Online labs and the MARVEL experience

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***Abstract*— MARVEL is a Leonardo da Vinci project that provides a framework to analyse the pedagogic effectiveness of online labs in various heterogeneous areas that include solar energy, robotics, electronics and electro-pneumatics. It is also used as a test bench to compare the implementation of purely remote labs, where all devices are real, versus mixed-reality environments, where real devices work together with simulation models. This paper describes the basic concepts underlying the implementation of such online labs and presents two case studies (which are openly available to the public). A final section discusses the main pedagogical implications of online labs and presents the research directions that are being considered as a follow-up from this project.**

***Index Terms* — remote / mixed-reality laboratories, e-learning, vocational training in mechatronics.**

I. INTRODUCTION

Engineering education and technical training are confronted with the need to develop and integrate theoretical and practical learning sequences that are able to fulfill the demands for multi-qualified engineers and experienced technicians. The claim for work-related learning based on the interleaving of theoretical learning and learning by practical work and experimentation is obvious [1]. Accordingly there is a growing need for innovative learning concepts, capable of supporting the necessary education and training platforms. E-learning systems and virtual learning sessions (online labs, simulations) extending to real labs or even to the workplace are able to contribute significantly to a successful outcome of this learning process.

The pilot project MARVEL (Virtual Laboratory in Mechatronics: Access to Remote and Virtual E-Learning) is intended to stimulate learning concepts, that serve these actual needs. A main aspect within MARVEL is to implement and evaluate learning environments for mechatronics in engineering education and vocational training that allow students ubiquitous online access to physical workshops and laboratory facilities from remote places. Remote and mixed reality techniques are used collaboratively within a network of colleges, industry partners, and other institutions. Accordingly the project has an organisational development goal, which is the co-ordination of learning facilities in different institutions and countries to form a transnational learning network of remote laboratories and distributed workshops. Currently the MARVEL project consists of seven member institutions, who provide various online resources to the network.

The MARVEL project includes online labs in solar energy, robotics and electro-pneumatics, providing examples of fully remote experimentation settings, where all devices and equipments are real and available via the internet, and also of mixed-reality environments, where real devices interact with simulation models [2,3]. For details concerning the other online labs and experiments, visit the MARVEL website at http://www.marvel.uni-bremen.de.

II. PEDAGOGIC FRAMEWORK

The MARVEL project is focused on supporting learning practice based on social constructivism, combined with experiential and collaborative learning. The theory of *experiential learning*, which is an important reference point in our approach, propagates learning through experience and by experience. Within this theory learning is understood as an iterative process whereby knowledge is created though the transformation of experiences. David A. Kolb [4], one of the main exponents of experiential learning, proposes a four-stage model, as illustrated in figure 1. Accordingly a learning process begins with a concrete experience, which is followed by reflective observation. The reflection is then assimilated into a theory by abstract conceptualisation before finally new (or reformulated) hypotheses are tested out in new situations. The model can be characterized as an iterative learning cycle within which the learner tests and modifies new ideas and concepts as a result of reflection and conceptualisation. The use of "here-and-now" experience to test theories in practice, as well as the use of feedback to change these theories, are two significant elements of experiential learning.

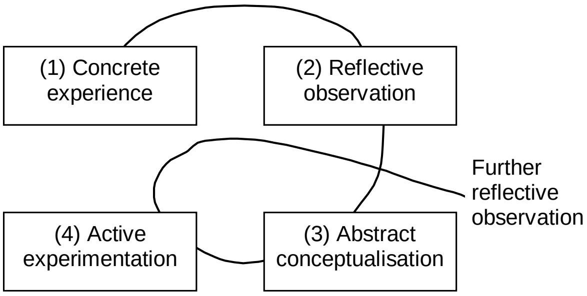

Figure 1. Experiential learning cycle

Hands-on learning in real-physical labs or workspaces provide reach opportunities for experiential learning, because the learner can 'experience' theory in a more familiar form, since the practical experiment enables the students to "observe and reflect on" the results of learning tasks and assignments. Each experiment or practical work task may therefore be seen as a starting point to understand its underlying theoretical principles.

According to the theory of social constructivism, collaborative activities improve the learning effectiveness [5]. Thus in several MARVEL learning scenarios students are involved in collaborative[1] learning tasks. Two basic aspects of collaboration might be important in this context. The first one involves the relationship among students: students work together as peers, applying their combined knowledge to the solution of a problem. The dialogue that results from this combined effort provides students with the opportunity to test and refine their understanding in an ongoing process. The second aspect of collaboration involves the role of the teacher: teachers should serve as moderators during the learning process by supporting students how to reflect on their evolving knowledge and providing direction when students are having difficulties. Thus, collaborative learning does not occur in a traditional classroom where students work independently on learning tasks and are responsible only for themselves. Apart from the psychological learning aspects, collaborative learning is important in engineering education for the following reasons:

- students acquire various soft-skills, such as the ability to work in teams and to achieve objectives in cooperation with others;
- students learn to communicate with each other using technical expressions that are specific of their professional engineering domain;
- students learn to integrate the know-how of others in order to accomplish a given work task;
- students acquire remote collaboration skills, when the teamwork is carried out from several locations simultaneously.

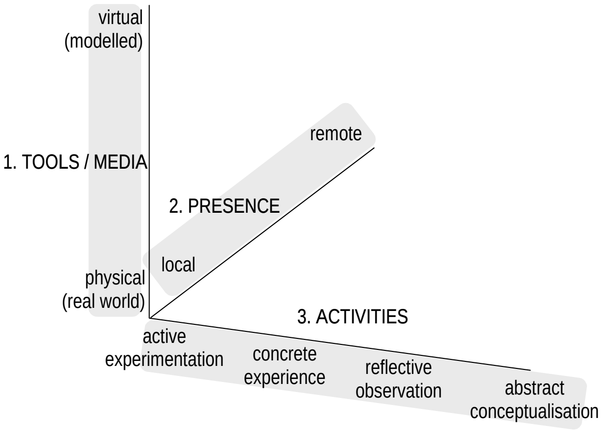

Figure 2. Mixed reality learning space

On the basis of the experiential and collaborative learning theories that were referred, MARVEL adopted a taxonomy that helps to arrange online labs, combined with simulation training and learning-by-doing on real-life systems, in an enriched learning environment. It is based on the concept of *mixed reality learning spaces* which comprise learning tools or media, learning places and learning activities (see figure 2).

Because our learning settings in MARVEL are strongly focused on the integration of online labs together with virtual labs (simulations) and physical learning resources or workshop facilities, we are looking for corresponding pedagogical, organizational and technical concepts. Integrating physical objects of real work spaces with the digital representation of information spaces, is an approach that witnessed an increasing interest during the last decade [7]. This concept – also known as Mixed Reality – has a high pedagogic potential and comes close to our requirements. The set of technological building blocks where such mixed-reality learning spaces are based will be presented in the following section.

III. BUILDING BLOCKS FOR ONLINE LABS

The basic feature that qualifies an experiment as remote — either purely remote or as part of a mixed-reality environment — is the use of a communication network to intermediate access to (at least part of) the laboratory equipment. Within the scope of this work, we will consider that such communication network is the internet, although this may not necessarily be the case. There are pros and cons in this approach, but the detailed discussion of such aspects does not fit into the scope of this section. What we would like to stress at this point is that online labs share a common technological infrastructure, which is largely independent of the application domain or target user groups. The following list summarises the main building blocks comprised in this infrastructure:

- the remote equipment and devices used must be interconnected by a “remote” communication network, which is itself connected to the internet. Actually the remote communication network may be based on TCP / IP as well, although there are areas where field-buses or other specific LANs may be preferable (and indeed a remote experiment may be based on clusters of such networks, distributed over a wide area);
- any remote equipment used has to be associated with a representation of its functionality, accessible over the communication network that separates the experiment from the user. Such representation may be built using standard commercial tools, or alternatively it may be tailor-made to interface less common devices or pieces of equipment;
- synchronous communication tools are also a fundamental building block, since most experiments are carried out by a group of students, instead of an individual working alone. Moreover, when an instructor is available online, the students must be able to ask (or answer) questions while the experiment takes place.

Additionally, and although not strictly necessary, it is recommendable to provide live images of the remote experiment. The use of webcams to show what is going on at the remote workbench increases the awareness of

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[1] With the term *collaborative* we follow the definition of Roschelle and Teasley: Collaboration involves the “... mutual engagement of participants in a coordinated effort to solve the problem together" [6].

the user to the fact that she/he is dealing with real devices, instead of just simulation models. More important than that, webcams also enable the visualisation of specific aspects that may in some cases have to be observed (e.g. the colour of a flame during a chemistry experiment).

The learning model illustrated in figure 1 shows that each experiment is not a stand-alone product, but rather a learning object in a wider framework that is likely to include an e-learning platform and a set of underlying theoretical learning contents. The technical requirements to set up such wider educational / administrative contexts are outside the scope of our analysis, and therefore we will restrict ourselves to the list presented above.

Many proprietary or standard communication networks may be used to interconnect the remote devices and the equipment used. Standard commercial products, such as those based on PXI, are frequently used and provide a straightforward solution to interconnect measuring equipment such as oscilloscopes, multimeters, etc. Such standard solutions work well with virtual instrumentation packages, such as those made available by National Instruments (LabView) or Keithley (TestPoint). In such cases, building a representation of the functionality provided by the remote equipment becomes a very straightforward task, and a coherent work environment may be developed quickly. The collaborative features enabled by synchronous communication tools may or may not be integrated into the experiment window. Video-conferencing channels may be embedded into the work environment, in which case a single browser window will be sufficient to carry out the experiment. Some users express a preference to work in single-window environments, arguing that having to swap between different applications / windows is a factor of distraction. However, separating the collaborative tools from the experiment window(s) gives the users the freedom to select whatever tools they prefer to use or find more appropriate for each task. In many cases the added-value of video-conferencing is too small in the face of its bandwidth requirements. Many students prefer to use chat tools (e.g. MSN Messenger), which they use extensively for social purposes.

Finally, when the number of students is high and the remote resources are scarce, booking may become necessary. In general terms, a booking tool is useful to enable M groups of students to share access to N remote experiments (M > N). Even when the remote experiment interface already provides application sharing mechanisms (such as the “request control” feature of LabView virtual instruments), it is important to help the students to organise their activity, by enabling them to book their access during pre-defined time slots. In such cases, a booking application will be associated with each remote experiment workbench, and each group of students will have to reserve a time slot at an appropriate date.

IV. SELECTED CASE STUDIES

This section presents two examples of online labs, one providing access to a purely remote electronics experiment and the other one mixing remote devices and simulation models in a mixed-reality electro-pneumatics experiment.

A. *A remote electronics workbench*

In order to illustrate the operation of a Sallen-Key second-order active filter, the circuit represented in figure 3 was set up in the remote workbench (R1 = R2 = 3K3, C1 = 100 nF and C2 = 15 nF). The input signal is driven by a PXI waveform generator and the output is observed using a PXI oscilloscope. LabView scripts were produced to enable access to these instruments over the web.

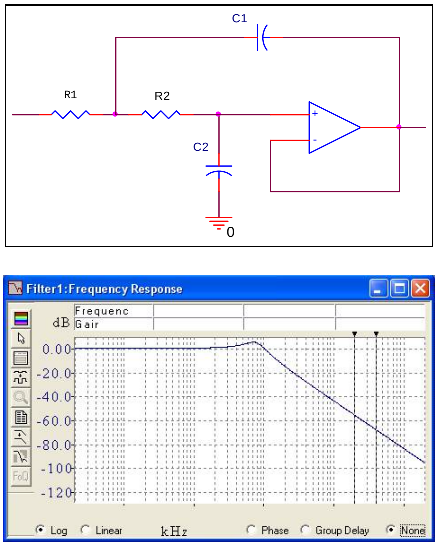

Figure 3. A Sallen-Key second-order low-pass filter and its frequency response

The objective of this work assignment consists of confirming that the operation of the filter is in accordance with its theoretical cut-off frequency. During their reserved time slot, each group of students controls the waveform generator and uses the oscilloscope to observe the input and output signals. One student in the group will take control of the experiment window and apply a low-frequency sine wave to the filter input. The frequency of this waveform is then progressively increased until it becomes visible that the cut-off frequency has been reached (notice that the 2232 Hz input sine wave illustrated in figure 4 is already above the cut-off frequency).

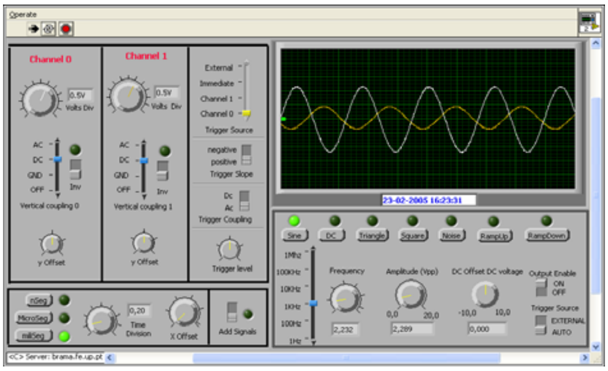

Figure 4. Interface (LabView VIs) to the equipment available in the remote workbench

A video-conferencing room provided by a Macromedia Flash Communication server is available to the students, which may use this resource to co-ordinate their actions. This collaborative tool is not strictly necessary for simple cases like the one described in this section, and may eventually be replaced by other alternatives with less bandwidth requirements, such as any instant messaging tool (e.g. MSN Messenger) or internet telephony application (e.g. Skype). The availability of a synchronous communication tool, be it video-conferencing or not, is however an important added-value to ensure pedagogic effectiveness, particularly when an instructor is available to help the students overcome unexpected difficulties or to clarify doubts that may arise while the experiment is carried out.

The experiment described above may be accessed from our Moodle server at http://ptse.fe.up.pt/moodle. Visitors should use demo / public as username / password and follow the booking link displayed under the lab script to reserve access time (course Electronics / Introduction to electronics) [8].

B. *A mixed-reality experiment in electro-pneumatics*

In addition to purely remote labs, where all devices are real, we test mixed-reality environments, where real devices work together with simulation models. Thus we introduce the *deriveServer*, a distributed and collaborative e-learning platform, which integrates real and virtual, local and remote media for electro pneumatics under one common interface. The deriveServer is a direct outcome of the European project "Distributed Real and Virtual Learning Environment for Mechatronics and Tele-service" (DERIVE). The system is based on the Hyperbond-technology [9], providing means to freely combine real and virtual worlds (see figure 5).

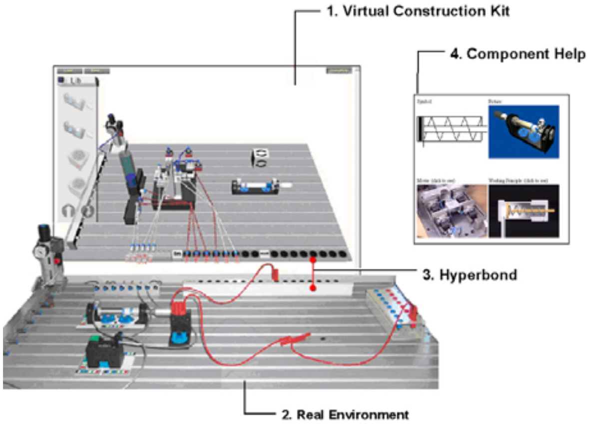

Figure 5. Mixed-reality environment for training in electro-pneumatics (deriveServer)

With the *deriveServer* local / remote learners can work together on different levels of abstraction ranging from real components, three dimensional virtual worlds, up to symbolic representations. A key feature of the system is the function of freely replacing virtual parts by real ones and vice versa. Thus it is possible to build hybrid electro pneumatic circuits which are a mixture of real and virtual components. By dragging and dropping objects from a library onto the working area new elements are added to the system and interconnected to build the experiment. If the status of the real system changes the virtual simulation model reacts accordingly: modifications in the real world lead to an update of the virtual system.

The mixed-reality environment described above is located at http://lab.artec.uni-bremen.de. After the index page has loaded, the user is guided through a set of pages where she/he can create a new experiment or join an on-going experiment, get help or additional materials.

V. CONCLUSION

Among the lessons learnt during the course of MARVEL, there are a few aspects that deserve special attention. First and foremost, it is important to stress that the ultimate objective of any online lab is to improve the pedagogical effectiveness of the learning process. Our trials led us to conclude that online labs achieve this objective because of the following main reasons:

- Flexible working hours — the students are able to work at any time, and from any location;
- Real experiments may be carried out without safety concerns;
- Networks of online labs provide a multi-cultural environment that is appreciated by the students (and which effectively contributes to improve their communication and language skills).

Institutional benefits may be envisaged as well, since it becomes possible to share resources among institutions and to reach a wider public. The same reasons that bring an added pedagogical value to online labs also explain some of its drawbacks. Loss of haptic experience and susceptibility to network problems are among the main limitations identified, when compared to on-lab experimentation.

The main research directions that are currently being considered address instructor support and automated assessment: The examples that were presented in section 4 represent the student side. It is of course necessary to build the experiment interface, where the various resources made available to the students are put together. Instructor support, in the form of an experiment interface building tool, becomes of fundamental importance to shorten the development cycle and to separate experiment-specific knowledge from web application skills (which the instructors do not necessarily possess).

Many of the actions of the students provide insight into their knowledge and skills. Instructors normally collect this type of information while helping students during traditional laboratory work. There is no reason why this type of information should not be collected by the experiment window, in particular in those cases where it brings into evidence that a student is particularly capable or is noticeably unprepared. Automated formative assessment methods and tools are therefore within our priorities as a follow-up from the work done so far in MARVEL.

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