available in the LabVIEW environment are all IVI compliant. It is possible to use various instrument hardware platforms such as PXI, LXI etc. as long as they are supported by IVI drivers.

For novice students it should be possible to wire simple circuits with few nodes from discrete components and connect instrument test probes to the circuit nodes. The BTH concept described here is one possibility. More advanced students familiar with circuit wiring perform experiments on more complex circuits; they prefer pre-wired circuits. However, some type of manipulator comprising a number of switches is always required because students must be able to connect test probes to various nodes. One idea is to create a printed circuit board arrangement with integrated switches similar to the BTH card stack to which boards with fixed circuits can be added. It should then be possible to perform experiments with fixed circuits as well as wire simple circuits. In both cases, it must be possible to connect instrument test probes. Whatever the case, the mechanical arrangement should be compact and the switches should be integrated to obtain a reasonable bandwidth.

In the laboratory in Fig. 4 it is possible to detach the breadboard. As a result, it is possible to switch breadboards and even attach a breadboard with a pre-wired circuit. This feature is made possible in the BTH concept. It is possible to load a pre-wired circuit where instrument test probes can be connected to several nodes even if it may not be possible to access all nodes or move the wires. Thus the BTH virtual breadboard or similar technology can be used for experiments on fixed pre-wired circuits

Producing standards for other laboratories is a project for the future. There is as yet, for example, no signal analyzer in the signal processing laboratory which is IVI class defined.

## Conclusions and future work

It has been demonstrated at BTH that it is possible to implement successfully the principles of the concept discussed in two instructional laboratories. These are being used in regular education as a supplement to local lab sessions both for campus students and for distance learning students. Clearly it is possible to extend the open laboratory concept from electronics to incorporate the mechanical domain. BTH has started a project known as VISIR (Virtual Instrument Systems in Reality) to disseminate the open laboratory concept using open source technologies in collaboration with other universities and organizations. A number of universities will participate in the project. Global instrument and measurement system vendors such as National Instruments, Agilent Technologies, and VXI Technology are interested in joining the VISIR project. The goal is an international standard, enabling teams worldwide to expand and develop jointly this powerful approach by using standardized software and equipment platforms. Instructions for software download can be found at http://distanslabserver.its.bth.se/opensource/.

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# SECTION V

# New challenges

# A Configurable Remote Laboratory for the Flexible Setup of Experiments in Electronics

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**Abstract**

*Nowadays, a great number of web laboratories are available on the web. They are quite different one from another, but a common aspect is that most of them have been implemented for the execution of specific tasks, without taking care of issues related to management and upgradeability. At the contrary, the possibility of easy upgrade, in terms of number and type of experiments is a key factor for an effective laboratory development. In this chapter, the Authors present, as a case study, the experience they did developing a remote laboratory on electronics, where the solutions for management and upgradeability have been emphasized.*

## Introduction

During these last years the concepts of accessing devices via web and to execute remote experiments have emerged, and they are now consolidated practices. The fact that today's market offers tools and solutions for remote control of laboratory apparatus is a clear proof of this, and, thanks to these facilities, an uncountable amount of web laboratories, targeted to various disciplines, have been made available online. They are quite different one from another, but a common aspect is that most of them have been implemented for the execution of specific tasks, without taking into account management and upgradeability issues.

In our opinion, the possibility of easy upgrade, in terms of number and type of experiments is a key factor. For the sake of the didactical quality, this work has to be done by teachers. They should be autonomous, and their work should be supported and guided by proper tools. The approach could be the same that has already been experienced with the traditional educational contents, delivered via web. At the beginning of the Internet era, the educational contents appeared as pioneering web pages edited directly by the teachers. When the web technologies became more complex, and the amount of the didactical materials became very huge, this approach was no more sustainable. The importance of separating the organizational and technical aspects from the contents emerged, together with the need of classification, in order to ease the retrieval of existing contributions.

Web laboratories have to follow the same path. Multidisciplinary skills are required when setting up a new web experiment: teachers define the educational objectives and the best path for learning, laboratory technicians make the hardware set up available, and experts in computer-based instrumentation control and distributed computing develop the necessary software interfaces. We need the contribution of all these actors whenever the laboratory must be updated, to include new equipments and experiments.

Compared with the traditional educational contents, web experiments are more complex elements, because they deal with hardware devices and the software architecture of a remote laboratory spans diverse levels

In the following we present, as a case study, the experience we did with the remote laboratory on electronics ISILab. Its development has been carried out emphasizing the requirements of re-configurability and modularity that characterize such environments.

## 1. **The case study**

This section contains a brief overview of the web laboratory ISILab (Internet Shared Instrumentation Laboratory) [1], developed at the University of Genoa. ISILab is currently used to deliver online access to experiments on electronics for the benefit of some engineering courses. It allows practicing with electronic instruments and measurement methods, executing real experiments of scalable complexity on both analog and digital circuits. The experiments deal with basic electronic measurements, such as delays in digital circuits or the gain and the distortion of amplifiers, and use devices such as waveform generators and oscilloscopes.

Users access the laboratory from a web portal: a unique access point that links several real laboratories via the Internet. Real laboratories can be distributed over a wide geographic area and are accessed seamlessly by users, whose activity is not influenced by the physical location of the experimental set up. The portal offers an indexing service of the available experiments, it is in charge of the security policies and initializes the direct communication between the client and the servers, named Real Laboratory Server (RLS), The RLSs host the instruments and the circuits under test, which are connected to the instruments by IEEE 488 interfaces, serial lines and PCI bus, and control the experimental setups.

Each RLS acts as a scheduler and allows sharing the same workbench among different users. In case of simultaneous measurement requests, the RLS uses a time sharing technique; it queues the requests and serves them one by one, in a rapid sequence. If each measurement time stays within 1 and 2 seconds, users have the perception of having the exclusive control of the experimental setup. In this way no booking facility is needed.

Every time a user starts a new experiment, the RLS creates a new data space and assigns it to the user. It contains the setting of the devices involved in the experiment. After this phase, the engine waits for the client requests. When a command is received, it is applied to the device of destination in the experimental workbench. If the workbench is not available because it is processing commands from other clients, the RLS puts the new request in a queue, waiting for a free time slot.

Switch matrixes let to share the same instrumentation among different circuits available on the same workbench. Each circuit under test is dynamically connected to the instruments when the user demands it, and it stays connected just the time necessary to complete the measurement. Each experiment is presented by a detailed description, the electric diagram and the synoptic view of the workbench that shows the components and their connections. The documents, associated to each experiment, cover:

— the theoretical concepts that are behind the experiment;
— the goal and the expected results;
— the description of the experimental set-up,
— the proposal of a set of exercises;
— bibliographic references;
— handbooks of the instruments.

Users can execute the experiments in two different ways, called "guided" and "independent" mode. In guided mode there is a privileged user who is the only one able to modify interactively the operational conditions, acting on the instrumentation controls, and the other users are only able to see the response of the system on their computer screens. This mode can be very effective in a context of distance education as teachers can show real laboratory experiments via Internet. When an experiment is carried out in independent mode, all users are able to interact with instruments in parallel mode and see only the results related to their own commands.

Fig. 1 shows the execution of an experiment on the student side. The circuit under test is an integrator; it is based on an operational amplifier and the user is required to verify the circuit responses when it is stimulated using different waveforms. The web page shows the electrical diagram of the circuit, and states the steps for the execution of the experiment. The circuit bread-board represents a possible real implementation of the hardware set up and lets students visualizing the circuit. The waveform generator and the oscilloscope panels: allow setting the instruments. Students can use the circuit panel to move the probe of the oscilloscope from a test point to another one on the real circuit. When executing experiments in independent mode, the instruments panels show the status of the instruments as they were when the last cycle of measure had been completed. These panels do not change if another user executes a new measurement and, in this way, the user feels to have the complete control of the experimental set-up.

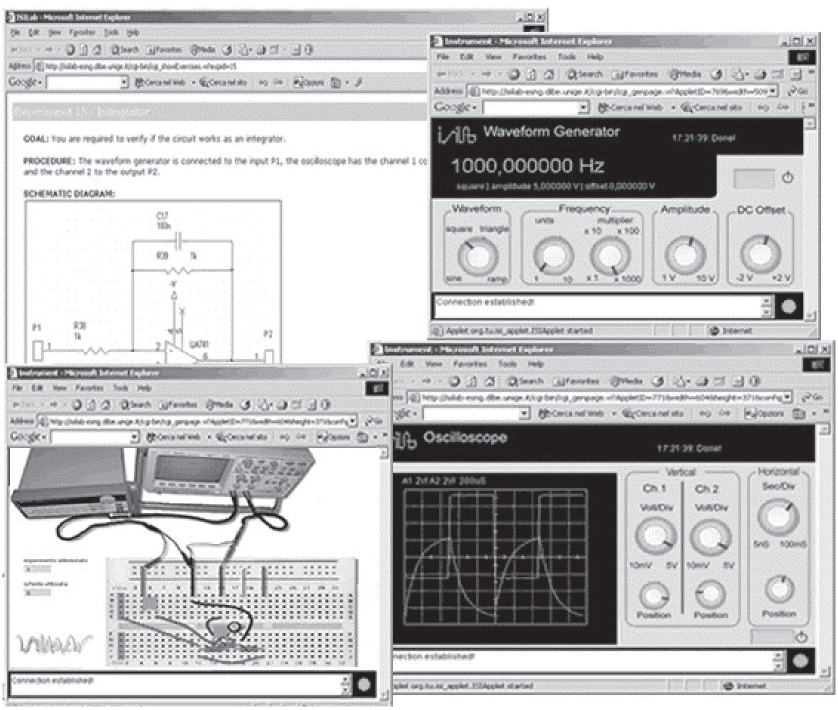


**Figure 1**

The views of circuit diagram, instruments and equipment displayed on the client computer monitor during the execution of an experiment

A key-point of ISILab is the high re-configurability. It is possible to insert new instruments or new experiments without code modifications, thus without to be expert in programming.

ISILab supports both stand-alone (rack-and-stack) instruments, as well as computer-based ones. It abstracts hardware devices (instruments connected via local buses, DAQ board, etc.) as resources that offer homogeneous APIs (Application Program Interfaces) to the RLS engine, a device-independent software layer, in charge of managing the communication with remote clients. The insertion of a new device does not require recompiling or modifying the RLS. It is sufficient to wrap the instrument driver with an appropriate driver adapter that exposes the device functionalities, and to change some configuration files. The driver adapter is a small software layer in charge of intercepting the calls from the RLS engine, translating and forwarding them to the instrument drivers in the right format. It provides the connection between the virtual panel and the instrument driver and can embed mathematical functions or algorithms that extend the features of the device. For instance, an oscilloscope can be managed by a device driver that, executing the FFT (Fast Fourier Transform), allows using it as a spectrum analyzer. We have developed driver adapters for the most common instruments of an electronic measurement laboratory: oscilloscope, function generator, and digital multi-meter. They are based on IVI [2] technology and are reusable to connect instruments from different vendors, belonging to the same class.

In general, the process of publishing a new experiment in ISILab does not require programming tasks, but only configuring the system. We need:

1. to create the new experiment board that will be tested by students,
2. to select existing instruments virtual panels or to create new ones,
3. to create the didactical contents related to the experiment.

These tasks are supported by proper tools that will be described in the next sections.

## 2. Hardware Management

Ideally, the best way to allow users to practice with different circuits is to let them compose the circuits starting from discrete components. This approach allows creating any circuit they want, with the only constraints of the available components. Moreover, the use of a virtual breadboard reproduces the task of assembling the circuit exactly as it goes on in the real world. Remote laboratories adopting this approach are described in [3, 4]. Unfortunately, the number of switches, required to assemble the circuits, increases exponentially with the number of the components. In case the circuits under test are not limited to very simple ones, this makes the approach very expensive; furthermore, as the signal must pass through several switches, it can become corrupted. Thus, the approach is suitable only when we deal with a reduced number of components. Another drawback is the possibility of creating dangerous connections and consequently, the need of validating the circuit design before applying the configuration to the switch matrix.

Such considerations suggested us the adoption of a different approach. We have created a modular system named ISIBoard, consisting of a motherboard with sixteen slots, where we can insert cards hosting the circuits to test (an example is shown in Fig. 2). Each card has an area of about 45 $cm^2$ for the circuit. Eighteen lines are available for the power supply, and for connections with the instruments. In particular there are:

— five lines for power supply (+12V, -12V, power supply GND, +5V, signal GND);
— one line for input signals;
— three lines for output signals;
— eight lines for circuit identification.

The definition of a single form factor for hosting the circuit under test lets to create interchangeable modules that can be easily designed by the teacher, and built by the laboratory technician.

The circuit identification lines give the possibility of associating a bit code identifier to each circuit. The goal of this feature is the automatic configuration of the system on the base of the connected cards.

When the circuit card is mounted on the motherboard, the connections to the instruments (power supplies, waveform generator, oscilloscope, etc.) are dynamically managed by a set of switches properly controlled by the RLS, according to the schema in Fig. 3.

The selection line routes the stimulating signal (e.g. coming from the waveform generator) to the selected experiment board, and then to the recording instrument (e.g. the oscilloscope). In this way we can share instruments among several experiments on the same hardware asset. Furthermore, the selection line can move the probe of the recording instrument on different test points of the circuit board.

Recently, a new version of ISIBoard, dedicated to digital circuit has been developed. It is characterized by:

— 8 slots for the insertion of the circuits under test.
— Embedded microcontroller.
— 12 input lines.
— 16 output lines.
— JTAG interface.

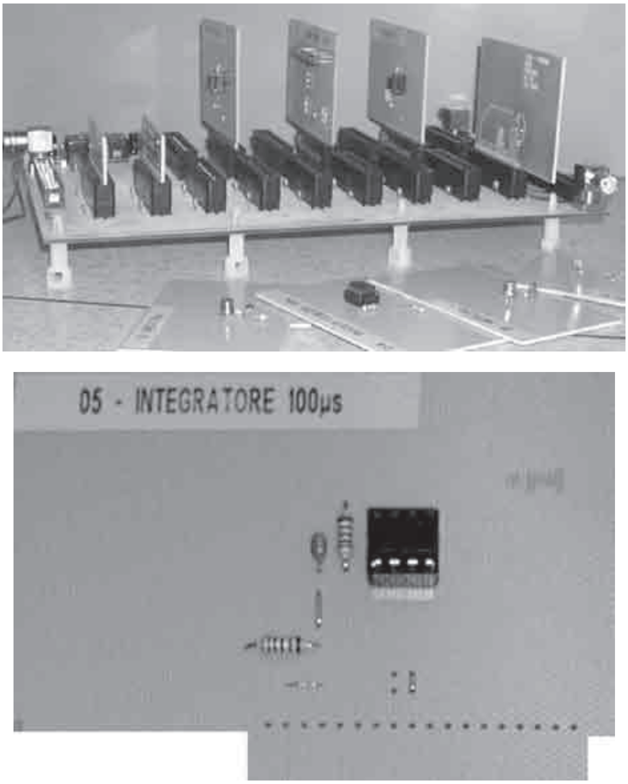


**Figure 2**

The ISIBoard and an example of modular board hosting the circuit under test

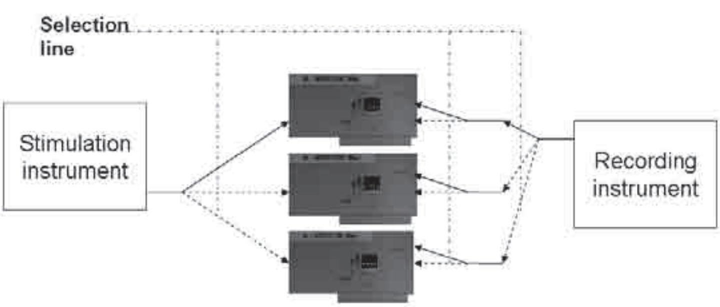


**Figure 3**

The switching schema used by ISIBoard

Using the analog and digital ISIBoards, teachers can design the circuits according to their educational objectives, without limits on the number of components and, once these are assembled, each circuit occupies a slot in the motherboard. This allows proposing more complex circuits to the evaluation of the students without using complex switching systems. The reduced number of switches results in signals of better quality and in a cheaper laboratory setup.

## 3. **Instrument Panels Management**

The instrument panels are the graphical user interfaces (GUI) that allow remote clients to control the real devices. They contain graphical objects, such as knobs, menus, waveform charts that are bounded to specific run-time parameters.

Panels of different level of complexity may be used to control the same instrument. They allow custom interfaces targeted to the educational objective and to the users profile. A simple panel, containing only the controls that are strictly necessary to the execution of the specific experiment, is more appropriate for a novice, than a complex panel offering a wide range of control possibilities. On a simple panel, the novice can focus the attention on the measurement and postpone the knowledge of the real instrument. Nevertheless, some situations require the most realistic, and thus complex, interfaces. If this is the case, the virtual panel development may become quite difficult and a considerable programming effort is required. This argument strongly impacts with laboratory expansibility and represents the main rationale behind our engagement in the development of a tool that simplifies the creation of instrument interfaces and allows assembling virtual panels with arbitrary functionalities and look&feel.

The basic idea is to have a general purpose, reconfigurable software module that can be used to control different instruments. Such application must be able to change its appearance and its behaviour according to a given configuration file. ISILab, since from its early development stages [5], describes experiments and instrument panels in XML format, and the authoring of new panels is supported by a proper user-friendly authoring tool. A device-independent software module visualizes the GUIs and communicates with the RLS.

The process is not completely new [6, 7 ], and some commercial products exploit it. For instance, Nacimiento [8] shipped a product called AppletVIEW. It offers a library of general control components, as knobs, switches, etc. Developers can assemble them using a graphical editor, and build a specialized Java GUIs. The editor application produces an output file that defines the graphical proper-ties of the components of the virtual interface (type, position, dimensions, colour, etc.) and drives the behaviour of the applet used to instance how many virtual panels as required by the experiment. AppletVIEW configuration files are written using an XML-based language called VIML (Virtual Instrument Mark-up Language). VIML merely describes the graphical objects and the associated parameters in a 1:1 ratio, and, in other words, any action on the virtual panels causes a transmission to the server. This simplistic approach limits the development of complex and realistic interfaces.

Improvements in flexibility and data-exchange performance have been the main motivations to develop a new tool for authoring instrument interfaces, This tool, called ISIApplet[9], has the main goal of overriding the limit of the 1:1 mapping between object manipulation and data transmission. Examples of actions, which don't require data transmission, are: pressing a shift key to change the operational mode of another key, changing the offset in waveform visualization.

The ISIApplet Editor tool captures different attributes for each graphical object: the cosmetic aspect, such as shape and colour, the functionality and the changes generated by the users' actions. These attributes are registered in XML format, and can be rendered by the ISIApplet Viewer. This is a Java applet that works on the base of the XML configuration file that is uploaded by the client together with the applet itself.

## 4. **Putting all together: the configuration file**

In ISILab, both the lab web portal and the RLSs operate on the base of well structured configuration files. The lab web portal engine does not need to be modified to link a new RLS and to enlarge the number of workbenches, the RLS engine must not be changed to add new experiments to an existing workbench. We can state that from the architectural point of view, the laboratory has a modular and scalable structure, but other components play relevant roles in the laboratory management. Anytime a teacher decides to deliver a new experiment, the remote laboratory requires describing the experiment, setting up the hardware reference, and developing software interfaces to the equipments and the experiment itself. The description of the experiment and the related GUIs are recorded in XML files, with two goals: to catalogue web experiments as learning resources, and to facilitate the management of the remote laboratory.

Web experiments are described as learning objects on the base of a subset of the IEEE LOM conceptual schema [10], nevertheless some extensions have been done to deal with the specificity of these learning objects, and to store all the information that allows the ISILab engine to work properly. These extensions cover the declaration of the instruments, the virtual interfaces used to run the experiments and the assignments that are associated to each experiment.

Fig. 4.a and 4.b map the schema of the experiment data structure. Fig. 4.a groups the metadata matching the LOM standard, and Fig4.b collects the data that are specific to ISILab.


**Figure 4.a**

XML schema of the laboratory configuration file:
the metadata matching the LOM standard

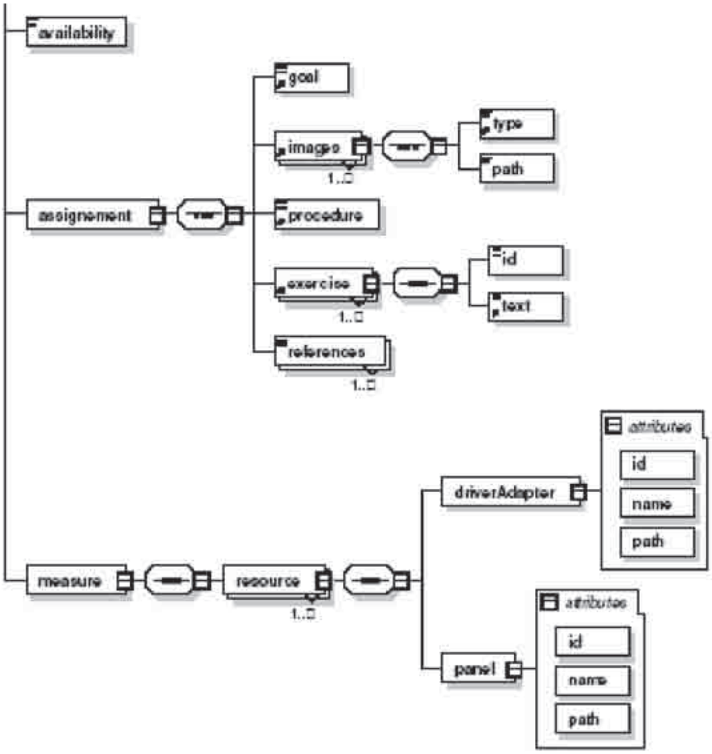


**Figure 4.b**

XML schema of the laboratory configuration file:
the data that are specific to ISILab

The process of creating the XML files describing the experiments is supported by a tool, named ISIAuthor. It offers a user friendly way to describe the laboratory experiments according to the schema presented in the previous section.

ISIAuthor collects information via diverse panels, which correspond to the groups of metadata listed above. A snapshot of the application graphical user interface is reported in Fig. 5.

This application is strictly linked to the ISILab environment. Data input is saved as an XML configuration file. It will be used to dynamically generate the experiment web pages and allows the core engine of the laboratory to manage the communication between virtual instrument interfaces and real workbench.

It is worth noting that this application collects both the metadata related to the experiment as a learning object, and the information that allows the RLS to work properly. It is easy to extract the metadata part for indexing purposes

In Fig. 4-B the “assignment” label groups the exercises that are proposed to the students while doing the experiment. These assignments allow the online generation of the web pages that are presented to the students when they access the remote laboratory. Exercises could be treated as stand-alone learning objects and combined with web experiments at the level of the Learning Management System.

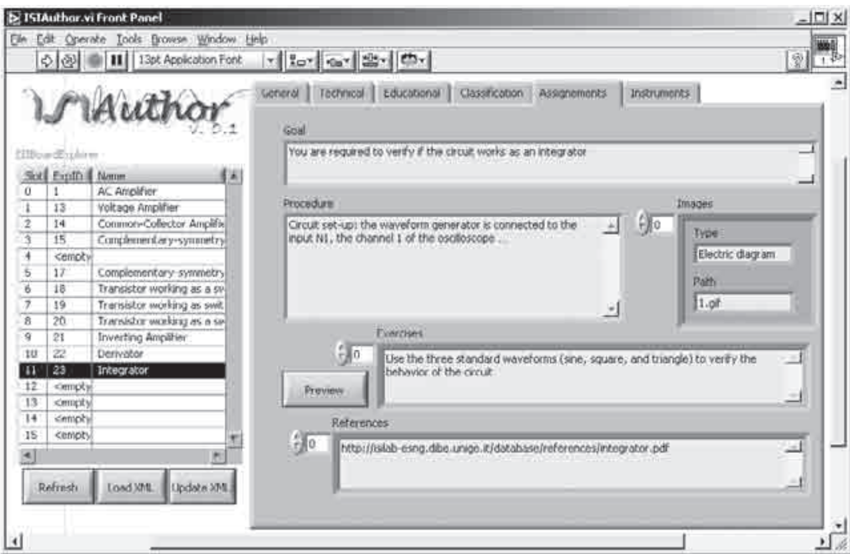


**Figure 5**

The user interface of the ISIAuthor tool

## Conclusions

The approach that we have adopted in managing resources (circuits, instrumentation, virtual panels) match the most important initiatives in the field of standards for e-learning [11] and makes easier managing the web laboratory and sharing experiments among a wider community.

Web experiments should not be isolated events, but e-learning components that can be easily integrated within Learning Management Systems.

We are testing this approach with the Moodle [12] platform and are engaged in evaluating how remote experiments can be treated like learning objects compatible with the Shareable Content Object Reference Model (SCORM) [13].

We hope that our experience can contribute to stimulate a profitable collaboration among the developers of web laboratories.

## Acknowledgement

The authors thank Giorgio Carlini for the precious contribution to the development of the ISIBoard system.

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# Toolkit for Distributed Online-Lab Grids

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**Abstract**

*A lot of online-labs for educational and industrial environments have been developed. A large number of online-labs have been set up, most of them as stand-alone-solutions. Unfortunately all these solutions are only special solutions with different kinds of software tools and different description languages. Furthermore incompatible hardware has been used for e.g. setting up online-labs. Here we present a distributed online-lab concept in conjunction with easy to reuse standard tools to solve these problems. The use of standard tools and technologies will expand the possibilities of online-labs.*

## Introduction

The use of laboratories is essential for the education in engineering and science related fields at a high qualitative level. Laboratories 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.

Labs were always playing an important role in education. In modern times, nevertheless, the relevant experiments have become more complicated and these demand, therefore, specialised and expensive equipment.

Such equipment only some large research centres and perhaps some universities can afford, and even these can only have a limited number of what is desired. The online laboratories are, therefore, the solution.

Many remote and virtual laboratories have been developed in pilot projects during the last years. But it is difficult for a learner to access and to use them, as they are not integrated into a common framework. They differ widely in their user interface, user management and time reservation scheme. This large diversity makes it very difficult for educational institutions to integrate online laboratories from different sources into their course offering.

From this point of view we especially need standard lab environments, which are not require deep knowledge of surrounding technologies but are easy to use from all interested lecturers.

At the Carinthia Tech Institute we developed together with partners the following easy to use and reuse online lab technologies:

— Virtual Electronic Lab (VELO) [6]:

- for tools with Web interface (e.g. MATLAB) [9], [12];
- for tools without Web interface based on Citrix MetaFrame [10], [12].

— Remote Electronic Lab (REL), based on LabVIEW [7]:

- with real instruments connected by GPIB interface;
- with virtual instrumentation by data acquisition cards.

— Online ASIC Design System as a combination of simulation and test/measurement.
— Microcontroller Remote Lab.
— Remote Hardware Control with Embedded Web Servers.
— Self-growing Lab Portal System.

In this work we show application examples for some of these technologies.

Together with partners we developed also helpful applications for an easy use of online lab solutions in educational contexts:

— a switch matrix board,
— a reverse proxy architecture,
— XML templates for interactive course scripts.

In the following we will describe some of these solutions in more detail.

## 1. A Distributed Online Laboratory

The main idea of a distributed online laboratory grid is to provide a module based intelligent lab grid with the expanded feature of doing live-online-experiments for blended learning. It covers experiments with locations in Austria, Brazil, Jordan, Spain, Romania and others.

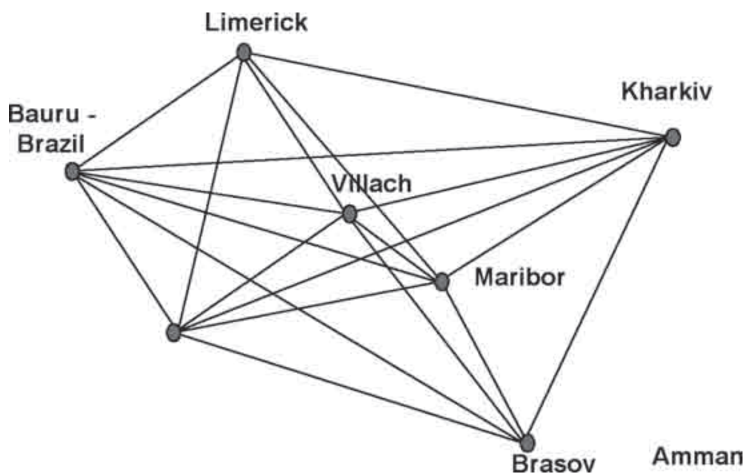


**Figure 1**

Locations of the distributed Test Lab

A lot of existing e-learning platforms either in companies or in conjunction with e-learning activities of universities and schools have been developed. A large number of online-labs have been set up, most of them as stand-alone-solutions. Unfortunately all these solutions are only special solutions; the possibility to reuse them is very low. Most of them have been developed with different kinds of software tools and different description languages. Furthermore incompatible hardware has been used for e.g. setting up online-labs. The Distributed Online Lab solves these problems and furthermore it will expand the possibilities of online-labs. This distributed lab grid introduces a global view of ubiquitous, remote access learning and productivity promoting resources to allow individual access to these resources by reducing the impact of existing technical limitations. The reuse of the developed tool set is easy possible in a wide range of applications and subject areas.

## 2. **Remote Electronic Lab with LabVIEW**

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

The essential software running on this computer is LabVIEW. 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.

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

The interfaces to the user at a remote computer are either ActiveX-controls or the runtime engine of LabVIEW. 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.

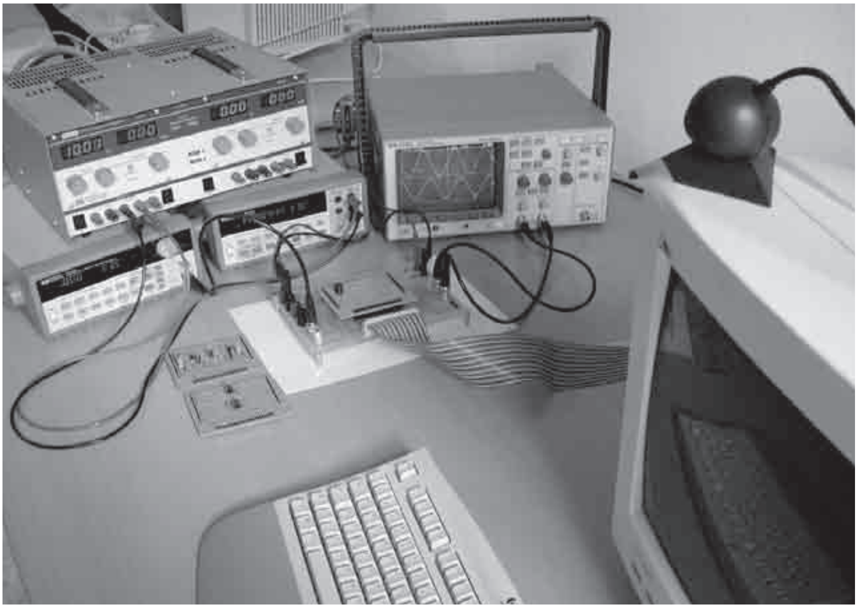

**Figure 2**

Remote Electronic Lab (REL)

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.

## 3. Switch Matrix Board (controlled by LabVIEW)

One of the problems coming up with remote labs using real instruments is, that they have to be hard-wired to the circuit. To make an access to more than one node in the circuit with a single measurement instrument possible, we designed a simple and very cheap switch board.

This switch board allows connecting each of its 4 inputs to 4 different nodes in the circuit. The switch board is connected to the PC via the parallel interface and is controlled like the other instruments in our lab by a LabVIEW program.

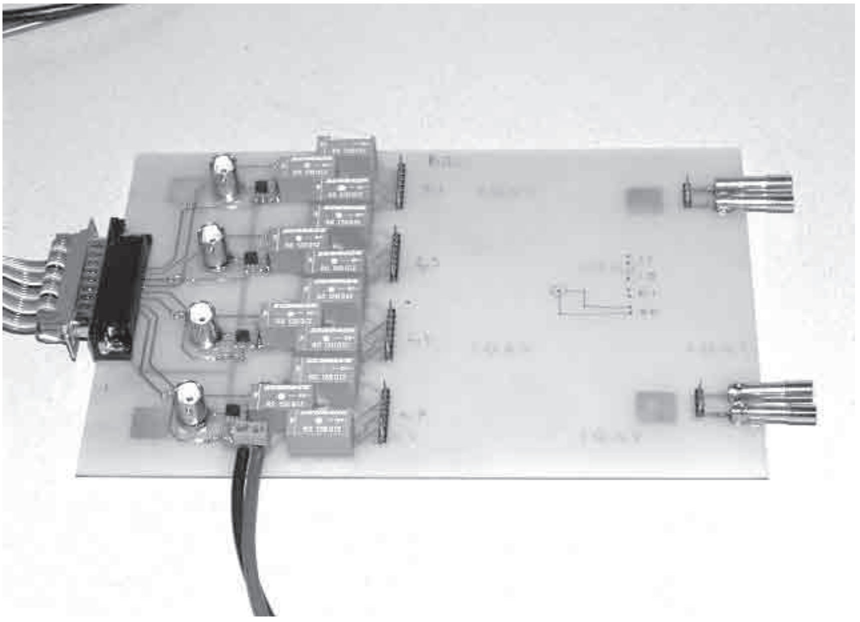

**Figure 3**

Switch Matrix Board

The board consists of a standard 25-pin D-SUB connector for the PC connection, 4 BNC-Connectors for connecting the measurement instruments, 12 relays switching both, signal and ground, connections of the BNC connector to a pin array, which carries the circuit under test. An external 12V power supply is needed to provide the energy for the relays. As power supplies for most experiments don't have to be switched, these are hard wired to a second pin array.

## 4. Online ASIC Design System as a Combination of Simulation and Test/Measurement

As a very complex solution and a combination of a virtual lab and a remote lab we realized systems for online development of digital (Xilinx) and analog (Lattice) ASIC's. Such labs are often called hybrid labs.

The following steps are implemented:

— ASIC design system (digital/analog) running on a lab server. The user only needs a web browser.
— Simulation of the design on the lab server.
— Download of the design to the connected hardware (evaluation boards).
— Test and measure with real or virtual instruments via the Internet (REL, see above).

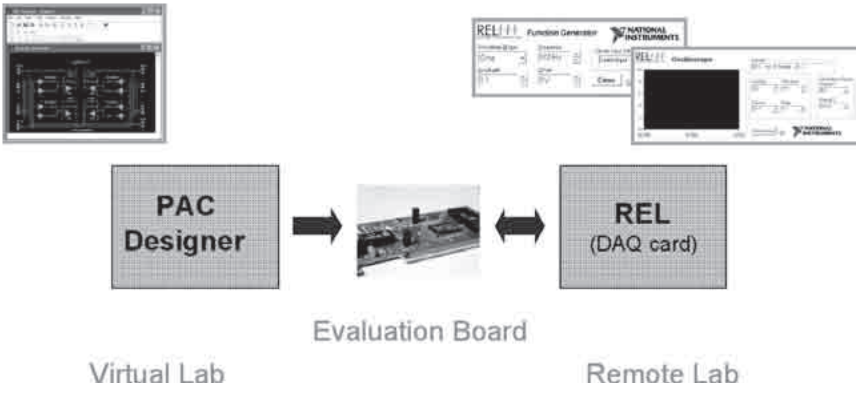


**Figure 4**

Online ASIC Design System Structure

The PAC-Designer software was installed on a Citrix server. The Citrix MetaFrame is a Windows application for delivering Windows based applications to several desktops and supports up to 15 simultaneous connections. Once installed, the PAC-Designer becomes available to be remotely accessed.

Lattice Semiconductor offers the ispPAC10 evaluation board for design and test of analog ASICs. The remote lab idea was to make the same functionalities of this board also available to a remote user. In order to accomplish that, a new board was assembled. Within this board, each DAQ card terminal was directly connected to its respective node in the circuit and no extra wires were needed.

So a complete design cycle can be realized for example from a home working place. Also simulators and real hardware (evaluation board) can be on different locations (distributed online lab).

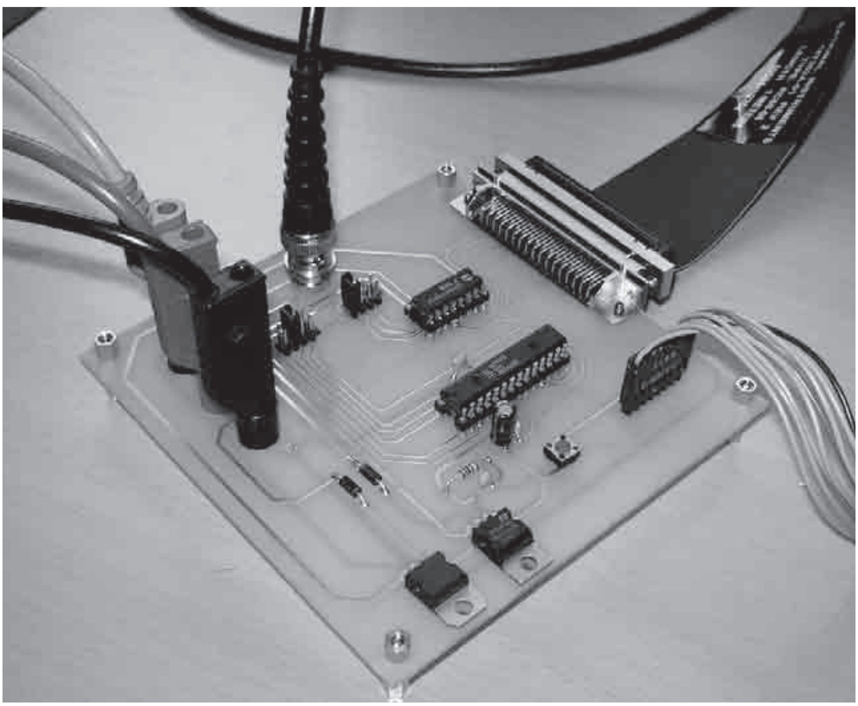

**Figure 5**

ASIC Design System Hardware

## 5. **Web Enabled Lab Portal and Time Reservation System**

Usually Remote Labs are single user systems. To control the access to online laboratories, some time-slot and resource-management system is needed. Our approach is based on the idea to unify access control, time management and resource management for a cluster of labs at different locations.

All the work is based on Software which has been published under the GNU - general public license to ensure that the costs will be as low as possible.

The Web-Portal offers users the possibility to get information about Online Laboratories and furthermore it provides the feature for doing time reservation of Online Labs. The Web-Portals are working completely independent from the Group servers. These Group servers basically are the same as the global Web-Portals and are meant to be used as institutes Online Web-Portal. The COM-Layers are responsible for user authentication and also store the reservation details. This concept of storing the reservation data "external" is absolutely new in this field and offers several advantages.

If the web-server is down for some reason, either for booking an Online Lab or for accessing it, nobody is able to use a Laboratory. Since the concept of the Network also implies, that one Laboratory can be included in different Web-Portals, it can also be booked if one server is down - the user simply has to do the reservation on another web-portal. Furthermore after a Reservation has been done there is no longer a need for the Web-Portal since all reservation data are stored in the COM-Layer which is located next to the Online Laboratory. This implies that the authentication process when accessing an Online Lab is done locally without the need for a Web- Portal. So the Web-Portal is "only" used for getting information, reading news and doing a reservation. Access control for the Labs is done independent from the Web- Portals - thus making the system on the one hand scalable and on the other hand quasi redundant.

Before someone can access a lab experiment he has to allocate a time-slot. Each remote laboratory site is linked to the reservation system. Usually a user authentication is required to access a lab experiment. After choosing an online-laboratory (Figure 6), someone is linked to a list showing all available the time-slots (Figure 7). By simply clicking on one of these fields, its content changes to a cross. So the time is reserved for the current user.

A maximum of four reservations at a time is allowed. Reservations which have already been done can also be cancelled.

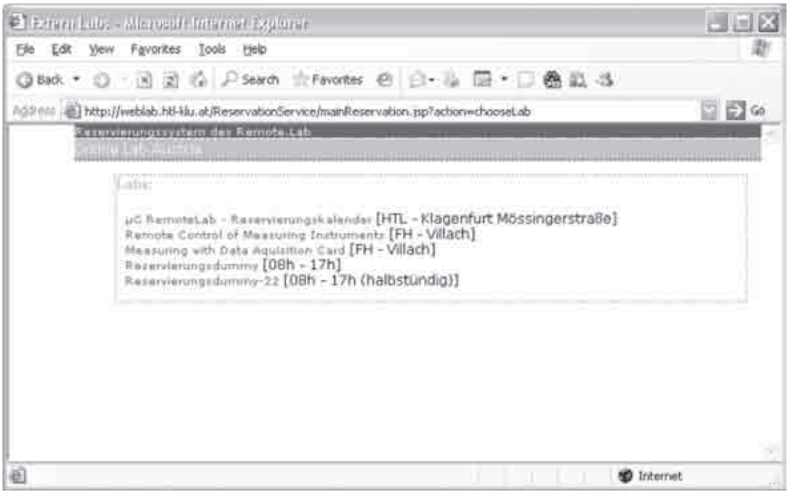


**Figure 6**

List of available Labs

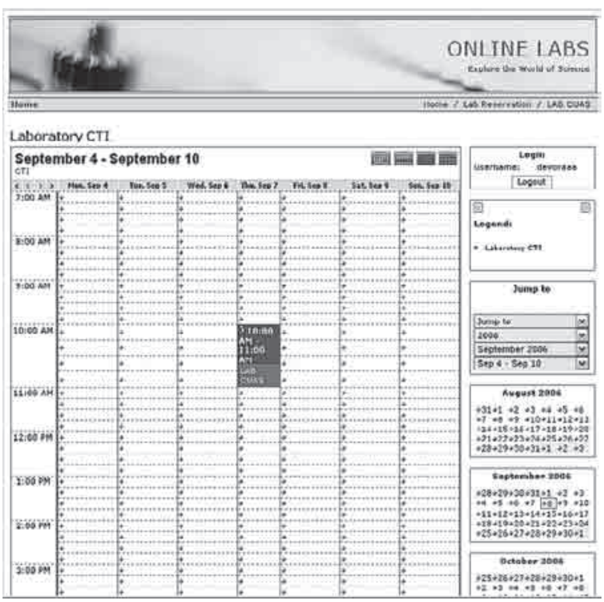


**Figure 7**

Lab Schedule

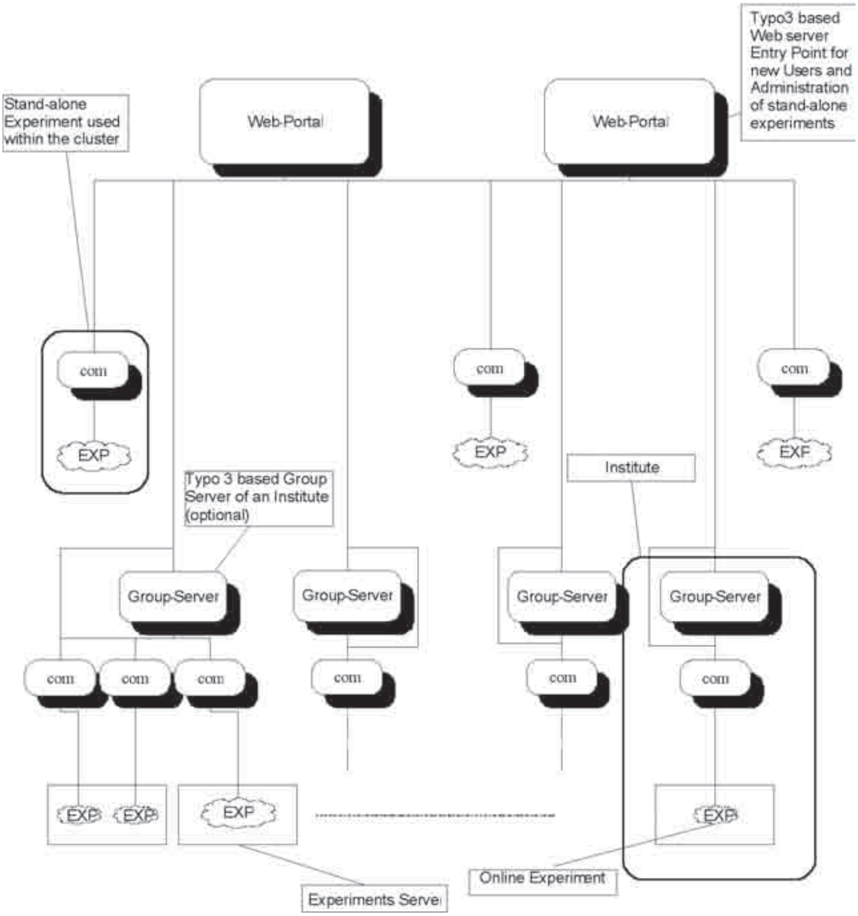


**Figure 8**

Self-growing Online Lab Grid

Figure 8 shows the structure of our self-growing Online Lab Grid. In this relation Grid means a set of networked lab nodes with equal rights. It's not primary a client-server architecture but a system with a distributed data base (experiment properties, lab structure, reservations, etc). Therefore the distributed lab is running and experiments are accessible also if the portal or some nodes are not operable. Further details see [12].

## 6. Reverse Proxy Configuration for Security Reasons of Online Labs

Security is one of the main problems of online lab structures.

A reverse proxy is a gateway for servers to enable one Web server to provide content from another Web server in a transparent way. The most common reason to run a reverse proxy is to enable controlled access from the Web to servers behind a firewall.

We use the Squid Web Proxy as reverse proxy. Within our lab we have a lot of different application servers. Each of these application servers (laboratory experiment-servers) has a private IP address. Furthermore these servers are located behind a firewall and can only be accessed within the private network.

The main idea of a reverse proxy server is the mapping of external IP-addresses to internal IP addresses. A lot of possibilities to control the access to the different lab servers are available with help of a special configuration file. This file is easy to understand and to edit.

## 7. Reuse und experience with the online labs

The experiments in the labs were designed for several target groups: students in technical high schools, students of electronics and electrical engineering in the courses electrical engineering, circuit design and microcontroller in the university. On the remarks of the students is going on a continuous process of improvement. For the reuse of these solutions we use two ways: for the virtual lab solutions we gave short training to our cooperation partners and than they work autonomous. Especial for solutions with the Matlab Webserver this works well. For the solutions with remote labs and also with the Citrix MetaFrame server a longer training of one of the lab engineers or experienced students from our partner universities was necessary. As usual they worked for half a year in our lab, set up their own solution on their lab server. Exchange programs like Erasmus, but also financial support from the National Instrument Foundation or IEEE Foundation was used for this. We successfully tried also a remote support (e.g. for the labs in Romania), but this requires already very experienced partners the other site.

## Conclusion

This paper has shown different types of Standard Modules for distributed Remote Electronic Laboratories and their practical implementation. The combination of different types of standard modules like a LabVIEW controlled remote lab, a switch board, a system for Online ASIC design or the use of Micro-Web-Servers leads to an increasing amount of online-experiments that can be easily installed, controlled, combined and be accessed.

This paper has also introduced a lab portal system, which facilitate the integration of online laboratories from different sources into any e-learning course.

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# A Proposal to integrate Mixed Reality Remote Experiments into Virtual Learning Environments using Interchangeable Components

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**Abstract**

*The paper presents a proposal to integrate mixed reality remote experiments into virtual learning environments (VLEs) using the concept of Interchangeable Components, which can represent either real or virtual devices or software in industrial automation systems. Combinations of real and virtual technical plants and automation systems are used in different learning scenarios for teaching control and automation concepts. Configurations of Interchangeable Components can be dynamically made via the virtual learning environment by configuring database parameters. The proposed system includes a remote web interface that follows a thin client strategy and is designed to be compatible with web browsers including basic Java support. As the architecture that supports the integration of virtual and real components is located in the server side, remote students/users are only concerned on the experiment and do not need to be aware of the system that provides this integration and flexibility. In the current version, interchangeable components are integrated via an OPC – OLE for Process Control – interface, a widely adopted standard in the control and automation area. The proposed approach also provides practical and theoretical support for experiments within a collaborative virtual environment. This work is part of the RExNet consortium, supported by the European Community within the scope of Alfa program.*

## Introduction

The growth of Internet has brought new paradigms and possibilities in technological education. In particular, it allows the remote use of experimental facilities that can be used to illustrate concepts handled in classroom and serves as an enabling and powerful technology for distance teaching. Through its world wide connectivity, the Intern*et al*so allows to have learning materials available to a much larger audience of students, giving them a greater flexibility in terms of defining by their own the speed and sequence of subjects during learning. Local and remote experimentation allows the application and testbeds of theoretical knowledge in practical situations [1]. The use of laboratories support students activities both in terms of active learning [2, 3], distributed learning [1] and team learning [4]. Web accessible laboratories with remote experiments have become an attractive economical solution for the increasing number of students [5]. They represent a "second best of being there" (SBBT) [6] solution for students and laboratories with expensive equipments. Remote experiments increase the accessibility to laboratory equipment and also provides space and time flexibility, i.e. students can be anywhere anytime performing their experiments via Internet [5]. Following this trend, many institutions around the world have been engaged in the development of Web based experimental settings. Systems aiming at teaching and research in several different areas have been proposed, such as digital process control [20], [19], aerospace applications [20], PID control [21], predictive control, embedded communication systems [18], and real-time video and voice applications [22]. Mostly, these experiments utilize customized devices and software to make small-scale textbook-like experiments remotely available.

Considering education on control and automation systems, a key issue is the reduction of the gap between classical theoretical courses and real industrial practice. Hence, it is important to allow students to operate with devices, systems, and techniques as close as possible to those they will be confronted in industrial settings. Unfortunately, to reproduce in an academic environment a real industrial plant is not an easy task. Industrial equipments are in general very expensive (both in terms of acquisition and also in maintenance costs) and usually require a large area for installation. Furthermore, safety constraints should also be taken into account.

All above-mentioned factors restrict the use of real industrial devices in academic laboratories, which in general are then structured as small-scale experiments with little connection to industrial reality. Within this context, making an industrial lab facility available via Web and therefore accessible

- at flexible times - to a larger number of individuals, helps to improve the overall cost-effectiveness of such solution.

However, experience has shown that allow the availability of remote experiments is not a sufficient condition to ensure success in the learning process. Remote lab experiments that are not offered together with learning material explaining the topics that are to be learned in the experiment usually lead students to the use of a "trial and error" strategy with a lower learning impact than expected. Additionally, the fact that remote labs are made available 24/7 for a large audience of students increases the demand in the number of faculty members and tutors that are necessary to provide on-line guidance to students.

In order to alleviate these problems remote experiments can be integrated into virtual learning environments (VLEs) [7, 8, 9] that manage and provide learning materials before, during and after the experimentation. This work proposes such an integrated learning environment, on which mixed reality lab experiments and student guidance tools are combined for control and automation education.

Mixed reality experiments [10], on which simulated components can be combined to real equipment to provide more practical situations, are used to illustrate different learning situations according to the knowledge level of remote students.

## 1. **Proposed Environment**

With the goal to reach more students and to provide a common environment to learn automation and control system theory, an environment called *GCAR-EAD* is proposed in this paper, which supports remote experimentation and mixed reality. The *GCAR-EAD* uses an architecture that integrates virtual learning environments (*VLE*s), educational materials, remote experiments, mixed reality [10, 23, 24], interchangeable components [7], post-experiment analysis [12] and simple student guidance tools [12].

Fig. 1. depicts the proposed architecture. Students can only access the remote experiment through the *VLE*, which includes an experiment analysis tool. Based on the results obtained by students on a given experiment as well as on a simplified student model, a student guidance tool can make suggestions about learning material to be reviewed [12].

Fig. 2. illustrates how the different modules communicate through the central database. Note that the experiment manager supplies a *Java Applet* interface that can be viewed by the client (student) with a simple *JRE* compliant web browser (thin-client computing [13]).

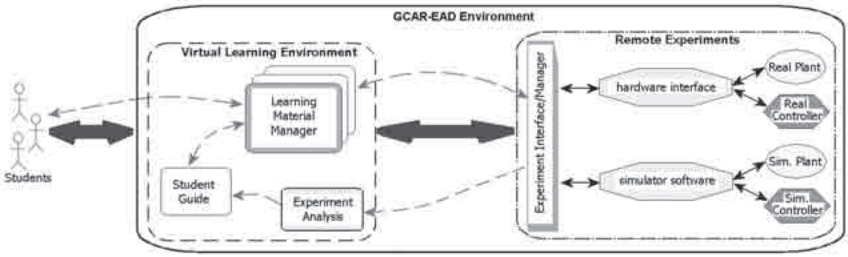


**Figure 1**

GCAR-EAD Environment

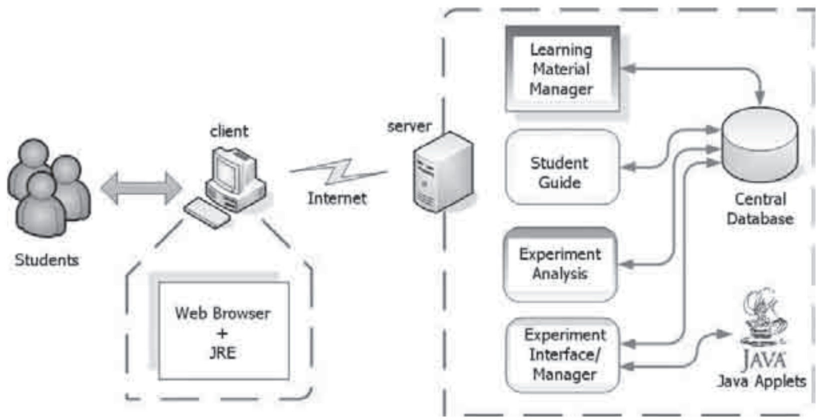


**Figure 2**

Access strategy and architecture modules interaction

### 1.1. *VLE integration with Mixed Reality supporting Interchangeable Components*

The *VLE* controls user access and allows remote experiment configuration according to the user (student) level, i.e., students with no previously recorded interaction with the experiment should start with basic experiments (usually the ones with only simulated equipments) while mode advanced students can directly go to more complex experiments. All the communication between the VLE and the remote experiments is done via a central database, on which consistency and security checking is performed before that a given experiment is configured or operated.

The interchangeable components strategy [7] (see Fig. 3) enables the definition of a variety of learning scenarios. For instance, simulated plants can be used to evaluate robustness of control algorithms when the (simulated) technical plant presents unexpected behaviour. On the other hand, simulated automation systems can be useful to show step-by-step execution of industrial controllers.

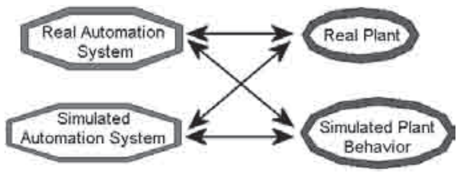


**Figure 3**

Interchangeable components strategy

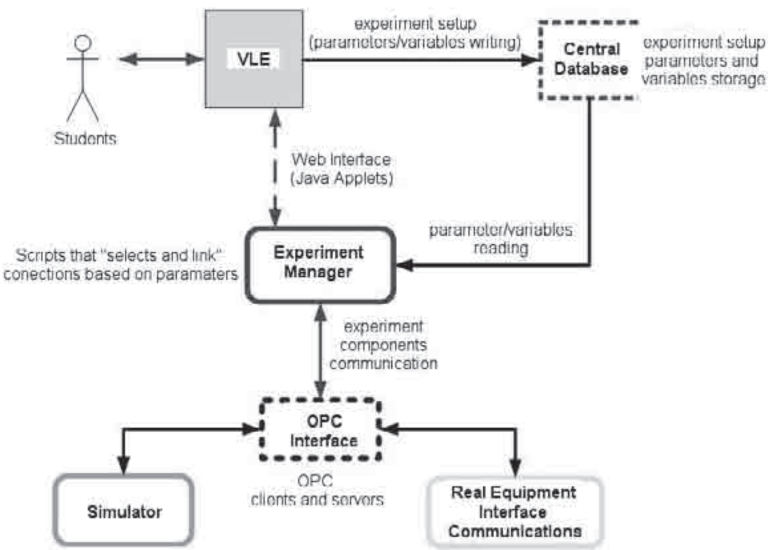


**Figure 4**

Integration with the VLE

As depicted in Fig. 4, the "Experiment Manager" module mediates the integration of real and simulated components with the VLE. The *OPC-DA* [15] standardized interface is used to provide a common, simple and reusable interface to interchangeable components. Basically the same interface is used for students interaction with real and simulated components (and therefore they are considered “interchangeable”).

### 1.2. *VLE integration with Tutoring Systems*

The experiment analysis tool compares the results of experiments performed by students with the problem specification. Usual control systems metrics such as maximal overshoot, rise time and settling time are adopted as comparison criteria. These metrics are directly related to the performance of remote experiment executed by the student. Based on these metrics, a student guidance tool suggests learning materials to be reviewed by the student when experiment goals are not reached. Fig. 5. illustrates which modules (and their interactions numbered in order) are involved in this process.

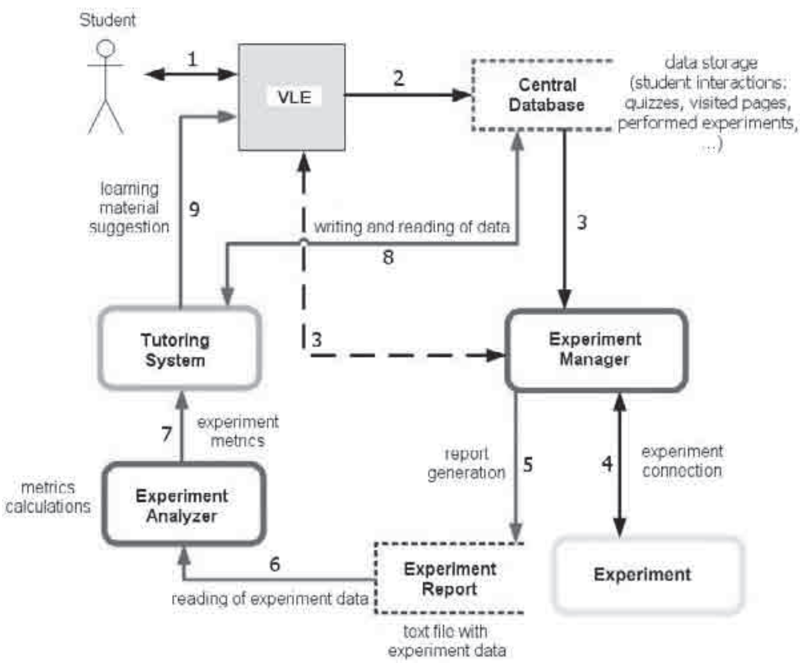


**Figure 5**

Student Guidance (tutoring system) control diagram

## 2. **Applications**

This section will describe some applications developed using the GCAR-EAD architecture presented in this paper. Most of the applications were developed within the scope of the RExNet Project [11]. *MOODLE* [14] was chosen as VLE in the RexNet consortium, and all courses and learning materials are organized to provide maximum intuitive perceptions, simplicity and knowledge transfer. *MOODLE* have a simple to use MySQL interface witch is used as database manager.

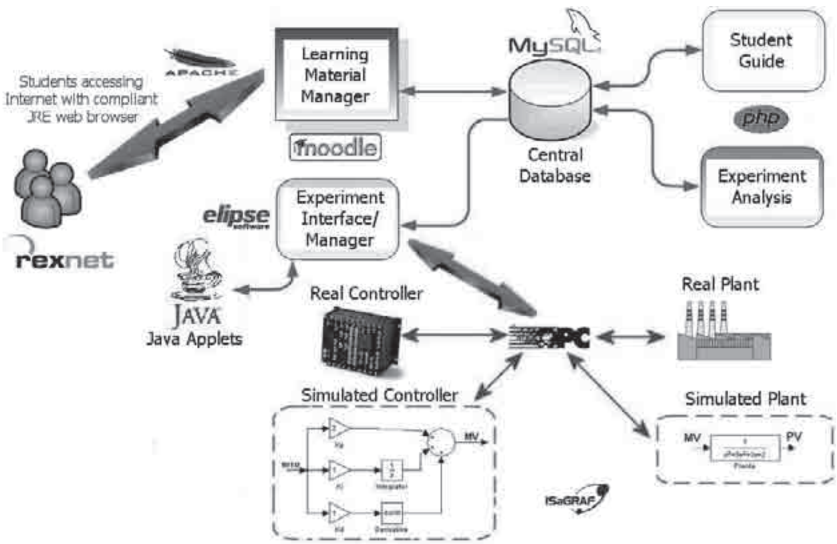


**Figure 6**

GCAR-EAD

The student guidance and experiment analysis tools are written in *PHP* code to simplify the integration and the interaction with the *MOODLE* software. A simple *SCADA* software, named *Elipse SCADA* [14], is used as experiment manager and is responsible to provide connections with the real/simulated equipment and to supply Java *Applets* as interfaces. *Elipse SCADA* also has interfaces to deal with *ODBC* (with *MySQL* connector) and with *OPC* servers.

The first prototype was developed using a Foundation Fieldbus Pilot Plant [17, 7], which has been used as a remote laboratory for several years at UFRGS for teaching PID controller theory, in particular how to tune PID parameters. Using MOODLE, the original remote laboratory was integrated into the GCAR-EAD by including new learning material on PID control theory as well as incorporating an experiment analysis tool to calculate control metrics from the results of the experiments performed by students. In this experiment students have to control the water level in two tanks by acting on pumps and valves. Additional to a course on "PID Controller Tuning", some other courses explaining how to use the experiment as well as a course of the Foundation Fieldbus industrial communication protocol were included. Fig. 7 presents a snapshot of the compute screen as viewed by remote students when performing the experiment

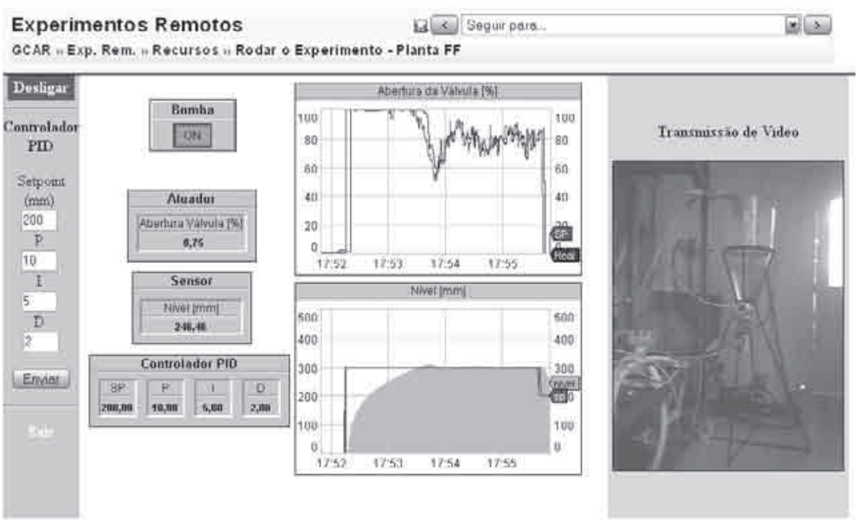


**Figure 7**

Foundation Fieldbus remote experiment interface in GCAR-EAD environment

The second prototype uses a simple thermal plant [18] built with a PID industrial controller and simple electronic equipment to illustrate temperature control techniques and the use of industrial controllers (see Fig. 8). Again, special courses were elaborated and similar student guidance and experiment analysis tools were developed. This prototype was easily adapted in the environment due to the reuse of modules previously developed for the Foundation Fieldbus plant.

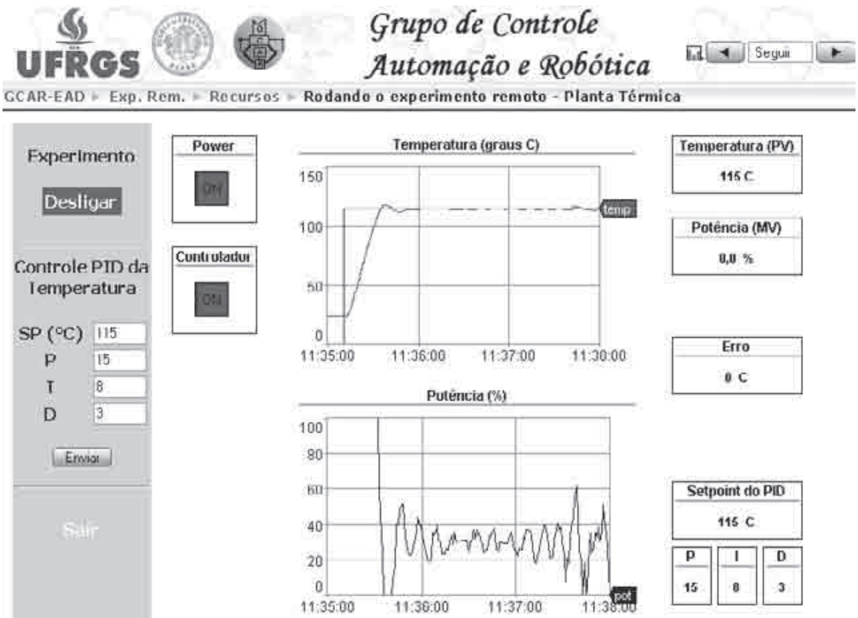


**Figure 8**

Thermal Plant remote experiment interface in GCAR-EAD environment

The third prototype, a mixed reality workbench for teaching mechatronics (electro pneumatics) for industrial apprentices, was developed in collaboration with researchers from the Universities of Bremen and Berlin [10], our partners in the RExNet project. In this case, the so-called DeriveSERVER developed in Germany, is integrated via an OPC interface to the GCAR EAD environment. This system is very flexible and has great interactivity with the apprentices (see Fig. 9).

The fourth prototype is a simulated bottle production plant [12], whose behaviour is simulated using the ISAGRAF tool using IEC61131 programming languages (see Fig. 10). It provides a very didactic and reusable experiment that can be combined to with the others to form a complete combined experiment, i.e., interactions with the mechatronics workbench produce a flexible way to control the experiment and also to integrate with other external OPC servers (other simulations). This prototype has a built-in analysis tool, integrated into the simulation model, which can check the behaviour of automation systems developed by students to control the bottle production process.

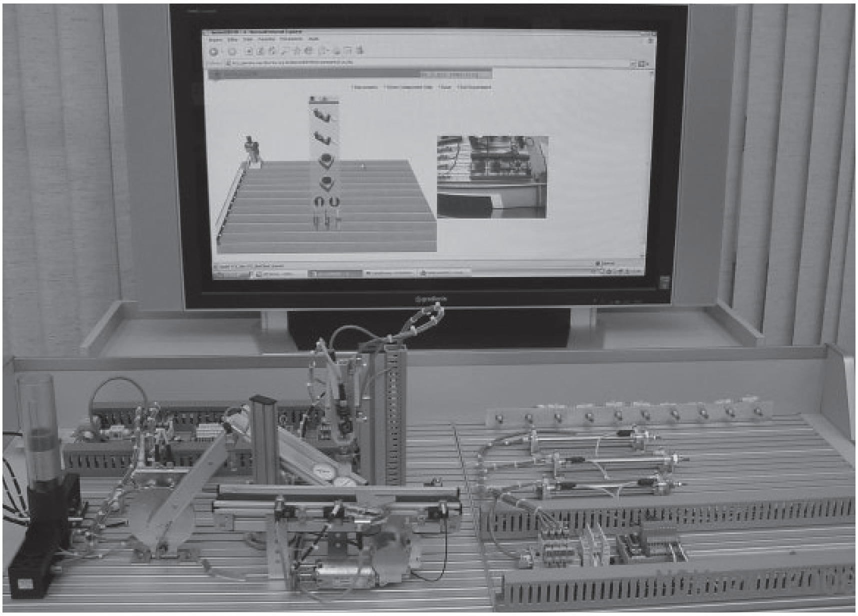

**Figure 9**

Mechatronics Mixed Reality Workbench Experiment

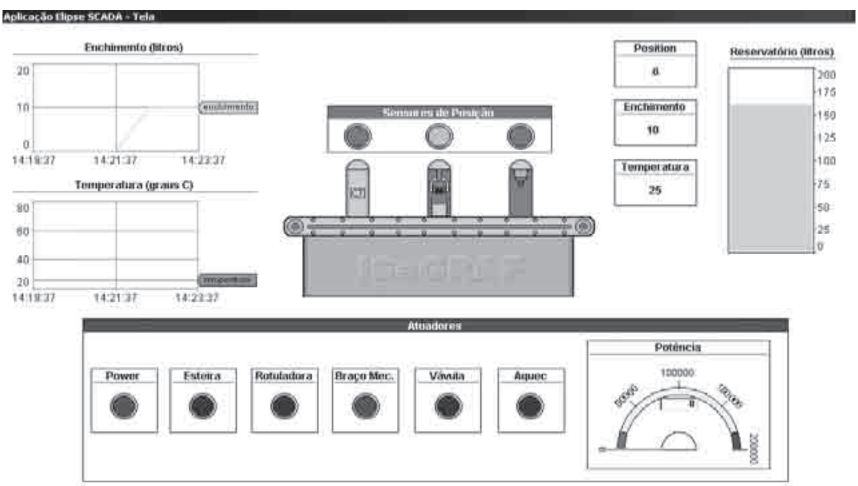


**Figure 10**

Simulated Bottle Production experiment interface

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All these prototypes can be combined using the concepts of interchangeable components, allowing the definition of a very interesting mix of experiments, on which different concepts can be explained and demonstrated.

## Conclusions and Future Work

This paper has presented the GCAR-EAD environment, which has the following characteristics:

- allows an integration of mixed reality experiments with virtual learning environments;
- introduces the concept of interchangeable components, allowing multiple combinations of virtual (simulated) and real technical plants and automation systems, which can be used in different learning scenarios;
- includes experiment analysis tools, which evaluates the results of experiments performed by the students, trying to infer if they correctly applied the learned concepts;
- provides student guidance through the learning material, helping students to identify topics to be reviewed in order to fulfil the goals of the assigned experiments.

While the proposed environment has proven to be very useful for control and automation education, there are still some challenges to be faced:

- the synchronisation in the timing behaviour of the virtual and real equipment is dependent of the communication delays in the network infrastructure. In the current implementation, this delay is of around 2 seconds for the whole communication between client and the end actuators even in intranet communication. While this is OK for technical plants with slow dynamics (what is the case in the selected experiments) it has to be improved. Of course there is a trade-off in having geographically distributed applications and the higher communication times that are required;
- while in its current version the GCAR EAD environment does allow the configuration of mixed reality experiments, tools with a higher level support to tutors is need in order to ease the definition of complex experiments.

The proposed environment can also be used for collaborative engineering since experiments can be distributed into several sites and several students (users) can interact using the same environment (see for instance, the chapter from Müller and Erbe in this book for more information on collaborative engineering education using remote laboratories).

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Luís Gomes and Javier García-Zubía (eds.)

**Advances on remote laboratories and e-learning experiences**

A comprehensive overview on several aspects of remote laboratories development and usage, and their potential impact in the teaching and learning processes using selected e-learning experiences is provided.

The book is based on the presentations and discussions carried out at «International eeting on Professional Remote Laboratories», which took place in University of Deusto, Bilbao, in the period of November 16-17, 2006. Apart from chapters based on the presentations, some others have also been included in this book. In this way, we hope to give a broad, well balanced and up-to-date picture of the current status of remote labs and their role within the e-learning paradigm.

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