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MARVEL – Mechatronics Training in Real and Virtual Environments

Concepts, Practices, and Recommendations

Edited by Dieter Müller

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MARVEL - Mechatronics Training in Real and Virtual Environments

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PROJECT PARTNERS

Universität Bremen, Laboratory for Art-Work-Technology (artecLab) – Bremen, Germany

Higher Technical Institute (HTI), Department of Mechanical Engineering – Nicosia, Cyprus

Berufsbildende Schulen II Delmenhorst – Delmenhorst, Germany

Bildungswerk der Niedersächsischen Wirtschaft (BNW) - Delmenhorst, Germany

Festo Didactic GmbH & Co. KG – Denkendorf, Germany

Zenon S.A. Robotics & Informatics – Athens, Greece

University of Porto, Faculty of Engineering (FEUP) – Porto, Portugal

Scottish Qualifications Authority (SQA) – Glasgow, Great Britain

West Lothian College (WLC) – Livingston, Great Britain

Swiss Occidental Leonardo (SOL) - Sion, Switzerland (external partner)

Haute Ecole Valaisanne (HEV) – Sion, Switzerland (external partner)

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FOREWORD

This publication on the topic of "Mechatronics Training in Real and Virtual Environments" is one of the outputs from MARVEL, a pilot project under the LEONARDO DA VINCI action programme for implementation of the European Community's vocational training policy. The aim of MARVEL was to create and evaluate virtual learning environments for mechatronics training in which learners are provided with ubiquitous online access to physical workshops and laboratory facilities from remote places and learning venues.

The project developed novel concepts for learning communities and inter-site cooperation in which the stakeholders involved (e.g. vocational colleges, training enterprises, universities) can share and use costly plant and laboratory facilities via the Internet. A variety of learning environments were implemented and tested. The main target groups for MARVEL were students, trainees and instructors in vocational education and training.

This publication covers only some of the early results from MARVEL. It highlights innovative concepts, examples, and recommendations for the use of 'real worlds' in virtual learning environments in order to accelerate the deployment of work process oriented training with real-life systems in mechatronics.

The study is structured into three parts. In Part I we present a short overview of MARVEL and the project objectives. We also identify typical training needs and summarise key characteristics of new job profiles in mechatronics, before focusing on distributed environments for mechatronics training. More specifically, this chapter describes ideas for designing, providing and evaluating interlinked virtual and real learning spaces with a special focus on educational, psychological and organisational aspects.

In the following chapter we provide an overview of technical concepts that were important for MARVEL. This includes a survey about remote and distributed workshop and lab assignments focused on the technological backbone common to the various training environments implemented during the course of the MARVEL project: a solar heating plant, a solar energy lab, a robot training lab, an electropneumatics workshop, a mixed-reality mechatronics workbench and an electronics workbench.

In Part II we present various case studies, practical learning scenarios, and course trials which were implemented and tested within MARVEL by the project partners. The authors provide recommendations on how mechatronics training in real and virtual environments (e.g. laboratories, simulators, remote laboratories and workshops) might be implemented. They describe their experience within MARVEL under different perspectives, as well as the results of evaluations carried out during course trials.

Finally, in Part III, we provide some extra material, including an extensive glossary. The glossary is intended to support the reader while reading this study.

On behalf of MARVEL, I would like to express my appreciation of the work done by the members of the project team. I would also like to thank all academic and industrial partners, especially those who have contributed to this study. Without their active co-operation and support it would not have been possible to bring out this publication. My thanks are also due to the German Leonardo National Agency (NA), which offered to publish our work as part of the IMPULS series.

Bremen, July 2004

Dieter Müller
Project Coordinator of MARVEL

THE MARVEL PROJECT

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1. Introduction

In modern technical education and training, an important role is played by learning concepts which closely link learning and work, and which develop key skills that equip employees to cope with open work assignments and the rapid pace of change. The need for work-related learning based on the interleaving of theoretical learning and learning in practical tasks, experimentation and field work is obvious (Attwell et al, 1997). Accordingly, there is a growing need for innovative concepts, capable of supporting the necessary education and training platforms. eLearning systems and virtual learning sessions (online labs, simulations) extending to real labs or to the workplace can contribute significantly to a successful outcome of this learning process. The MARVEL pilot project (Virtual Laboratory in Mechatronics: Access to Remote and Virtual eLearning) was designed to foster learning concepts that serve these actual needs in the subject area of mechatronics.

2. The objectives of MARVEL

The aim of MARVEL was to implement and evaluate virtual learning environments for mechatronics training that provide engineering students and trainees with ubiquitous online access to physical workshops and laboratory facilities from remote places and learning venues. The project was focused on how to use mechatronics equipment and machinery in virtual learning environments in order to support work-process-oriented and distributed cooperative learning with real-life systems.

MARVEL had to develop concepts for learning communities and inter-site collaboration in which the stakeholders involved (e.g. vocational colleges, training enterprises, universities) can share and use costly plant and laboratory facilities via the Internet. This involved teacher training courses and investigations into how training institutions, technology suppliers, universities and industry (especially SMEs) can profit actively and passively from distributed remote workshops and laboratories.

The project had an organisational development goal, namely the transnational coordination of distributed physical and virtual learning resources. As a result, MARVEL had to produce evaluated working examples of remotely accessible practical environments, as well as support material for eLearning and student assessment. This included demonstration models in partner institutions and industry for evaluation purposes. Telematics, remote and mixed reality[1] techniques had to be used cooperatively within the MARVEL partner network.

3. Target group of MARVEL

The main target group of MARVEL comprises stakeholders in initial vocational training and engineering education (e.g. vocational colleges, training enterprises, universities). Other potential target groups are organisations offering further training courses for skilled workers, technicians and engineers. The main teaching subject is mechatronics, with the focus on system control, maintenance, process monitoring and automation technology of networked plant and machinery. Learning scenarios relating to remote concepts and technologies such as eMaintenance, teleservices, remote repair, diagnostics and maintenance, played a key role in the project. Accordingly, working examples of remotely accessible practical environments, including eLearning and student assessment materials, were developed in the following application fields: industrial robotics, digital electronics, electropneumatics, modular production systems and process control of energy systems.

4. Project consortium

The MARVEL consortium is led by artecLab (laboratory of the Art, Work and Technology) at the University of Bremen, and brings together educational institutions (technical colleges and universities), companies, national bodies and other institutions from Cyprus, Germany, Greece, Portugal, Switzerland and the United Kingdom. The organisations supporting the project have experience in

[1] For special terms such as telematics, mixed reality, etc., see Glossary in the addendum.

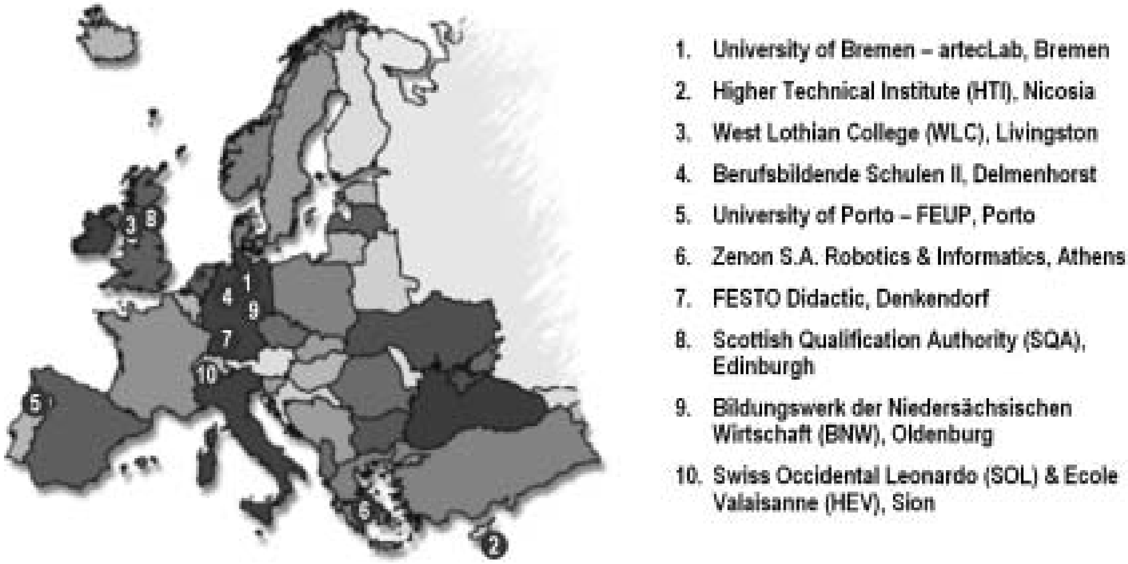

Fig. 1: MARVEL project consortium

mechatronics, either in research and education, or manufacturing and application of mechatronics.

4.1 Technical colleges and universities

Partners from the educational area are the project coordinator, artecLab, the Higher Technical Institute (Cyprus), West Lothian College (Scotland), Berufsbildende Schulen II Delmenhorst (Germany) and the University of Porto (Portugal).

University of Bremen , artecLab, Bremen - Germany

ArtecLab is a central research institute at the University of Bremen. ArtecLab's research focuses on cooperative mastering of increasing complexity in industrial production, as viewed from different perspectives in the art-work-technology triangle. The research focus is on new forms of human-computer interaction, especially mixed reality and tangible media for new learning environments and industrial design concepts. ArtecLab has been active in national and regional research programs relating to Humanisation of Working Conditions (HdA) and socially oriented shaping of work and technology. ArtecLab is or has been involved in different national and transnational R&D projects (e.g. BMBF, BLK, DFG, Leonardo, EU-IST, ESPRIT).

The Higher Technical Institute (HTI), Nicosia - Cyprus

The Higher Technical Institute (HTI) provides training at the higher technician level in civil, electrical, mechanical and marine engineering and computer science. The institute is equipped with laboratories and workshops backed by Industry Support Centres and test facilities. Training courses and research activities at HTI include energy research, computer-aided engineering, automation and information technology, software engineering and other technical fields. The extent of involvement and level of complexity of teaching and research projects varies from applied to pure science. In some cases, projects are carried out cooperation with European universities and other institutions within E.U. programmes (e.g. SAVE, Leonardo etc.).

West Lothian College (WLC), Livingston - Scotland

West Lothian College (WLC) is a Further and Higher Education College that delivers vocational education and training to the local community and businesses. Situated in the heart of "Silicon Glen", it has specialised in the development and delivery of training for advanced manufacturing, particularly in relation to the semiconductor fabrication industry. It pioneered the development and delivery of courses in mechatronics to meet the needs of local companies, winning several prestigious awards as a result. A specialist unit called the Scottish Advanced Manufacturing Centre was set up to take this work further. Close liaison is maintained with local companies, with courses and training solutions being developed as an ongoing process to meet their lifelong learning needs.

Berufsbildende Schulen II Delmenhorst - Germany

Berufsbildende Schulen II Delmenhorst is a vocational education centre in northern Germany offering a high standard of teaching in electrical and mechanical engineering, including energy conversion and management. The college offers initial VET and technician's degrees. The college has a fully-equipped process laboratory for a solar heating system. The lab is used for all kinds of teaching projects relating to solar energy, process control, data acquisition and other subjects in which process automation plays a role. The college has strong links with local industry and universities, in particular the University of Bremen.

University of Porto, Faculty of Engineering (FEUP), Porto - Portugal

FEUP is the school of engineering at the University of Porto. More than 5,000 students are enrolled on FEUP's eight undergraduate engineering degree courses: electrical and computer engineering, informatics and computing, chemical engineering, civil engineering, industrial management, mechanical engineering, metallurgy and materials, and mining and geo-environmental engineering. In addition to education (teaching and training in all levels), FEUP provides a range of other services with particular relevance to research activities in all departmental areas. Educational applications of information technology are a key area within FEUP for both current research and development projects, specifically under the European IST and Leonardo da Vinci programmes.

4.2 Companies and enterprises from the mechatronics industry

Companies and enterprises in the MARVEL consortium are involved in automation technology, robotics and training technology, and include ZENON S.A. Robotics and Informatics (Greece) and FESTO Didactic GmbH & Co. KG (Germany).

ZENON S.A. Robotics and Informatics, Athens - Greece

ZENON supplies innovative solutions bridging the fields of information technologies, robotics and business consulting. It accomplishes this with three interactive units, namely ZENON Consulting, ZENON Informatics, and ZENON Robotics. ZENON Consulting activities are mainly focused on business and technology consulting. ZENON Informatics specialises in creating and implementing advanced custom IT solutions. ZENON Robotics specialises in industrial robotics, automation, computer visualisation and computer-integrated manufacturing (CIM). ZENON collaborates with prestigious institutes and participates in EU-funded R&D projects, having successfully carried out numerous such projects as both Project and Technological Coordinator.

FESTO Didactic GmbH & Co. KG, Denkendorf - Germany

FESTO Didactic is a subsidiary of Festo AG and has factories in Germany, Brazil, Bulgaria, Hungary, India, Korea, Mexico and Ukraine, as well as 49 autonomous Festo companies with regional offices. The business units within FESTO are Pneumatic (components and systems), Cybernetic (complete solutions for automated processes and production) and Didactic (basic and further training in automation and communications technology). FESTO offers a broad spectrum of products related to mechatronics training, with a worldwide market share of about 25%. One well-known FESTO product is its MPS (Modular Production System), a set of real-life industrial production equipment of varying complexity.

4.3 National bodies and other institutions

Two other organisation within the MARVEL consortium that act as members of the Advisory Board. These partners are the Scottish Qualifications Authority (SQA) and the Bildungswerk der Niedersächsischen Wirtschaft (Advanced Training Institution of the Federation of Company Associations for Lower Saxony). The role of each partner is to give further advice on assessment with regard to practice-based knowledge transfer between colleges and industry. They also help to disseminate project results.

Scottish Qualifications Authority (SQA), Glasgow - Scotland

The Scottish Qualifications Authority (SQA) is the national body in Scotland responsible for the development, accreditation, external assessment and certification of qualifications other than degrees. SQA's functions are to: (1) devise, develop and validate qualifications, and keep them under review (2) accredit qualifications (3) approve education and training establishments as being suitable for entering people for these qualifications (4) arrange for, assist in, and carry out, the assessment of people taking SQA qualifications (5) quality assure education and training establishments which offer SQA qualifications (6) issue certificates to candidates.

Bildungswerk der Niedersächsischen Wirtschaft (BNW), Delmenhorst - Germany

The Bildungswerk der Niedersächsischen Wirtschaft (BNW) is an organisation of the Federation of Industry Associations in Lower Saxony. Its main fields of activity are professional training for young people, retraining and education for unemployed persons, reintegration programmes for young people, women, disadvantaged persons and social welfare recipients. In its mission to improve and reinforce vocational integration and reintegration at all levels, BNW has developed concepts for work-based vocational training and apprenticeship. BNW works in close cooperation with local industry and national employment offices.

4.4 Associated partners

Finally, there are two associated partners from Switzerland in the MARVEL project. These are Swiss Occidental Leonardo (SOL), an association promoting the participation of Switzerland in the Leonardo da Vinci programme, and the Haute École Valaisanne (HEV). Both partners provide links to the vocational training system in Switzerland, and are engaged in disseminating project results from MARVEL.

5. Work plan

The work plan of the MARVEL project included the development of a conceptual framework (pedagogical, technical), the design of courses and development of eLearning content, the creation of learning scenarios and environments, the organisation of courses and, finally, the dissemination of project results. In addition to these activities, a core element within MARVEL was the creation of demonstration models (learning scenarios and environments) for evaluation purposes. The project therefore had to coordinate learning facilities in different institutions and countries in order to form a transnational learning network of remote laboratories and distributed workshops. Figure 2 shows the MARVEL work plan structure.

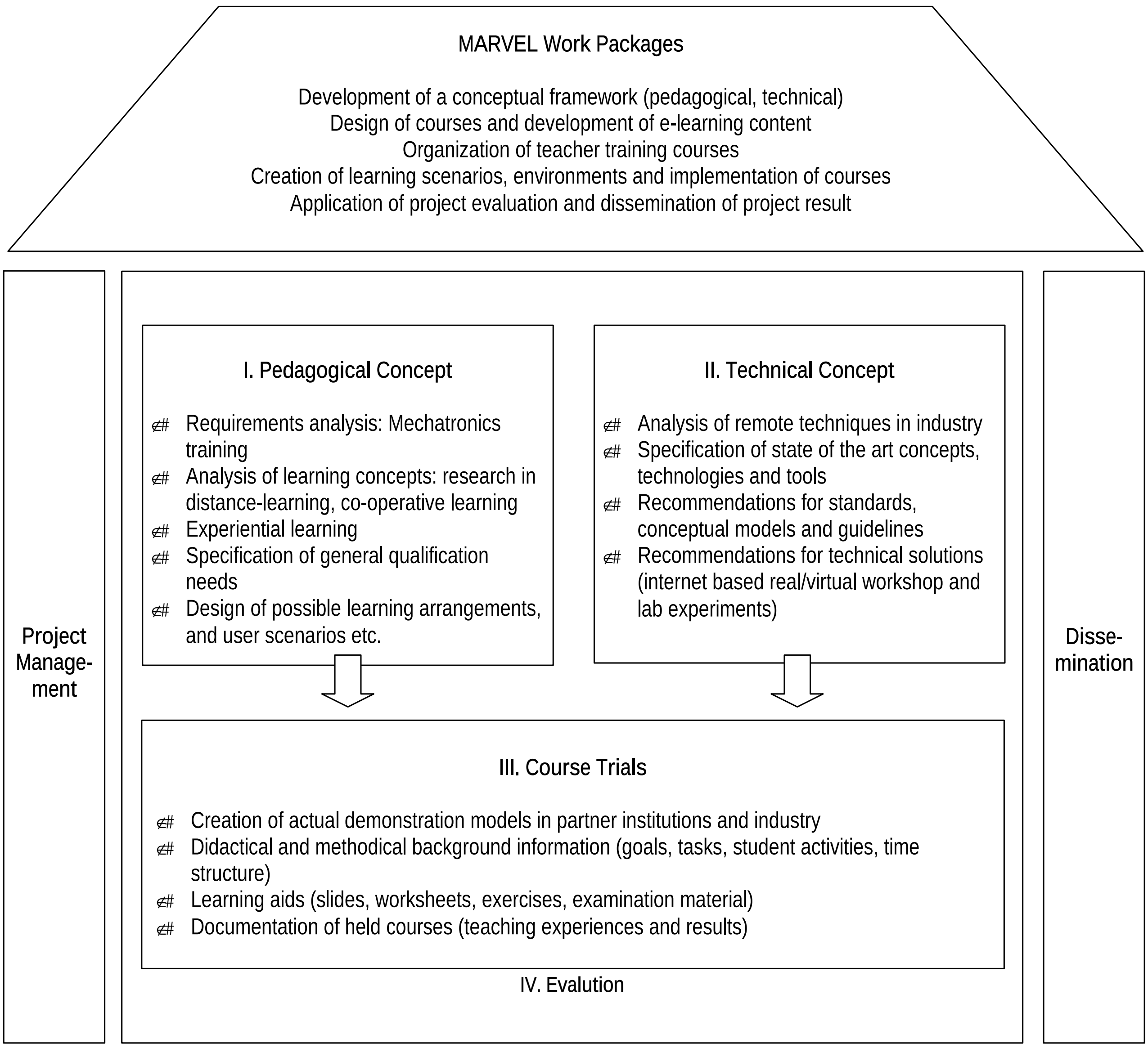

Fig. 2: Work plan structure

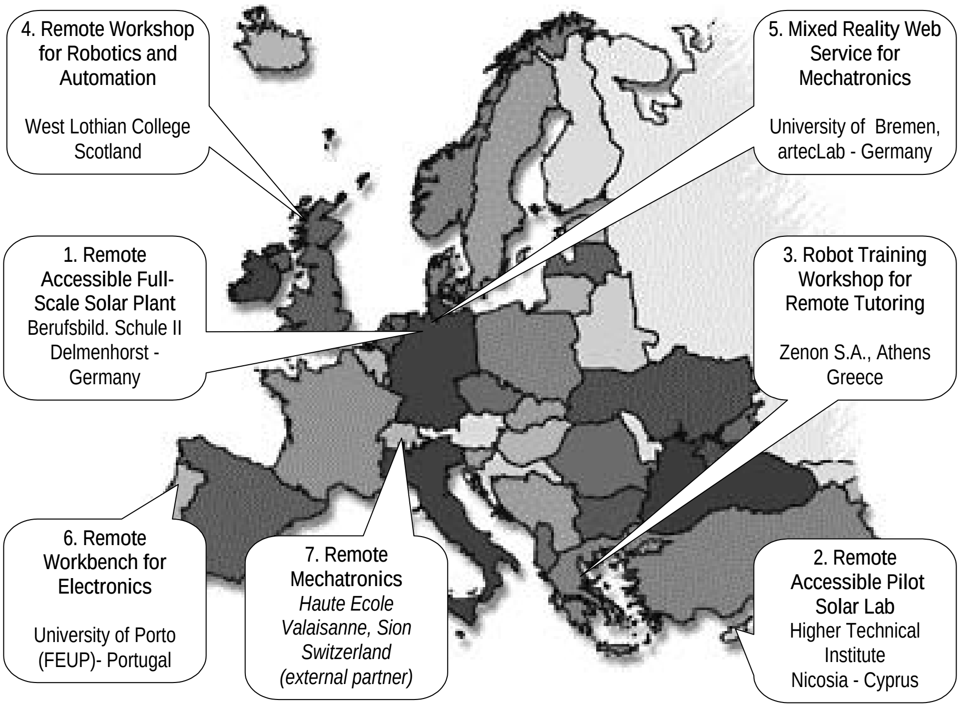

Fig. 3: The MARVEL network of distributed labs and workshop facilities

6. Case studies and learning scenarios

The MARVEL project evaluated and made available working examples of remotely accessible environments, including eLearning and student assessment materials for various application fields and cases. This included labs and workshops for solar energy, digital electronics, industrial robotics and electro pneumatics, providing examples of fully remote experimentation and workshop settings in which all devices and equipment are real and available via the Internet, and also of mixed-reality environments in which real devices interact with simulation models.

6.1 The MARVEL network of distributed labs and workshop facilities

The geographic distribution of labs and workshop facilities that were used in MARVEL course trials are presented in Figure 3. A brief description of each is provided below. Further details can also be found in other articles within this book.

1. Remote accessible full-scale solar plant – Berufsbildende Schulen II Delmenhorst: The hardware setup of the full-scale solar plant at Delmenhorst Technical College consists of four different, commercially available, collector sub-assemblies on the flat roof of the college building. The system provides the college with warm water (up to 1200 litres/day). The heated water is stored in 500-litre tanks and fed to various faucets via a plumbing system. The solar heating system is continuously controlled by a programmable logic controller (PLC), connected via a field bus to about 40 sensors (for temperature, volume flow, etc.) and numerous actuators (valves, pumps and servomotors). The PLC has an Ethernet I/O module to provide remote access to the real process via an Internet-based connection. To supervise the behaviour of the overall system, the data acquired is stored continuously on a server and may be monitored remotely. The process interface – enabling students to access the process and read or modify parameters – is realized with the SCADA package WinCC.

Fig. 4: Remote accessible full-scale solar plant

2. Remote accessible pilot solar energy laboratory – Higher Technical Instiute (HTI): The HTI solar energy eLearning laboratory comprises a pilot solar energy conversion plant equipped with all the instrumentation and control devices needed for remote access, control, data collection and processing (Michaelides et al 2004). The installed hard- and software includes features for controlling external devices, responding to events, processing data, creating report files, and exchanging information with other applications. All relevant weather data as well as operational and output data from the system are registered during an experimental session and can be stored on the user's PC for various calculations and/or documentation. Students from collaborating partner institutions will have remote access to the system. A booking tool is available with which instructors can control access to the equipment. A number of laboratory experiments and learning tasks were already developed, including familiarisation exercises as well as system performance investigations and eMaintenance tasks. All exercises and learning tasks are supported by web-based learning materials in form of 'virtual books'.

Fig. 5: Remote accessible pilot solar energy laboratory

3. Robot Training Workshop at ZENON: The general concept of the Robot Training Workshop is to provide an opportunity to perform training exercises with industrial robotics in a remote scenario. The student can act either as the advisor or the person seeking advice, in a setup where the robot platform is either distant from the expert or from the person seeking the advice/programming the robot.

ZENON's robotics training program aims at turning inexperienced persons into skilled experts capable of programming robots for a variety of industrial applications. The training is individually tailored according to the trainee's background and is regularly modified to accommodate for the trainee's progress. Most training is based on a trainee-tutor relationship, and lectures are rarely held. The trainee, assisted by a tutor, is given various tasks or problems to solve. The training course follows basic modules i.e. health and safety, familiarisation with the equipment, basic programming, advanced programming, and industrial programming. ZENON tries to get the trainee involved in industrial programming as quickly as possible, because we consider 'learning on the job' to be the most efficient and productive method.

Fig. 6: Robot training workshop (wet chemistry)

4. Remote Workshop for Robotics and Automation Technology - West Lothian College (WLC): The intention of this remote workshop is to have several 'mechatronic-type' experiments that can be accessed through the college's own Virtual Learning Environment (VLE). The intention is to put in place all the resources the learner needs in order to interact fully with each experiment. This includes the software, the hardware, suitable instructions, as well as guidance and assessment.

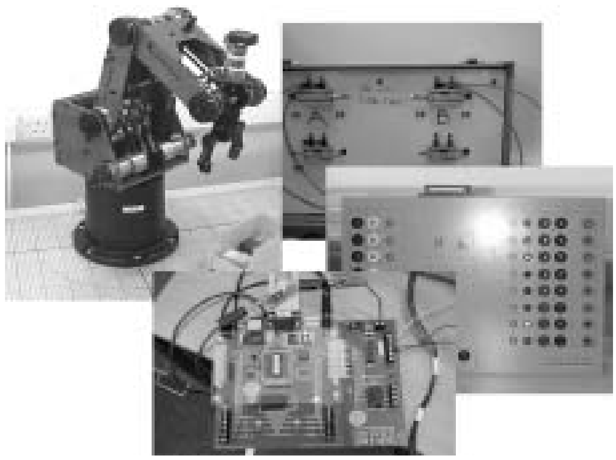

Fig. 7: Remote Workshop for robotics and automation Technology

Typical workshops may include some of the following:

- Pneumatic System: The student can interact with the pneumatic system. Programming, diagnostic checks may be carried out remotely.
- Deltronic Control System: Students can control inputs and outputs remotely.
- Programmable Controller (PIC): Various control and response devices can be attached to the PIC controller and controlled remotely.
- Robotic System: The greatest challenge posed is remote control and programming of a robotic system.

5. Mixed Reality Web Service for Mechatronics (artecLab): The Mixed Reality Web Service at artecLab makes mechatronic experiments accessible via the WWW. The system – called deriveSERVER – is available 24 hours a day for exploration and experimentation. All that is necessary is to install some special plugins on the client computer.

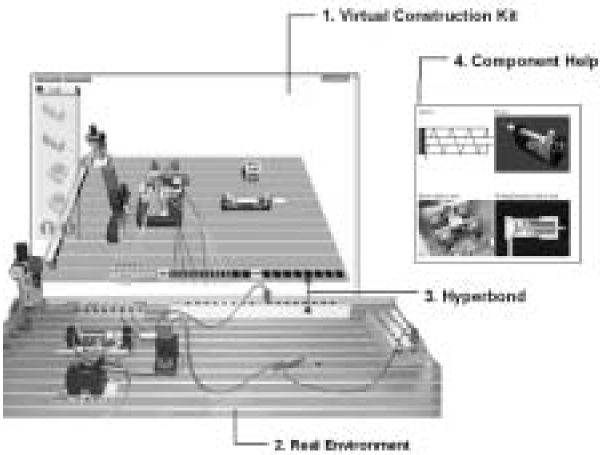

Fig. 8: Mixed Reality Web Service for mechatronics (deriveSERVER)

In addition to purely remote or local labs, where all devices are real, the deriveSERVER is a 'mixed-reality environment'[2], a distributed and collaborative eLearning platform that integrates real and virtual, local and remote media for electropneumatics under a common interface. The deriveSERVER is a direct outcome of the European project entitled "Distributed Real and Virtual Learning Environment for Mechatronics and Tele-service" (DERIVE). The system is based on hyperbond technology (Bruns 2001), which provides the means to combine real and virtual worlds freely. With the deriveSERVER, local/remote learners can work together on different levels of abstraction ranging from real components, to three-dimensional virtual worlds and symbolic representation. A key feature of the system is the function of freely replacing virtual parts by real ones and vice versa. This makes it possible to build hybrid electropneumatic circuits combining 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 result in an update of the virtual system.

6. Remote Workbench for Electronics – University of Porto (FEUP): The remote workbench for electronics was set up at FEUP to provide three types of experiments: testing digital and mixed-signal circuits, introductory logic design, and microcontroller-based design. The architecture of the remote workbench comprises a waveform generator and an oscilloscope, both implemented in the form of PXI[3] boards. The lab server is implemented in the form of a PXI single-board Pentium computer running MS Windows NT, which enables the users to control the waveform generator and the oscilloscope via LabVIEW virtual instrument panels. The remote hardware is implemented in a breadboard at the remote lab. Taken together, the components comprising the system occupy only a small part of a standard workbench.

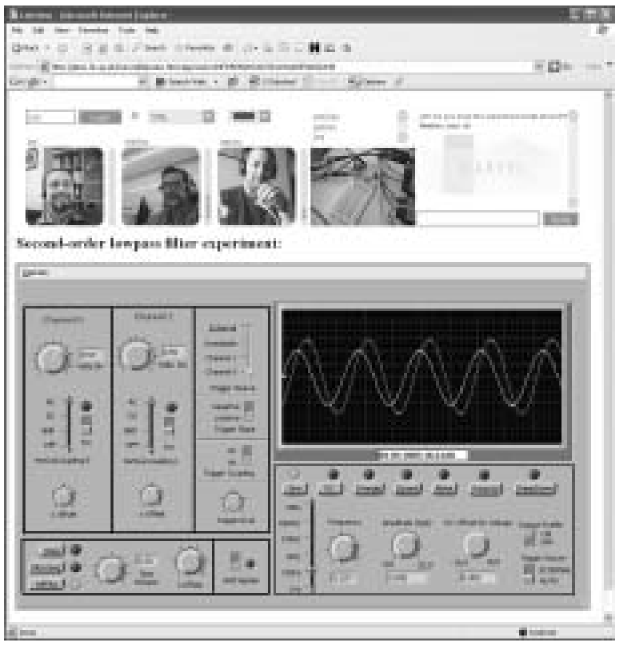

Fig. 9: Remote workbench for electronics (user interface)

[2] For the term *mixed reality environment*, see Glossary in the annex.

[3] PXI is an industrial computer architecture for interfacing measurement and automation devices.

7. Remote Control of Mechatronic Systems - Haute Ecole Valaisanne (HEV) – Switzerland: The intention of this Lab is to provide practical experiments in remote engineering. Students can learn how to design and implement a remotely accessible system. The main subjects are web services for mechatronics, network technologies, sensors and actuators for remote devices. The lab is run by the external project partner Haute Ecole Valaisanne (HEV) and receives no financial support from MARVEL.

6.2 MARVEL learning scenarios

The learning scenarios assessed in MARVEL address various mechatronics projects and cases of application, but concentrate initially on process control, industrial robotics, electropneumatics and electronics. An overview of these learning scenarios is presented in the table below (Table 1). For further details, visit the MARVEL website at http://www.marvel.uni-bremen.de.

In the first step, course trials were tested in local settings with students (Müller and Ferreira 2003). Distributed learning scenarios were then evaluated, in which students accessed virtual and physical laboratories and workbenches from a remote partner institution (Fig. 10, next page). A teacher, assuming the role of a tele-tutor, supported these learning sessions via the Internet. In further course trials, distributed learning groups collaborated via the Internet and solved a typical maintenance task, requiring them to program and/or configure a real mechatronic system. For safety reasons, their ability to modify parameters remotely was limited, and the learning task were supervised by an instructor at each site. As a complementary action to distributed settings, teachers held a joint teaching session with partner colleges, using their local lab facilities. An important aspect within MARVEL is that concepts and examples for real working and learning were developed and accessed virtually through remote processes. These support the social aspects of learning, as learning is necessarily integrated in communication processes among different learning groups while working at the same machine.

The educational content is based on existing factsheets, learning task descriptions, and other sources that were already available in digital form. We used the MOODLE software package for course management and delivery, and as a gateway to give access to the remote resources and tools. For communication and collaboration, various tools were used and tested. Generally, all learning settings addressed the following learning objectives:

- Theoretical knowledge and operational competence to monitor complex processes from remote locations (using IT tools for process monitoring and control).
- Theoretical knowledge and operational competence to determine the efficiency of different system configurations (using IT tools for data acquisition).
- Competence to maintain complex systems (e.g. finding faults) with IT tools and adequate methods.
- Ability to collaborate with technicians speaking a different language, and having different cultural and professional backgrounds (e.g. in a company with several branch offices all over Europe).

By studying the effects of teaching and learning through remote techniques and tele-cooperation tools in these different learning scenarios, the following issues were investigated as part of the evaluation:

- Will the proposed pedagogical framework meet the MARVEL criteria for functionality and usability?
- To what extent will the needs of students, as well as those of their current and future employers and of vocational colleges, be satisfied as a result of the greater flexibility to create learning settings?

	Learning scenarios	Partner involved	Settings and course trials
1	Distributed process monitoring, control and maintenance of full scale solar plants	Berufsbild. Schule II Delmenhorst Higher Technical Institute (HTI)	Classroom-only and various types of mixed classroom-work place learning settings, including remote experiments and teaching sessions with teams from partner colleges in different countries.
2	Distributed process monitoring, control and maintenance of pilot solar plants	Higher Technical Institute (HTI) Berufsbild. Schule II Delmenhorst	
3	Configuration and programming of an industrial robot with tele-tutor support	Zenon S.A., West Locian College (WLC)	
4	Distributed diagnosis and maintenance of a modular production system	University of Bremen, artecLab University of Porto, FEUP	
5	Exercises in remote engineering and mechatronics	West Lothian College (WLC) Zenon S.A.,	
6	Remote experiments in electronic circuit design	University of Porto, FEUP University of Bremen, artecLab	

Table 1: MARVEL learning scenarios

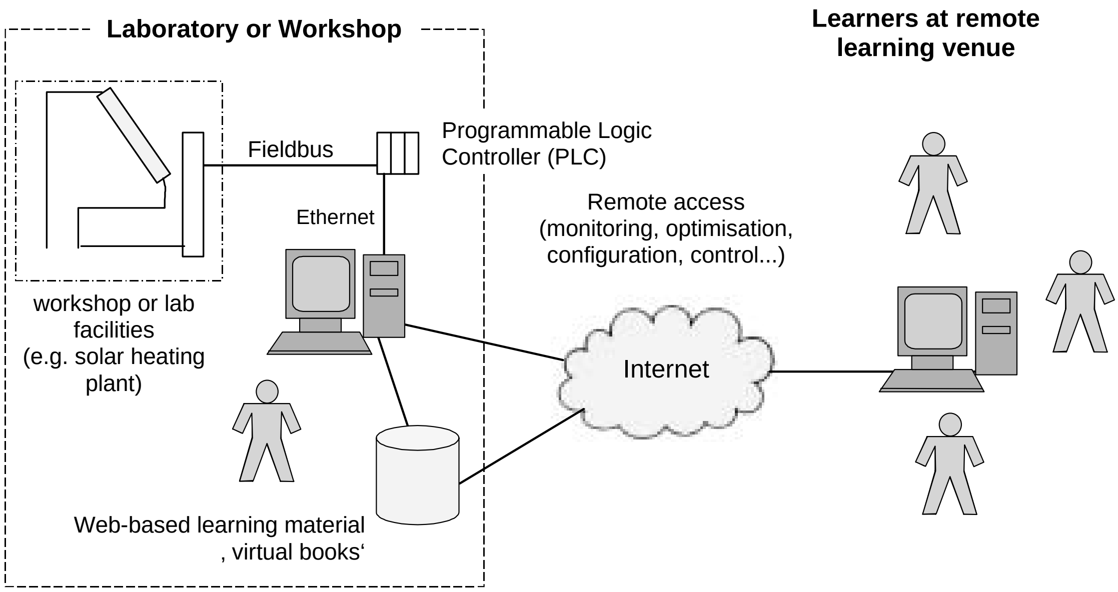

Fig. 10: Distributed real and virtual learning environment

- Does the linking of virtual and real systems (i.e. virtual and real learning objects, as well as abstract classroom and concrete work place settings) improve the educational effectiveness of the learning process?
- Which particular advantages and disadvantages are created by the new learning environment and learning settings, regarding cultural differences between the participating countries?

Data from the evaluation process have been gathered by means of questionnaires and interviews aimed at students, teachers, and industrial experts. Result from these evaluation studies will be described in further detail later in this volume.

7. Results and impact of the project

In this chapter, we provided a brief overview of the MARVEL project, including its objectives, the project consortium, the work plan, the ideas behind the project and a summary of our learning environments and course trials. Of the main lessons learnt during MARVEL, a few deserve special attention. First and foremost, it is important to stress that MARVEL stimulated innovative concepts in mechatronics training, and the impacts of the project can be summarised as follows:

Supporting teaching curricula for a key future work profile, comprising remote technologies, process automation, supervisory control and data acquisition of complex mechatronics systems.

- Facilitating ubiquitous availability of scarce and expensive learning resources using remote access technologies.
- Supporting lifelong learning by better integration of learning and work: The MARVEL concept increases student access to lab facilities and real-life workplaces, since physical presence is not always necessary.
- Training teachers to use new remote techniques and virtual lab devices and work place facilities.

In the MARVEL approach, we try to combine simulation training, remote lab experimentation and learning-by-doing on real-life systems to reduce problems in knowledge transfer between virtual and real systems. The MARVEL project pursues an innovative paradigm in engineering education and vocational training, by supporting local and distributed learning based on merging virtual and real labs and workshop facilities. This allows combinations between workplace-oriented and cooperative learning in a training network of different stakeholders.

An important innovation within this project is that concepts for, and examples of real working and learning were developed and accessed virtually using remote processes. These concepts and solutions foster the social aspects of learning, as learning is necessarily integrated in collaboration between different learning groups while working on the same tasks. One interesting aspect is that the media and tools used in MARVEL are at the same time a part of the working/learning process itself.

Our approach is a step to achieving “Virtual-Reality eLearning” in a particular field. eLearning or even Blended Learning – characterized in the classical sense as web-based training combined with classroom teaching – is limited in scope, because learning experiences are restricted to virtual situations. That is why a learning concept based on mixed reality could promise new learning perspectives and could go further than Blended Learning.

References

Attwell, G., Jennes A., Tomassini, M. (1997): Work-related knowledge and work process knowledge. In: A.Brown (ed): Promoting vocational education and training: European perspectives, Tampere: University of Tampere Press 1997.

Biehl, M., Prater, E., McIntyre, J. R.(2004): Remote repair, diagnostics, and maintenance. In: Communications of the ACM Volume 47, Number 11 (2004), pp 100-106.

Bruns, F.,W. (2001): Hyperbonds – enabling mixed reality. Technical Report ARTEC paper 82, ARTEC, University of Bremen, 2001.

Ferreira, José M.; Müller, D. (2004): The MARVEL EU project: A social constructivist approach to remote experimentation. 1st Remote Engineering and Virtual Instrumentation International Symposium (REV'04), Villach (Austria), 28 - 29 September 2004.

Michaelides I., Eleftheriou P., and Economides K (2005): HTI e-learning Laboratory –Remote Experimentation over the Internet. 2nd International Conference on Remote Engineering and Virtual Instrumentation (REV2005), Brasov, Romania, 30 June – 1 July 2005.

Michaelides, I., Eleftheriou, P.; Müller, D (2004): A remotely accessible solar energy laboratory - A distributed learning experience. 1st Remote Engineering and Virtual Instrumentation International Symposium (REV'04), Villach (Austria), 28 - 29 September 2004 .

Müller, D. (2005): Zwischen Realem und Virtuellem - Mixed-Reality in der technischen Bildung. In K. Lehmann & M. Schetsche (ed.), Die Google-Gesellschaft. transcript-Verlag: Bielefeld 2005.

Müller, D., Bruns, F. W. (2005): Experiential Learning of Mechatronics in a Mixed Reality Learning Space. Paper to be presented at the EDEN 2005 Conference, Helsinki University of Technology, Finland. June 20-23, 2005.

Müller, D., Ferreira, J. M. (2003): MARVEL: A Mixed Reality Learning Environment for Vocational Training in Mechatronics. International Conference on Technology Enhanced Learning 03 (TEL'03), Nov. 2003, Milano, Italy.

Müller, D., Ferreira, J. M. (2005): Online labs and the MARVEL experience. International Journal of Online Engineering. Vol. 1, No. 1, 2005.

MECHATRONICS IN VOCATIONAL TRAINING

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1. Introduction

Mechatronics is the synergistic combination of mechanical engineering, electronic control and computer technology (Fig. 1). It relates to the design of systems, devices and products with the aim of achieving an ideal balance between basic mechanical structure and its overall control (Bradley et al, 2000). Mechatronic devices are currently of great importance in almost all sectors.

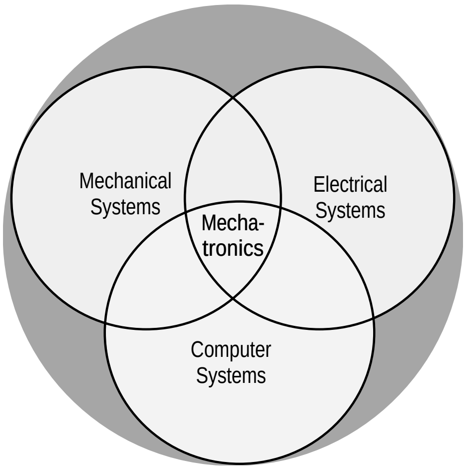

Fig. 1: Key elements of mechatronics

The multidisciplinary concepts that merge in mechatronic engineering require an academic education that provides an appropriate balance between research and development capabilities, as well as skilled workers and technicians trained for manufacturing, implementation and service provision in their professional area. In many countries, new job profiles and corresponding training schemes for mechatronics have thus been created as a mix of mechanical, electrical and ICT knowledge (IVTO 2003). Compared to specialised job-profiles such as those for mechanics or electricians, training in mechatronics requires the teaching of 'multi-skills' in different contexts, as well as a good mixture of classroom learning and work-related training.

As a consequence, engineering education and technical training are confronted with the need to integrate theoretical and practical learning sequences in ways that enable the skill profiles for multi-qualified engineers and experienced technicians to be achieved. The need for work-related learning based on the interleaving of theoretical learning and learning by practical work and experimentation is obvious (Attwell et al, 1997). Accordingly, there is a growing need for innovative learning concepts capable of supporting the necessary education and training platforms. eLearning systems and virtual learning sessions (online lab courses, simulation training) extending to real labs or even the workplace are able to contribute significantly to a successful outcome of this learning process. But the current generation of eLearning environments does not yet provide an integrated solution (comprising educational, technical and organisational aspects) able to meet these requirements in mechatronics training (Erbe & Bruns 2003).

2. Training needs in mechatronics

A major goal in mechatronics training is that students have to acquire theoretical and operational knowledge and practical competencies in terms of *core technical skills*. These types of skills generally relate to the assembly and service of complex machines, plants and systems, in the field of plant construction and mechanical engineering, and in those companies that purchase and operate such mechatronic systems.

Because of their complexity, mechatronic components and systems can often be installed and operated only in combination with support and after-sales services: specialist know-how and – in the case of maintenance or repair work – skilled customer support by the manufacturer's specialists are required. Hence, there is a growing need for qualified service personnel in mechatronics, rather than pure mechanics or electronic control technologies, with the following qualifications and skills:

- knowledge about potential and probable causes of malfunctioning in mechatronic systems (cause-effect relationships),
- handling both uncertainty and complexity in sophisticated mechatronics systems,

- knowledge about system-related service procedures and tools.

Mechatronic components can easily be integrated into telematics environments supporting applications such as teleservice and telemaintenance (Maßberg et al, 2000). In a survey conducted by *VDI-Nachrichten*, one of the most important engineering magazines in Germany, teleservices were considered to be the key service of the future (VDI 1999). In a comparative study about after-sales services to the machine tool industry in the U.S., Japan, and Germany, Biehl et al (2004) even noted that applications such as teleservice and telemaintenance had now expanded to a wider field referred to as remote repair, diagnostics, and maintenance (RRDM).

Engineering is undergoing significant structural changes worldwide. The studies mentioned above are evidence of the increasing importance of telematics-based work environments in the context of geographically distributed commissioning, installation, maintenance and repair of plant and machinery. Remote engineering, remote maintenance, teleservice or eMaintenance are all catchwords for these novel engineering and management applications with which the construction and maintenance of plant and machinery are monitored and managed over the Internet (Westkämper et al. 2002). The emergence of these techniques is rooted in the dissemination of mechatronic components – which are nowadays available in almost all modern systems. Remote servicing techniques have benefits for the engineering and plant construction industries, as well as for their customers: problems can be diagnosed off-site, and local engineers can be supported by a central team of remote experts. At the same time, communication between the manufacturer and the user of mechatronic systems is being improved. This helps to reduce service costs while increasing the availability of systems.

As remote engineering becomes increasingly important, there is also a growing need for qualified employees in maintenance departments, production, customer service and other fields. Such demands imply further training needs for skilled workers, technicians and engineers, who need to acquire qualifications and skills in the following areas:

- installation and use of remote diagnosis and service tools,
- creating and operating communication access points,
- acquiring data for eMaintenance purposes,
- providing remote services in different network and communication structures.

In contrast to 'traditional' engineering, experts in remote engineering are deployed in a relatively broad range of activities that span different sectors of industry. They typically work in locally distributed teams and coordinate their work amongst themselves. This requires not only competent handling of tools and methods for diagnosis, maintenance, monitoring and repair, but above all the ability to communicate effectively with others (e.g. customers, users, installers) with the help of computer-aided communication. Skilled service technicians must solve the 'mutual knowledge problem', for example by integrating the know-how of others in order to accomplish their goals using appropriate tools (e.g. electronic conferencing or groupware applications). Special focus must be placed on accessing distributed information from suppliers, customers and manufacturers over the Internet. Because remote engineering work is primarily immaterial, the quality assessment made by customers is highly dependent on those employees who perform such services. For this reason, technicians and engineers must be trained in customer orientation, with an emphasis on communication training and customer-centred action.

Besides normal communication problems, one should not underestimate the role of language barriers that may arise at work. Training in foreign languages, especially in English, seems to be very important in vocational training of mechatronics. In addition to adequate foreign language competence, 'intercultural competence' is also an important soft skill, enabling service personnel to be aware of cultural differences between European and other countries, for example in Asia or South America.

3. Important training principles

In relation to real work tasks, the training of non-technical skills such as teamwork, the ability to communicate in foreign languages, intercultural competence and customer orientation, was an important goal within the MARVEL learning scenarios. Working with remote experiments, collaborating in distributed teams and communicating in a foreign language with students from a partner college helped to develop and train these skills. With these requirements in mind, the MARVEL approach was grounded on the following training principles: action orientation; teamwork; work process orientation and customer orientation.

- *Action orientation:* Action orientation applies learning and work assignments where students can learn from hands-on experience they gain with concrete tools and systems. Laboratory exercises therefore play a fundamental role in our learning settings.

- *Teamwork:* Teamwork is the core principle for future workforces in the mechatronics field. The ability of students to work in teams must therefore be fostered and trained through collaborative learning settings. However, the ability to work in teams can only be experienced and practised within learning situations that are themselves organised in a team-centred manner.
- *Work process orientation:* Work process oriented training focuses on learning scenarios where students can learn in a situated context. Real work tasks as learning assignments and *holistic* problem-solving originate from engineering practice, so work situations are important.
- *Customer orientation:* Customer orientation relates to intercultural competence and the training of non-technical skills such as communication training. Learning in distributed environments, collaboration in distributed teams and communication in a foreign language with students from a partner college may help to develop and train these skills.

4. Educational approach in MARVEL

The training principles listed above (e.g. action orientation, teamwork, work process orientation) made it necessary to look for appropriate learning theories.

The MARVEL project was thus focused on supporting learning practice based on social constructivism, combined with experiential and collaborative learning. The theory of *experiential learning*, which built an important reference point in our approach, advocates learning through experience and by experience. This theory understands learning as an iterative process in which knowledge is generated by processing experience.

4.1 Experiential Learning

David A. Kolb (1994), one of the main exponents of experiential learning, proposes a four-stage model, as illustrated in figure 2. According to this model, a learning process begins with a concrete experience, followed by reflective observation. 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 characterised 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 modify these theories, are two significant elements of experiential learning.

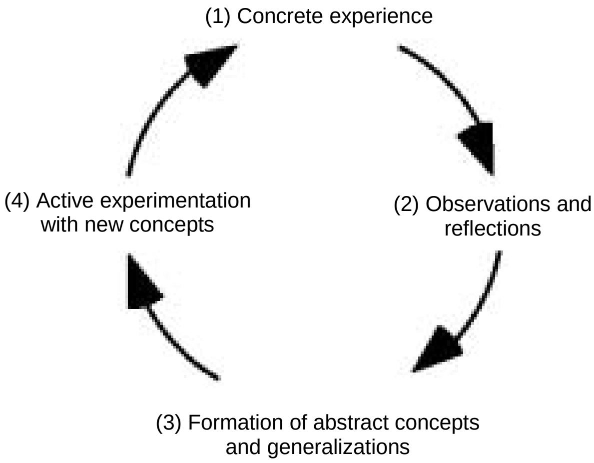

Fig. 2: Experiential learning cycle

Hands-on learning in physically real labs or workspaces provides 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 for understanding the underlying theoretical principles.

Action and reflection are the core attributes of learning through experience or experiential learning. This requires a teaching methodology in which students are engaged in doing activities and reflecting on what they did. Our knowledge acquisition techniques are based on virtual and remote labs, simulations, or real life experiences in local labs and work spaces. We tried to maximise the learning effectiveness by looking for the right mix of such methods.

Combining lab experiments with virtual learning accords with the concept of experiential learning, in that lab experiments are used as a learning aid, rather than a learning objective in itself. Lab experiments and practical exercises provide a 'hands-on' approach to learning. They allow a learner to 'experience' data in a more familiar form, since the practical experiment proposed to the students enables them to 'observe and reflect' on what they have just witnessed. Each experiment may therefore be seen as a starting point that will lead them to an understanding of its underlying theoretical principles.

4.2 Collaborative learning

According to the theory of social constructivism, collaborative[1] activities improve learning effectiveness (Burr

[1] With the term *collaborative* we follow the definition of Roschelle and Teasley (1995): Collaboration involves the "... mutual engagement of participants in a coordinated effort to solve the problem together".

1995). In several MARVEL learning scenarios, students were involved in such collaborative learning tasks. Two basic aspects of collaboration may be important in this context. The first 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 allows students 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 helping students to reflect on their evolving knowledge and by 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. In addition to the psychological aspects of learning, 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 to their professional field of engineering;
- students learn to integrate the know-how of others in order to accomplish a given work task;
- students acquire remote collaboration skills when teamwork is carried out from several locations simultaneously.

5. Training curricula

The German National Institute of Professional Education (BIBB), responsible for occupational training profiles in industry, defines the following skills for workers and technicians in the field of mechatronics (Borch, Weißmann 2000):

- plan and control work processes, monitor and evaluate the results and apply quality management systems;
- process mechanical parts and assemble sub-assemblies and components into mechatronic systems;
- install electrical sub-assemblies and components;
- measure and test electrical values;
- install and test hardware and software components;
- build and test electrical, pneumatic and hydraulic control systems;
- program mechatronic systems;
- assemble, dismantle, secure and transport machinery, systems and plant;
- set up and test the functioning of mechatronic systems;
- undertake the commissioning of mechatronic systems and operate such systems;
- deliver mechatronic systems to clients and provide training in their operation;
- carry out maintenance operations on mechatronic systems;
- work with technical documents in the English language and communicate in English.

The technical colleges teach in ‘learning fields’, i.e. approximately 12 to 14 *holistic* problem-solving assignments or tasks distributed over three years of training with increasing demands on learners. This is a new didactic concept avoiding the former distribution of learning contents into separate classes for mathematics, materials, electrical engineering, mechanics, manufacturing, etc., whereas the learners had been left alone to find out the connections between these contents.

At the European level, there have been several initiatives to develop new transnational mechatronics curricula for vocational training, the aim being to foster congruence between courses, teaching subjects and certificates in different countries. The MoFIT2 project, for example, aims to mainstream the results of a previous Leonardo project in order to establish ‘Mechatronics Technician’ as a recognised occupation in different EU member states. This occupation is concerned with the maintenance, modification and design of industrial automated production equipment (MoFIT2). WorldSkills[2] is a global association dedicated to promoting international high-standard mechatronics training. They also have published quality assurance standards in connection with the WorldSkills Competition in mechatronics, which takes place every year. However, it is still the case that vocational and technical training in mechatronics are geographically fragmented within the EU, and that there is a lack of transparency in the evaluation and validation of acquired skills.

In MARVEL, we could not invest much time in this problem, or analyse various national mechatronics curricula. So we agreed on a common definition of mechatronics, the German job profile, and the aforementioned guidelines and resources (WorldSkills), which then formed the basis for our learning scenarios and course trials. Beyond that, the project partners relied also on their national mechatronics curricula and syllabi, which were not always compatible with those of other partners working

[2] Home page: www.worldskillsmechatronics.com

together on the same work package or course trial. This was not a real problem, however, because the planned learning scenarios and course trials provided enough room for individual adaptations.

6. Conclusion

Because our learning settings in MARVEL are strongly focused on the integration of online labs with virtual labs (simulations) and physical learning resources or workshop facilities, we were searching for corresponding educational, organisational and technical concepts. On the basis of the experiential and collaborative learning theories referred to above, MARVEL adopted a taxonomy that helps to design 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* that comprise learning tools or media, learning venues and learning activities[3].

References

Attwell, G., Jennes A., Tomassini, M. (1997): Work-related knowledge and work process knowledge. In: A.Brown (ed): Promoting vocational education and training: European perspectives, Tampere: University of Tampere Press 1997.

Biehl, M., Prater, E., McIntyre, J. R.(2004): Remote repair, diagnostics, and maintenance. In: Communications of the ACM Volume 47, Number 11 (2004), pp 100-106.

Borch, H./Weißmann, H. (2000): Mechatroniker/Mechatronikerin - ein neuer staatlich anerkannter Ausbildungsberuf; Bundesinstitut für Berufsbildung; Der Generalsekretär (Hrsg.); Bielefeld 2000.

Bradley. D.A., Dawson, D., Burd, N.C, Loader, A.J. (2000): Mechatronics – Electronics in products and processes, Stanley Thornes, 2000.

Burr, V. (1995): An Introduction to Social Constructivism, London: Routledge, 1995.

Erbe, H.-H., Bruns, F. W. (2003): Didactical Aspects of Mechatronics Education. SICICA 2003.

Ferreira, José M.; Müller, D. (2004): The MARVEL EU project: A social constructivist approach to remote experimentation. 1st Remote Engineering and Virtual Instrumentation International Symposium (REV'04), Villach (Austria), 28 - 29 September 2004.

IVTO (International Vocational Training Organisation): Worldskills Quality Assurance Standard. Description – Mechatronics. [http://www.worldskills.com/TechnicalDescriptions/TD04_E.pdf] (14.7.2003).

Kolb, D.A. (1984): Experiential Learning. Englewood Cliffs, NJ: Prentice-Hall, 1984.

Maßberg, W., Hermsen, M., Zuther, M. (2000): Telec: Multimedialer TeleService. Technik – Organisation- Vermarktung – Erfahrungsberichte. Aachen 2000.

MoFIT2: EU Leonardo da Vinci project „Model for Flexible Training (MoFIT)“ [http://www.mofit.net/].

Müller, D.(2005): Zwischen Realem und Virtuellem - Mixed-Reality in der technischen Bildung. In K. Lehmann & M. Schetsche (ed.), Die Google-Gesellschaft. transcript-Verlag: Bielefeld.

Müller, D., Ferreira, J. M. (2005): Online labs and the MARVEL experience. International Journal of Online Engineering. Vol. 1, No. 1, 2005.

Müller, D.; Bruns, F. W. (2005): Experiential Learning of Mechatronics in a Mixed Reality Learning Space. Paper to be presented at the EDEN 2005 Conference, Helsinki University of Technology, Finland. June 20-23, 2005.

Roschelle, J., Teasley, S. (1995): The construction of shared knowledge in collaborative problem solving. In O'Malley, C. (ed.): Computer Supported Collaborative Learning, pp 69-97. Springer-Verlag, Heidelberg 1995.

VDI 1999: Survey of VDI Nachrichten and MSR Consulting Group 1/99.

Westkämper, E., Niemann, J., Stolz, M. (2002): Product Life-Cycles in Web-Based Networks. In: Feldmann, K.: Integrated Product Policy - Chance and Challenge: 9th CIRP International Seminar on the Life-Cycle Engineering, April 09-10, 2002, Erlangen, pp. 61-72.

[3] See next chapter: *Designing Learning Spaces for Mechatronics*

DESIGNING LEARNING SPACES FOR MECHATRONICS

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1. Introduction

This chapter describes some ideas for designing, providing and evaluating interlinked virtual and real learning spaces with a special focus on educational, psychological and organisational aspects. In the MARVEL project, such environments for mechatronics and automation technology were implemented and tested in various course trials.

The concept of combining, linking and merging real work systems with virtual learning environments to create something like a virtual-reality learning space marks a change of perspective in technical training. Integrating virtual learning platforms in real-life work situations, and vice versa, replaces traditional setups involving eLearning, on the one hand, and learning at the work place, on the other.

2. Limitations of virtual learning environments in engineering education

Although recent years have seen major efforts being invested in virtual learning environments (VLE) as tools of supporting and fostering learning geared to real work processes and activities, current studies in this field have revealed some general shortcomings and above all a lack of options for integrating digital learning systems in real-life work situations (Severing 2003). One of the main causes for this is that most VLE platforms are relatively closed systems and cannot be synchronised with operating data in a way that advances learning – for example by importing real-time operating data, simulating current real-world projects, and integrating existing descriptions of processes and products. The result is a lack of authenticity in learning assignments and hence a relatively disconnected mix of eLearning-based theory courses, on the one hand, and on-the-job learning, on the other. It is obvious that under such conditions the transfer of what is learned from the learning context to the actual field of application or practice, and vice versa, will not succeed, or receives too little support from VLEs and eLearning tools. There appears to be a lack of didactic and corresponding engineering concepts for networking real work systems and processes with 'virtual learning worlds', in a way that fosters learning by enabling transitions between virtual and real worlds. Implementing virtual learning environments on the basis of classical educational concepts is obviously inadequate as an approach. Combining new and old learning media in the form of 'blended learning', but leaving their conventional teaching methods untouched is also not enough.

3. Learning in mixed-reality environments

Learning in the form of eLearning with virtual media or tools, and learning in the midst of the real physical world seem to represent opposing learning cultures that are difficult to blend. Mixed reality opens perspectives for overcoming this opposition, because it eliminates the original separation of the real and the virtual, and focuses attention on the extent to which they can reciprocally reproduce and link to each other.

The term 'Mixed Reality' was coined by Milgram and Kishino (1994). Their first publications on mixed reality were influenced by visualisation technologies and computer graphics, and concentrated on the question of how real environments can be enriched with virtual objects (e.g. computer-generated 3D graphics, animations and simulations) such that the information content of the real world is expanded, and conversely so that the real-world environment can serve as an interactive interface for manipulating virtual objects. They mostly focused on purely technological projects, such as the realisation of autostereoscopic 3D displays, head-mounted displays, immersive environments (CAVES) or haptic feedback systems.

Mixed Reality was essentially a movement aimed at countering increasing virtualisation using computer technology. This counter-movement had taken shape in the research domain from the early 1990s onwards. Pioneering work was carried out in the Palo Alto Research Center (PARC) and the Massachusetts Institute of Technology (MIT) in the US, including Ubiquitous Computing (Weiser 1993) or the Tangible Media developed in the MIT Media

Lab (Ishii and Ullmer 1997). Our own work in this direction was motivated by experience with simulation techniques in factory automation, and were aimed at conceptualising and designing simulators that can be coupled to real-world systems (Bruns, Heimbucher and Müller 1993, Müller 1998). Mixed Reality is no longer just a buzzword familiar to insiders only, but represents an established research field within computer science.

Our current Mixed Reality research efforts in connection with the MARVEL project are geared towards integrating real and virtual learning venues in order to forge stronger links between theory and practice (figure 1). Efforts are focused on the enrichment of real-life work environments with virtual learning worlds, on the one hand, and using real plant and machinery in virtual learning systems, on the other hand. Learning scenarios and environments were developed and tested that allow access, from different learning venues, to real production plant and engineering laboratories. The intention was to facilitate collaboration between different learning venues (e.g. technical colleges, training enterprises, universities), and to put the actors involved (apprentices, students, instructors) in a position where they can jointly use real production plant and laboratory facilities over the Internet and deliver collaborative courses and lectures within a learning community.

One practical objective in MARVEL was to create physical and digital interactive spaces for learning and work, in which complex realistic material can be worked on in small groups with maximum independence and collaboration. We refer to these spaces as *mixed-reality learning spaces*, borrowing from the concept of Mixed Reality. Our aim here was to show that such learning spaces can be created with relatively simple means by using existing Internet applications for remote observation, control and maintenance, and by networking them via an eLearning portal.

Learning and working with the MARVEL platform was supported with a variety of virtual tools (e.g. simulations) and combined with different training methods (theory courses, laboratory teaching, learning in the workshop, online tutoring, self-paced learning, etc.). Learners and teachers can log onto the MARVEL eLearning network from home, from the workplace or from school, work on their current project and coordinate their activities with other team members.

In order to develop a feasible approach to the design of mixed-reality learning spaces, compromises have to be made between the aim of maximum coverage of the specific field of training, and the desire for an easily handled system that necessarily reduces this complexity, and helps to improve the scope for decision-making and activity within the educational setup. In MARVEL, we developed a model that is described in the next section.

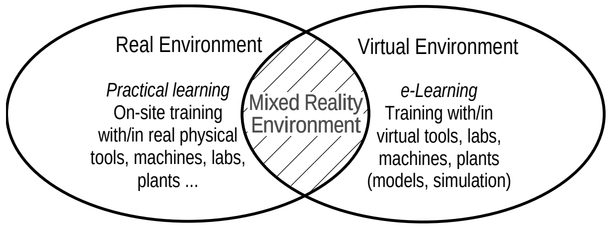


Fig. 1: Mixing real end virtual environments

4. A model for designing mixed-reality learning spaces

Learning and working in mixed reality ultimately involves an interplay between many factors, and depends on the spatial, temporal, human resource and instrumental features of a specific learning situation. The use of mixed-reality systems in initial and continuing training can therefore be analysed on different levels and with regard to different aspects: at the micro-level from a technical and functional perspective, at the meso-level from the educational and psychological perspective, and at the macro-level in terms of organisational, institutional and sociocultural aspects.

Our analysis concentrates on three selected aspects, and provides an overall model from an educational, psychological and organisational perspective. To illustrate the multi-dimensional dependencies involved, we propose a spatial taxonomy (see figure 2).

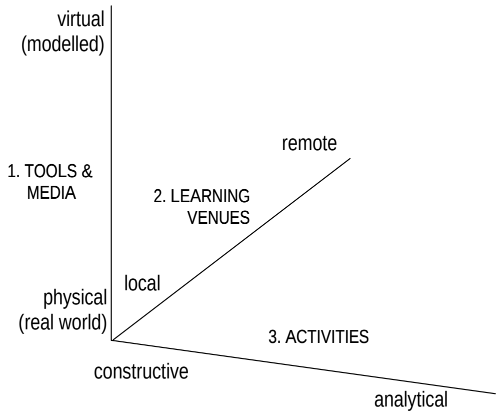


Fig. 2: Mixed Reality Learning Space

A distinction is made between the following dimensions:

(1) learning media and tools, and the specific form in which they are represented (physical and real, or digital and virtual),

(2) learning venues (e.g. school, university, factory, learning at home) and the associated types of learn-

ing (e.g. face-to-face or remote learning, distributed learning) and

(3) learning activities (analytical or constructive) and the associated learning styles (e.g. abstract, concrete, active or reflective).

4.1 Learning media and tools

The first dimension in this taxonomy is the continuum between physical reality and digital virtuality in respect of different learning media and tools. These range from physical, real-world objects and media to purely virtual objects and media (figure 3-5). An example of the former is learning on and with real tools and machines in an actual work process. At the other end of the scale we have learning with digital media, in virtual laboratories or with computer simulations (Fishwick 1995). Between these two extremes there are various mixed forms, such as learning with and on physical systems and processes of reduced complexity, but close to reality nevertheless. Learning in physical reality involves direct contact with said reality, i.e. with physical objects, real events and other people.

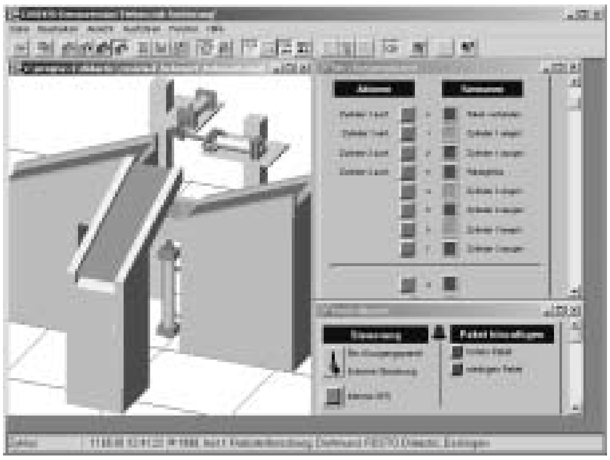


Fig. 3: Learning with a Simulation tools (production line)

Fig. 4: Lab learning: Set up and test of a solar energy plant (Higher Technical Institute)

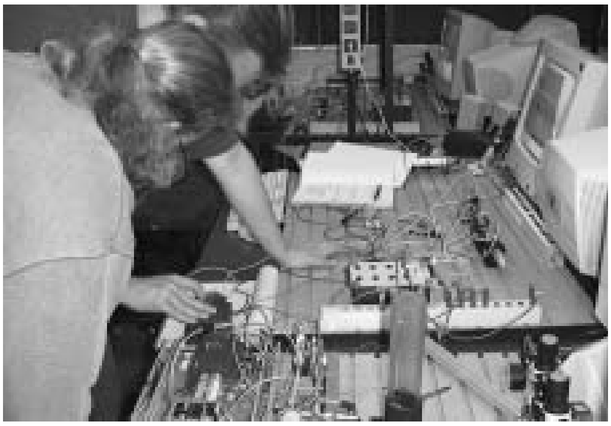
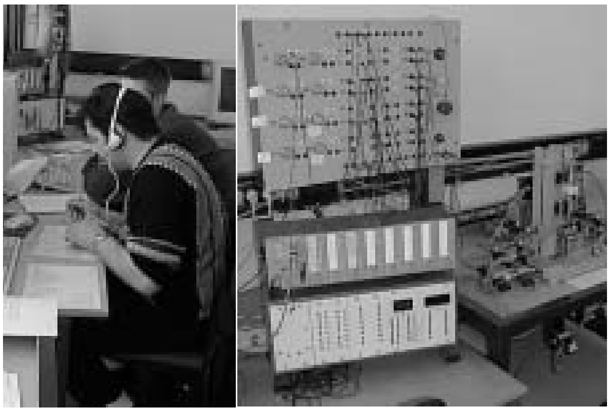


Fig. 5: Lab learning: Programming a PLC



A typical student workplace Remote lab workbench

Fig. 6: A student workplace and the remote lab workbench

Virtual learning involves symbolic activities that are not based on direct experience, but are communciated instead through digital and graphic media; this is the method normally found in classroom learning. What is important here is that symbolic media and instruments can be very real, especially when they are connected to real work processes and are not just visualisations of imagined or fictitious situations.

As can easily be seen, the dimension of learning media and their specific form of representation implies very different types of experience with real and virtual objects. Let us look, by way of example, at learning with computer-based simulators, i.e. at experimentation using virtual, digital models (figure 3). Examples of such systems for training and skilling purposes are training simulators for working with specific equipment, machines, technical plant or other devices and apparatus. In most cases, the aim is to learn how to operate the system under different conditions, and to train particular responses to malfunctions or emergencies. Examples here are simulators for turning and milling, or for assembly robots. The most important didactic aspect of such training systems is the reduced risk associated with operator error, and the opportunity to experiment and practise without being exposed to hazards.

On the other hand, direct, sensomotoric experience with physical objects are a basic requirement for 'grasping' the material involved. Piaget (1973) drew attention to this phenomenon long ago, when he described how cognitive development is generally rooted in the child's manual, tactile interaction with the objects in its environment. In the same way as manipulated objects respond with a specific reaction (due to hardness, elasticity, roughness, heat, cold, etc.), the manner in which individuals deal with them is rooted in action schemes, mental images or cognitive models. Technical education and training must take this aspect into consideration and devise appropriate learning situations in which handling specific tools, machines and facilities in a holistic and haptic manner is not only a key prerequisite for learning psychomotoric skills, but also an excellent opportunity for creativity – in developing innovative ideas, or communicating something to other in a relatively simple and uncomplicated way, and demonstrating this on real objects. To that extent, sensory interaction with objects also has a key supportive function that can be very helpful in learning about complex interrelationships. It should be obvious that virtual systems and computer simulators are unable to achieve this, and that physical objects must be used in their place. For this reason, it makes didactic sense to combine virtual/digital and real/physical learning objects, as described in the following learning scenario from the MARVEL project: "Vocational trainees perform an assignment in the field of control engineering. A computer-based model is generated in order to simulate malfunctions in virtual reality. An identical real-world system is then constructed using components typically used in industry. The main focus in working on this assignment subsequently consists in different groups of learners jointly devising a solution that is subsequently implemented on the real system."

4.2 Learning venues

A second dimension derives from the fact that learning may occur at different places (school, university, factory, home, etc.), and with corresponding time structures. Distinctions can therefore be drawn between many different forms of learning, such as classroom-based learning, telelearning, distributed learning and self-organised learning, etc. Every type of learning has advantages and disadvantages. A key challenge in supporting learning based on work processes is to create networks linking different learning venues. Networks that integrate work environments, workplaces and work processes in new learning venues can be exceptionally complex. The constituent elements of such networks include, for example, lessons in collaboration venues, collaborative further training of teaching staff, development and delivery of learning resources independently of learning venue, and support for the exchange of information and knowledge between different learning venues. There is a need for coordination on the issue of how different learning venues can be networked technically and organisationally so that theoretical and practical components are intermeshed, and the mobility and flexibility of participants enhanced.

Mixed Reality supports learning networks that link theory and practice, because it allows flexible couplings between distributed virtual and real systems. These links can be unidirectional or bidirectional, so it is possible, for example, to use real learning media remotely, and combine these with virtual representation at the local venue. This is illustrated by another learning scenario from the MARVEL project: "A group of learners reconfigures and programs an automation system. Use is made of available materials and simulation software. In a further step, the result is then tested on a real system at a remote location (e.g. an enterprise). Access to the real system is obtained by transmitting control programs and parameters into the system via the Internet and a virtual reality interface. A second group of learners monitors the process on site and provides feedback via the respective communication systems."

What is interesting here from the didactic perspective is the networking of different workshop facilities or real laboratories that are located in different educational institutions or enterprises. The quality of training can be improved as a result, because distributed and scarce resources can be shared in a network of learning venues. Supporting telecollaboration between different technical education institutions at regional and supraregional level raises certain research issues regarding synchronous and asynchronous learning, but these will not be pursued any further at this point.

4.3 Learning activities

Finally, the third dimension of the model derives from the fact that learning processes are based on a broad diversity of activities. These can basically be constructive or analytical in structure. Constructive activities are practical in nature, whereas analytical activities consist of observing, interpreting, reflecting, etc. The latter do not interfere with reality, but only subject reality to analysis. To that extent, they are risk-free and non-committing. In the case of constructive activities, in contrast, which interfere with reality and produce or indeed destroy new objects and facts, the person engaged in such activity bears responsibility for its effects. The level of earnestness is greater here than is the case with analytical activities. Its relevance for vocational training is clearly apparent.

A mixture of constructive and analytical learning activities is certainly expedient in most learning situations. Different learning styles that can vary according to situation, problem or previous experience play a central role in this regard. In addition to visual, auditory, kinaesthetic and haptic learning types, a distinction is also made in the literature between abstract, concrete, active and reflective learning (Kolb 1984). Mixed Reality resolves the strict separation of real and virtual, and permits a focus on how they can be linked and imaged as networks of real and symbolic systems. The concept facilitates bridges between practical, direct experience from constructive activities and symbolically communicated experience from analytic activities. Viewed in this way, Mixed Reality is a link for connecting aesthetic experience and abstract modelling in the educational context.

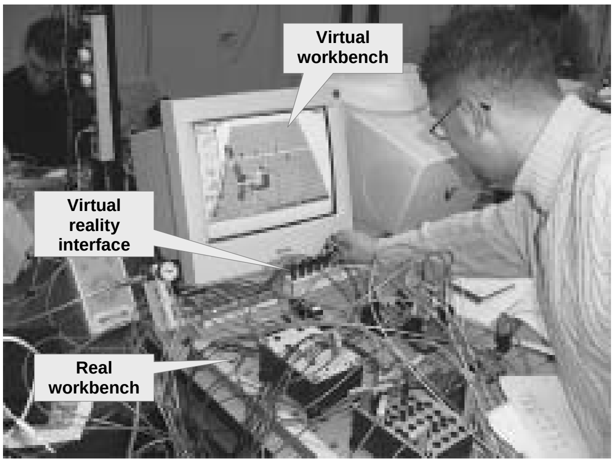


Fig. 7: Novel learning platform for mechatronis

In the MARVEL project, we used a novel learning environment for mechatronics that was developed in the DERIVE project and based on hyperbond technology (Bruns 2003). Hyperbonds enable a complex technical system, such as a complete production system, to be implemented in the simulation model, i.e. in virtual reality, and selected components, for example a pneumatically controlled production station, to be decoupled as tangible real-world systems (see figure 7). This generates new perspectives for linking constructive and analytical learning, in that virtual and real components can be compiled to form complex machinery. Constructive activities are aimed at building real components, analytic activities at cognitive understanding of virtual components.

5. Conclusion

Our concept of mixed-reality learning spaces is an orientational guide for designing, providing and evaluating interlinked virtual and real learning environments. We pursue a three-fold objective with this model: firstly, we want to provide an instrument with which the didactic range of virtual and real learning media and tools can be better evaluated. The second aim is to evaluate the role of the learning venue (face-to-face learning, remote learning, distributed learning, etc.) in a more differentiated manner with regard to the other dimensions. Thirdly, we aim to provide a orientational framework with which different learning activities (both constructive and analytical) can be analysed in relation to different learning venues, media and tools. It is essential that this approach is not seen as a purely procedural model, but rather as a heuristic system for research and development centred on work and learners. Consideration must be given to the fact that every human has his or her own, individual way of learning, and prefers different strategies and approaches. It is important to take different learning styles into account, and that learning situations leave plenty of room for different ways of acquiring knowledge and skills. Having recourse to a variety of different forms of learning is particularly necessary in the case of eLearning.

Due to their origins in research contexts, many of the ideas and examples described here and developed in the MARVEL project are prototypes, and need to be developed and consolidated in terms of practical usefulness and educational effectiveness. This requires a great deal of time and effort. In order to design viable and sustainable concepts, many studies and experiments still need to be conducted.

Experience gained in the MARVEL project showed that the concept as presented here gives rise to new options for networked learning media centred on work processes. The idea of networking real work systems and processes with ‘virtual learning worlds’ in mixed-reality learning spaces is aimed at changing perspectives – setups involving eLearning, on the one hand, and learning in the specific field of application and practice, on the other, are replaced and superseded by integrating the media of digital learning platforms in real, physical work situations and business processes. This generates new perspectives for learning, with transitions between virtual and real worlds of experience, because better media support can be provided for the transfer of learning from the learning environment to the practical world, and vice versa. Integrating digital learning environments and real work processes also results in greater authenticity of learning situations. The model of mixed-reality learning spaces serves in this sense as a navigational aid in designing, providing and evaluating the respective learning spaces. They open up a broad field for empirical studies and additional applications.

References

Aktan, B., Bohus, C.A., Crowl, L.A., Shor, M.H. (1996): Distance Learning Applied to Control Engineering Laboratories", IEEE Transactions on Education, Vol. 39, No. 3, August 1996.

Böhle, Fritz and Milkau, Brigitte (1988): Vom Handrad zum Bildschirm. Eine Untersuchung zur sinnlichen Erfahrung im Arbeitsprozeß. Campus: Frankfurt/Main, New York.

Bruns, F. W. (2003): Hyper-Bonds - Human skills oriented systems design with mixed reality. IFAC 8th Symposium on Automated Systems Based on Human Skills and Knowledge, Gothenburg, 2003.

Bruns, F. W., Heimbucher, A. and Müller, D. (1993): Ansätze einer erfahrungsorientierten Gestaltung von Rechnersystemen für die Produktion. artec-Paper 21, Bremen.

Esche, S. (2002): Remote Experimentation – One Building Block in Online Engineering Education, Proc. of the ASEE / SEFI / TUB Colloquium, American Society for Engineering Education, 2002.

Federal Ministry for Education and Research (BMBF) 2004: Berufsbildungsbericht 2004. Bonn, Berlin.

Fishwick, P. A. (1995): Simulation Model Design and Execution: Building Digital Worlds. Englewood Cliffs, New Jersey 1995.

Foss, A., Malvig, K., Eikaas, T. (2001): Remote Experimentation – New Content in Distance Learning, Proc. of the International Conference on Engineering Education (ICEE01); Oslo; Norwegen; 6. -10. Aug. 2001.

Ishii, Hiroshi and Ullmer, Brygg (1997): Tangible Bits: Towards Seamless Interfaces between People, Bits and Atoms. Proceedings of Conference on Human Factors in Computing Systems (CHI '97), ACM, Atlanta, March 1997, pp. 234-241.

Kolb, David, A. (1984): Experiential Learning. Englewood Cliffs, NJ: Prentice-Hall.

Milgram, P., Kishino, F. (1994) A Taxonomy of Mixed Reality Visual Displays, IEICE Transactions on Information Systems, Vol E77-D, No.12 December 1994.

Müller, D. (2001): Entwicklung rechnergestützter Simulatoren aus der Perspektive eines erfahrungsbezogenen Lernkonzepts. In: Petersen, W. et al: IT-gestützte Facharbeit - Gestaltungsorientierte Berufsbildung. Ergebnisse der 12. HGTB-Konferenz, Baden-Baden, pp. 255-266.

Müller, D., Ferreira, J. M. (2003): MARVEL: A Mixed Reality Learning Environment for Vocational Training in Mechatronics. Proceedings of the Technology Enhanced Learning International Conference (TEL'03), Milano, Italy, November 2003.

Ohta, Y., Tamura, H., (eds.) (1999): Mixed Reality - Merging Real and Virtual Worlds. Springer, Berlin, 1999.

Piaget, Jean (1973): Das Erwachen der Intelligenz beim Kinde. Klett: Stuttgart.

Saliah, H., Villardier, L., Kedowide, C., Assogba, B., Wong, T. (2000): Resource management strategies for remote virtual laboratory experimentation, Proc. of the 30th ASEE / IEEE Frontiers in Education Conference, 18-21 October 2000.

Severing, E. (2003): Anforderungen an eine Didaktik des E-Learning in der betrieblichen Bildung. In: Dehnbostel, P. et al.: Perspektiven moderner Berufsbildung. Bertelsmann, Bielefeld, 2003, pp 19-32.

Tuttas, J., Wagner, B. (2001): Distributed Online Laboratories. Proc. of the International Conference on Engineering Education (ICEE01); Oslo; Norwegen; 6. -10. Aug. 2001.

Tuttas, J., Wagner, B. (2002): The Relevance of Haptic Experience in Remote Experiments. ED Media 2002; Denver / Colorado; USA; 24. -29. Juni 2002.

Weiser, Mark (1993): Some Computer Science Issues in Ubiquitous Computing. Communications of the ACM, Vol. 36, No. 7, 74-78.

TECHNOLOGICAL INFRASTRUCTURE AND TOOLS FOR REMOTE AND DISTRIBUTED WORKSHOP AND LAB ASSIGNMENTS

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1. Introduction

This chapter presents the technological backbone that is common to the various instances of MARVEL remote/mixed-reality labs implemented during the course of the project: a solar heating plant (Delmenhorst in Germany), a solar energy lab (Nicosia in Cyprus), a robot training lab (Athens in Greece), an electropneumatics workshop (West Lothian in Scotland), a mixed-reality mechatronics workbench (Bremen in Germany) and an electronics workbench (Porto in Portugal). In spite of the differences among these various labs, there is a common technological concept underlying their implementation. Said concept is the subject of this chapter, which starts with a domain definition section, followed by three sections addressing the main types of technical requirements involved, namely content management and delivery, communication and collaboration, and interface to remote equipment.

2. Domain definition

MARVEL addresses the implementation of eLearning environments for mechatronics in vocational and professional training, including the ability to access physical workshops and laboratories from remote places. Such activities are generally known as *remote experimentation* and may be defined as *an activity where an individual (alone or as part of a team) uses a communication network to carry out a laboratory experiment that involves the use of real devices and items of equipment* (Ferreira, Müller 2004) (see Figure 1). This definition enables a wide variety of scenarios, including the case where the participants and the workbench are located in the same room. The distance factor is actually not relevant, since what qualifies an experiment as remote is the fact that one or more of the participants have to use a communication network in order to carry it out (and indeed the equipment used in the experiment may be distributed among various locations).

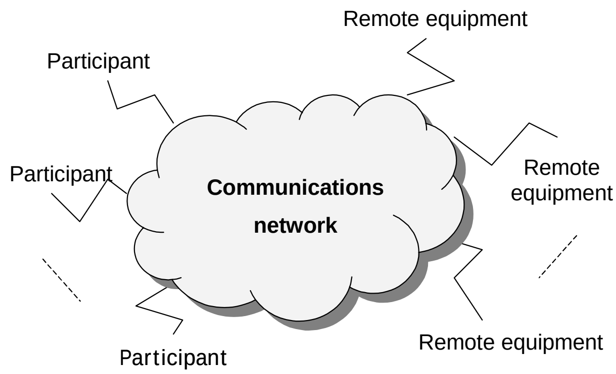

Fig. 1: Representation of a general remote experimentation scenario.

MARVEL therefore relates to the general area known as *online labs*, which covers a wide spectrum ranging from pure simulation to full remote experimentation. However, the type of online labs addressed by MARVEL is restricted to those that extend from mixed-reality to full remote experimentation settings, as shown in figure 2.

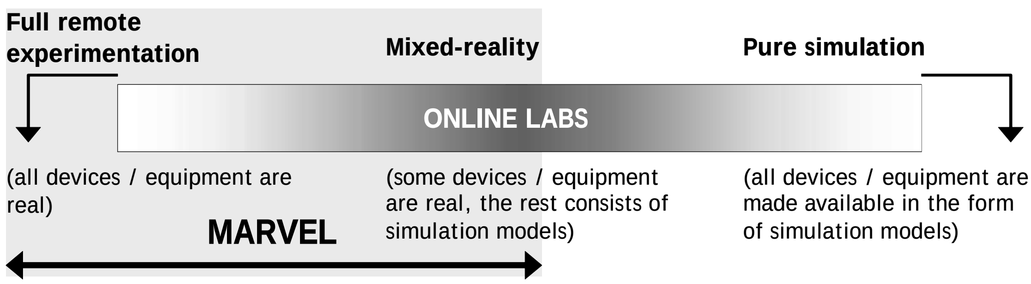

Fig. 2: The scope of MARVEL within the wider area of online labs.

The typical MARVEL scenario corresponds to several students 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 included in their curricular activities. This is actually the scenario that underlies the work described in this document, and as such we will consider the participants as students and the remote experiments as instructional activities. However, it should be stressed that remote/mixed-reality experimentation is not necessarily an academic activity. 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 (e.g. an electron microscope). From the technical point of view, these two scenarios are exactly equivalent – one or more participants need to access a technical facility via a communications network.

Remote experimentation has been a buzzword since at least the second half of the 1990s, and it is not difficult to find publications and R&D projects in this field (Foss et al 2001, Esche 2002, Cyberlab 2000). A proper taxonomy of remote experimentation has yet to be devised, but one could easily devise a list of possible classification criteria, such as:

- Area of activity: mechanical engineering, electronics, chemistry, basic science, etc.
- Duration of the experiment: a typical electronics experiment may last from 15 minutes to one hour, but experiments in physics can conceivably last for less that one second.
- Repeatability: some experiments may be repeated many times using exactly the same resources (e.g. an electronics experiment), while others may require periodic maintenance work in the remote lab (e.g. chemistry experiments), or even be one-off experiments (when the experiment destroys all or part of its resources).

These are just a few examples with a bearing on the technological infrastructure supporting remote experimentation. Experiments based on interactive procedures in which every action of the student produces some visible effect that subsequently helps him or her to decide what to do next are impossible, of course, in the case of experiments that last for only a fraction of a second. In such cases, the students will simply specify the experiment parameters and trigger its execution. Whatever the case, the following building blocks will be required to support remote experimentation:

- A learning content management system that delivers the theoretical background required to successfully achieve the learning objectives associated with the experiment.
- A synchronous communication tool that enables the students to exchange information in real time (e.g. video-conferencing over the web).
- An experiment-user interface that supports resource management (e.g. a booking tool) and provides the instrumentation panels that enable access to the remote equipment.

Most online labs are based on a client-server architecture, where the general structure illustrated in figure 1 can take the specific form shown in figure 3. In this example, a client uses a remote electronics workbench to test an active filter using a waveform generator and an oscilloscope that are interconnected using a standard PXI[1] laboratory instrumentation bus (a detailed presentation of this workbench will be presented in Part II). The desktop computer that works as a web server may host a video-conferencing application to enable the students to interact while carrying out the experiment, and an e-learning server to deliver the underlying theoretical concepts.

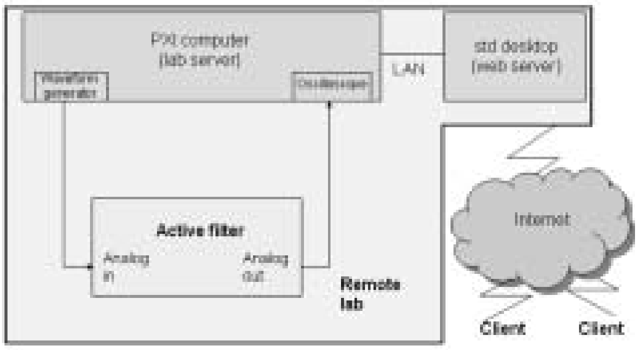

Fig. 3: A remote workbench supporting electronic experiments.

One could also envisage other instantiations based on different paradigms. Peer-to-peer architectures may also be used, and are indeed common in some areas. Skype, widely used as an internet telephony application, is one example of a peer-to-peer solution capable of supporting synchronous communication for online labs.

3. Content management and delivery

Successful delivery of practical mechatronics courseware involves a number of specific requirements that go beyond what one can normally achieve using common eLearning platforms. The main obstacle to overcome is to develop eLearning contents that integrate access to real

[1] **PXI**: **P**CI (Peripheral Component Interconnect) e**X**tensions for **I**nstrumentation.

workbenches. Most platforms were originally developed to convey theoretical concepts, where the eLearning contents are traditionally presented in the form of eDocs, such as PDF, HTML, animations, etc. Dealing with real equipment goes one step beyond and raises questions that are not applicable to the type of eDocs used. As an example, an action that consists of reading an HTML page may be carried out by a large number of users simultaneously. However, if the required action is to calibrate a remote oscilloscope, only one user at a time is able to perform it (or at most a number of users equal to the number of oscilloscopes). This limitation calls for a complementary application that enables a user to reserve a specific time slot, when he or she alone is permitted to interact with the remote equipment. Such a complementary application may actually become an additional resource made available by the eLearning platform used for content management and delivery, if access to the original source code is possible, or if appropriate means or tools are available to add user-developed features. As far as the MARVEL consortium is concerned, the requirements for content management and delivery may be summarised as follows:

- Access to remote/mixed-reality experiments must be made available to students and staff (instructors and technicians).
- Appropriate access management tools must be made available to enable interactive contents, including the means to deal with remote equipment (where any given item of equipment cannot be controlled by more than one user simultaneously).
- The diversity of institutions present in the MARVEL consortium indicates that expensive eLearning platforms would not be acceptable to all partners, and as such a low-cost or open source solution is recommendable.
- Practical mechatronics courseware is typically an experimental activity that is carried out by a group of students under the guidance of an instructor and/or a technician, and the process of building knowledge is largely based on a task-centric approach – a system supporting a social-constructivist learning model therefore seems recommendable (although the learning model is of course more related to course organisation than to the technical features of the eLearning platform).

There are many alternatives available, and any readers interested in deepening their knowledge of eLearning platforms should visit two excellent sites: Edutech and Edutools. Edutech's database (http://www.edutech.ch/) enables the evaluation of learning management systems, and provides technical support to the Swiss Virtual Campus programme. Edutech's site, generates a comparison table for any pair of products that were evaluated within the programme.

Edutools is available at http://www.edutools.info and "provides independent reviews, side-by-side comparisons, and consulting services to assist decision-making in the e-learning community". Far more comprehensive than Edutech, this site is an excellent tool for obtaining a quick overview of any eLearning platform. The output of the decision-support tool is illustrated in Figure 4.

An overview of the alternatives available, combined with the list of requirements presented above, suggested that the best choice for content management and delivery is an eLearning platform. Moreover, such specific requirements as low cost and support for social constructivism led our choice in the direction of MOODLE. As commonly accepted within the MOODLE (http://www.moodle.org) community, social constructivism refers to *a social group constructing things for one another, collaboratively creating a small culture of shared artifacts with shared meanings*. This statement actually highlights the most important aspects underlying remote experiments, and could hardly be better phrased if it was originally planned to refer to the main subject of this document. Remote experimentation requires an active role from the students (*constructing*, also in the sense of learning by doing and exploring), who must share their knowledge and skills (*collaboratively*) to carry out a work assignment where some form of remote equipment is used to reach a common understanding of reality (*shared artifacts with shared meanings*). MOODLE's main website, illustrated in figure 5, provides ample documentation and a live community that greatly facilitates implementation of the eLearning content management and delivery platform that is required within MARVEL.

MOODLE is provided as Open Source software under the GNU Public License and is now widely accepted worldwide, being available – at the time of writing - in 50 languages. Ease of installation and use, as well as its acceptance in the education and training world, make this tool the best choice to deliver the practical mechatronics courseware of MARVEL. It is also important to refer that the resources available within MOODLE to support content development include a option entitled "workshop", which assumes peer-review tasks and other features that provide an excellent match to the pedagogical requirements of remote / mixed-reality experiments.

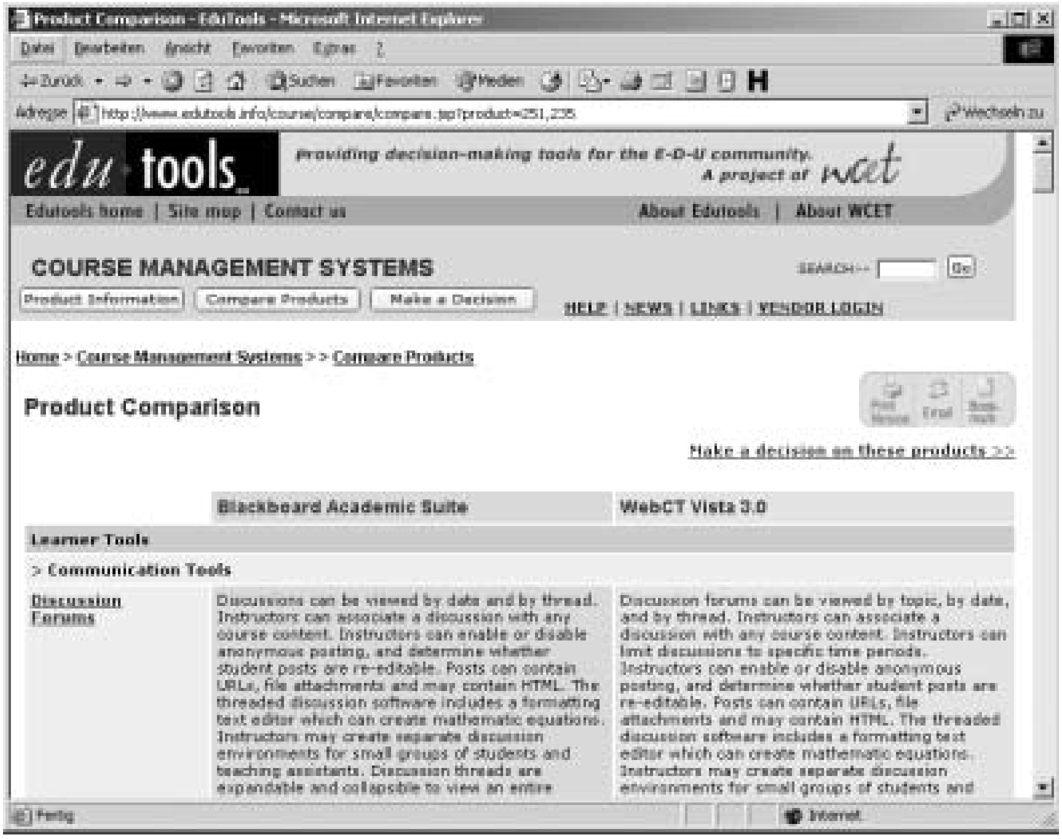

Fig. 4: Edutools' web site.

Fig. 5: The MOODLE course management system.

4. Communication and collaboration

Practical mechatronics courseware is typically an experimental activity that is carried out by a group of students, under the guidance of an instructor and/or a technician, and the process of building knowledge is based on a task-centric approach. Teamwork is therefore the rule, not the exception, so an efficient communication mechanism must be available. The number of alternatives to consider in this area is not very large, and a few of them are already established as everyday tools by our main target users (instructors, technicians, and – last but not least, not only in importance but also in number – the students). The main alternatives are summarised in the following paragraphs.

NetMeeting is a real-time collaboration and conferencing client. It may not be an entirely satisfactory solution for MARVEL's requirements, since it is restricted to point-to-point audio and video (meaning that in groups of more than two students, video-conferencing among all team members would not be possible). NetMeeting may be downloaded from their website at Microsoft [2].

The MSN Messenger (http://messenger.msn.com/) is a synchronous communication tool that is widely disseminated and constitutes a good example of another application that may be used to support collaboration. It is highly popular among young people, but the video-conferencing mode is again restricted to two users, which may not be sufficient to meet all of MARVEL's requirements.

More versatile than the MSN Messenger, Skype (www.skype.com) is becoming a *de facto* standard for supporting synchronous communication, including chat and Internet telephony. Besides supporting file transfer and text-based chat, Skype enables the users to call regular phones all over the world at very low rates. Moreover, when the users are online, calling each other from computer to computer is free of charge. Besides providing excellent sound quality, Skype also supports conference calls with up to five participants (a particularly useful feature with respect to MARVEL's requirements). At the time of writing (version 1.1.0.79), Skype does not yet support video-calling. The company states that *our current focus is to make the best voice-application on the planet. But we will be adding many new and exciting features in the future and video-calling is high up on the wish list* (Skype 2005).

Fig. 6: Skype ("free internet telephony that just works").

Macromedia's Flash Communication Server[3] produces video-conferencing rooms as illustrated in figure 7, and comprises enough features to meet all the requirements associated with MARVEL's remote/mixed-reality experiments. It is a commercial tool, but the prices are reasonable enough to enable low-budget solutions that are able to meet our functional requirements. While Skype does not support video-calling, and if financial restrictions do not apply, the acquisition of a Flash Communication Server package may be the ideal solution to meet MARVEL's requirements with respect to communication facilities.

A further advantage of the Flash Communication Server is that it is possible to record the communication flow at high compression rates. This feature may be useful for various purposes, such as student assessment, to build automated presentations, etc. The audio and video recording illustrated in figure 8 was made at approx. 4 Kbytes/sec and produces perfectly acceptable sound reproduction quality, at video quality that is acceptable for web delivery.

[2] http://www.microsoft.com/windows/NetMeeting

[3] http://www.macromedia.com/software/flashcom

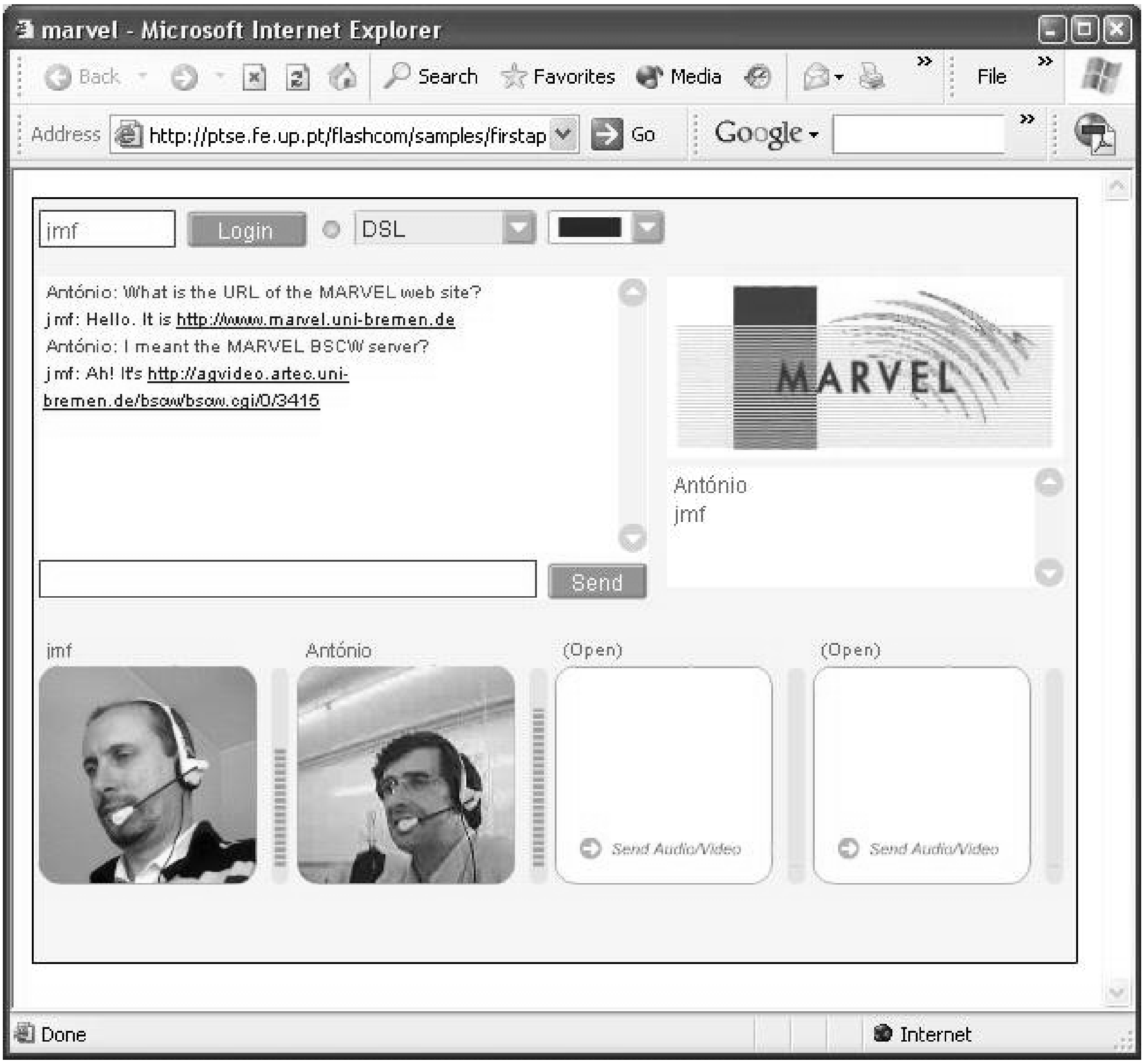

Fig. 7: A video-conferencing room set up with MM's Flash Communication Server.

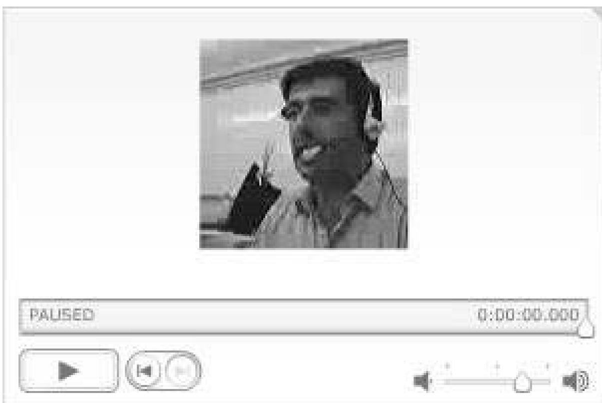

Fig. 8: Audio and video recording with MM's Flash Communication Server.

5. Interface to remote equipment

Interface tools are frequently intrinsic to the remote/mixed-reality experiments supported, and in such cases there is no need to provide any recommendations as to which solutions to adopt. In the case of a remote electronics workbench, the user interface seen by the user may take the form shown in figure 9 (this example actually refers to the same remote electronics workbench that was illustrated in figure 3, with the exception of the active filter circuitry, which had been replaced by a microcontroller board). Notice that the user interface presented in figure 9 shows an embedded solution where video-conferencing, remote equipment access and remote device access are all integrated into a single browser window.

This user interface was built using National Instruments' LabVIEW, together with JAVA applets and video-conferencing channels using CUseeMe-technology from First Virtual Communications, Inc. (http://www.fvc.com). Further information about LabView may be obtained from the company's web site at http://www.ni.com/labview/.

There are of course other user interface building packages available. The TestPoint development package, presented in Keithley's web site illustrated in Figure 10, is another example. Both National Instruments's LabVIEW and Keithley's TestPoint enable access to electronic equipment over the web (e.g. oscilloscopes, multimeters, etc.), facilitating the development of remote workbench facilities.

User interface development packages that enable web access usually provide a simple mechanism to restrict control privileges to only one user at a time (multiple users controlling the same equipment at the same time should normally be avoided).

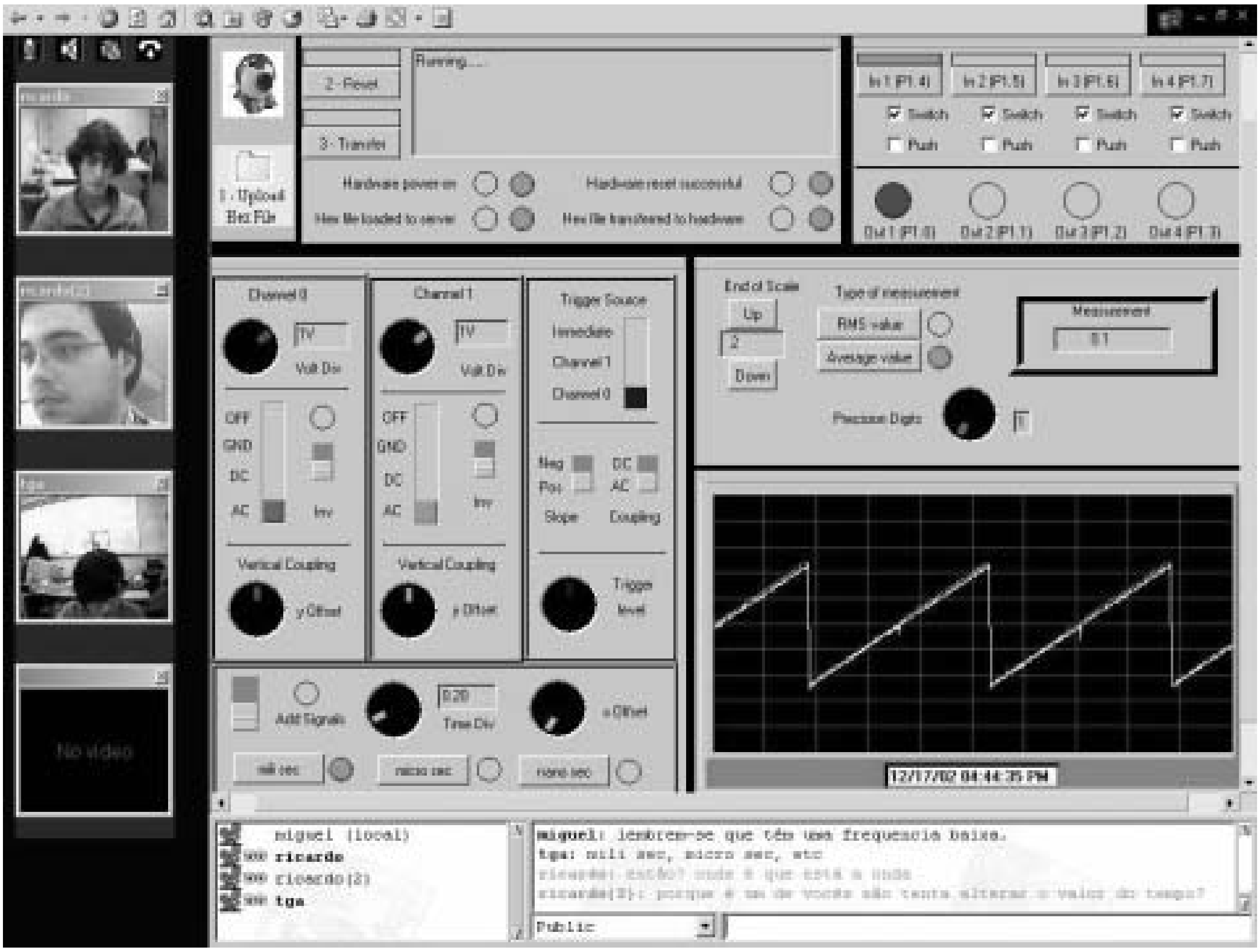

Fig. 9: Video-conferencing and remote equipment access in a single window.

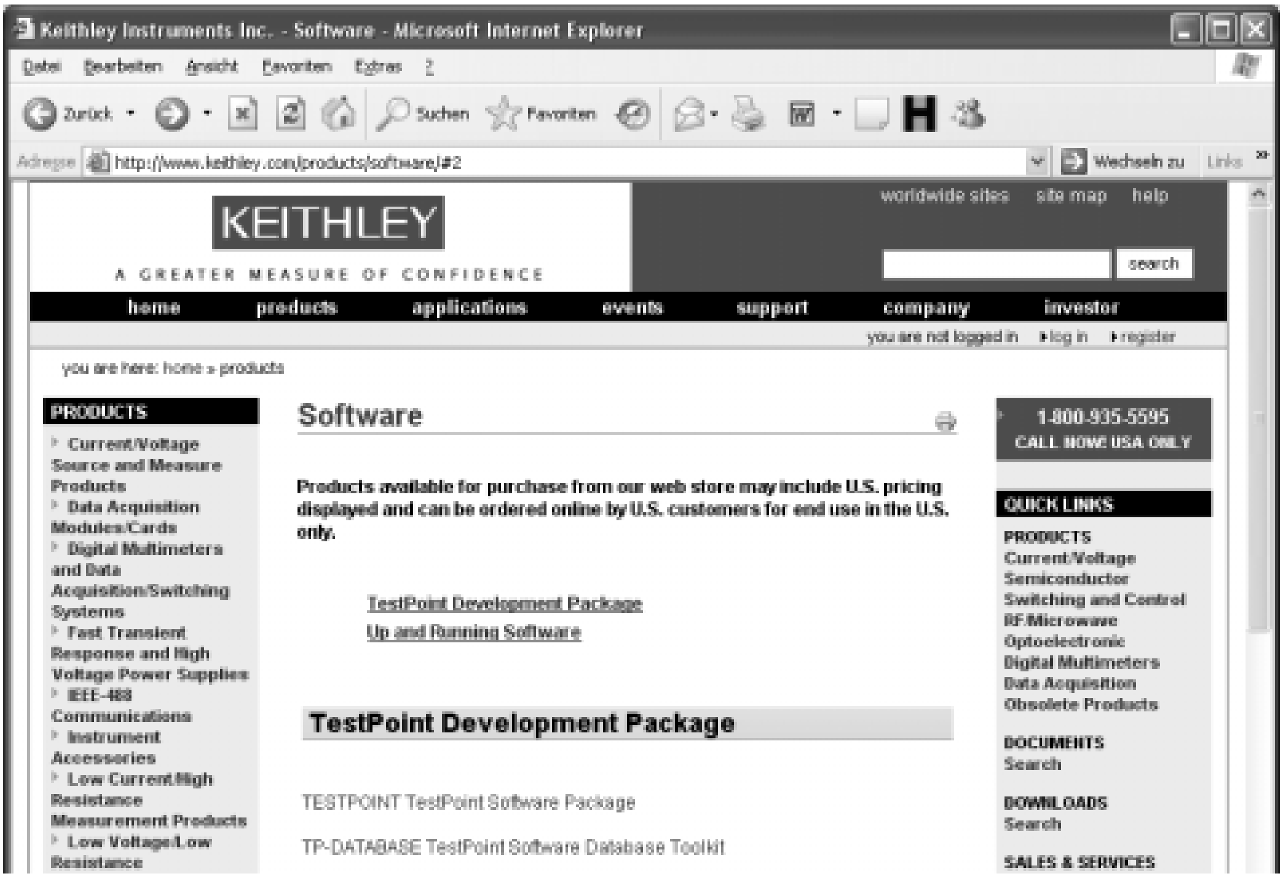

Fig. 10: Keithley's TestPoint web site

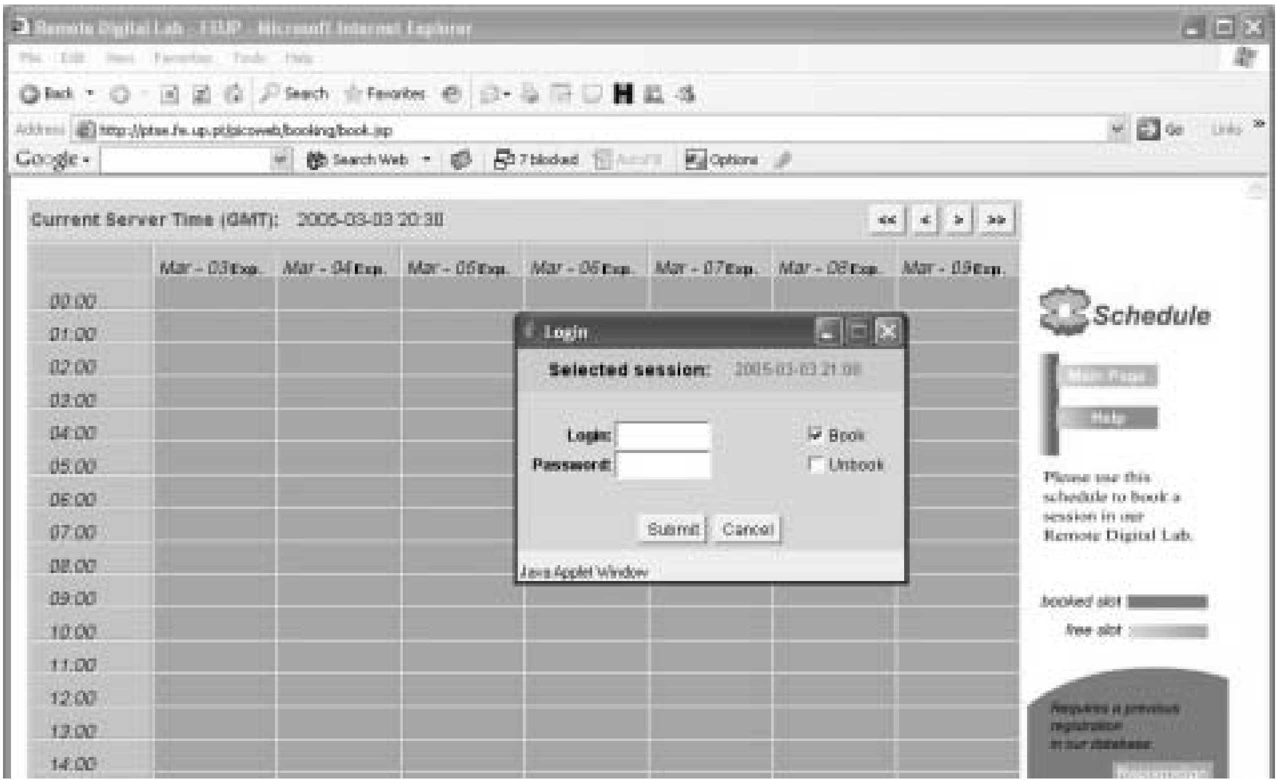

Fig. 11: A booking tool used to co-ordinate access to a remote workbench.

LabVIEW supports a 'request control / release control' mechanism that enables several users to exchange control of the remote equipment while the experiment is being carried out (a user that wishes to control the remote instruments must press the right button of the mouse to select 'Request control of VI', and wait for the 'Control granted' response; the 'Release control of VI' option is used to pass control to another user). However, when the number of user groups is higher than the number of remote workbenches available, a booking tool such as the one illustrated in figure 11 is necessary to coordinate access times.

The booking tool shown in figure 11 enables all registered users to submit requests for one-hour slots, at a date of their choice. A slot that has been booked will display the name of the user and only he/she will be able to access the remote workbench during that period. This booking tool is independent of any eLearning platform and may be associated with any remote/mixed-reality experiment.

In those cases where an open-source platform is used, an integrated booking solution may be preferable. The example presented in Figure 12 shows a booking mechanism embedded into the MOODLE eLearning platform.

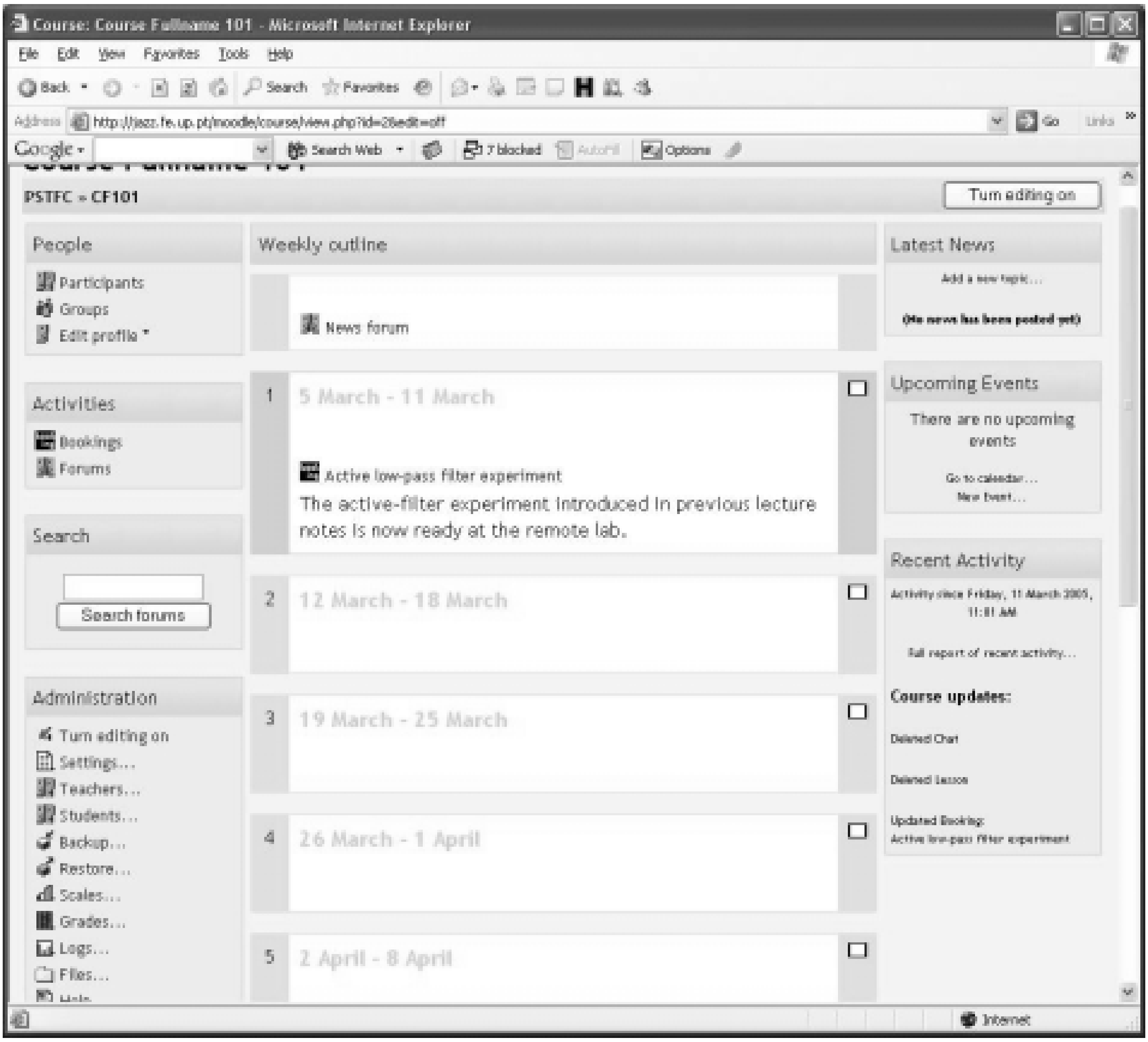

Fig. 12: A booking tool embedded in MOODLE.

In this case, a booking resource is available within MOODLE and may be added by the instructor when the eLearning contents associated with the experiment are being created (exactly as happens with other standard resources available, such as a chat room, discussion fora, etc.). Further details about installation and use of the booking tool are presented in Part II.

References

Ferreira, J. M., Müller, D. (2004): The MARVEL EU project: A social constructivist approach to remote experimentation. 1st Remote Engineering and Virtual Instrumentation International Symposium (REV'04), September 2004, Villach, Austria.

Foss, B. A., Malvig, K. E., Eikaas, T. I. (2001): Remote Experimentation – New Content in Distance Learning," Proceedings of the International Conference on Engineering Education (ICEE'01), Oslo Norway 2001.

Esche, S. K. (2002): Remote Experimentation – One Building Block in Online Engineering Education," Proceedings of the ASEE/ SEFI / TUB International Colloquium, Berlin Germany 2002.

Cyberlab (2005): Cyberlab – The Experiment Service Provider. http://www.cyberlab.org (accessed on March 2005).

Skype (2005): Skype Knowledgebase, "I have a webcam. Can I use Skype to make video calls as well?" http://support.skype.com/?_a=knowledgebase&_j=subcat&_i=3 (accessed on March 2005).

REMOTE ENGINEERING EDUCATION: REAL-WORLD EXPERIMENTS IN SOLAR ENERGY OVER THE INTERNET

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1. Introduction

Remote engineering is becoming an important element of engineering education, giving rise to a growing need for new learning media and tools. Remote engineering, remote maintenance, teleservice or eMaintenance are all catchwords for these novel engineering and management applications (Michaelides, Eleftheriou, Müller 2004) with which the construction and maintenance of plants and machinery can be monitored and managed over the Internet (Lee et al 2004; Graupner, Westkämper 2003). The emergence of these techniques is rooted in the dissemination of mechatronic components – which nowadays are available in almost all modern systems – and the Internet, of course. Remote servicing techniques produce benefits not only for the engineering and plant construction industries, but also for their customers, in that problems can be diagnosed off-site and local engineers can be supported by a central team of remote experts. At the same time, communication between the manufacturer and the user of mechatronic systems is being improved. This helps to reduce service costs while increasing the availability of systems. As remote engineering becomes increasingly important, there is also a growing need for qualified employees in maintenance departments, in production, in customer service and in other fields (Erbe, Bruns 2003).

Today, Internet use is not only widespread, but also very cheap, and available to almost all schools and students. Our real-world experiments in solar energy management is a step towards introducing engineering students to collaborative learning by providing real-life experiments and costly experimental setups to any who have Internet access. The following system is available for use as a learning task, both as teamwork and as an independent exercise.

In this chapter, we describe the solar energy eLearning laboratory developed as a prototype at the Higher Technical Institute (HTI) as part of the Leonardo da Vinci 'MARVEL' project (Müller, Ferreira 2003). The HTI solar energy eLearning laboratory is based on a pilot solar energy system equipped with all the instrumentation and control devices necessary for remote access, control, data collection and processing. A major goal of the HTI solar energy eLearning laboratory in particular, and of the MARVEL project in general, is to use physical devices and machinery in virtual learning environments in order to support work process oriented learning with real-life systems.

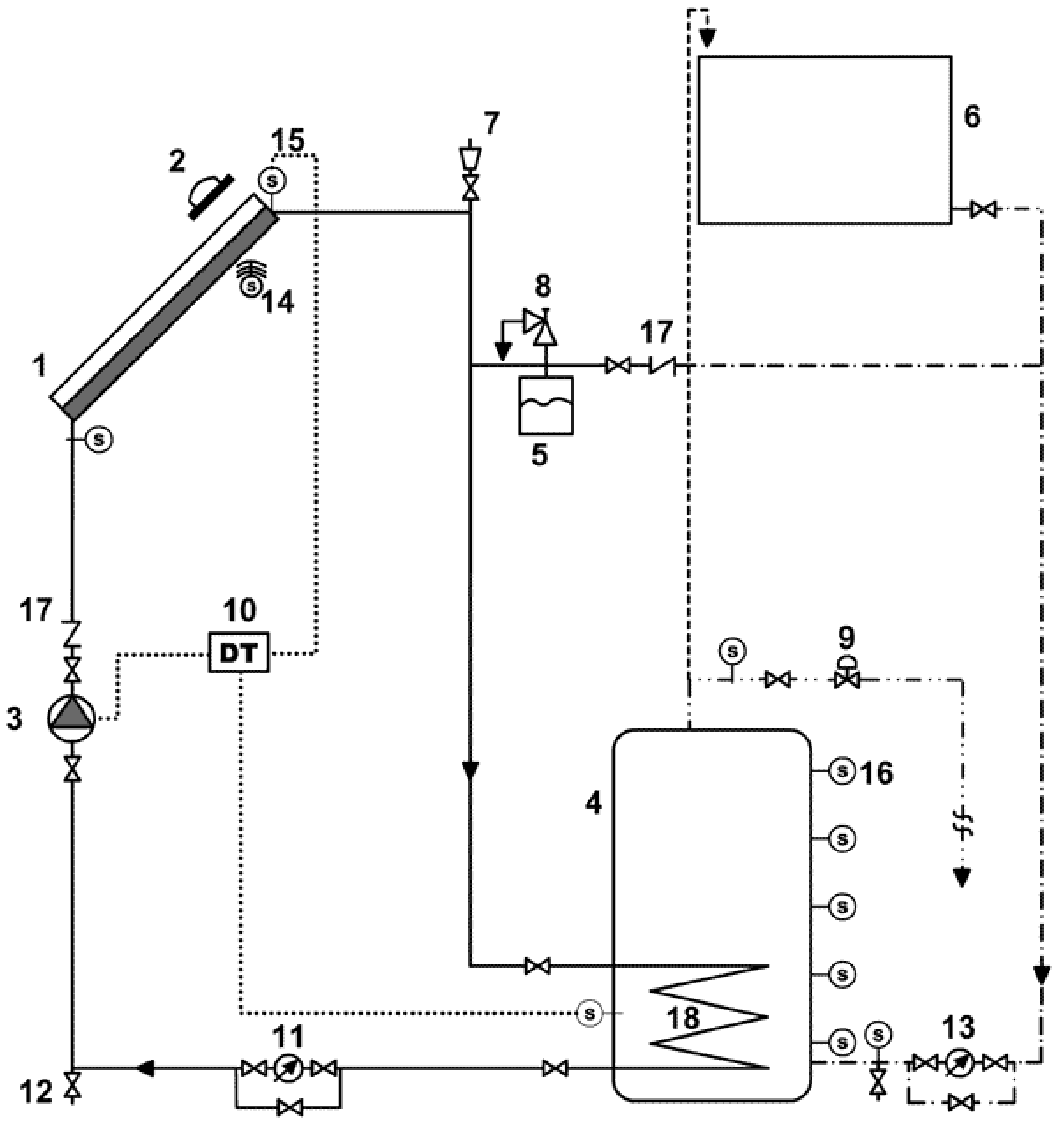
This chapter presents the main features of the solar energy eLearning laboratory, describes the system architecture and the eLearning platform deployed, and provides an overview of the learning scenarios and course trials.

2. Basic system design

The HTI solar energy eLearning laboratory comprises a pilot solar thermal system consisting of two flat plate solar collectors with a surface area of 3 m^2 and located on the flat roof of the central HTI building, an insulated thermal storage tank located in the solar energy laboratory, as well as other auxiliary equipment and accessories. It is also equipped with all the necessary instrumentation, control and communication devices for remote access, control and data collection/processing. A schematic diagram of the system is shown in Figure 1.

The hard- and software installed includes features for controlling external devices, responding to events, processing data, creating report files, and exchanging information with other applications. All relevant weather data as well as operational and output data of the system are registered during an experimental session and can be stored on the user' PC for various calculations and/or documentation.

The aim is to use the Internet as a tool to make the laboratory facilities accessible to engineering students and technicians located outside the HTI premises, including overseas. In this way, the solar energy e-learning lab and its equipment and experimental facility will be available and be shared by many people, thus reducing facility costs.



	Gate valve		Check valve
DT	Differential Temperature controller		Automatic air vent
	Temperature sensor		Ambient air temperature sensor
	Motorised valve		Flow meter
	Cold water line		Hot water line
	Pump		Pyranometer
	Signal Line		Vent pipe

Fig. 1: Schematic diagram of MARVEL Solar Pilot System, HTI

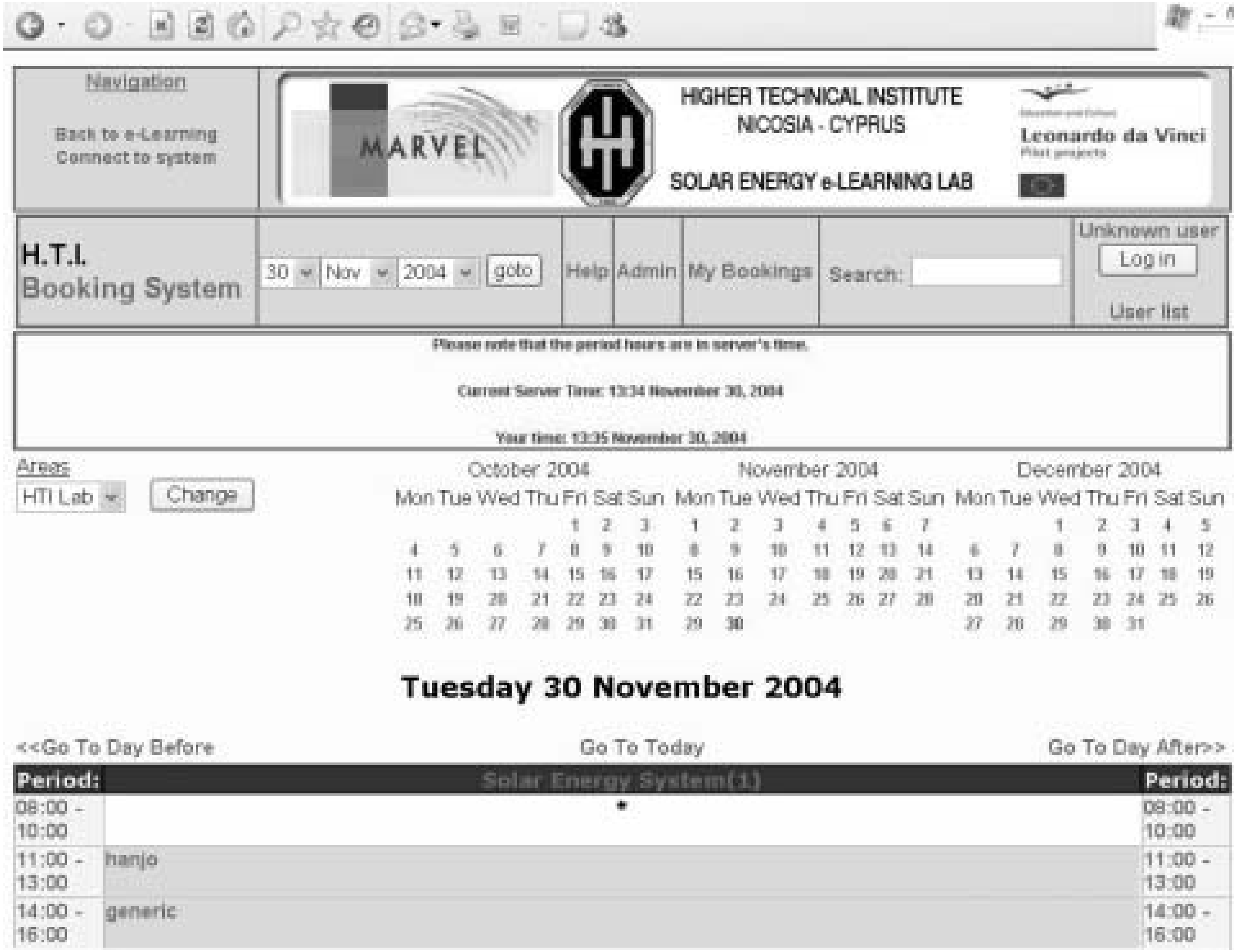


Fig. 2: The HTI Solar System booking system which allows for time slot reservations

Furthermore, the field of solar energy chosen for this purpose will offer a unique opportunity to students from countries with little sunshine to have access under real conditions to experiments with abundant solar radiation. The system will enable real-time remote control, data acquisition and evaluation. It will allow remotely located students to conduct experimental work in an interactive and independent way.

Students from collaborating partner institutions will have remote access to the system. A booking tool (Figure 2) is available with which instructors can control access time for the equipment. A number of laboratory experiments and learning tasks have already been developed including familiarisation exercises as well as system performance investigations and eMaintenance tasks. All exercises and learning tasks are supported by web-based learning materials in the form of 'virtual books'.

3. Software architecture

3.1 Overview

The system has a layered or tiered architecture with four different layers, each layer providing its services to the next lever by using the services of the layer below it. A description of each components is given in the sections that follow. Figure 3 outlines the different layers with a brief description of their respective functions.

To implement this architecture, two different computers were used. Figure 4 shows this architecture in a graphical way with the four layers separated by dotted lines.

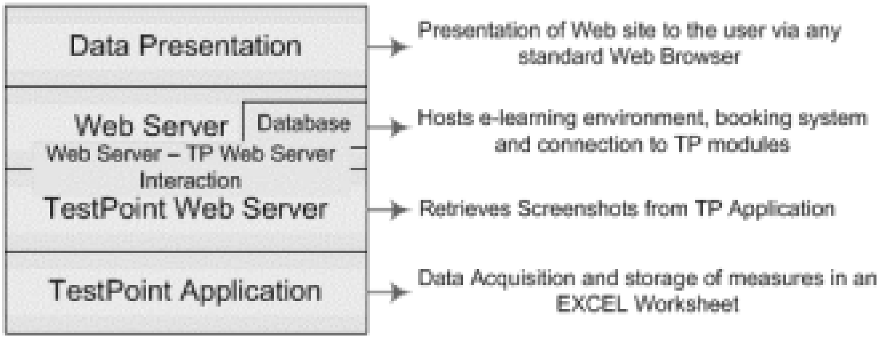


Fig. 3: The software architecture of the solar system

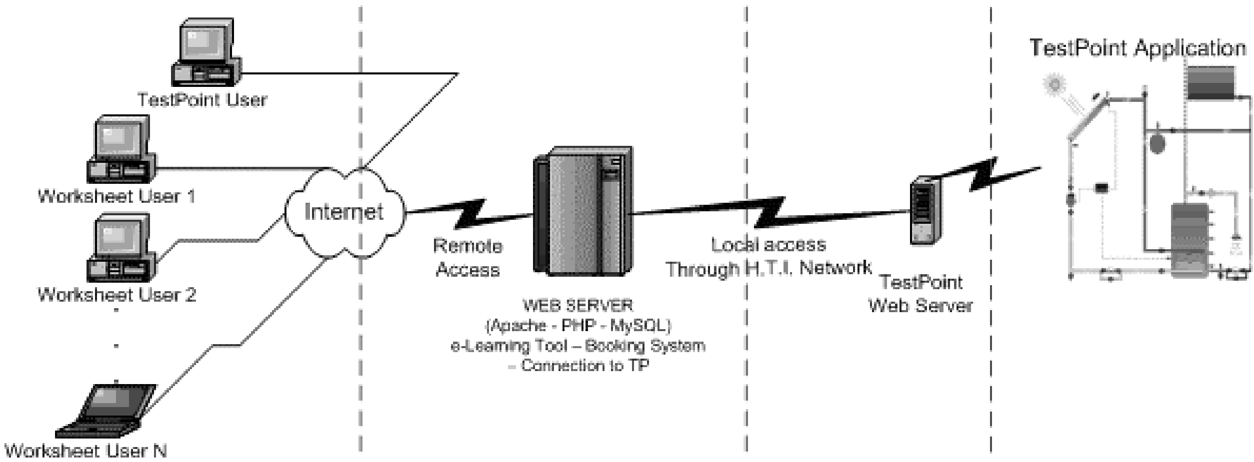


Fig. 4: Schematic representation of the system, showing the four different layers

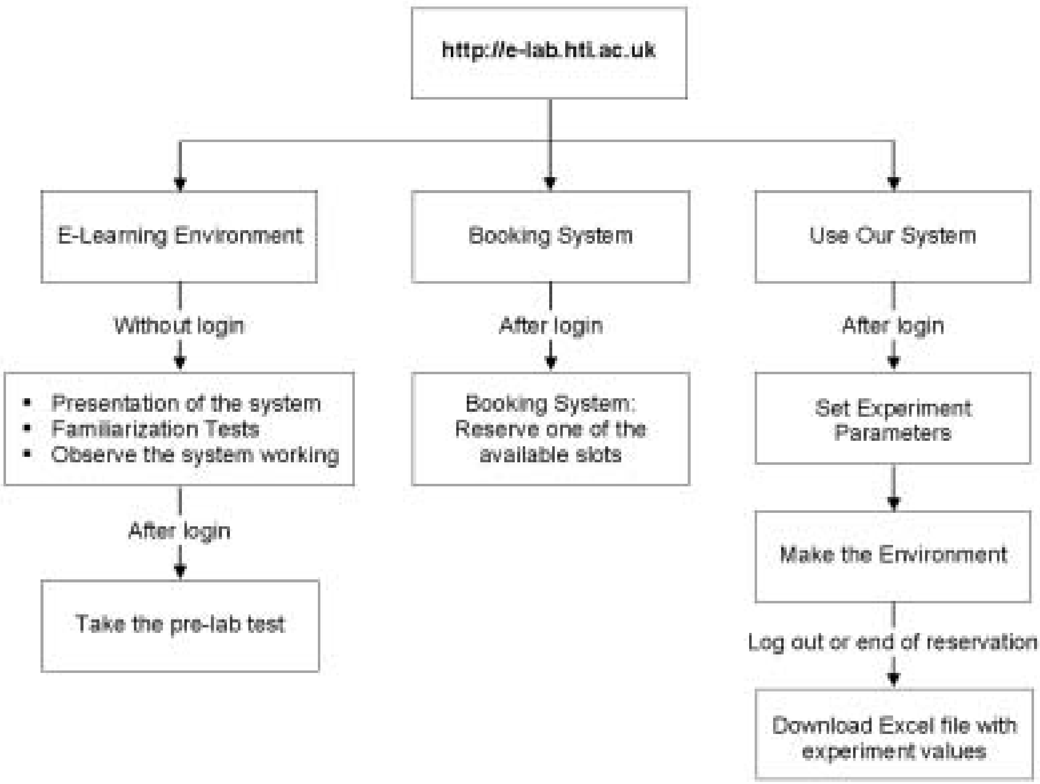


Fig. 5: Activities in the Solar Energy e-Lab

3.2 Description of the four layers

Data Presentation: A user may visit the laboratory website anytime from anywhere in the world. The only requirements are a computer connected to the Internet, and any of the standard web browsers. By entering the address of the HTI solar energy eLearning laboratory (http://e-lab.hti.ac.cy), the user can visit the entry page to the website. It is possible for visitors with little interest in solar energy to read about and study the subject without having to meet prior requirements, register, or pass a test. Only some of the pages require a login. Indeed, most of the pages can be read without having to create a user account. Login, which requires an account to be created, is only needed when the user decides to take the 'Pre-lab Test'. The available activities in the web site are presented in Figure 5.

Web Server and Database: The initial idea was to use the very popular LAMP (Linux – Apache – MySQL – PHP [8]) platform to implement our system. This idea was reinforced by the fact that Moodle, the eLearning environment used, was written in PHP using MySQL as the supporting database. So the team decided to use this platform, with the difference that MS Windows XP rather than Linux was used as the operating system. Apache is considered to be one of the best web servers, and the fact that PHP and MySQL are now precompiled in the kernel of this server made its use imperative. On the web server, all the files needed for Moodle are installed, i.e. the booking program and the module used to connect to the system. The MySQL database is also installed on the same machine with all the tables needed to support the installed modules. What is not stored on this server are the screenshots of the system during its normal operation. When the user is connected (or requests to see the system working as an observer), an HTTP request for the picture of the system with the values at that specific time is sent through PHP to the machine hosting the TestPoint web server.

Web Server and TestPoint Web Server Intermediate Level: The interaction of the web server with the TP web server requires actions at both ends. Once the user logs onto the system, he/she has to set the parameters of the experiment. These parameters are written to a text file and the text file is copied to the machine where TestPoint is installed.

TestPoint Web Server: TestPoint's web server is part of the Internet Toolkit, an add-on module to make TestPoint commercially available. Its job is to supply screenshots of a part or the whole of a defined TestPoint application that is currently being run. In the web server's settings, it is possible to define the port that is going to be used by the client when requesting these screenshots. No further configuration is needed on the part of the laboratory, since its task is very simple and straightforward.

TestPoint Application: Once the application has been started and initialised, it looks for an initialisation file in order to begin measuring. When the system detects this file, it reads the configuration parameters, takes any actions required (e.g. replenishing the water) and starts measuring the values from the various instruments installed. Every 30 seconds, these values are also written to an Excel file. When the user wishes to logout (or when the reservation slot reaches its end) the configuration file is deleted and the system stops working. The Excel file is then copied to the web server, and at the logout screen the user is given the option of downloading the file with the stored data. If the user closes the browser window without logging off first, and to prevent the system from running continuously, a batch job was added as a safety measure to the computer running TestPoint. This batch job runs five minutes after the each of the reservation slots ends, and takes all the actions required to ensure that the system is properly stopped and initialises the various parameters for the next user.

3.3. Challenges and solutions

There is one issue that concerns everyone who offers services through the Internet – security. One of the primary objectives when the system was being designed was to ensure the security of both the main web server and the TestPoint web server. The web server is a member of the HTI domain, so the security mechanisms for the whole institute are inherited by the computer hosting the web server. This meant it was necessary to provide additional security protection for the machine hosting TestPoint and its web server. This computer is also part of the HTI domain, but restrictions had to be applied from within the institute. By creating a Virtual Local Area Network (VLAN), restrictions were applied to this machine allowing the computer hosting the web server to only send requests.

Another interesting aspect was the various alternatives tested in an effort to set the experimental parameters and to start or stop the system. The final solution has been described above, but at least two other approaches are worth mentioning. The first approach was to set the parameters by sending HTTP requests and then to start and stop the system in some way, depending on user actions. This solution was abandoned because of some limitations of TestPoint's web server. The second effort included the creation of two standalone applications using C# and taking advantage of Microsoft's Remoting Technology (.NET), a protocol within the .NET framework for programs that need to send or receive data through any network. The module installed on the Web Server would send requests, and the module installed on the TestPoint web server would serve them. This solution also failed. At that time, the experimental parameters were changing while the file was opened by the TestPoint Application. In this case, the C# application was unable to open an already opened file (especially while it was opened by a different application). What the program does now is that it reads the file and then immediately closes it, making it possible to run the system.

4. Learning platform

The eLearning platform selected for the web server is MOODLE, a course management system provided freely as Open Source software (under the GNU Public Licence). MOODLE will run on any computer that can run PHP, and can support many types of database, particularly MySQL (Riordan 2005). This choice provides flexibility in respect of learning tools, as well as various learning environments to suit the requirements of the different courses (Moodle 2005). In this particular case, MOODLE is used as a demonstration, a quiz and an experimental tool.

MOODLE's capabilities were enhanced so that running the actual experimental setup is only allowed after successful completion of preliminary exercises. With this platform, the user can work independently, or work as a team with people from the same class, or even from a different school far away, talking to each other using the special tool provided by the platform.

5. Learning scenarios - experimental work

The learning scenario comprises a series of exercises of differing degrees of difficulty and complexity. For each exercise, the student undergoes an online assessment and is allowed to proceed to a real experiment only if he/she is successful in the pre-lab test. It also includes an indexed glossary containing a good number of terms and definitions relating to the solar energy laboratory. The following is a brief description of the four categories of learning exercises.

Familiarisation with the HTI Pilot Solar Energy Plant: Two introductory exercises were prepared for the prospective user. Their objective is to familiarise the student with the HTI solar energy eLearning lab and make him/her conversant with the components of the pilot solar energy conversion plant. Once having completed these exercises, the student should be able to name each component in the plant and identify the various components needed to construct a solar plant.

Component functions: Two more advanced exercises for the interested student were also prepared. The objective of these exercises is to familiarise the student with the system layout, make him conversant with the function of each component and the system operation. At the end of these exercises the student should understand the function and operation of each piece of equipment in the system and appreciate its role in the system, and will have been introduced to the hydraulics and flow circuits of the plant. Figure 6 is a screenshot from the eLab website, showing an exercise for familiarising the student with the HTI solar energy plant.

Live online experiments, data collection, storage tank stratification, investigation of collector efficiency at any instant: This module takes the student into the real world of experimentation. The student is acquainted with remote control of the system (accessing the system via the Internet, switching the system ON and OFF), and practises taking readings from the various measuring devices, such as temperatures, flow rates and solar radiation. The student takes sets of readings for various conditions and different scenarios. One of the scenarios is to elaborate on the stratification of temperatures in the vertical storage tank and gain first-hand experience of the variation of temperatures across the tank at different operational conditions, to explain the stratification effect and to comment on the results.

Fig. 6: A screenshot from the HTI eLab – familiarisation with the HTI solar energy plant

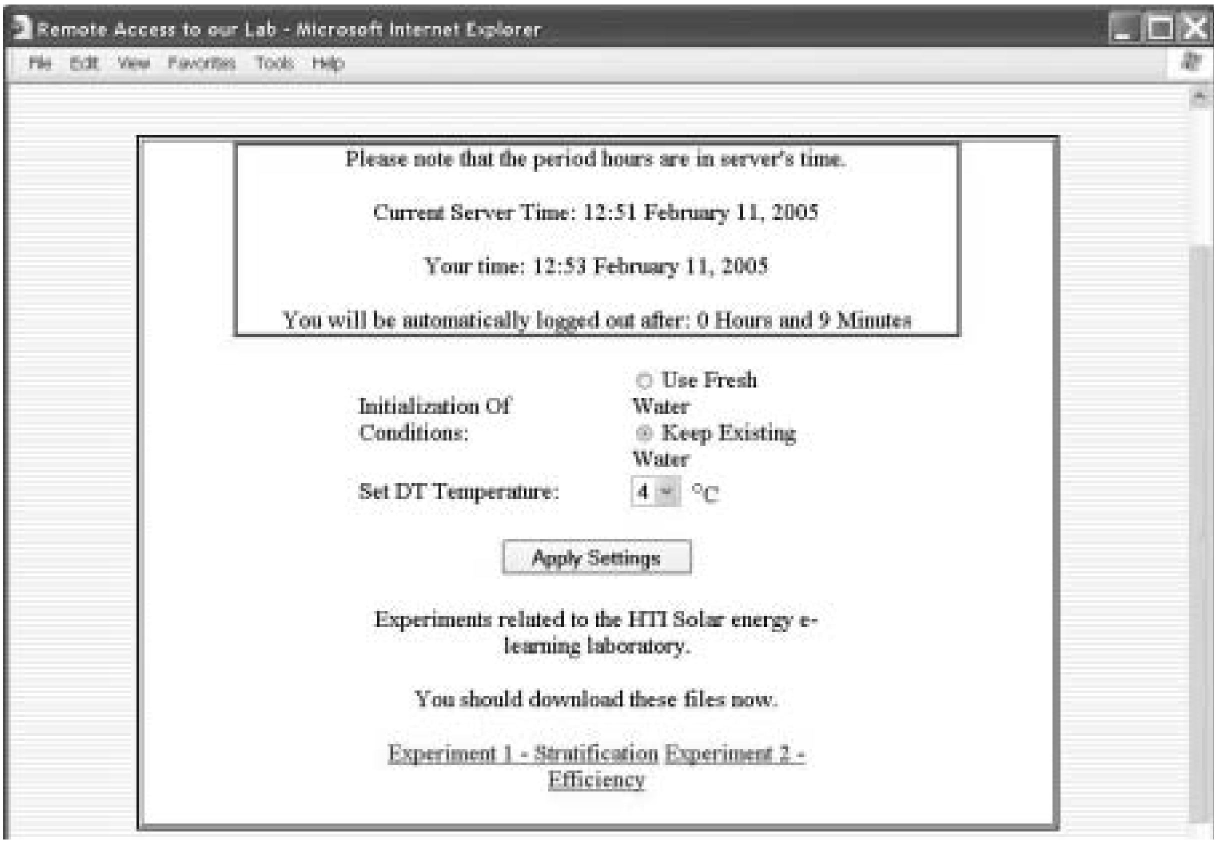


Fig. 7: Initialisation of test conditions

Another experiment involves investigating the efficiency of the collector at any instant, or determining the rate of thermal energy removed from the storage tank by a consumer. For this purpose, the student records a number of readings (incident solar radiation, water flow rates, temperatures, etc.) and using certain thermodynamic equations (Duffie, Beckman 1991) he/she determines the performance characteristics of the collector and compares these with the figures specified by the manufacturer.

The test is conducted under various conditions and with different scenarios. For example, the user can select initialised conditions by clicking either on 'Use Fresh Water' if he/she wishes to remove a quantity of hot water from the storage tank and replace it with fresh cold water, or on 'Keep Existing Water' if he/she wishes to perform the experiment with the existing water in the storage tank. In the same way, he/she can select the setting of the Differential Temperature Controller (DT) to 2 or 4 or 6^{o}C from an on-screen menu (Figure 7).

Should the student have more time available, he/she could use the data recorded in the Excel file, downloaded at logout or at any time during the experiment, to plot collector efficiency. Figure 8 is a screenshot of what a student performing a live – online – experiment over the Internet sees on his/her computer monitor: the system diagram labelled with the real readings and information about time available and server real time. The screen image is refreshed at 5-minute intervals, allowing the students adequate time to observe all the readings and encourage a discussion on the results displayed. For example, a discussion could be initiated on the subject of temperature stratification in the storage tank: how do the temperatures at various levels differ, why the temperature at the top of the storage tank is higher, etc.

'Passive' participation in the experiment - watching the system working (no interaction): If the system is busy because an online user is performing an experiment, another user may access the eLab as an observer, without any booking and without needing to conduct the pre-lab test. The system opens a new window, allowing the observer to view the system in operation and obtain readings, but not to intervene in the operation of the system, or to control the system. However, he/she can record the readings and use them for calculation purposes if so desired. There is no limitation to the number of 'passive' participants.

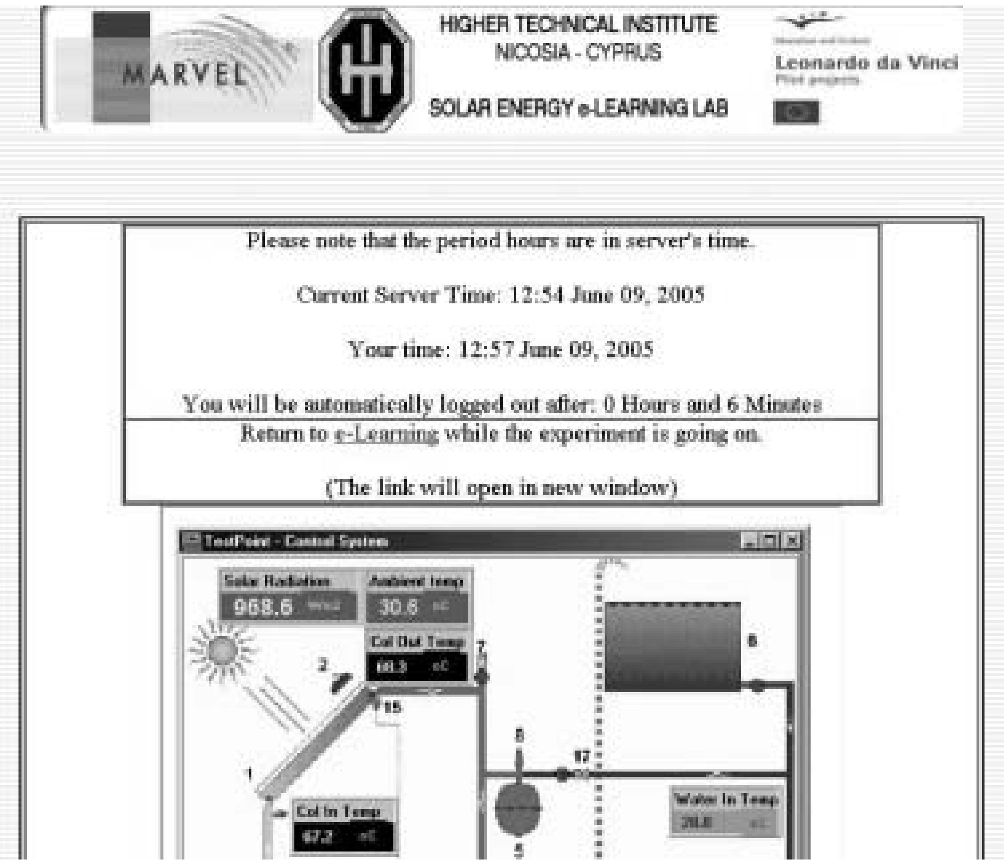


Fig. 8: Remote access to live online experiment over the Internet

6. System trials and validation

Since commencing operation (in November 2004), the HTI solar energy eLearning lab has been accessed by remote users from locations all over the world: Australia, Austria, Belgium, Brazil, Canada, Cyprus, France, Germany, Greece, India, Israel, Lebanon, Mexico, Netherlands, Portugal, Poland, Romania, Russia, South Africa, Switzerland, United Kingdom, United States, etc. 14382 logons to the eLab were recorded during the period between November 2004 and May 2005, including all activities of all participants (see Figures 9 and 10). Many visitors logged into the website as 'guests' and surfed through the various parts of the course. Other users registered and went through the various steps ending with remote access to the live experiments; some of them gave us feedback on their experience. Several course trials were conducted at HTI to test the the operation and reliability of the system, and to check the consistency and reliability of data acquisition and transfer, as well as the validity and reliability of the Temperature Differential Controller settings. During these tests, a number of problems were identified, and appropriate correctives were implemented to produce the final system.

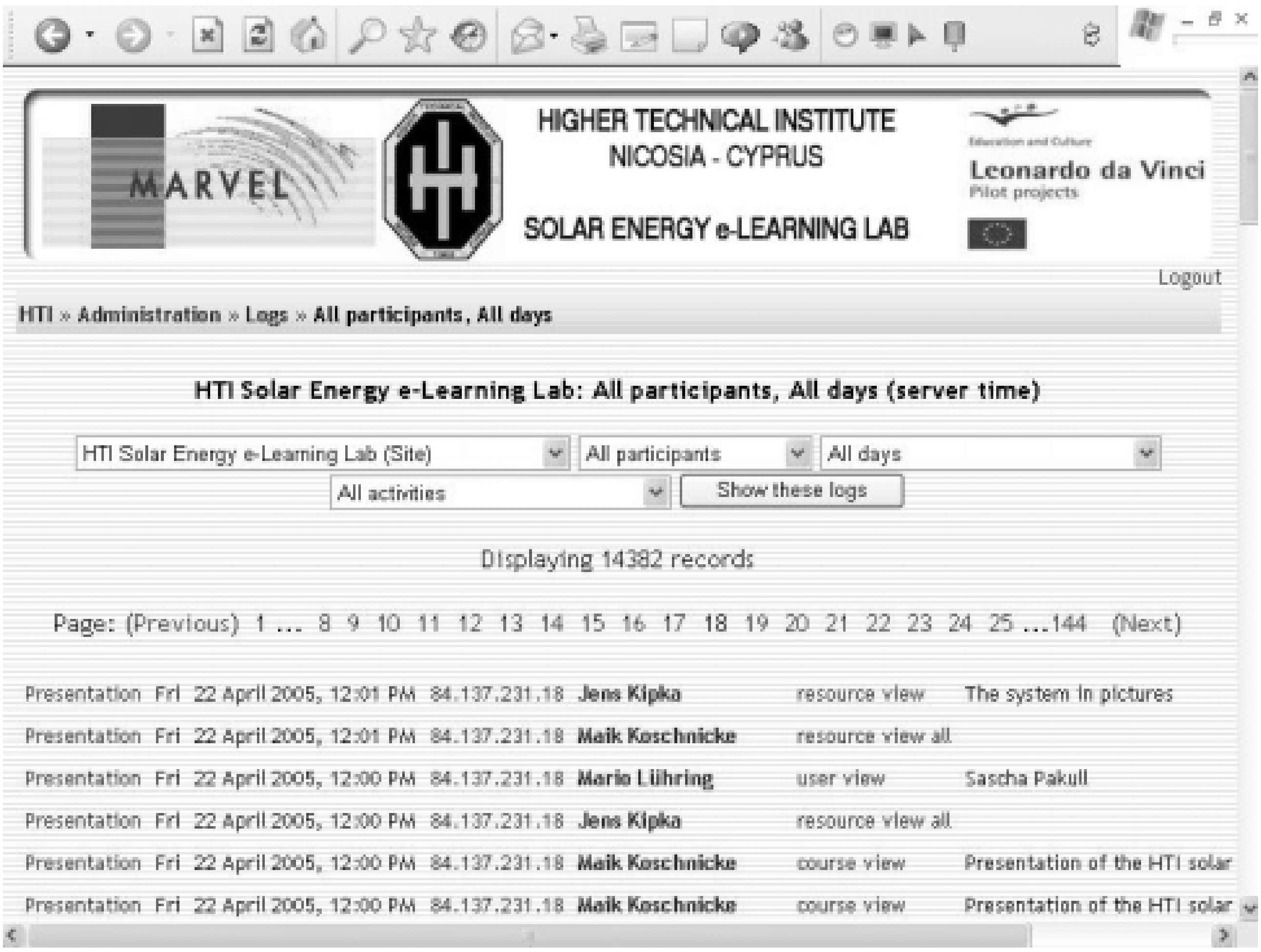


Fig. 9: A screenshot showing 14382 records of logs on the HTI solar energy eLearning lab, all activities, all participants (November 2004 – May 2005

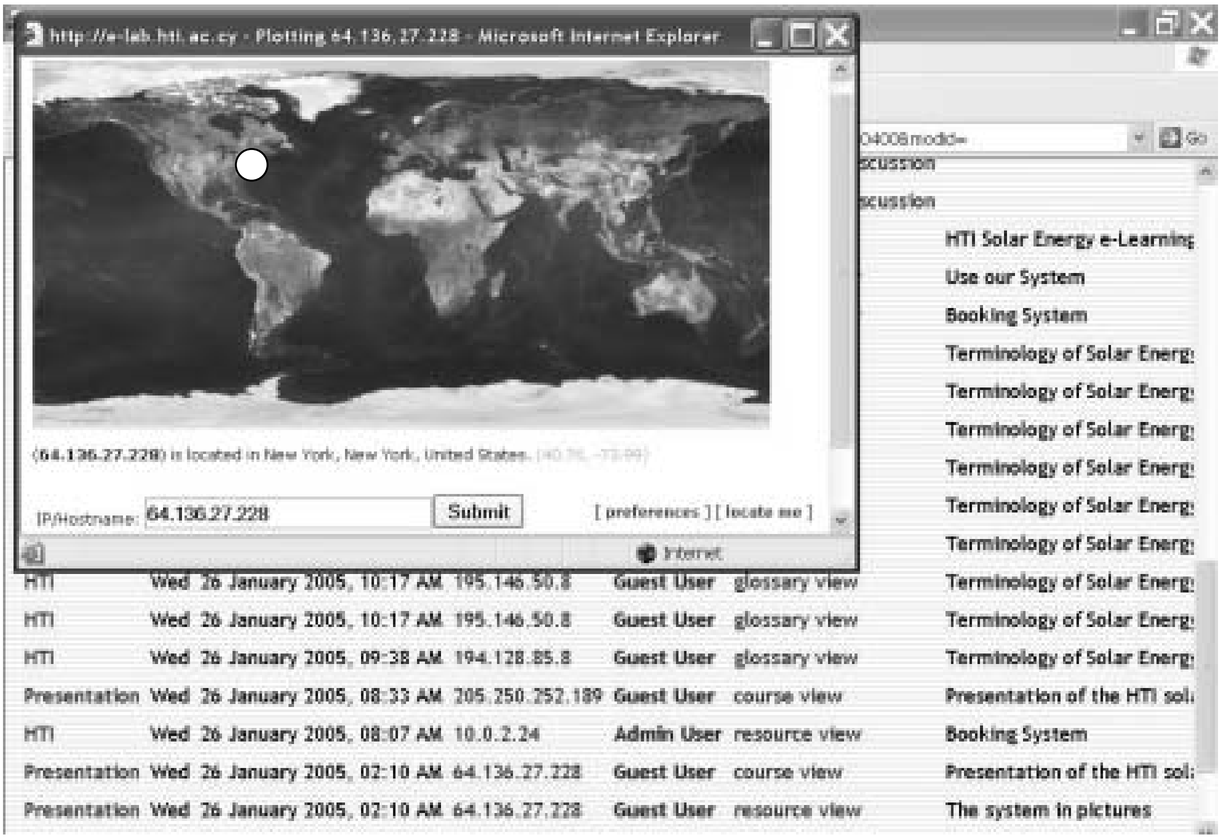


Fig. 10: Selection of logs to the HTI solar energy eLearning lab from various locations: U.S.A., and Brazil

Figure 11 is a screenshot showing the system layout and the real-life readings during a live experiment. The screen refreshes every 5 minutes to allow the student enough time to see the readings and discuss them with his/her classmates or the teacher. The student can see, for example, the temperature stratification in the storage tank, the solar radiation intensity, the water temperatures at the inlet and the outlet of the solar collector, etc. All the data are recorded in an Excel file and can be downloaded at the end of the live experiment.

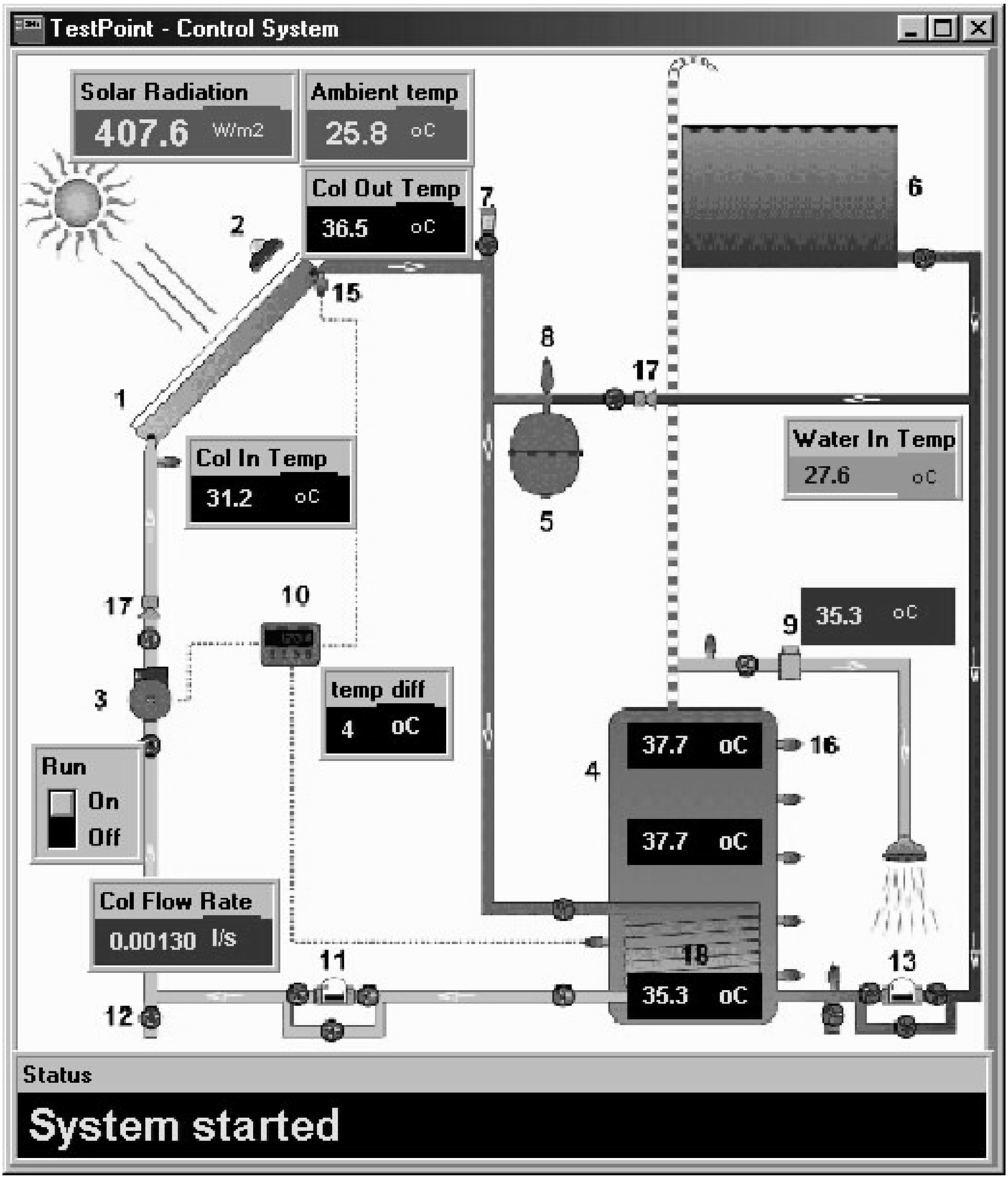


Fig. 11: Live online experiment – system readings

One of our main concerns was whether the data was being transferred to the user in the appropriate format and in the correct way, and whether the differential temperature controller was controlling the pump in accordance with the settings. After a considerable number of validation tests, it was verified that the system works perfectly. This is clearly demonstrated in the screenshot in Figure 11: the collector outlet temperature is 36.5^{o}C and the storage tank temperature is 37.7^{o}C; since the setting for DT is 4^{o}C, the pump remains deactivated (see flow rate close to zero), as expected.

Remote experimentation via the Internet was tried and validated from Thessaloniki (Greece) in November 2004, from Delmenhorst (Germany) several times in the March-April 2005 period, and from Brussels in April 2005. The validation tests included navigation through the eLearning module, although the main emphasis was on the reliability of the booking system and the live connection, and the remote experimentation aspect.

7. Telecollaboration with Delmenhorst College, Germany

Delmenhorst College (DEL) in Germany is likewise engaged in activities related to solar energy applications, and their courses are relevant, so there has been continuous collaboration between DEL and HTI, especially in conducting course trials. Figure 12 is a screenshot from the HTI eLab website showing some of the many logs from Delmenhorst College. Within the framework of this collaboration, a good number of online experiments were conducted by the DEL partners, initially by the teachers involved in the project and at a later stage by the students of the College who were in fact the first organised groups outside Cyprus to perform remote online experiments with the HTI solar energy eLearning lab. There was continuous communication by telephone and eMail, an exchange of views and experiences that helped us to improve the system.

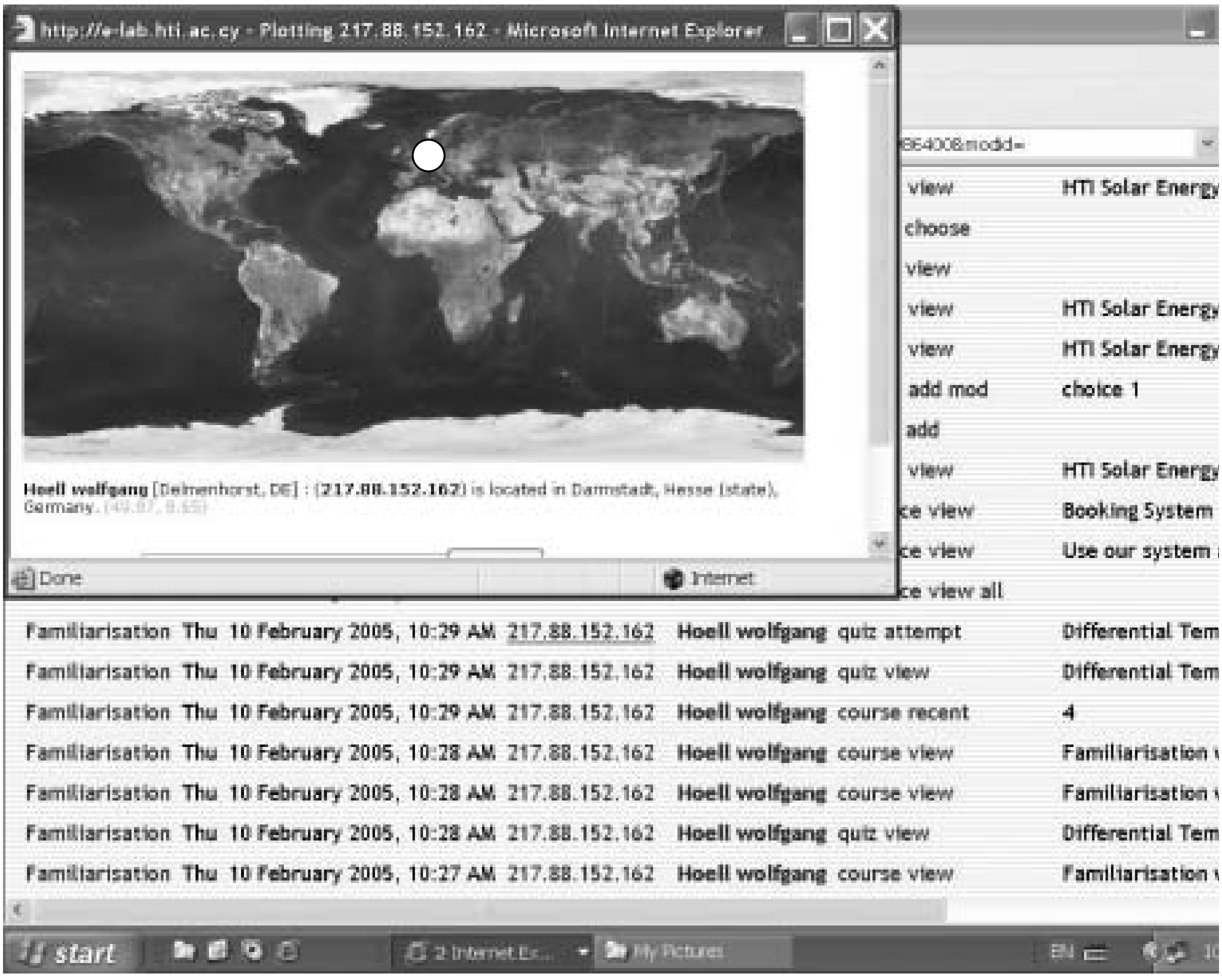


Fig. 12: Remote access to the eLab from Delmerhost College, Germany

8. Evaluation

An Online Course Evaluation Form is available on the eLab website (see appendix). The aim of evaluation is to help us understand how well online delivery of the HTI Solar Energy eLearning Lab and its courses has enabled the users to learn, and hence to improve the way this course is presented online in future.

The Evaluation Form consists of a number of statements inquiring into the user's experience with the course. Users are asked to fill in the empty boxes next to each statement by inserting the number corresponding to his/her experience (1 = Poor, 2 = Fair, 3 = Good, 4 = Very Good, 5 = Excellent, N.A = "Don't know").

Several aspects of the eLab and its courses are included in the evaluation form, such as: ease of access to and navigation of the solar energy eLearning lab website, ease of registration, functionality and reliability of the system, quality of resources in the course, structure of content, the booking system, overall impression of the eLab website, etc.

Online course evaluation feedback

The feedback obtained from users was certainly helpful. For example, the German-speaking students from Delmenhorst College found it difficult to read and understand the instructions in English. As an improvement, we translated all the User Guides into the German language and uploaded it to the eLlab website.

All the users agreed that the booking system is excellently organised, so we see no reason to modify it! However, there were some conflicting answers. For example, some of the users found "laboratory time slots of two hours" more than satisfactory, whereas others said that this is too much. Evaluation is conducted on a continuous basis and the feedback obtained is analysed accordingly.

9. Conclusion

The HTI eLearning lab goes beyond traditional remote labs by providing distributed workplaces for complex remote learning/work tasks. Learning by and through experience in a real and social context is restricted in virtual environments. In this paper, we presented an approach in which learning is understood as a process for acquiring information and processing experience in which learners select and construct knowledge that is useful and appropriate for them, and use this knowledge to drive and shape their own continuous learning process. In this way, learning becomes a process of interaction between individuals and their work environment, in which the subjective reality of the learner is actively constructed by the learner. Such approaches support the social aspects of learning, in that learning is necessarily integrated in communication processes between different learning groups while working on the same system or machine.

One important innovation in our approach is that concepts and examples for real working and learning are developed and accessed virtually through remote processes. This means we are going beyond 'traditional' remote laboratories, by trying to provide distributed workplaces for remote engineering in technical and vocational training.

References

Michaelides I., Eleftheriou P., Müller D. (2004): A remotely accessible solar energy laboratory - A distributed learning experience. Proceedings 1st International Conference on Remote Engineering and Virtual Instrumentation (REV2004), Villach, Austria, 28-29 September 2004, ISBN 3-89958-090-7, (2004).

Lee, J., Qiu, H., Ni, J., Djurdjanovi, D. (2004): Infotronics Technologies and Predictive Tools for Next-Generation Maintenance Systems. 11th IFAC Symposium on Information Control Problems in Manufacturing. Salvador, Brasil April 5-7th, 2004.

Graupner, T.-D., Westkämper, E. (2003): E-maintenance - Web-based services for production systems. In: Qu, Liangsheng (Ed.) et al.: Proceedings of Int.l Conference on Intelligent Maintenance Systems. Oct. 30 – Nov. 1, 2003, Xi'an, China. National University of Defense Technology Press, 2003, pp. 637-645.

Erbe, H.-H., Bruns, F. W. (2003): Didactical Aspects of Mechatronics Education. 5th IFAC International Symposium on Intelligent Components and Instruments for Control Applications (SISACA). Aveiro - Portugal 2003.

Müller, D., Ferreira, J. M. (2003): MARVEL - A mixed-reality learning environment for vocational training in mechatronics. Proceedings of the Technology Enhanced Learning International Conference, (TEL'03), Milan, Italy, November 2003.

The Apache HTTP Server Project: a secure, efficient and extensible server, http://httpd.apache.org/.

MySQL - The world's most popular open source database, http://www.mysql.com.

PHP: A widely-used general-purpose scripting language that is especially suited for Web development, http://www.php.net/

TestPoint - Keithley Solutions for Data acquisition. http://www.test-point.com.

.NET Remoting: http://msdn.microsoft.com/library/default.asp?url=/library/en-us/dndotnet/html/introremoting.asp.

Riordan, M. (2005): MOODLE – An electronic classroom, Teacher Manual, http://moodle.org/.

Moodle (2005): MOODLE – A Open Source Course Management System for Online Learning, http://moodle.org/.

Duffie J. A., Beckman W. A. (1991): Solar Engineering of Thermal Processes. John Wiley, New York, 1991, pp. 301-307.

Appendix

PART OF THE ONLINE COURSE EVALUATION FORM

Each of the 28 statements that follow asks about your experience in this course. Please fill in the empty boxes by inserting the number corresponding to your experience next to each statement (1 = Poor, 2 = Fair, 3 = Good, 4 = Very Good, 5 = Excellent, N.A = "Don't know").	
Ease of accessing the solar energy e-learning lab website	
Ease of navigating the solar energy e-learning lab website	
I could register with no trouble	
Functionality of the system	
Reliability of the system	
Guidelines and instructions were clear	
The resources in the course (quizzes, notes, glossary, etc.) were straightforward and easy to use	
The structure of the content was easy to follow	
The e-learning course was interesting and enjoyable	
The objectives for each course were clear	
The content was clear and easy to understand	
The content gave me sufficient information	
The course materials were easy to read	
Diagrammatic layouts and animations were clear and helpful	
The course was a valuable learning experience	
Lessons flowed in logical order	
The material was well prepared and organized for a remote laboratory	
The material was explained in a clear and understandable manner	
The course was flexible and met my time expectations	
The pre-lab test as a condition for the live access to the system was reasonable	
The pre-lab test was well prepared	
The booking system was well organized	
The laboratory sheets contained useful information and instructions	
The Excel file with the results was well organized and presented	
The time allocated for each online experiment (2 hours) was satisfactory (if your answer is 1, please write your suggestion at the end of this form)	
The time slot of one hour between two successive lab sessions is satisfactory	
Overall impression of the e-lab web site	
I would recommend this course to others	
What aspect of the e-learning course needs the most improvement?	
What suggestions do you have for improving the course?	

A REMOTE ELECTRONICS WORKBENCH

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1. Summary

This chapter describes a remote electronics workbench that was set up at Faculdade de Engenharia da Universidade do Porto (FEUP) to illustrate an implementation of the technological concept that was presented in Part I. The specific case study considered here consists of a remote experiment that aims to determine the cut-off frequency of a low-pass active filter

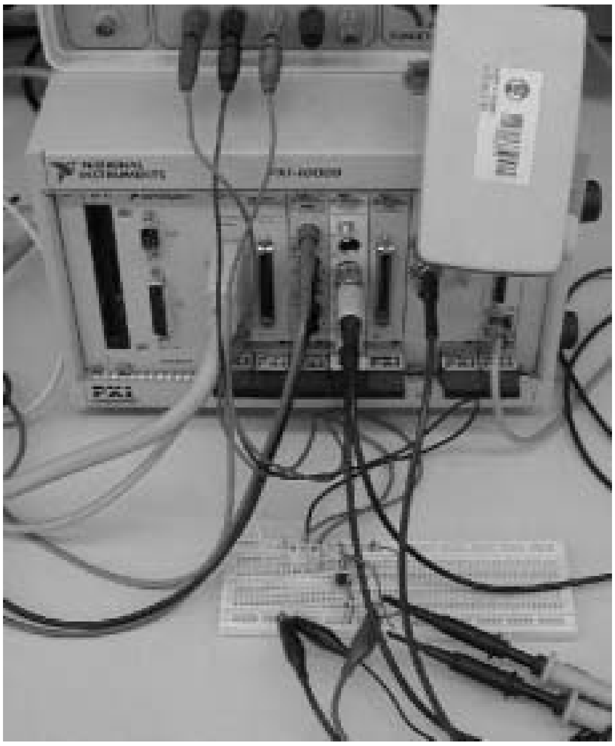

Fig. 1: The (physical) remote workbench at FEUP.

2. System components and organisation

The architectural setup underlying this remote workbench comprises a waveform generator and an oscilloscope, both implemented in the form of PXI boards. The lab server is implemented in the form of a PXI single-board Pentium computer running Windows NT, which enables the users to control the waveform generator and the oscilloscope via LabVIEW virtual instrument panels. The remote hardware (a second-order Sallen-Key low-pass filter) is implemented in a breadboard at the remote lab. Altogether, the components comprised in this system occupy a small part of a standard workbench, as illustrated in figure 1.

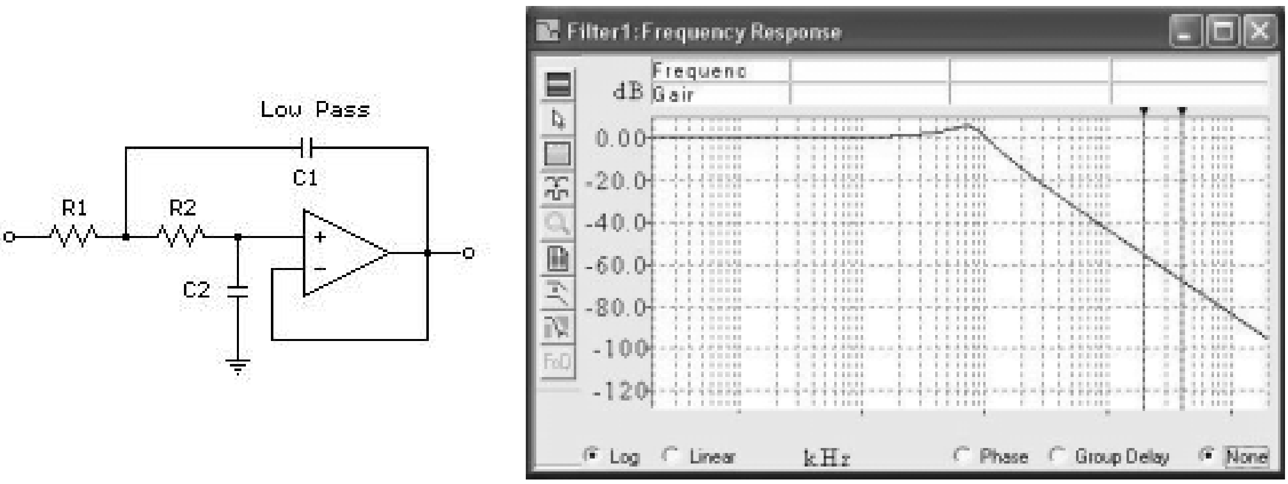

Fig. 2: The remote circuit and its frequency response

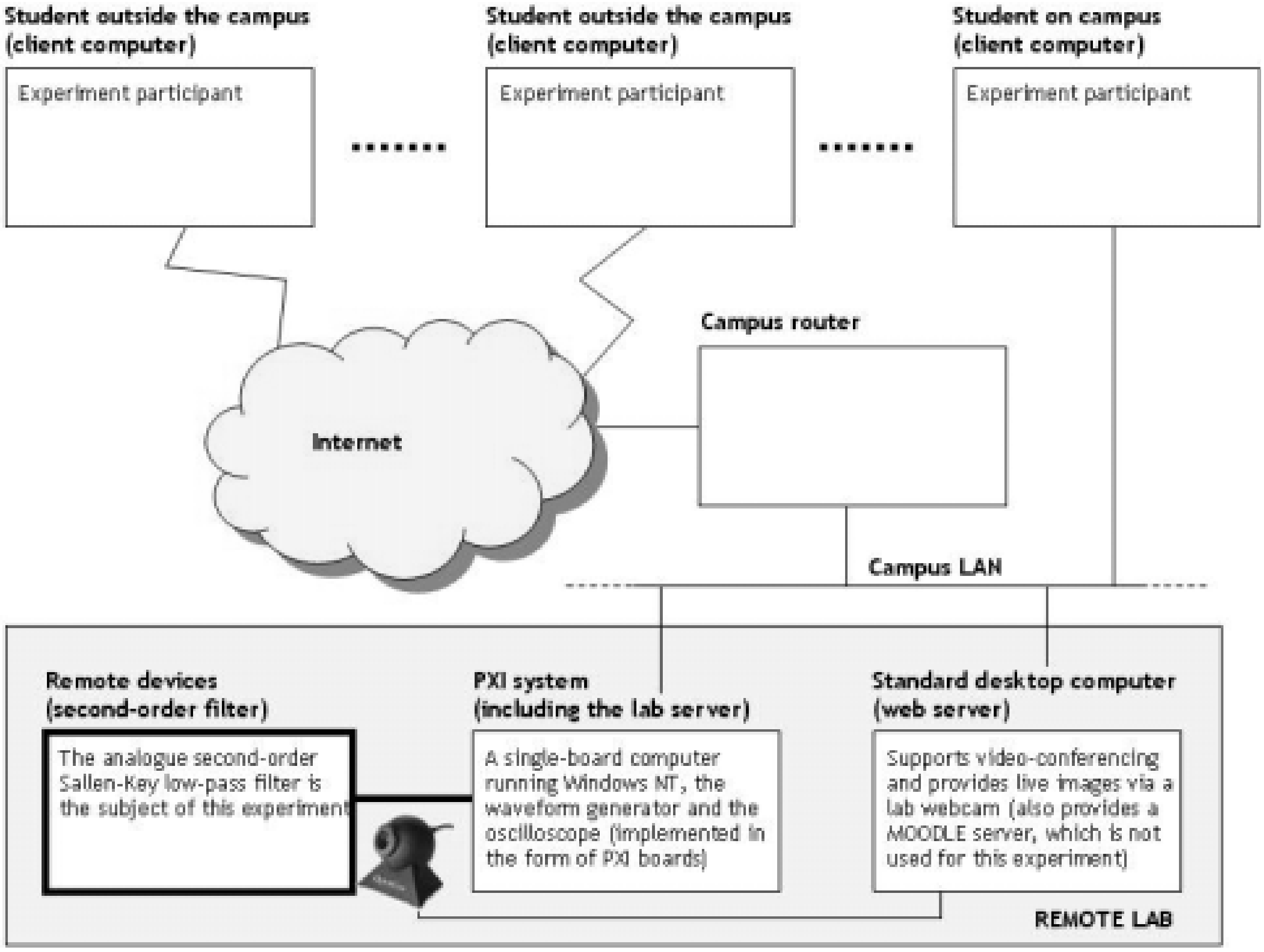

Fig. 3: Organisation of the remote electronics workbench implemented at FEUP.

A standard desktop computer supports video-conferencing via a Flash Communication Server and provides live images of the remote circuit, using a web-cam that is also visible in figure 1. The organisation of the remote workbench implemented at FEUP may be represented as shown in figure 3.

3. Experiment description

The objective of the proposed experiment consists of determining the cut-off frequency of a second-order low-pass filter. The topology of the remote circuit and its frequency response are illustrated in figure 2.

The experiment script recommends the following sequence of actions:

- Set up the remote equipment, adjusting the oscilloscope (time base, trigger, Volt / division, etc.) and the function generator (waveform, frequency, amplitude).
- Verify that the circuit behaves as expected for low frequencies.
- Verify that the gain of the circuit is much lower for high frequencies.
- Determine the filter cut-off frequency.

When made available within Moodle, the experiment script may be presented as illustrated in figure 4. This script contains a summary description of the remote hardware and proposes a sequence of steps that help the students to reach the experiment's objectives. Interested readers may access this experiment at FEUP's Moodle server[1].

[1] Moodle Server: http://ptse.fe.up.pt. Using 'demo' as username and 'public' as password (select Electronics / Introduction to Electronics).

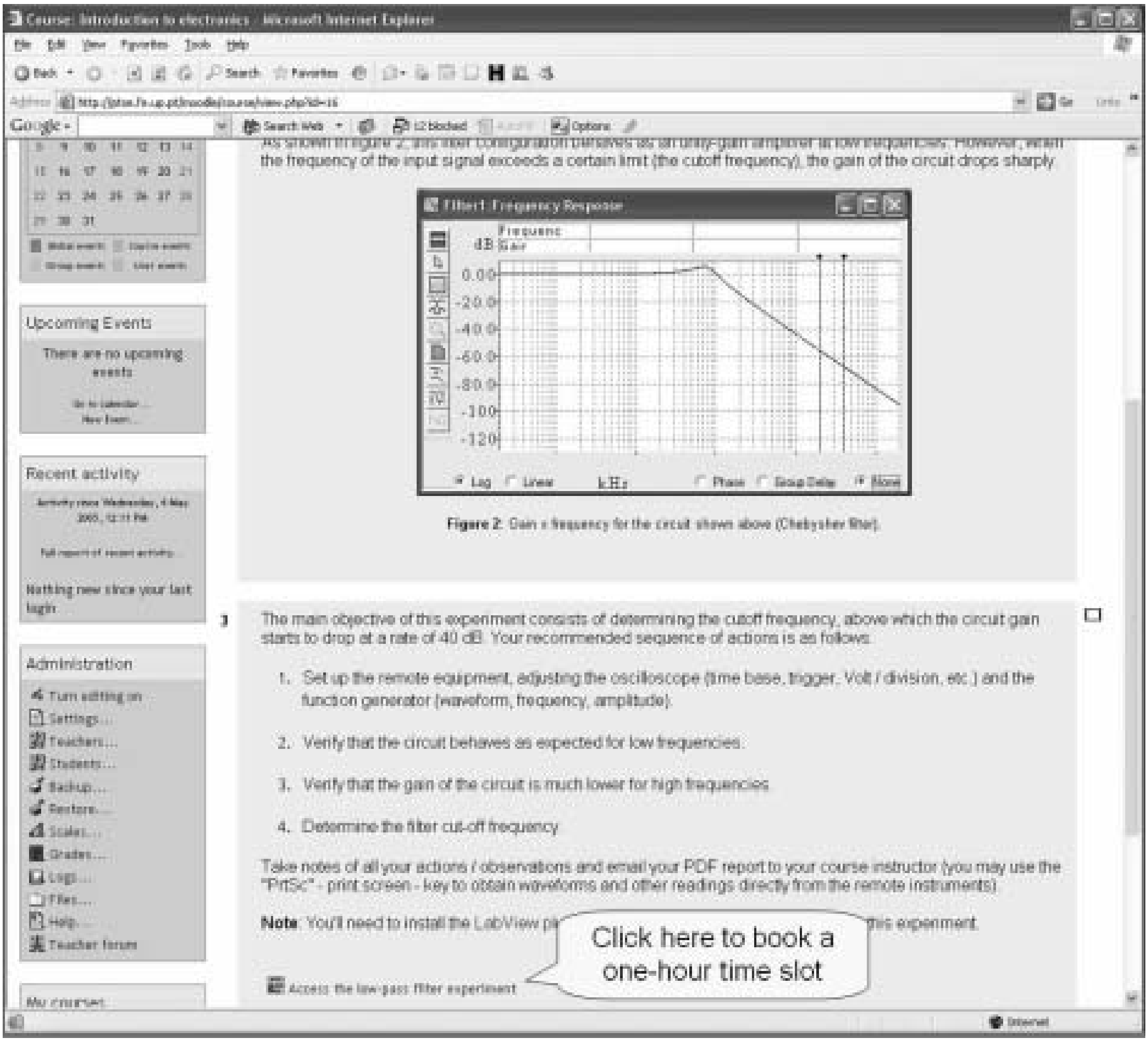

Fig. 4: Access to FEUP's remote electronics workbench (active filter experiment).

Students willing to access the experiment will book an appropriate time-slot using a booking tool that was developed by FEUP and made available as a Moodle extension (Ferreira, Cardoso 2005). By clicking on the booking link shown in figure 4, a 7-day calendar is displayed, as shown in figure 5 (next page). The first day shown corresponds to today's date, and its weekday/date cell is displayed with a blue background. With the exception of today's column, all weekday/date cells contain a link that shifts the calendar to the left, so as to bring that column into the leftmost position. If that same link is clicked on today's column, then the calendar is shifted one day to the right, and yesterday becomes the leftmost column. The left and right arrows shown below the summary description on top are used to shift the calendar in 7-day slots.

The calendar page shows the local time (in the user's time zone), which may of course be different from the server time (in the remote lab's time zone). The time conversion takes place automatically, so that users at any time zone see the free/booked slots market according to their local time zones.

By clicking on the book icon (), the client is able to book the required one-hour slot. Any reserved slot may be released by its owner by clicking on the unbook icon (). When the reserved slot becomes the current one-hour slot, a red arrow link is displayed and enables access to the remote experiment, as shown in figure 6 (next page).

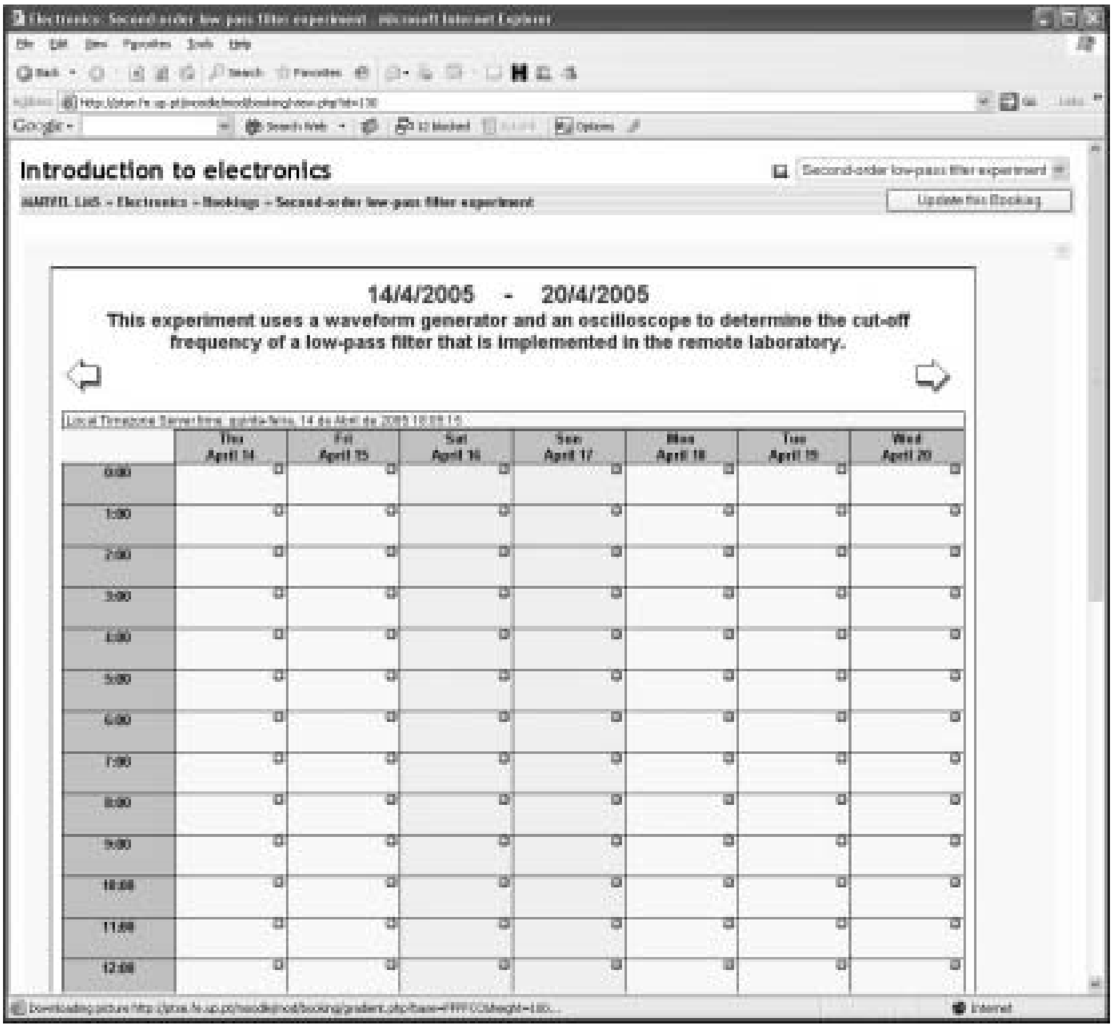

Fig. 5: The calendar displayed by the booking module.

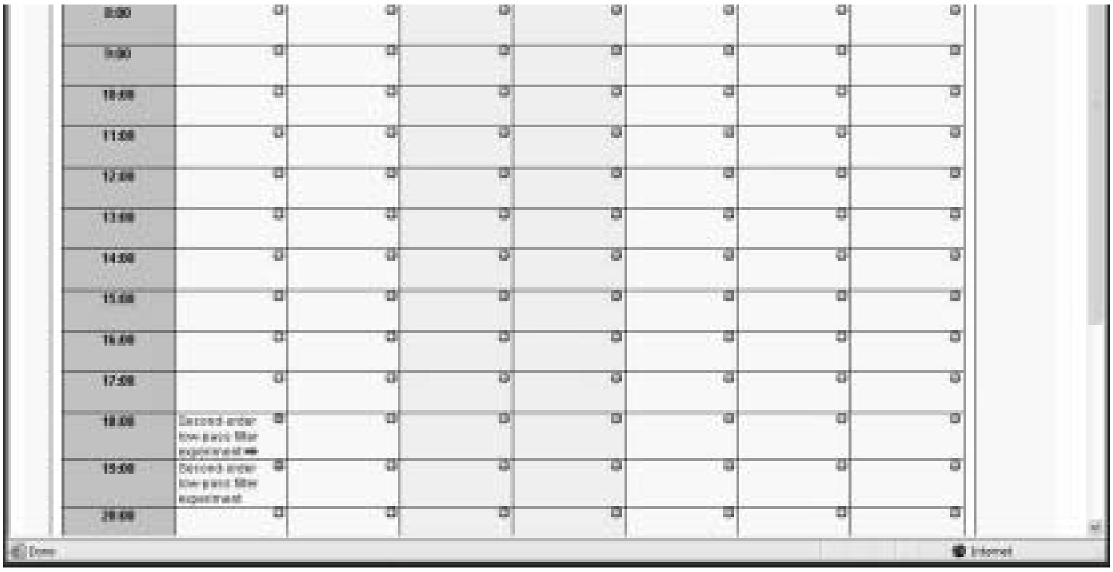

Fig. 6: The link to the experiment (➡).

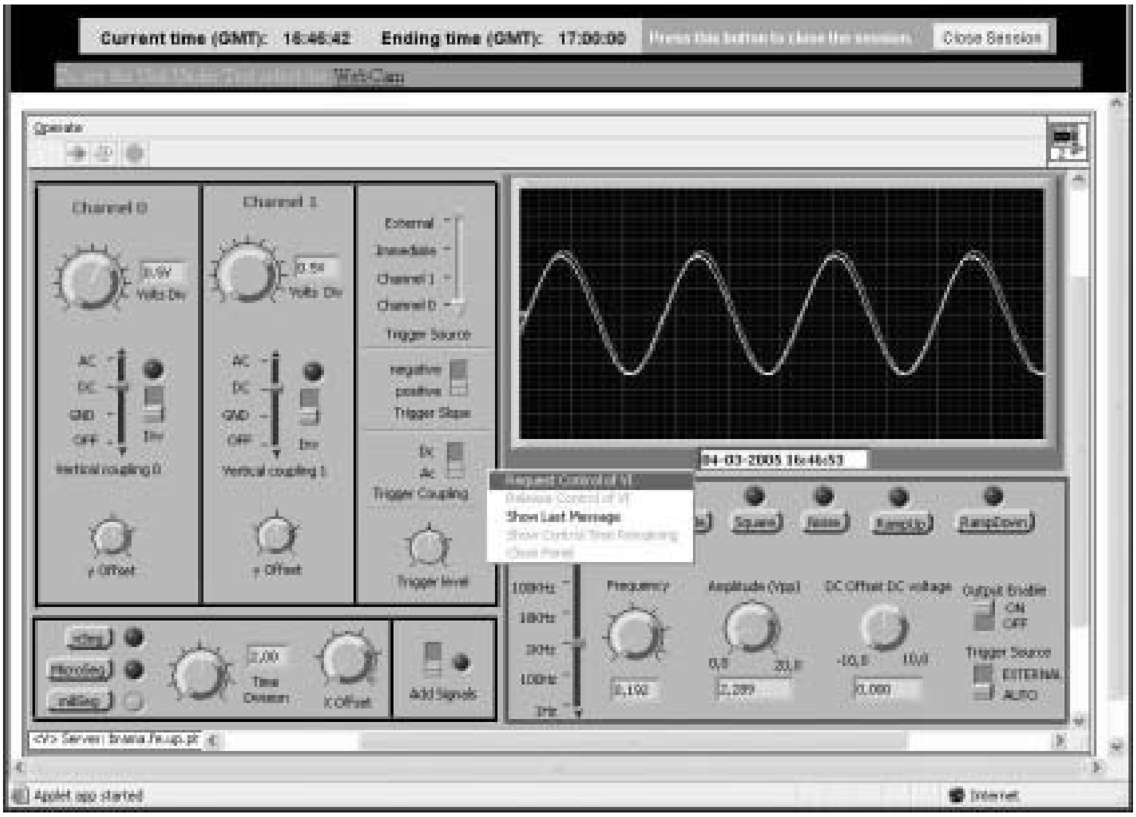

Fig. 7: Requesting control (notice that we are below the cut-off frequency).

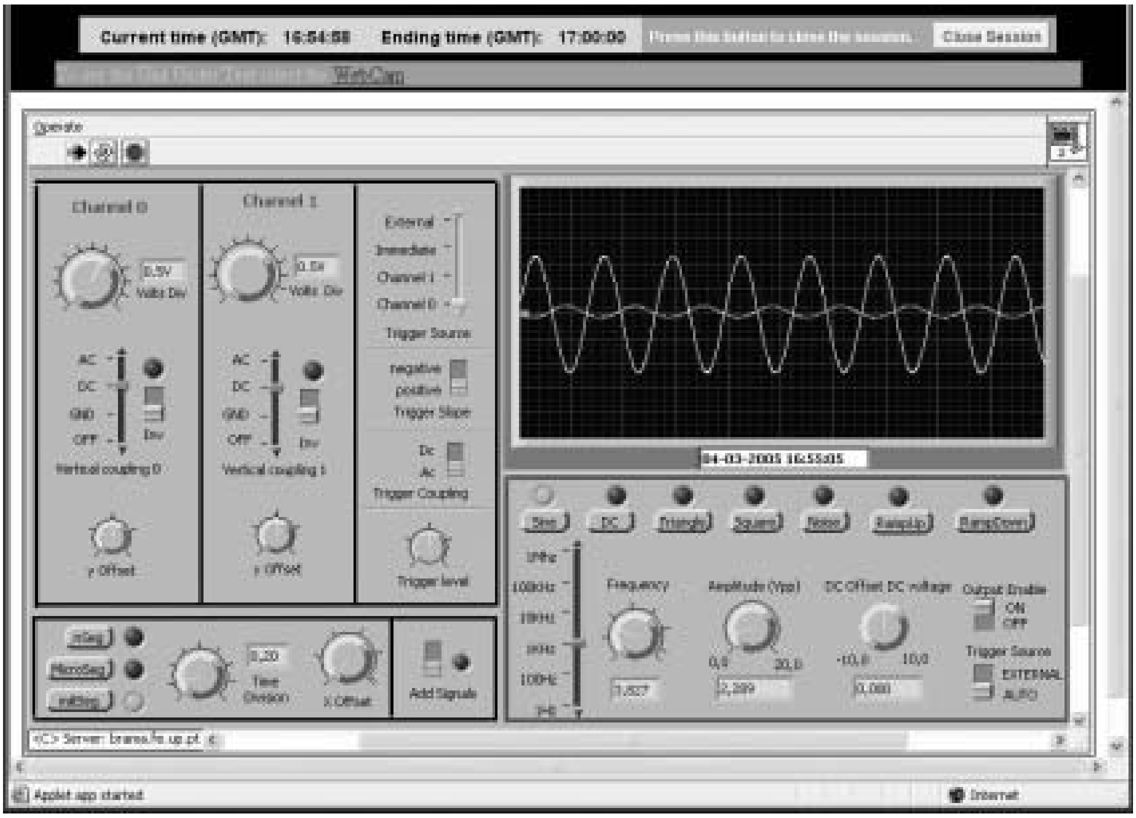

Fig. 8: The input waveform frequency is above the cut-off point.

Clicking on this link downloads the virtual instruments (VI) control panel. With nearly 770 Kbytes, the VI control panels will take a few tens of seconds to download at typical ADSL speeds. Note that the synchronous communication tool is made available in a different browser window, and may even be inactive, if the experiment is done by a single student. Whenever necessary, the students may communicate via internet telephony or videoconferencing, so as to have everything prepared when their one-hour slot is reached.

Once the VI control panel finishes downloading, the user who is going to work with the remote instruments should request control, by pressing the right mouse button. figure 7 illustrates this situation. It also shows that the initial input frequency was sufficiently below the cut-off point, and as such there is an almost perfect overlap between the input and output waveforms.

By increasing the input frequency, the user will soon arrive at a situation as illustrated in figure 8, where the output waveform clearly has a lower amplitude than the input waveform (meaning that we have gone above the cut-off frequency). To complete the experiment, the student should decrease the input frequency and repeat the procedure until the cut-off point has been identified (notice that the time base of the oscilloscope has different values in figures 7 and 8).

It is also possible to integrate equipment control panels, videoconferencing channels and live images from the remote experiment in a single browser window, as illustrated in figure 9. In this case, a Flash Communication Server was used to provide the three videoconferencing channels ('AVPresence' communication components) and the live images from the remote workbench (an embedded video object).

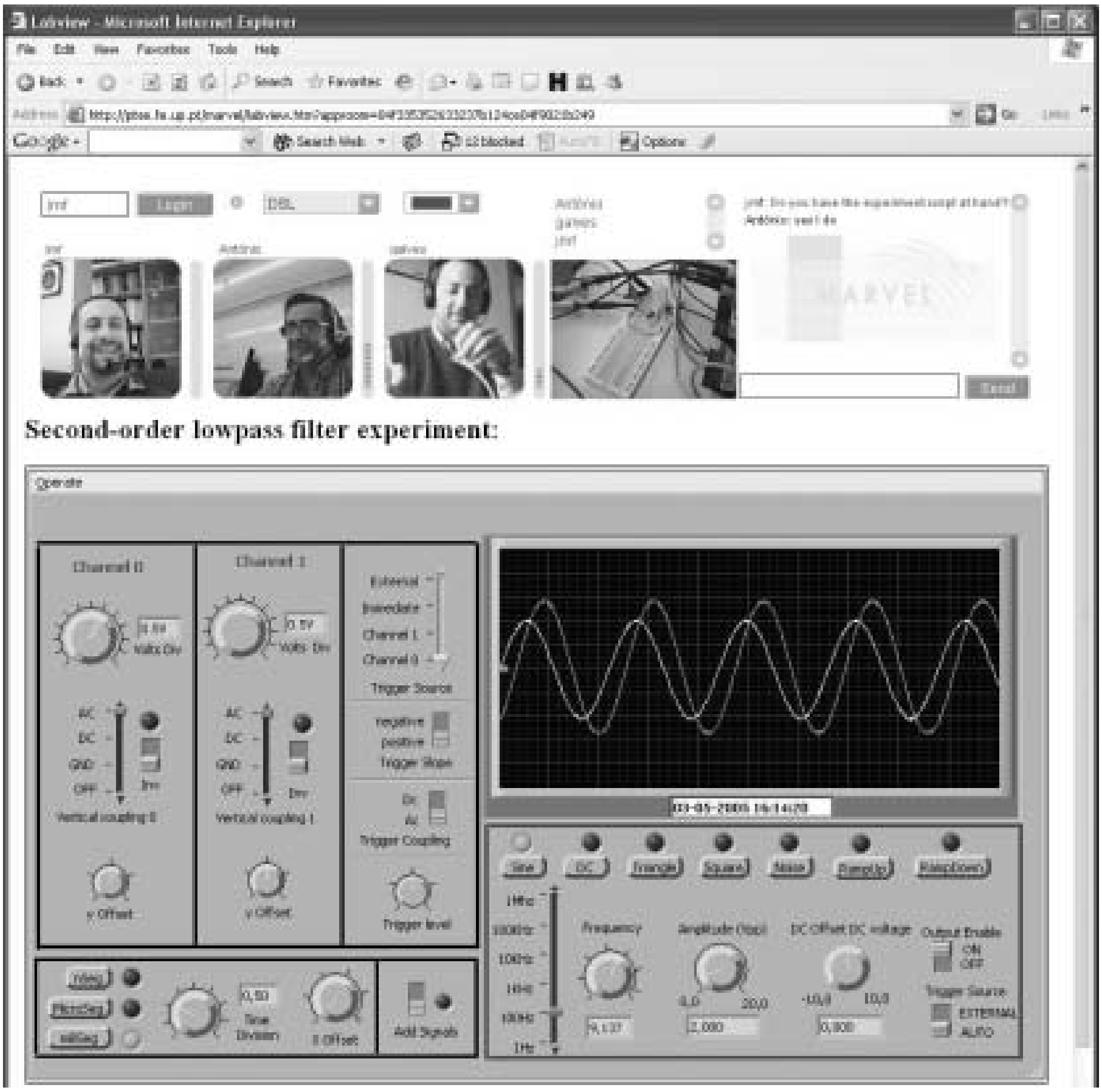

Fig. 9: FEUP's remote electronics workbench integrating videoconferencing and live workbench images

4. The booking tool: Tutors' view

When creating the lab script for a given experiment, tutors will use Moodle in editing mode (selected by the "Turn editing on" button that is available on the upper right of the course contents page). Inclusion of the booking link will be done by selecting the corresponding entry in the "Add" drop-down list, as illustrated in figure 10.

The tutor is then prompted for information concerning the experiment, as shown in figure 11 (next page). The "booking name" will be shown to the student to identify the experiment. The summary "description" will be displayed above the calendar, when the student proceeds to book his one-hour time slot. The "maximum number of students" field enables the tutor to specify the acceptable team size for each experiment. The URL of the experiment is generated dynamically at runtime, and is created randomly using the base URL indicated by the tutor in the "URL base (fixed string)" field. Experiment URLs are not predictable and therefore the experiment page may not be accessed directly.

The "Command file location" field contains the path to the file that is used by Moodle to generate the runtime URL of the experiment. This file is automatically created by Moodle, so the only action required from the user is the specification of its path and filename. When a new experiment session is launched, Moodle creates a new command file with the contents illustrated in figure 12 (next page).

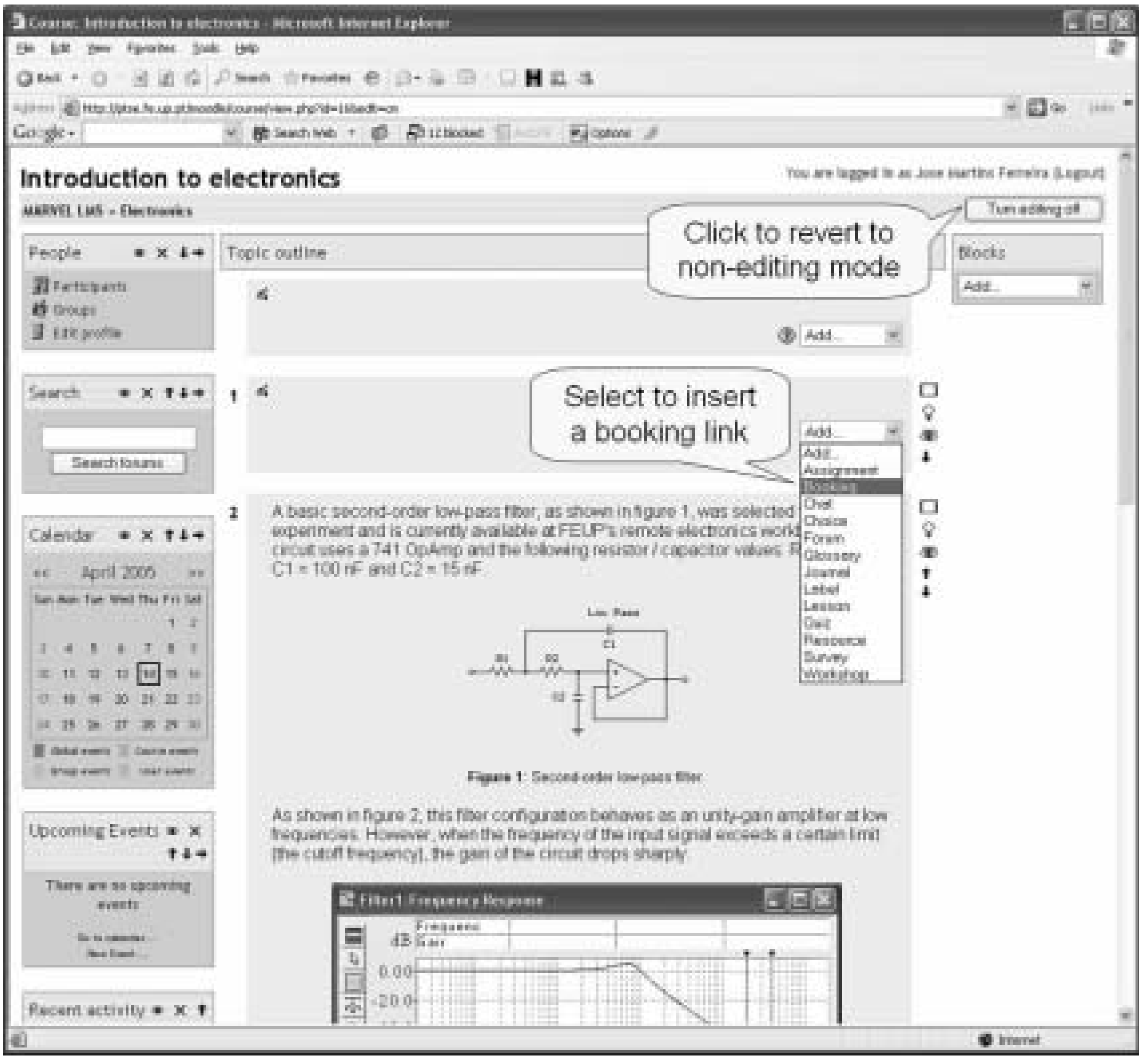

Fig. 10: Adding a booking link while building pedagogical contents.

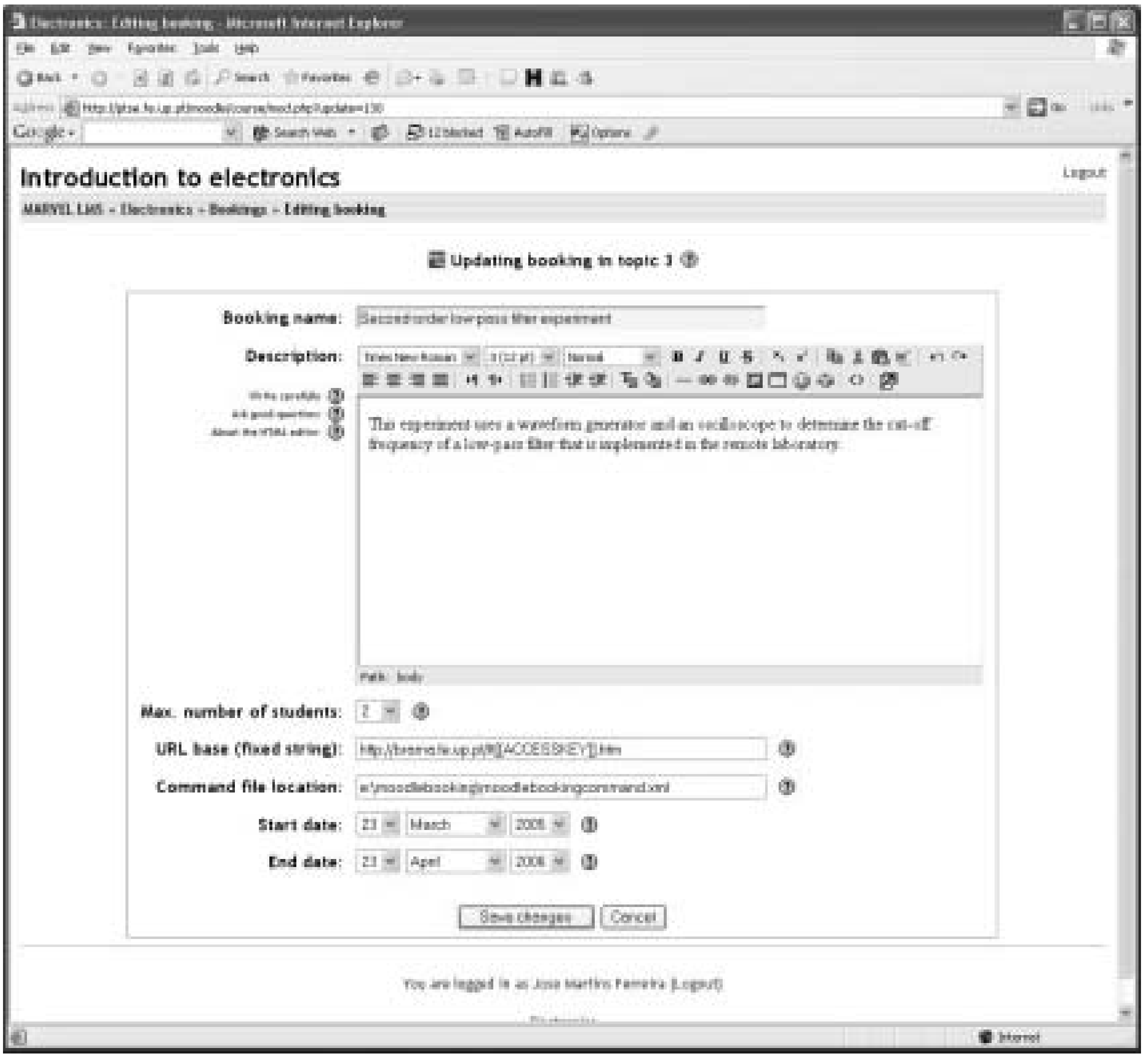

Fig. 11: The information required by the booking module.

```
- <LVData>
    <Version>7.0</Version>
    - <String>
        <Name>Event</Name>

    <Val>02df8cd7bd31742a975c60ba8a84e4ac</Val>
     </String>
    - <String>
        <Name>EventTime</Name>
        <Val>1702</Val>
     </String>
    - <String>
        <Name>EventStart</Name>
        <Val>1116603098</Val>
     </String>
    </LVData>
```

Fig. 12: Contents of the experiment command file that is created by Moodle.

The 32-character string is written by Moodle in this command file when the user clicks on the experiment access link (➡), and is later used to build the [ACCESSKEY] that is referred in the "URL base" field. The first numerical value indicates the number of seconds left to the end of the experiment and is used to close the session at the appropriate time. The second numerical value represents a time reference in seconds counted from January 1st 1970, and is used for internal synchronisation purposes. Finally, any experiment is associated with a "start date", when the booking link becomes available, and an "end date", when it ceases to be displayed.

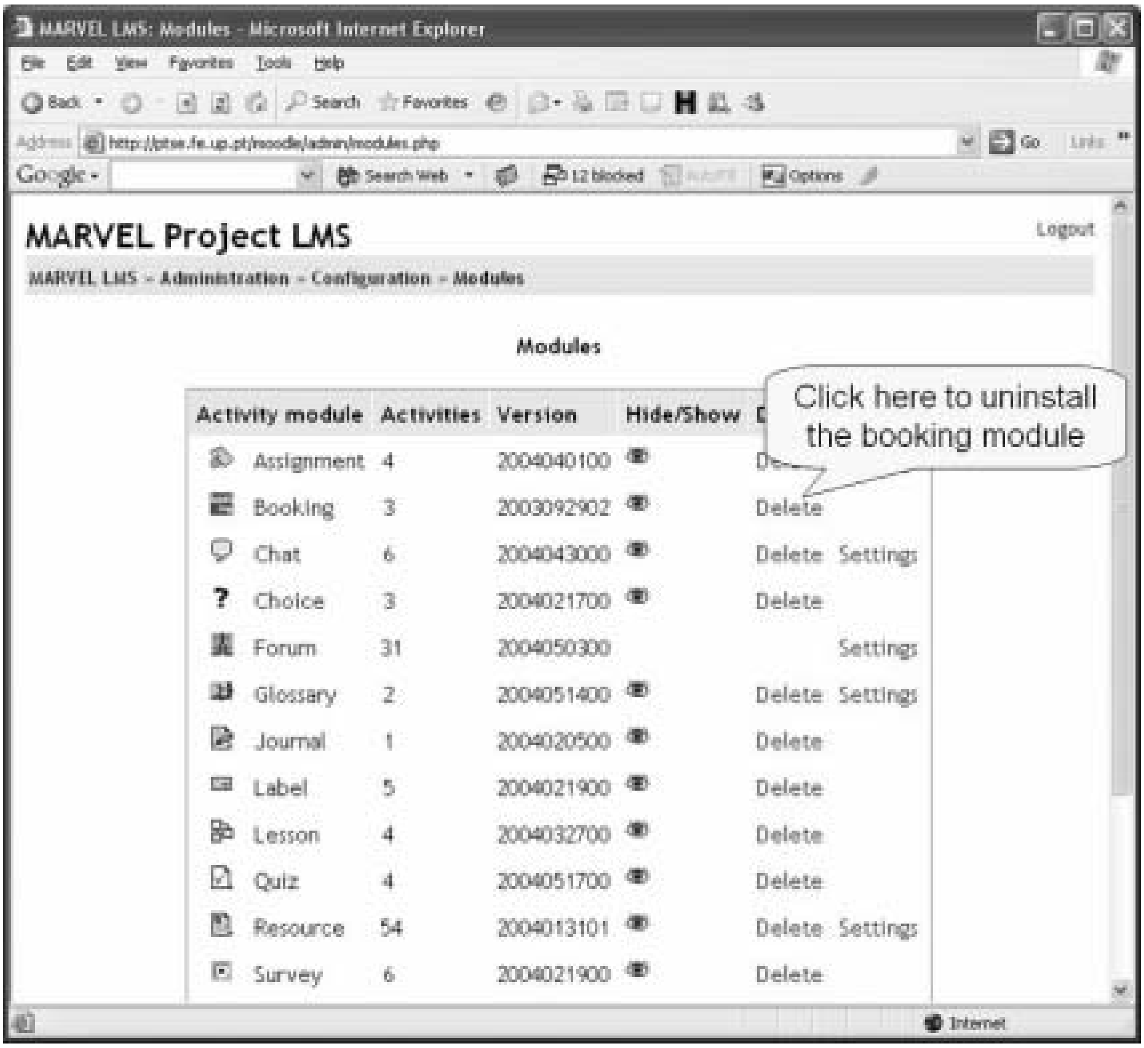

Fig. 13: Uninstalling the booking module.

5. How to install / uninstall the booking module

The booking module that was developed at FEUP is an extension that is not yet part of a standard MOODLE installation. To install this module follow the steps presented below (the "booking.php" file and the "booking" folder referred below are available in the CD-ROM that accompanies this document, and also in the MARVEL web site at http://www.marvel.uni-bremen.de):

1. Copy the file "booking.php" into the "lang\en" directory at MOODLE's root. This file defines the names of the fields shown in figure 11 (last page). Whenever a user wishes to provide a translation into another language the new file "booking.php" shall be copied into the corresponding language folder.
2. Copy the folder "booking" into the "mod" directory at MOODLE's root. This folder contains all the PHP, Javascript and HTML files that comprise the booking module.

3. Login as administrator and enter the administration area of MOODLE.

The booking module will be installed automatically on execution of step 3, since MOODLE will look for any new modules and proceed to their registration. The next time that a tutor enters the “editing on” mode, the booking module will be available on the drop-down menu that is used to create learning contents (see figure 11).

The following procedure will uninstall the booking module:

1. Log in as administrator, go to Administration / Configuration / Modules, and delete the booking module (see figure 13).
2. Go to the “mod” folder at MOODLE’s root and delete the “booking” folder. *Note:* This action must be done before refreshing the current MOODLE page, since loading any administration page while the “booking” folder is present will reinstall the booking module.

Future plans include extending the current version of this tool to support booking in a multi-user / multi-lab context (the first version is multi-user / single-lab). The new version will enable several groups of students to access multiple instances of the same online lab, in a way that is entirely transparent. There will also be a limit on the number of hours that a single user may book, as well as a time-out feature that will release a booked slot, when the experiment has not yet started after a pre-specified delay.

References

Ferreira, José M., Cardoso, António M. (2005): A Moodle extension to book online labs. 2nd Remote Engineering and Virtual Instrumentation International Symposium (REV'04), June 2005, Brasov, Romania.

Moodle – A Open Source Course Management System for Online Learning, http://moodle.org

REMOTE WORKSHOPS IN MECHATRONICS: COURSE TRIALS AND EVALUATION AT WEST LOTHIAN COLLEGE

Graham Clark, Gordon Weir
West Lothian College, Livingston - SCOTLAND

1. Introduction

West Lothian has seen many major industrial changes over the years. After moving from traditional coal mining industry and heavy manufacturing to more modern industries such as semiconductor manufacturing, these industries, too, have suffered downturns in recent years. Even though service industries now replace many of the jobs, engineering and manufacturing are still a very vibrant part of the local economy. Local community needs are constantly changing and West Lothian College, like most in Scotland, has met these ever-changing demands by modernising programs, finding new delivery methods and styles and making greater use of modern technology.

Partnerships between the college, local enterprise and business have been instrumental in forming the foundation on which some of the most up-to-date, innovative and industry-tailored courses in Scotland have been built.

Always willing and able to meet challenges and develop for the future, the college is now developing online practical workshops with remote eLearning. The college's Student Development Centre has created a multi-mode learning environment supported by specialist tutors and facilitated by learner assistants. Flexibility in education has been the mainstay for many local community needs, and the college continues to provide flexibility and choice in its many training options.

Collaboration between European colleges, universities and industry on the MARVEL project has increased the level of flexibility and the number of options, and should enable students to carry out remote practical workshops from anywhere in the world.

2. Remote practical training in MARVEL

The aim of the Marvel project is to enable engineering students to remotely access workshop equipment and facilities around the European Union from wherever they may be studying, while at the same time maintaining mergence between reality and virtual environments[1]. Engineering training facilitators are coming under increasing pressure to provide students with real-life engineering situations, but due the ever-increasing need for modern equipment, the expense becomes a burden on the already stretched colleges and universities finances. Due to recent advances in technology, remote access to equipment has become much more viable.

With greater collaboration between colleges, universities and industries throughout the European Union, the ability to share resources and provide all students the facility to operate, maintain and test equipment and systems in a real live situation has become a reality. Remote access is not confined to colleges and universities, but has wide-reaching applications within industry, where engineers can carry out tests, even repairs, remotely.

Remote Experiments in the field of Mechatronics, the subject of this project, has been investigated due to the need to build greater and greater levels of choice and flexibility into how training and education is delivered. This remote access requirement may be due to the learner living in a remote location, the learner being unable to travel easily to the nearest centre of education, or it may be due to work commitments or a disability. Whatever the reason, being able to carry out experiments from remote locations gives students the chance to take courses they were almost certainly unable to before.

The intention of the project was to have several 'mechatronic-type' experiments that may be accessed through the colleges Virtual Learning Environment (VLE). To this end, we provided all the resources the learner needs in order to interact fully with each experiment. This includes:

- the software and
- the hardware
- suitable instructions and guidance
- assessment.

[1] See chapter *The MARVEL Project* in part I of this book.

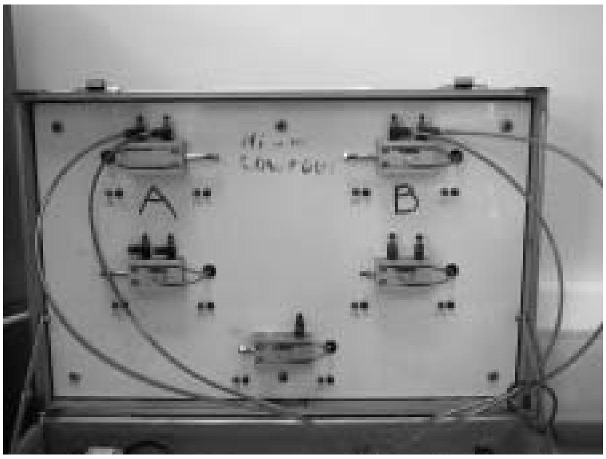

Fig. 1: Pneumatic training system

Fig. 2: Control system for training

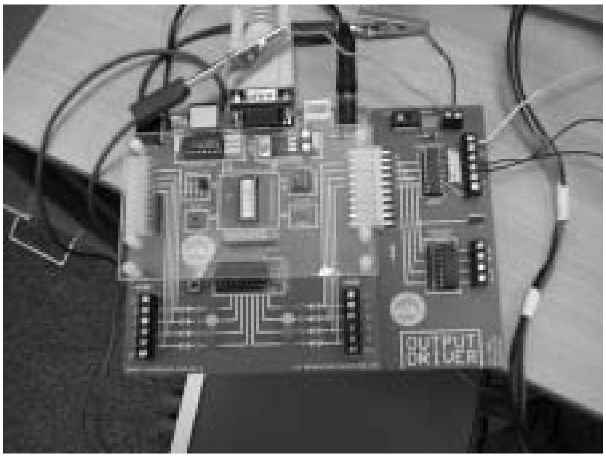

Fig. 3: Programmable interface controller

Typical workshops may include some of the following:

(1) Pneumatic Systems: The student can interact with the pneumatic system and write an operational sequence, change the sequence of operation, or control various inputs and outputs remotely. Diagnostic checks can also be performed remotely.

(2) Deltronic Control System: Students can control inputs and outputs and change program sequences in order to control many systems which may be attached to the control box system. Functional tests can also be performed remotely on systems.

(3) Programmable Interface Controller (PIC): Various control and response devices can be attached to the PIC controller and controlled remotely. Diagnosis and tests may also be carried out.

(4) Robotic System: The greatest challenge posed is the remote control and programming of a robotic system. The main challenge with this type of system comes from accurate visioning in real time of the end effector when accurately positioning the robotic arm.

Only in recent years has the technology existed to allow the remote learner this opportunity. Easier access to the Internet, advances in computer power and new high-speed data highways have all combined to make this possible. The learner is therefore able to interact with experiments on a more realistic, more rewarding level than before. This project, therefore, is an attempt to put such a system in place, but it should be noted that many other considerations will also require time and effort so that the final design will also include all the controls that are present in a more conventional teaching environment.

Fig. 4: Training robot

3. Course trials in robotics and mechatronics

West Lothian College has been running mechatronics courses for almost ten years. 'Mechatronics' as a title has many different interpretations, so for the benefit of the reader the term mechatronics should be understood in the following context. Mechatronics describes a complete engineering system that has the following elements:

(i) Programmable control: the benefits of having programmable control over more conventional electro-mechanical control is that it enables changes and/or modifications to be accomplished quickly and easily with the minimum amount of downtime for the system. Modern software packages, such as National Instruments' excellent Labview, also provide the user with user-friendly interfaces, making system performance and control easy to monitor. Individuals with little or no programming experience can now even tackle the programming side itself, previously a very specialised task. Labview is again an excellent example of this, using graphic symbols that are then linked together to form the program. So whatever the means of writing the code or the type of hardware used, more and more of the devices we use every day are now endowed with the ability to store and execute programs. Such ability is crucial to the flexibility of the device and also the need to upgrade its level of performance in the future.

(ii) Sensing and execution: the type of programmable systems referred to above would be of little use unless at some point during program execution they are supplied with data about how the system is performing. Similarly, they must also be able to change the performance of the system in some way – for example, by changing pressure to vary an applied force.

Both of these requirements are achieved by using transducers. On the input side, sensors convert quantities into electrical signals that will then form the basis of the data signals fed into the programmable processing element.

On the output side, actuators respond to signals from the controller to produce the system's end-effect. These two operations can be thought of sensing and execution since they closely mimic our own behaviour when guided by our senses before performing the movements and actions required for various tasks.

(iii) Electronics: many similar definitions of the term mechatronics would not include electronics since, in a way, all of the elements described so far will include electronic components to some extent. Here, however, electronics describes the circuits that are essential for the conversion of signals into the appropriate format or to the correct level. Examples include: analogue-to-digital and digital-to-analogue converters; voltage and current amplifiers; protection circuits and signal processing circuits.

Another definition of mechatronics that may appeal to the reader is the one put forward by The Open University (OU) in its Mechatronics course[2]. The OU sees three distinct elements that go together to make up the mechatronic architecture. These are:

- *Perception* - this is the sensing element and comprises the sensors and all the electronics required to convert signals into appropriate formats.
- *Cognition* - if perception deals with getting to grips with what is going on in the system, cognition is then the response to this information. Cognition considers what is happening, before producing the best response to allow the system to fulfil its intended purpose.
- *Execution* - the final element of the OU's architecture is execution. Here, signals from cognition are converted into the end-effect that, for the most part, comprises some form of movement.

3.1 Remote access issues in mechatronics

Remote access is all about being able to carry out experiments at a distance, be it somewhere else on the college campus, in another town or even in another country. What has made this possible is the recent advances in communication systems, most notably the Internet. The basic idea is for students to be able to carry out real experiments (as opposed to simulations) from the comfort of their own home by interacting with their computer.

Various pieces of software and hardware already exist to allow such experiments to take place, so design was never an issue. Instead, the main task involved selecting the most suitable of these. The selection process considered many aspects relating to both software and hardware requirements. These included:

- ease of use
- cost
- compatibility (including compatibility with the college's Virtual Learning Environment)
- security
- third-party requirements
- individual or group access.

[2] The Open University (OU) is a United Kingdom's university dedicated to distance learning (http://www.open.ac.uk).

For the learner, the project had to satisfy the following criteria:

- speed of access
- real time interaction - this will depend on the speed of access and the specification of the user's computer.
- ease of entry to online experiments – although present experiments may be accessed directly by simply specifying the IP (Internet Protocol) address of the computer controlling the relevant experiment, future access will be through the college's Virtual Learning Environment (VLE). This will mean the learner having to provide security information, such as passwords, to gain access.
- online guidance and support – an important requirement will be support for remote experiments by adequate instruction and notes. In addition, many sessions will be watched over by a tutor who will be able to respond immediately to queries or problems.
- effective feedback – since the learner may have to complete hours of work in preparation for his or her remote experiment, it is crucial that their view and interaction with the experiments makes the experience worthwhile. This may mean having the ability to obtain results or even just having a clear view of what is happening due to a high-quality visualisation system.

3.2 Awarding bodies

The Scottish Qualifications Authority (SQA)[3] is the principal awarding body for vocational further education in Scotland. The authority makes awards at non-advanced and advanced levels for a wide range of courses in the technical and business sectors.

All SQA modules take into account new technology and skills required by industry. SQA regularly checks all modules to ensure they remain current within the specified area of study and in light of new developments. Since one aim of the project is to allow certificated courses to be delivered entirely online, methods have to be found to ensure the integrity of these awards. In so doing, the project team will work closely with a representative from the SQA. Other awarding bodies the colleges have close links with include City and Guilds (C & G), the Engineering Marine Training Authority (EMTA), and the Business Training and Educational Council (BTEC).

Summary of aims

- to provide all users with an effective means of conducting experiments online.
- to satisfy awarding bodies of the security and authenticity of assessments.
- to offer greater flexibility to the learner.
- to allow learning institutions to share resources.
- to satisfy industries' demands for a better trained workforce.

4. Installation of remote workshops at West Lothian College

4.1 Hardware requirements

Due to the variety of courses available at the college, and the need for students to use several pieces of hardware during their particular course of study, it is necessary to identify the hardware that is common to most courses. The courses looked at included the Higher National Certificate and Higher National Diploma courses in Engineering and Mechatronics. The equipment requirement for these courses is as follows:

- robots
- Programmable Logic Controllers (PLC's)
- CNC mill
- CNC lathe
- computer software
- electropneumatic equipment
- Deltronics IT System – interface system based around the 8255 PPI.
- PIC controllers – Parallax.
- CAD packages
- CIM system – completely integrated system comprising manufacturing, material handling and inspection sub-systems.

Making all of the above available to the remote learner may be unrealistic in the short term, due to the support systems that have to be in place. Consideration must also be given to the needs of non-remote learners.

Another requirement is to control the length of time the student can use the equipment, so that other users also get a chance to work with it. A booking system would be available, and interfacing the hardware with some software applications would allow the college to control the access time for the equipment.

The hardware requirements for the college in order to put equipment online would be as follows:

- computer
- 2 web cams
- printer
- mouse and keyboard

[3] URL: http://www.sqa.org.uk

- equipment for remote experiments (robots, Deltronics IT control box, electropneumatic kits, Programmable Interface Controllers - PICs).

The candidate would require a suitable computer at home along with a web cam and input devices. Clearly, one problem that is still present when considering assessment online is that of security. Fortunately, there are many organisations with systems already available or being developed in order to solve the security issue These include simple systems using widely available equipment ranging from web cams to sophisticated software packages that are able to distinguish individuals from how they operate the keyboard. Whatever the eventual solution, which can probably never offer 100% security, security is an issue that will have to be looked at in some detail and would in itself warrant an entire project.

4.2 Software

The software package currently being used for the experimental stages is Remotely Anywhere, which allows users to access the equipment connected to the host computer from anywhere in the world via the world wide web. This concept was demonstrated at the Porto meeting and the user was indeed able to access the equipment situated at West Lothian College in Livingston from the University of Porto in Portugal. On this particular occasion, there were problems with time lapse, but the concept was demonstrated and proved to be feasible.

Investigations are still being conducted with regard to the system requirements for upgrading and eliminating these minor problems. The latter mainly involved the web cam and data transmission not being fast enough for real-time viewing and interaction. These problems should be solved once all the correct equipment is in place, even if the final intention is to use several cameras.

Another software package offering a more integrated and cohesive platform is National Instrument's Labview. Labview allows up to 50 students at a time to take part in online experiments. The approach is to create a virtual classroom where the tutor can hand over control of the experiments to one student at a time whilst the others are able to view what is happening. The benefit for the learning of using Labview is that it is relatively easy to use, in that front panels can be customised to suit the requirements of each individual group of learners.

One drawback of Labview is its cost. This is partly due to the need for expensive interface boards, particularly where the ability to read in analogue signals is required. Although the cost of Labview is not substantial, it could well form part of a larger future investment in remote learning; at present, however, there is the need to try to utilise existing equipment and resources, including the college's own Virtual Learning Environment (VLE).

Other systems for remote learning will be developed by other organisations, and at some point most educational institutions will make strategic decisions to pursue remote learning aggressively, investing time and money in the system that is best suited to their needs. This is still in the future, since before most courses are offered in this way there needs to be a clearer understanding of the pedagogical and social issues.

4.3. Remote workshop for robotics

At the moment, most effort has gone into a system whereby a remote learner can effectively train a robotic arm. This has involved the integration of various software packages, namely

- Scorbase for the robot
- separate packages to run the two web cams
- RemotelyAnywhere for remote access
- Learnwise VLE currently used by the college.

An obvious objective at this time would be to 'tidy up' the desktop, since all packages are currently installed in their normal form. This would involve the creation of a tidy, easy-to-use front end that the user can interact on but not interfere with – at the moment the whole desktop is prone to move around when in use. The VLE may offer a solution, or a separate piece of software that allows the combination of several packages into a single customised screen.

The robot is demanding in terms of the practicalities involved. Firstly, it moves. This produces enormous problems in terms of spatial awareness when trying to pick up and place an object. The benefit, however, is that when we eventually solve these problems of how, for example, to determine depth, then we should end up with a system that can be used for visualisation and interaction in most experiments. One solution is to have at least one camera with the ability to move around the robot's environment. A simple solution is to use a railway track with the camera attached to one of the train's carriages. However, this still only provides camera movement in two dimensions, but it is a start.

By means of web cams and Scorbase software, the user is able to train the robot. Video clips are also available in the learning pack to assist the user. When users have completed the activity, they simply return to the learning material on the VLE.

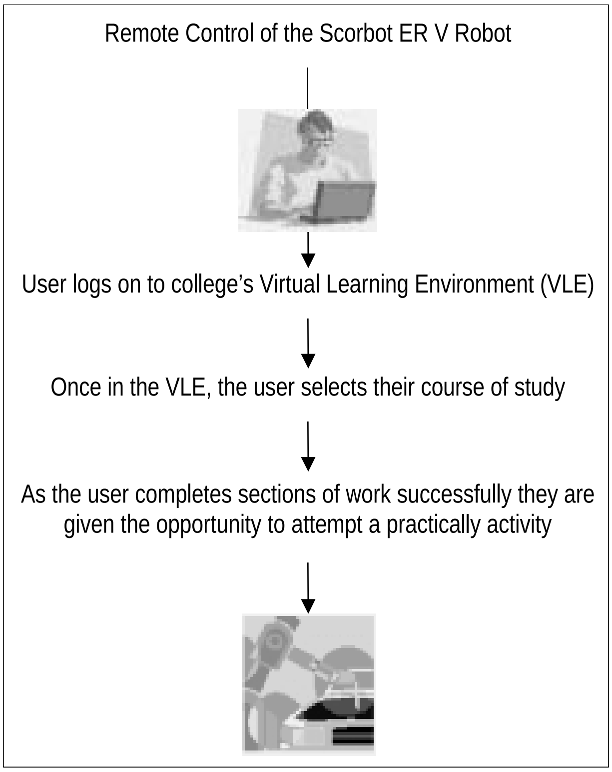

Fig. 5: Remote robot workshop access

5. Evaluation

In order to establish the true success and value of a project, evaluation is carried out on completion, although it is also essential to perform evaluation throughout the project in order to establish the best value requirements and the best technological requirements for development.

During the initial stages of the project, several options for development were considered and evaluated to ensure the best option was selected. The initial evaluation looked at methods of connecting students to the workshop, and the three options considered were:

- direct access via the World Wide Web
- access using third-party software
- access using a virtual learning environment (VLE).

The table 1 shows the areas evaluated and and the results obtained.

Although the virtual learning environment proved to be the most expensive option, it also offered best value by virtue of its allowing total control over student access and assessment. This option also provided greater flexibility, allowing various access options for group work and individual work while providing an environment that contained the complete learning package. Training notes, tutorials, practical exercise, formative/summative assessment and practical workshops could all be contained within the one package.

As planned access would be on a 24/7 basis it was important to establish the power of equipment and peripherals the students would have available to them either at home or at other learning establishments. The project would only be successful if the students had equipment and peripherals which were powerful enough to deal with the real-time access requirement. We also needed to establish current learning strategies to see how these would fit into the new learning methods proposed.

A questionnaire was provided (See Appendix) to about 100 students who were studying courses at different levels in the technology department, these levels are as follows

- Access
- Vocational
- National Certificate
- Higher National Certificate
- Higher National Diploma

We targeted present students who may be using the workshop facilities, as well as future students. It was evident from the results obtained that the majority of students already owned or had access to the necessary equipment and bandwidth.

A staff evaluation was also carried out to find out how many staff members had been involved with online remote experiments, and whether they felt these would provide good value for money and provide the student with a positive learning experience. The college is continually looking at methods of ensuring that the student learning experience is second to none, and the staff evaluation confirmed that online remote controlled assessment or experiments would provide the student with a more realistic approach to the practical element of the course of study they were taking.

With the ability to access practical workshops outside college operating hours, the student would be able to check results, retry experiments or test their own ability to carry out the task on their own or with a group of online students. The online practical workshop facility would also be available to other training providers or companies who had groups of students wishing to undertake specific training. Generic courses as well as specific training course could be provided.

Simulation versus real-life experiment

Whilst simulation software is widely used in education to provide students with practical experience and to acquire

	Direct Access through WWW	National Instruments Software	Access through Virtual Learning Environment
Cost	Inexpensive	Expensive	Very expensive
Flexibility	Can access many experiments	One software package for each experiment	Many experiments accessed through VLE
Host control	Limited control	Total control	Total control
Ease of use	Easy to use same method for all experiments	One software package to learn	Easy-to-use Common features of VLEs
Ease of Access	Easy to access	Easy to access	Easy to access
Access control	Limited control	Limited control	Extensive control
Number of experiments	Unlimited	Limited to software package	Unlimited experiments
Number of users	One	Fifty	Depends on licence held
Integration with study materials	No	No	Yes
Ease of understanding	Easy	Easy	Some learning involved but VLEs are similar

Table 1: Evaluation results

results on some of the theoretical work, simulation cannot replace the real-life experience of working with experiments and equipment which is working in a real-time environment. This does not mean simulation software would not be used, but that the students could work with simulation and real-time operations that together provide learners with the option of verifying what they have done using simulators prior to running real-time, real-life experiments. The learners' final interaction with an experiment will be as realistic as possible. Cameras are used to relay live pictures to the student that compare favourably to graphic or cartoon-like images of most simulation packages. Finally, live experiments contain the unpredictable nature of real life, whereas, in comparison, simulators tend to operate in an ideal world. With online workshops, therefore, the student will be dealing with issues they would have to deal with in the working environment.

Initial experiments controlling a stamp micro-controller and electropneumatics system were reasonably successful, and some simple workshop activities using the sensors and actuators that formed part of the stamp were monitored. During each of the experiments above, the tutor and learner were able to communicate by typing messages in a Word document. The view provided by the camera, although limited, still provided the learner with enough information to be able to assess how successful each experiment was.For the learner, clear, unambiguous instructions helped guide them through the requirements of each experiment. The camera view would show the element of the experiment they were undertaking. While the student carried out the experiment, the tutor viewed the same screen as well as the experiment in the workshop.

Safety

An important requirement of all experiments is the need to operate safely. This will inevitably mean that some experiments cannot be available to learners unless a tutor is present or all the necessary safeguards have been implemented. Safeguards should provide the ability to stop an experiment anytime the situation becomes critical.

Introduction of the Robotic system to the workshop proved to be slightly more problematic due to the bandwidth requirement for robotic operation and real-time viewing capability. Real-time operation with one camera and the available bandwidth is possible, but any additional camera option slows real-time operations considerably, yet additional cameras are necessary in order to provide some depth of field for accurate positioning.

With the workshop equipment in place and the college VLE used as a platform for the course materials and workshops, a practical evaluation of the package was carried out with students taking Robotics as a course option.

To ensure that the Scottish Qualifications Authority standards were met and that students were not disadvantaged by this evaluation, the normal method of delivery was run alongside the evaluation pilot; this also proved useful as a comparison between the two delivery methods.

After initial explanations and presentation of the system and some scepticism from students, they tried out the system and after a short period of operation eventually found it very useful, easy-to-use and trouble-free. Students found the various methods of contacting the tutor an essential part of the support system. Whether by email, telephone or appointment, support provided help with problems or supplied useful feedback on work submitted. The policy of 48-hour responses was acceptable and within a reasonable time scale.

All students involved in the pilot trial carried out most of their work using the online package and found the materials easy to navigate and very supportive. Students interacted well with the materials online and found them very useful in supporting the work already being carried out in the classroom environment. They found the links between the college course and the industrial course to be particularly relevant and found excellent continuity between them. The only difference between the college course and industrial course was the different robot make, but that has now been resolved.

Links with industry have always been an important part of any college course, in order to provide the students with opportunities to relate the teaching and learning to real-life situations. As far as this project was concerned, the link between the college course and the industrial element, provided by our Zenon partners[4], provided the links between the theory element, the practical workshop element and the reality of programming robots in real working situations.

Tutorials online were much easier for the students to carry out, as there were good hyperlinks between the notes, materials and tutorial questions, thus saving considerable time when revising their work. Some students did not use the online system as much as they could have, and this was evident in the learning process. Those students who interacted with the pilot project required very little classroom contact, whereas the ones who did not required much more classroom support.

The pilot evaluation provided useful information for future development of the system. Further development would see the ability of the robot to be used unsupervised 24/7, and the only costs regarding future delivery would be the redevelopment costs for upgrading materials, and the cost of a tutor whom the students can contact if required.

Creating VLE materials to a very high standard is expensive and time-consuming, but essential in providing support materials – especially if 24/7 access is provided. Sufficient time should be allocated for developing materials to ensure that exceptionally high standards are met. Students accessing a remote system and learning package need to be assured that all the materials are available on the system and that the package provides good, comprehensive coverage of the subject area.

The materials provided need to allow a natural progression through a course, as well as natural links between units. Materials should be supported by many links to industry, as well as other sources of information. We have found that using video clips to demonstrate the operating characteristics of the system has given students a better understanding of the concepts and requirements of the course.

6. Dissemination

Interest in engineering has waned in recent years, yet there are many opportunities to revitalise enthusiasm for engineering in this ever-changing environment. Introducing new and innovative ways of delivery, we use the MARVEL project as the launch pad for the Robotics programming sessions spent with 2nd-year students from all West Lothian colleges at the “Make it In Scotland” event. Twenty-four companies from the aerospace, pharmaceuticals, electronics, textiles, food and drink, construction and craft industries were represented. This event provided a perfect opportunity to promote the ideas behind MARVEL.

In Scotland, engineering as a career is perceived as a hard area of study, but we allay fears for young students by showing and explaining how studying engineering can be fun and exciting, as well as challenging and rewarding. Using our mobile Robotics workshop we were able to Promote MARVEL concepts as an innovative way of learning. The students found this to be a really exciting way of

[4] See article *Remote Programming and Configuration of a Robotic System: A Workplace Oriented Case Study* in this study.

carrying out practical workshop activities, and within minutes the students were writing and running their own programs online as well as offline.

Fig. 6: MARVEL dissemination at the "Make it In Scotland" exhibition

Events like these are very popular with the students and it is very encouraging to hear some of the following comments:

"Robotics looks very exciting, I never thought of it as a career option before"
"Wow! Can I really program the Robot from home?"
"I did not realise engineering covered such a wide range of areas".

Promoting these concepts at a very young age provides early learning opportunities for our engineers of the future. Disseminating information on the MARVEL project has been important in introducing the concepts to engineering companies, as well as in other teaching and learning environments. MARVEL concepts have been discussed with local engineering companies and other educational establishments, and they see real potential for the future if development continues in this area.

While conducting training needs analyses for local businesses, the opportunity arose to look at training needs for small and medium-sized enterprises, and to establish the areas where online workshops could support local industry in developing skills among their workforces. An example of requirements as identified by training needs analysis for a local company is shown below.

Training requirements

- Environmental Systems control
- Equipment programming and operation
- Diagnostics and testing.

Based on this outcome of analysis, a training programme could be established to develop the required skills using online workshops, without the need for the staff member to leave the working environment.

7. Summary

Online delivery is very expensive at the beginning, the time and effort to produce materials and the cost of purchasing and installing the hardware for a particular course are taken into account. If the cost is shared between many learning centres, then it may be possible for one learning centre to deliver a module such as Robotics to all other learning centres using the online facility, thus making costs more acceptable. This will avoid all learning centres wishing to deliver Robotics having to make large investments in hardware.

A considerable amount of time is required to produce materials which are of a high enough standard to be used in this method of delivery for remote operation or study, providers must consider the student experience and provide a comprehensive package which would assist the student under all conceivable situations.

Simulators these days provide very good graphics and it would be very difficult to tell some of them apart, so why the need for the real thing in learning? Our students found the simulator very good for practicing programming and testing programs, but they always felt there was no sense of reality with it, knowing that if they made a mistake then no harm would come of it. When they started to work on the real robotic system, they took a lot more time and care and worked with a great sense of safety in mind knowing the reality of the work. When programming a real robot over the Internet, even more care and attention was involved and in some cases a certain amount of nerves when it came to making final adjustments. The reality of programming a real robot can never be replaced by simulation, since in the real world the programmer has to be much more alert and aware of the surroundings and environment in which they are working, and must take into account unpredictable circumstances that are not present in simulation.

Online workshops provide learners with the real-time reality of carrying out workshop activities in many areas to which they would not normally have access. The real challenge now for training providers is to ensure that facilities are available which address the issues identified, to provide a wider range of participation amongst learners and industry within Europe and to foster harmonious integration between Europeans in the field of engineering.

The success of remote eLearning provides students with a whole new learning experience and will allow colleges and other institutions to be better placed in meeting the training needs of the 21st century and in providing the ultimate access solution in education, thus enabling access to teaching and learning resources and practical workshops wherever they may be, whenever it suits the learner.

References

Clark, G., Weir, G. (2005): Remote robotics eLearning course. West Lothian College, Livingston 2005 (also available on CD ROM).

Appendix

STUDENT QUESTIONNAIRE

Candidate ______________________ Course of Study ________________________

Level of study __________________________________

Please circle either yes or no. If you do not know the answer or it is not applicable then leave the question blank.

COMPUTERS

Do you have a computer at home?	YES / NO
Can you access a computer outside college working hours?	YES / NO
If you have a computer or have access to a computer does it have the following pieces of hardware connected?	
WEB CAM	YES / NO
PRINTER	YES / NO
MICROPHONE	YES / NO
MODEM	YES / NO
Do you know the specification of your computer?	YES / NO
If you have a computer or have access to a computer Can you access the Internet?	YES / NO
If you have a computer or have access to a computer Can you access the college WEB Site?	YES / NO

COURSE OF STUDY

Does your course include a practical element?	YES / NO
Do you require a computer for the practical element?	YES / NO
Do you feel you could carry out self-study unsupervised?	YES / NO
Have you ever used a virtual learning environment for study?	YES / NO
Have you ever used the student learning resource centre?	YES / NO
Have you ever borrowed course study books from the library?	YES / NO
Have you used the Internet for research or study information?	YES / NO
Have you ever carried out an online assessment?	YES / NO
Have you ever remotely operated an experiment on line?	YES / NO

REMOTE PROGRAMMING AND CONFIGURATION OF A ROBOTIC SYSTEM: A WORKPLACE ORIENTED CASE STUDY

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1. Summary

Robot technology is an applied science that is referred to as a combination of machine tools and computer applications. It includes such diverse fields as machine design, control theory, microelectronics, computer programming, artificial intelligence, human factors, and production theory. This article describes the development and implementation of an industrial robotic course that can contribute to remote vocational training and prepare the students for the industry. The first section describes the company ZENON and its role in the MARVEL project. The second section gives an overview of industrial robotic applications. The third section explains ZENON's robotic training program for its own personnel. The forth section describes the course developed in the project and the student learning environment. The last section reports the course trials experiences from the perspective of both students and ZENON.

2. ZENON Company Profile and Role in the MARVEL Project

ZENON S.A. – Robotics and Informatics is the largest robotics company and robotic services provider in Greece. The principle actions of ZENON are in the development, integration and delivery of complete solutions in the fields of automation technologies. The head offices are located in the company's privately owned facilities in Athens, Greece. ZENON is a member of the Athens Stock Exchange, having an annual turnover of 9.15 MEuros with a profit of 1.81 MEuros in 2003, employing 69 people. Products and solutions are directed to a broad range of industrial sectors from metal constructions, furniture and home appliances to food, transportation and defence industry. Applications include packaging, welding, assembly, painting, grinding, data collection, quality control through machine vision etc. The company is also involved in precision engineering, manufacturing precision parts, assemblies and systems for special applications. Over the years ZENON has developed considerable expertise in enabling technologies such as advanced sensors and actuators, motion and adaptive force control systems, real-time software development for demanding industrial applications including the ZENON automatic assembly system for a robot grinding cell for repairing aircraft turbine blades.

Since 1987, when the company was founded, ZENON has participated in numerous R&D projects, co-funded primarily by National and EU sources. ZENON R&D performs multi-disciplinary cutting-edge research based on the cross-fertilisation of robotics, sensors and IT technology. Prime target areas in robotics & automation are mobile autonomous robotics, automated inspection, rehabilitation engineering, tele-robotics and distance labs, smart sensors, as well as industrial robotic applications, such as automated packaging & tagging, welding and grinding and assembly automation. Recent research contracts focus on autonomous and cognitive robots (Robot Inspector, GNOSYS), smart sensors (LOCCATEC), Automated Inspection (RenewIT, PipeScan, FPSO Inspect), Image Processing and Machine Vision (Resew, D-SCRIBE), automated packaging (Spartacus), IT & automation in manufacturing (KoBAS) while several projects are a reflection of the emphasis given in key IT application areas, such as eHealth (ALLADIN), eLearning (eL-OTA) and eBusiness (WaCOM). Research is performed by well-qualified engineering personnel with expertise in mechanical, electrical, electronics and software engineering with competences in CAD/CAM, PCB & FPGA design, and software development for demanding real-time applications. Applications development is supported by well-equipped labs, assembly space and a modern workshop which includes CNC lathe and milling machine, 3-D coordinate measuring machine as well as conventional manufacturing equipment.

The ZENON Company, having substantial knowledge and experience coupled with availability of funds stemming from its entry into the Athens Stock Exchange, initiated a new series of investments. These investments are aimed at entrepreneurial utilization of advanced technologies, in developing new products and applications in fields of environment, energy, agriculture, security, training and the Internet.

The role of ZENON in the MARVEL project was, in collaboration with our partner West Lothian College (WLC), to provide to students an industrial robotic course that would contribute to remote vocational training and prepare them for the industry. The aim was for the students to experience and tackle tasks that are most commonly encountered in industrial robotics and that are fundamental to a person that would programme a robot for an industrial application

3. Industrial Robotic Applications

Robot technology is an applied science that is referred to as a combination of machine tools and computer applications. It includes such diverse fields as machine design, control theory, microelectronics, computer programming, artificial intelligence, human factors, and production theory.

The industrial robot is a tool that is used in the manufacturing environment to increase productivity. Robots are used to carry out routine and tedious assembly line tasks or tasks potentially hazardous humans in a variety of application areas. The principal reasons for placing robots in industry are summarized below:

1. Work environment hazardous for human beings
2. Repetitive tasks
3. Boring and unpleasant tasks
4. Multishift operations
5. Infrequent changeovers
6. Performing at a steady pace
7. Operating for long hours without rest
8. Responding in automated operations
9. Minimizing variation
10. Reduce labour cost
11. Eliminate dangerous jobs
12. Increase output rate
13. Improve product quality
14. Increase product flexibility
15. Reduce material waste
16. Reduce labour turnover

Typical application areas of robots include die casting, welding, forging, plastic moulding, spray painting, machine tool loading, palletizing, assembly lines in various industries, and replacing nuclear fuel rods in nuclear power plants. Hence the applications of robots in manufacturing are much broader than most people realize. More generally, the industrial robot applications can be divided into:

- *Material-handling applications:* Those involve the movement of material or parts from one location to another. They include part placement, palletizing and/or depalletizing, machine loading and unloading.
- *Processing Operations:* Those require the robot to manipulate a special process tool as the end effector. Applications include spot welding, arc welding, riveting, spray painting, machining, metal cutting, deburring, and polishing.
- *Assembly Applications:* Those involve part-handling manipulations of components/parts to build a product using special tools. Typically include material handling operations that are traditionally labour-intensive activities in industry.
- *Inspection Operations:* Those require the robot to position a work component/part onto an inspection device and to manipulate a device or sensor in order to perform the inspection. The robot may have an active or passive role. In the active role the robot is responsible for determining whether the part is good or bad (classification) whereas in the passive role the robot feeds a gauging station which determines whether the part meets the specifications.

4. Industrial Training at ZENON

In order to understand how the MARVEL training course was developed, it is essential to know how new personnel are trained at ZENON. ZENON's robotic training program aims at transforming inexperienced persons into suitably skilled experts capable of programming robots for a variety of industrial applications.

New personnel employed by ZENON - from now on labelled "trainees" - have diverse backgrounds. Many have no experience in the field of robotics or have only attended basic robotic courses at the college or the university.

Training is individually tailored according to the trainee's background and is regularly modified to accommodate for the trainee's progress. Most training is based on a trainee-tutor relation and lectures are rarely held. The trainee, assisted by a tutor, is given various tasks or problems to solve. The training program follows basic modules:

- Module 1 – Health and safety
- Module 2 – Familiarization with the equipment
- Module 3 – Basic programming
- Module 4 – Advanced programming
- Module 5 – Industrial programming

The basic training modules are described in detail below. ZENON tries to get the trainee involved in industrial programming as quickly as possible because we consider "learning on the job" to be the most efficient and productive method.

Module 1 – Health and Safety

This is the most important module. No matter how good someone is in programming, without the sense of safety the programmer will not only be in danger himself but will also create dangers for others. Most industrial accidents that occur are the results of unsafe acts by the worker. Such acts can take place due to improperly trained operators or careless programmers activating wrong controls. Other accidents occur due to component failure or other unsafe conditions in the industrial working environment. Safety is an important consideration and applies during software programming, installation, operation, and maintenance of industrial systems. The aim of this module is for the trainee to learn general guidelines and best-practices to minimize potential safety risks He/she must understand the three major differences between robots and conventional machinery that are of concern for safety:

1. Hazard zones
2. Predictability of movement
3. Speed of movement

In conventional machinery, recognized hazard zones are fixed in time. However a robot can be programmed to perform different tasks within a work cell and to react to changes in the process, thus the hazard zones changes with time. Reaction to process changes can result in unpredictable behaviour of the robot (e.g. a slow moving robot may suddenly accelerate to full speed).

These differences must be fully comprehended by the trainee because it is not possible to always remain outside the range of reach of a robot during programming. For example it is necessary for a programmer to be next to the robot when dealing with fine adjustments of the robot's movement.

Module 2 – Familiarization with the Equipment

This module is dived into two parts. The first part concerns robotic systems. The initial step for the trainee before starting to program a robot is to get familiarised with the equipment. The trainee is usually assigned an Adept robot and starts with studying the manuals. The trainee learns about the robot's arm geometry, controller and how to interface the controller and manipulator with the outside world through e.g. analogue signals, and digital inputs/outputs. This module provides the trainee with in-depth know-how for the specific system. The trainee follows the same procedure when assigned to a new system.

The second part concerns subsystems that together with the robot constitute a complete robotic working cell and additional subsystem that form part of the integrated automated solution. This part becomes relevant during the module Industrial Programming.

Module 3 – Basic Programming

When familiarised with the robotic system, the trainee starts to study the programming language for the specific robot. For example, the Adept robot uses a programming language called V+ that has long history and has evolved into a powerful, safe and predictable robot programming language. The trainee experiments with the commands and learns how to execute simple movements and record positions in an empty workspace. The trainee will be ready to program his/her first task after finishing this module.

Module 4 – Advanced Programming

Understanding the programming language enables the trainee to program his/her first real task. A typical task is a pick and place task in which the trainee builds a pyramid by placing 18 metallic cylinders (∴=20 mm, h=30 mm) in a rack on the table in front of the robot. He/She starts the general design of the task, e.g. deciding where to build the pyramid, how many cylinders to use and cylinder spacing in the pyramid. He/She then continues with deciding the workflow of the robot, e.g. which cylinders to use from the rack, in which order they will be picked and placed. The trainee is then ready to program the robot to execute the task. As mentioned before, the trainee is supported by a tutor to whom he/she can turn to for advice or to discuss encountered problems. The tutor also assists him/her by evaluating the workflow and code.

Module 5 – Industrial Programming

By now the trainee has obtained basic training, knows how to use a robot programming language and its basic commands, and is able to program simple robot tasks. That knowledge will now be applied in an industrial environment in which the trainee must not only take into consideration the robotic system but also the different subsystems that form a part of the whole work cell. Because of the increased complexity due to the interaction between the robot and the subsystems, the design of the program requires a great deal more time and experience. Therefore the trainee does not start with designing the program but is given old programs to examine. These programs have already been implemented in similar industrial applications and through analysis the trainee acquires understanding of the logic and flow behind larger programs. Together with the tutor, he/she then designs the program for his/her specific task.

The parts or dummy parts of the work cell that will affect the movement of the robot are constructed around the robot arm. The end effector or a dummy end effector is also attached to the arm. The trainee selects very slow travel speed of the robot and starts programming it using the teach pendant. The teach pendant is a hand-held device, which can be used to manipulate the robot instead of using a PC. The first step is to determine the new work envelope of the robot arm with the attached end effector. This is very important in order to avoid damage to the robot arm by the end effector, to the end effector, or to the work cell. The trainee then proceeds to program the robot, i.e. record the movements and positions of the robot needed for the application. As the industrial work cell is being constructed around the robot, the trainee also incorporates in the program the required interfacing with other subsystems included in the automated solution. For fine tuning, the program is downloaded onto a PC and is modified using an off-line editor.

The above sections gave a brief description of how personnel are trained at ZENON.

5. Industrial Training at a Remote Setting and Implementation

5.1 Remote Tutoring in Technical Training

At the start of the project we were very ambitious, we wanted students to have full control of the robot during the remote tutoring and to be able to program it over the Internet as in the course of West Lothian College. We examined this possibility because we wanted to go beyond the standard method for training on industrial robots. Today, in companies without in-house expertise, the normal procedure for learning how to programme a robot is to attend courses at the robot manufacturer premises or the manufacturer sends a trainer to the customer. Both options involve cost that the customer has to bear. To our knowledge no robotic training courses exist today that involve remote tutoring.

What are the limitations and requirements responsible for the absence of remotely programming industrial robots? It was found that the major obstacles and principal issues of concern for providing remote robotic access could be listed in the following order:

1. Equipment security – the need to safeguard the equipment from physical damage during remote operation
2. Computing security – this concerns Internet security, host PC security, and company network security
3. Programming environment – robotic interface

Equipment security relates to the possibility that the remote operator might damage the equipment if he/she is given full programming control of the robot. Even if supervised by a trainer, the trainer may not be able to react and press the emergency stop in a circumstance where the remote operator sends a command that will cause the robot to hit itself or objects in the work cell. To avoid such dangers specific supervisor software has to be developed that will monitor each command that the remote operator sends to the robot and decide if this is a valid command or not. It should be noted that if something is changed in the robot system environment then the supervisor software also needs to be updated to incorporate such changes.

Computing security involves normal network security to prevent unauthorised access to the equipment and/or the company's dedicated training network. Although this may seem as an ordinary problem for all companies, in the case of robotic training, it does not only concern the theft of company data, the spread of viruses, or server crashes but the possibility for someone to damage equipment with a value of many ten thousands of euros.

The programming environment is concerned with the fact that a special remote access architecture must be implemented to make the robotic interface system run under operating systems such as Windows instead of plainly accessing remotely the robot PC host. This is because most robots use their own operating systems. Special User Interfaces and Client -Server Software must be designed and implemented. Technologies that can play a role in the implementation of remote access software are Common Object Request Broker Architecture (CORBA) and Distributed Component Object Model (DCOM) architecture.

The above issues made us realise that it was not possible within the scope of the project to provide students with direct access to the robot but we still wanted to teach them remotely all the necessary steps involved in programming a robot in an industrial setting.

5.2 Overall Course Goal

The overall goal was, in collaboration with our partner West Lothian College (WLC), to provide to the students a robotic course that would cover all ZENON's training modules described in Section 4. Industrial Training at ZENON. We wanted students to experience and tackle tasks that are most commonly encountered in industrial robotics and that are fundamental to a person that would programme a robot for an industrial application. Modules 1-4 (Health and Safety, Familiarization with the Equipment, Basic Programming, Advanced Programming) do not require to be taught in an industrial setting and were implemented by WLC as a part of their Robotics college course. The challenge in the MARVEL project was how to use our industrial experience in order to transform Module 5 (Industrial Programming) into a course that can contribute to remote vocational training and prepare the students for the industry.

This transformation would not have been successful without the collaboration with WLC. Through fruitful discussions, mostly through emails, the WLC staff provided many useful suggestions during the progression of the course development. During this development WLC staff also actively evaluated our course as seen from a student's perspective.

5.3 Course Structure

As a requirement, in order to take ZENON's course, students would first need to complete the Robotics course at West Lothian College. Even if it is not realistic to assume that all aspects can be taught remotely, we identified which are the tasks that form the basis of all industrial robotic applications. These tasks are fundamental to a person that would programme a robot in an industrial application. The following tasks were identified:

1. Robot motion
2. Picking and placing of objects (palletisation, stacking operations)
3. Acknowledgment of external input signals from external subsystems
4. Provision of outputs to external subsystems
5. Error trapping for equipment safety.

For a student to encounter and apply each of the identified tasks in a holistic manner, the tasks were incorporated into four exercises that together form a complete workflow of an industrial robotic task. All the exercises are routine activities in industrial applications and students learn about realistic motions in a restricted workspace and the importance of controlling in/outputs that relate external processes automated by the robotic system. The following four exercises were designed:

<u>Exercise 1:</u> Pick and place – from the start position of the robot, pick a tray from the tray stack and place it in the designated place in the work cell working area.

<u>Relation to industry:</u> This exercise constitutes the most elementary and important task in industrial robotics. Most robotic processes in industry, in particular palletisation, stacking and unstacking operations, as well as assembly operations, make use of this simple task.

<u>Exercise 2:</u> Positioning a tool - pick a pipette from the pipette holder and prepare it for withdrawal and dispensing of chemicals.

<u>Relation to industry:</u> In this exercise the student will realize that the robot motion needs to be programmed very carefully according to the application and the restricted environment of the robot. In the exercise the student is put in a setting where it is crucial that parts of the motion are accurate and slow.

<u>Exercise 3:</u> Using the pipette for dispensing – extract chemical after lifting the lid of the chemical beakers (external subsystem) and dispense the chemical in the tray.

<u>Relation to industry:</u> This exercise is a continuation of the two previous exercises but it is extended by interfacing with external subsystems in the robot's environment, handling error trapping of the subsystems and using the pipette.

<u>Exercise 4:</u> Clean the pipette and return it – clean the pipette in the washing area (external system) and return it to the pipette holder before returning the robot to its starting position.

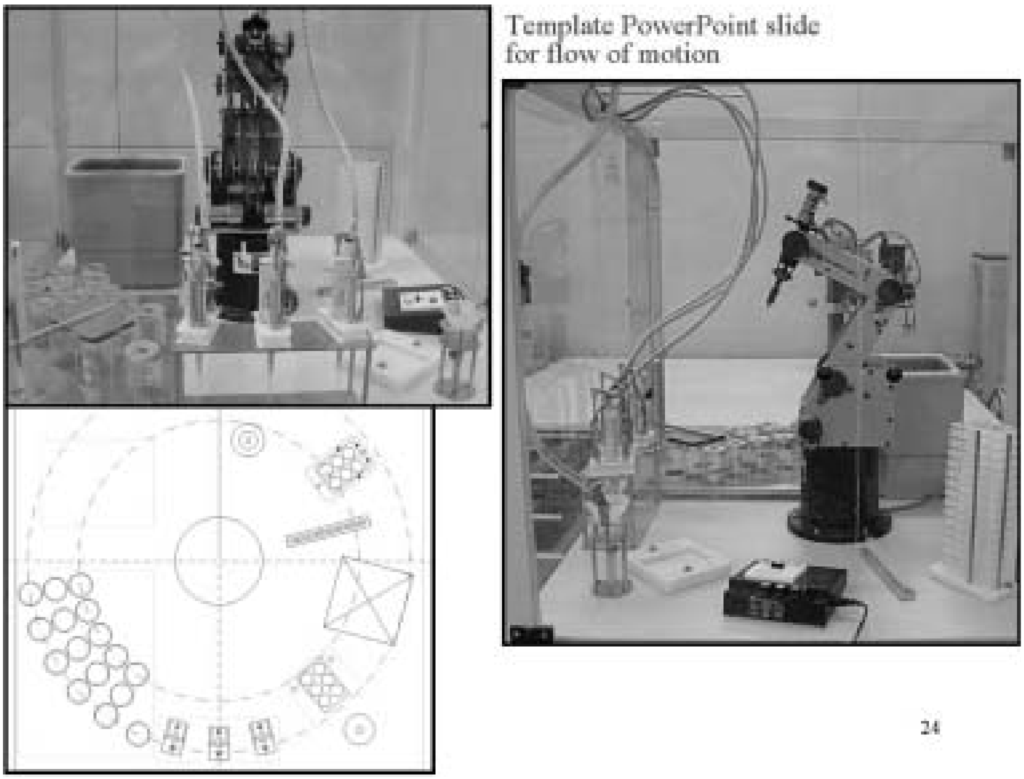
<u>Relation to industry:</u> In this last exercise the student finishes the complete workflow of the robot and the robot is ready to carry out another task.

The final result of each exercise is the program that when uploaded to the robot it will execute the tasks of the exercise. The student follows three steps to arrive at the final program:

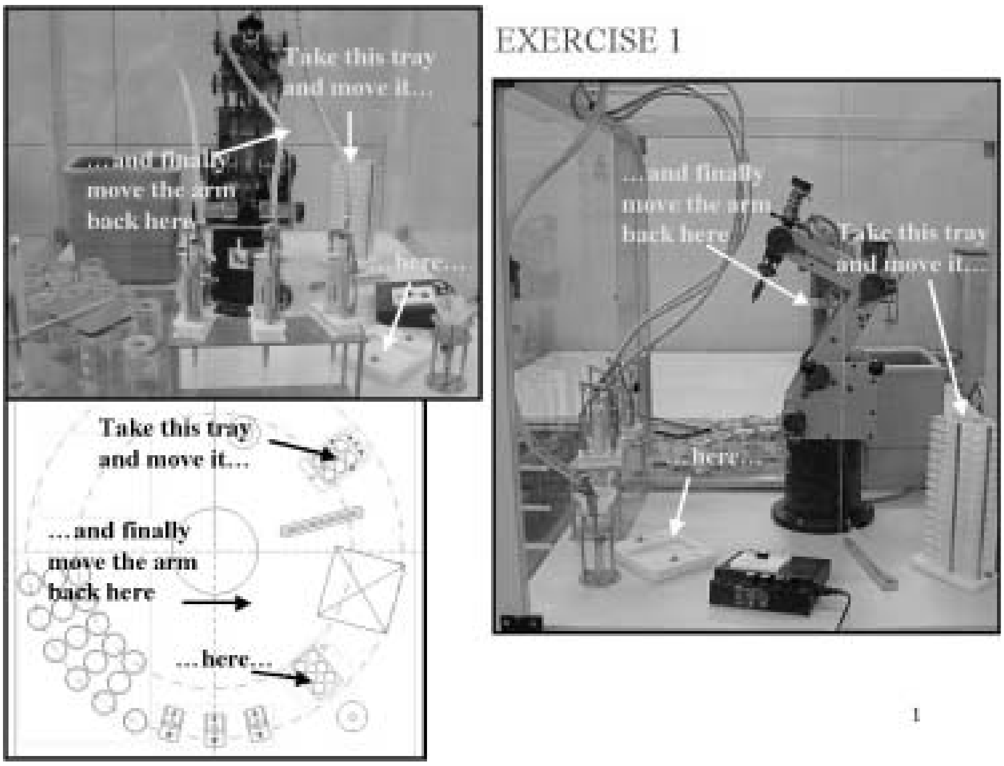
1. Motion programming
2. Writing pseudo code
3. Writing real robot controller code

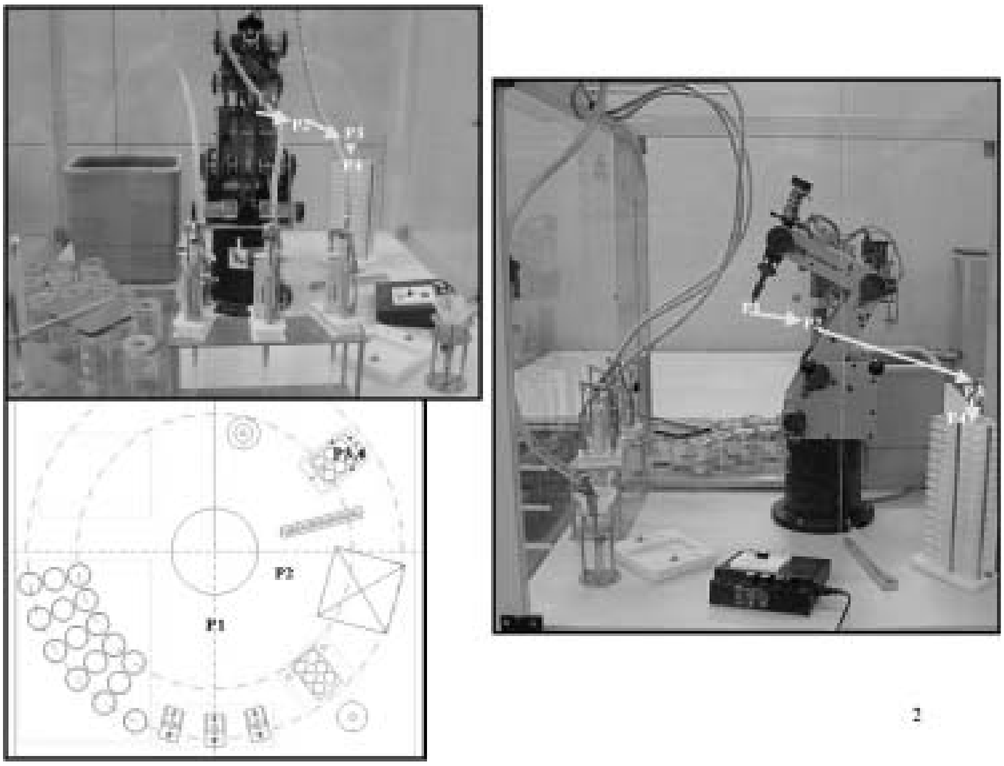
Motion programming

Students will first determine the positions through which the robot needs to move to carry out the exercise. The students are given PowerPoint slides with instructions of what to do. Using a standard template slide they will be able to fill in the motion sequence of the exercises. The template shows the robotic system from the front, side, and top view and allows for positioning the robot in the workspace. The students will then send this PowerPoint presentation to the tutor, and following discussion and feedback on the selected positions, the student will be able to proceed to writing pseudo code.



Below is the slide for Exercise 1 and the proposed solution for the first instruction.





Writing pseudo code

Following the motion programming with the PowerPoint file the student will write pseudo code of the robot controller code. The purpose of asking the learner to write the pseudo code is to enable him/her to think of the logic of the flow of events as well as other issues such as setting outputs, reading inputs, setting speeds, delays etc. and other factors that cannot be represented simply by flow of motion and sequence of positions. The students will then send the pseudo code to the tutor, and following discussion and feedback on the code, the student will be able to proceed to writing real robot controller code.

Writing real robot controller code

Following the above steps the student is asked to write the real code of the controller. In this step, the student is provided with a list of the pre-recorded positions that were selected in the motion programming which need to be used in the physical code as well as the output or input channels that may be required by the exercise. Following this step, the tutor provides feedback to the student with corrections to his/her code and this ends the exercise.

5.4 Robotic System Learning Environment

The robotic system was chosen in cooperation with WLC. We have a variety of training robots to choose from but since module 1-4 would be made in WLC, we selected to upgrade and modify a robotic system that was developed in the European project PEARL “Practical Experimentation by Accessible Remote Learning” and was used by students to carry out wet chemistry experiments in the same way as they would do in the normal lab (Figure 1).

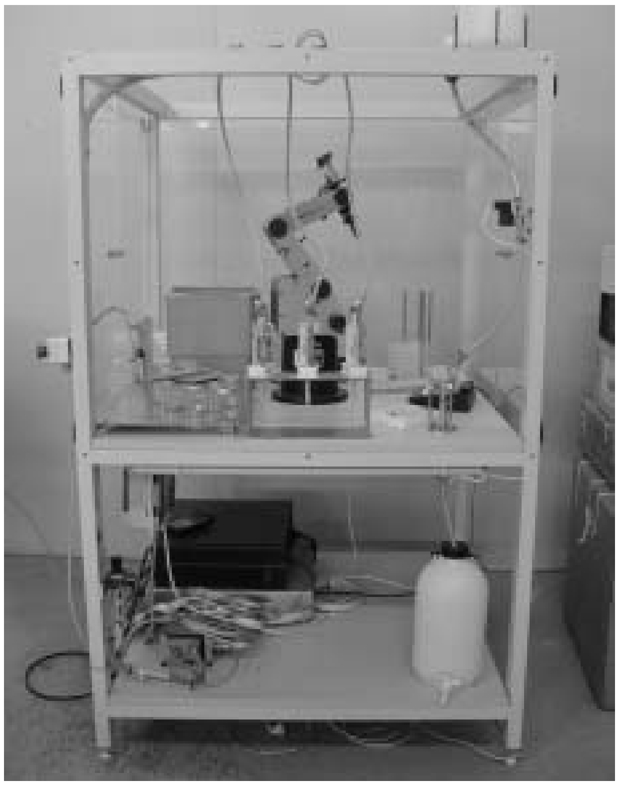


Fig. 1: The robotic system used in MARVEL

The reason for selecting this system is that it uses the same robot type as the one that is used in the Robotic courses of WLC. This means that the students will have acquired knowledge of its functions and programming language before carrying out ZENON's course.

The system has many features and can be regarded as an excellent scaled-down example of a large industrial robotic application but with fewer safety issues involved. The system includes a full work cell thus the robot has a modified work envelope that must be considered during programming because the robot has to avoid collisions with obstacles such as the pipettes, the trays, and tubes.

The system has three principal components: the frame, the experiment area, and the Eshed Scorbot ERV+ system. The frame supports the experiment area. It also provides an area for the placement of the robot controller, the electrical cabinet, and air pressure distributor. It contains two double doors so that the system operators can easily access the experiment. The exercises are carried out in the experiment areas, see Figure 2.

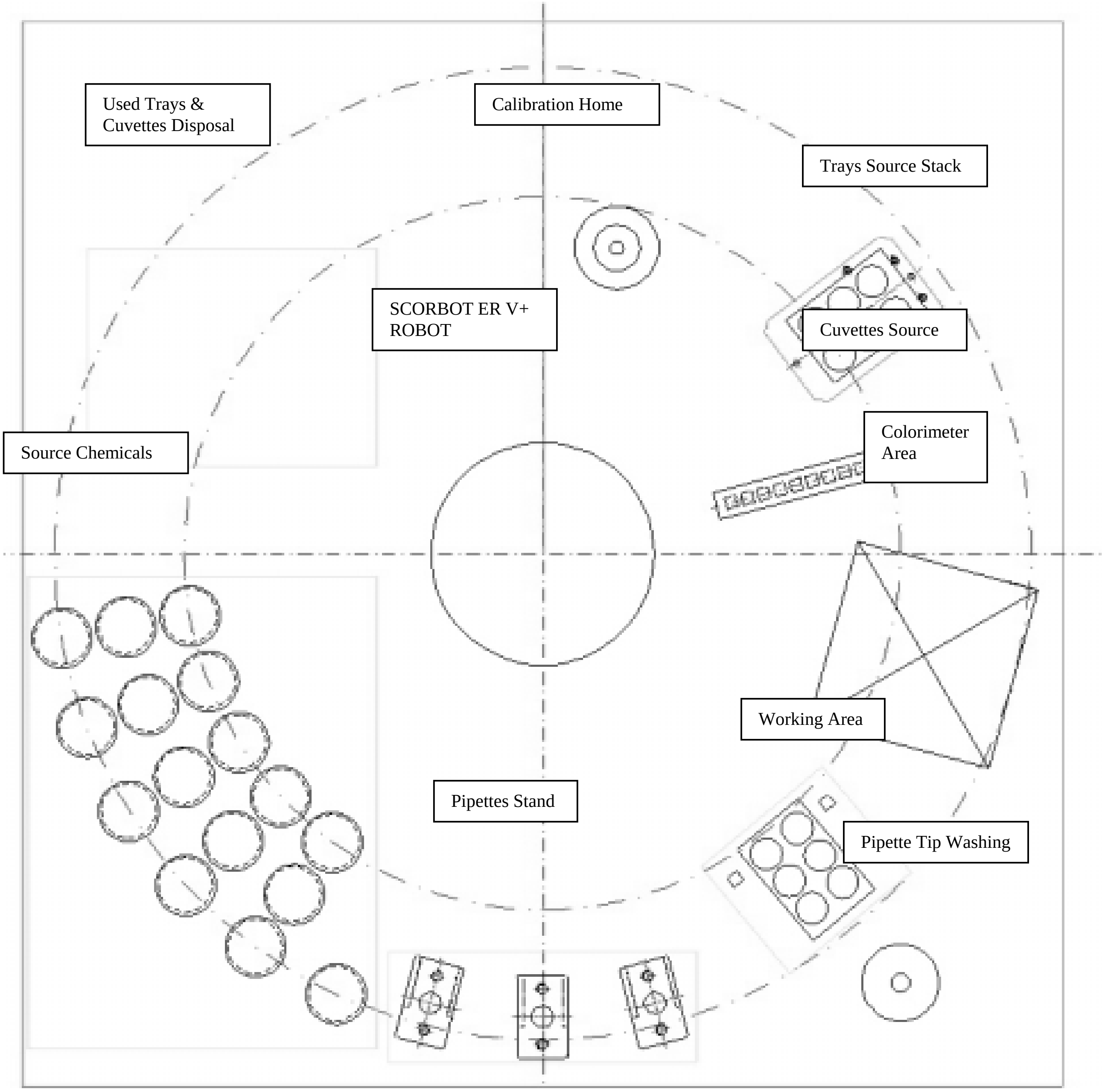


Fig. 2: Experiment Areas

The function of each area is as explained below:

- Calibration Home - This position is used by the calibration program to calibrate the robot and it must be executed by the tutor prior to using the system.
- Trays Source Stack and Cuvettes Source - These areas are the source of new trays and cuvettes for the exercises
- Colorimeter Area – This area contains an colorimeter but is not used in the MARVEL exercises
- Working Area - This area is used for placing trays and cuvettes used for chemical experimentation.
- Pipette Tip Washing Area - The tip washing is performed by utilizing a source container filled with deionised water (5 litres) which is located on the top of the jig. There is also a drainage container (10 litres) located below the experiment area. Two electric valves control the water flow and enable the rinsing of the pipette tips. Tips have to be washed prior to pipettes being placed back at the pipette stand.
- Pipettes Stand - This is where all 3 pipettes (1ml, 0.5ml, 0.12 ml pipette) are located. They are interfaced with a pneumatic system that controls the dispensing of liquids. Upon completion of every dispensing process all pipettes have to be returned to their designated positions.
- Source Chemicals - Chemicals for experiment are stored in the beakers numbered from 1 to 16. consisted of metal salt solutions, reagents, deionised water, and aluminium solutions.
- Used Cuvettes and Trays Disposal Area – This is a garbage bin for used cuvettes and trays.

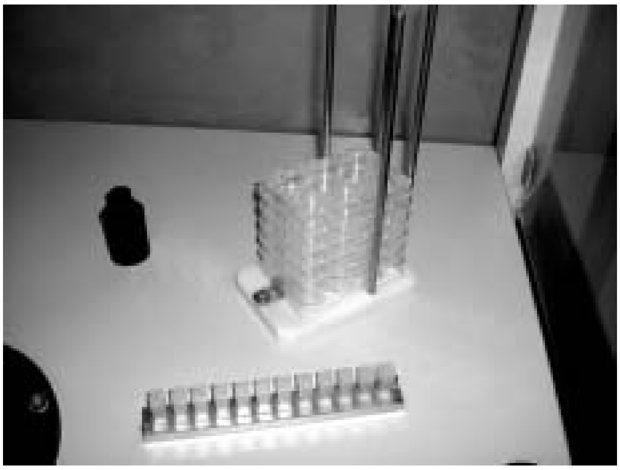


Fig. 3: Calibration Home (left top), Tray Stack (right top) and the Cuvettes Source (bottom)

Fig. 4: Colorimeter Area (top), Experiment Working Area (left), Pipette Washing Area (bottom)

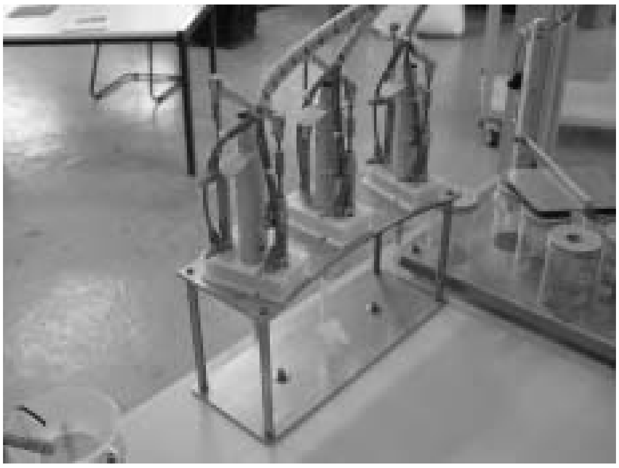


Fig. 5: Pneumatic system for dispensing liquids using pipettes, Source Chemicals (right)

6. Evaluation of Course Trials

Since the start of the project there has been a close collaboration between West Lothian College (WLC) and ZENON. During the development of the course the WLC staff trialled the course several times in order to ensure a smooth transition from the college to the industrial course. The concept of using a three-view PowerPoint slide depicting the robotic system arose from these trials because we discovered that bandwidths issues at ZENON would not allow using live streaming video during the exercises. It was only possible to use the webcam to take snapshots which were then sent over via email.

Following the final course design, students at West Lothian College that had participated in the college robotic course undertook the industrial course.

Fig. 6: Preparations before exercises

Their experience was evaluated by the WLC staff and students felt that the work with the industrial sector was a natural progression from the work they were carrying out with the college course. The theory and practice they had carried out on the college programme provided them with the skills they needed to tackle the industrial problems set by the industrial course.

As in the college course, the use of email communication for discussions between tutor and students while carrying out the exercises was found to be a good solution as the students could read, digest and discuss amongst themselves before carrying out the instructions set by the tutor. One major problem of using the telephone was that the students could understand the tutor but the tutor had issues with understanding Scottish accents.

It took the students a bit of practice to use the PowerPoint and determine the positions during motion programming; they sometimes found it a little bit difficult to form a 3D perception of the robotic system.

The students felt that the industrial course was very important in adding an important realistic aspect to their work linking college work with the real, industrial robotic world. By using the industrial connection they could see the true end-product of their studies.

Students also felt that the method of programming and operating the industrial robot was very appropriate and understood the need for the control measures in place to ensure correct programming and operation of such a system.

Students commented that the continuity and relevance between college work study package and the industrial package was very good however the one thing they felt caused a slight problem was the different versions of robots being used. Although the programming of each robot is similar the students felt continuity was slightly broken between the two. This has since been rectified and WLC has installed the same robot model.

From ZENON's perspective, the trial proved that students can be prepared remotely for industrial robotic programming. Remote tutoring can never substitute programming in an industrial setting but the evaluation showed that the students learned the principles and functions and most importantly the work flow of an industrial robotic work cell.

One problem with our course is inflexibility. Many times more than one solution to the task execution is possible but in order to program the robot the students need to have pre-recorded positions. It is not feasible to pre-record all possible positions and it takes time to record a new position for the student.

A second problem for an SME like ZENON is the infrastructure required to deliver this course. Apart from the need of high bandwidth connection for video/audio stream already mentioned, the course requires a considerable investment in a robotic system solely dedicated to remote training. For this to be financially viable there would be a need for fees from a regular flow of students over a period of time and a sufficient amount of training activities in order to justify a full time employee dedicated to training as it is generally not possible to schedule an employee with other responsibilities to perform remote tutoring activities.

References

IST Project PEARL "Practical Experimentation by Accessible Remote Learning" (Ref. No. IST-1999-12550) [http://www.kmi.open.ac.uk/projects/pearl/]

ENGINEERING FUTURE LABORATORIES

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1. Introduction

This chapter describes some ideas about how future laboratories might be structured. Experience gained in several European projects such as DERIVE (Distributed real and virtual learning environment for mechatronics), MARVEL (2005) and Lab@Future (2005), in which on-site and remote components, theory and practice merge into a cooperative learning process, are discussed and further perspectives elucidated. The laboratories envisaged allow users to work with complex and simple, real and virtual systems, isolated or embedded parts, local or distributed components, thus allowing a continuous shift between various degrees of abstraction and various levels of co-operation. The learning environments include supportive web databases with multimedia learning sequences, theoretical background, exercises and assistance with specific experimentation tasks. Hardware equipment can be connected to the virtual environment with special bidirectional sensor-actuator couplings (hyperbonds). Future laboratories will benefit from further developments in computer simulation technology, mobile computing and sensor/actuator devices, integrated equipment supporting hardware-in-the-loop functionality, and enabling connections to be made between real-life phenomena and their virtual representation or continuation.

2. Engineering laboratories for education

One advantage of engineering laboratories for education and training in mechanics, electrical engineering, electronics, electrodynamics, thermodynamics, fluid dynamics and the like is that they provide reproducibility and often safe conditions for experiments, reducing the complexity of real physical phenomena to a manageable and fruitful educational level. Fruitful in the sense that experiment and environment can be designed by the teacher to match students' level of knowledge, so that "zones of proximal development" (Vygotskij, 1987, Engeström, 1987) might be unfolded. However, engineering laboratories also have the disadvantage that they deliver predesigned and therefore predetermined conditions, reduced complexity, and presumedly optimised zones of development. In other words, their advantages can also be disadvantages. Depending on the underlying educational theory and practical experience of the teacher, the disadvantage might be seen as an advantage, or vice versa. The question arises as to whether we can design laboratories that provide both aspects – safe and dangerous, concrete and abstract, simple and complex conditions, bringing the laboratory into real life and real life into the laboratory. Some prototypical work in this direction will be presented.

3. Complexity in engineering

In engineering domains like mechatronics, we are confronted with the need to develop theoretical knowledge that is integrated into practical learning sequences in order to meet the requirements for multi-skilled engineers and skilled technicians. Task- and problem-solving in mechatronics requires cognitive and operational knowledge and practical experience in building systems, and in diagnostic and maintenance techniques. Understanding and designing mechatronic systems also requires experience with both physical elements and logical elements (i.e. computer implementation of control algorithms). Given that these elements are closely connected, however, it is important to study them not only separately, but also in closed loops. This means that interfaces between the two worlds, the physical and the digital, is becoming increasingly important.

Simulation tools may be useful for studying system behavior at a theoretical level. Using simulation tools has a number of benefits for education. The learner is not exposed to the hazards of the real world, is able to explore a range of possible solutions easily and quickly, and is able to use the software tools and simulated real tools that will be available in industry. Simulation tools are significantly less costly than real-world components, and allow greater participation and interaction than a limited demonstration. The question, indeed, is to what extent real experience can be replaced by simulation-based learning. There is no general answer to this broadly framed question. Depending on the pre-knowledge of learners, we suggest that the "zone of proximal development" is best expanded by a mixture of reality and simulation models, and that the learner understands the process of abstraction when real phenomena are represented by computer models and series of simulations replace real experiments.

Real and virtual components can be loosely mixed, with real and virtual parts of a system co-existing in a more or less uncoupled fashion. We call this coupling the *duplication of reality*. With this type of coupling, the real system may be observed and compared with the results of a separate simulation, with discrepancies leading to improvements in the simulation model and stimulating a new cycle of experiment and comparison. However, the mixture might also be based on a tight coupling of the real and the virtual world. We call this type of coupling the *continuation of reality*. This allows different types of experiments to be conducted: well understood and modelled components can be implemented in virtuality and used in conjunction with and connected to components still under investigation. A migration from the concrete to the abstract, but also from the abstract to the concrete would be possible, thus fulfilling an age-old aim of educationalists.

Another aim stems from the need for cooperation in laboratory experiments. In conventional laboratories, working as a group of experimenters with equal rights and balanced participation was not a problem. In the case of simulators, it is very difficult to establish balanced participation due to the restriction of having only one user interface. Multi-user environments with simultaneous access to the construction and processing of an experiment are very rare. To provide such features, new ways of interfacing the real and the virtual world are necessary. Hyperbonds are a technology we introduced in an effort to fill this gap (Bruns 2001).

4. Bond graphs and hyperbonds

Hyperbonds combine the unified, abstract systems view provided by bond graphs with their real-life implementation, by establishing 'hyper-connections' between physical phenomena in the computer-external environment and the logical structure of computer-internal schema, i.e. a blend of physical systems with their virtual counterparts.

Paynter (1961) devised his theory of bond graphs as a unified way of describing physical phenomena in terms of a continuity of power flow. Power flows through system components and connections in such a way that the product of effort and flow is continuous, obeying typical laws of energy conservation and power flow continuity. Effort (e) is the driving force for flow (f) and can be a pressure difference, force and torque, electrical potential difference, temperature difference etc. Flow (f) can be a flow of material, momentum, electric current or entropy. The bond graph theory has been further developed by Karnopp et al. (1990). Effort/flow pairs (e,f) in mechanical systems, for example, are force (F) and velocity (v), in electrical systems voltage (V) and current (i), in pneumatic/hydraulic systems pressure (P) and volume flow rate (dQ/dt). Figure 1 explains the correlation of pressure p, fluid flow q with force F, velocity v and mass/inertia I, compressibility C of the fluid and friction R in a simple pneumatic device.

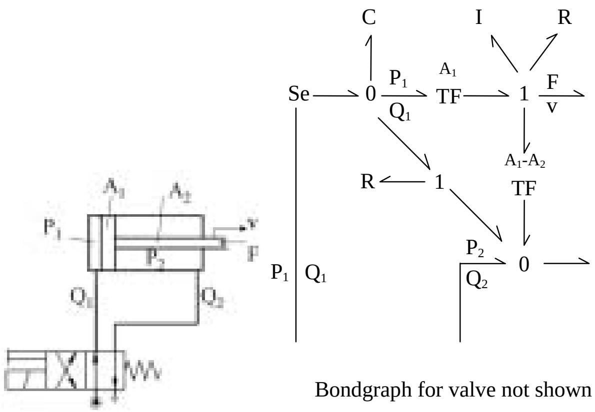

Fig. 1: 4/2 way valve controlling a double-acting cylinder and its bond graph

Components (valves, cylinders, etc.) are always connected by bonds having the value pair e and f, where one element can be seen as input from a cause-effect perspective, and the other as output. However, which one is input and which one is output can only be determined from an overall systems view by causal reasoning. Knowing e and f at one connection, as a result of calculation or measurement, allows the system to be cut into two parts for separate investigation.

In mechanics, one learns the principle of cutting a system at well-defined boundaries and replacing the external influences by some observable and measurable variables, reducing the investigation to the internal dynamics of the remainder. In laboratory work, this principle is used to construct reproducible experiments, but it is also used mentally to think about systems in terms of hypothetical and mental experiments. In modern-day laboratories, with their intensifying use of computers, free and easy distribution of a system between reality and virtuality offers a number of advantages. Certain well-known aspects of a system can be formally represented in the computer using algorithms, while other aspects being investigated in more detail are represented in reality, but coupled to dynamic surroundings. This allows completely new forms of simple experimental work and learning. This is where hyperbonds come into play.

In order to provide arbitrary boundary conditions, we must have a mechanism for switching between the source of effort and the 'sink' of effort (i.e. the output), and for generating one and sensing the other. Figures 2 and 3 explain how the connection between reality and virtuality (and vice versa) is realised with a special sensor/actuator coupling. Hyperbonds are also possible for other pairs, of course, such as voltage V and current i, Temperature T and heatflow dQ/dt, or mass M and velocity v.

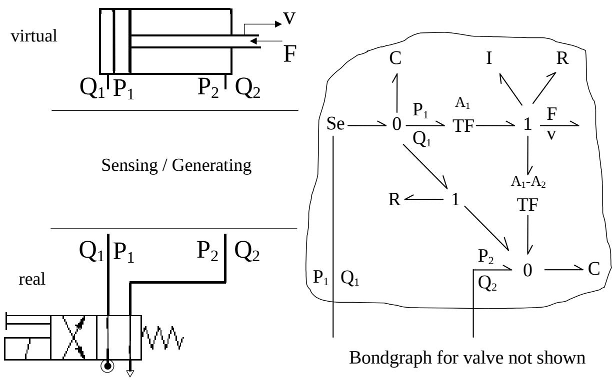

Fig. 2: Hyperbond for the system in Figure 1, maintaining mixed reality

Hyperbonds are a technique for translating physical effort/flow phenomena into digital data, just like any other analogue/digital and digital/analogue conversion. However, it aims at a unified, application-based solution connecting the physical, on the one hand, and its virtual representation and continuation, on the other. Figures 2 and 3 are highly simplified diagrams. For a deeper understanding of hybrid bond graphs and how to handle discontinuities, boundary cuts and transfers between power flow, signal flow and logic switches, see Mostermann.

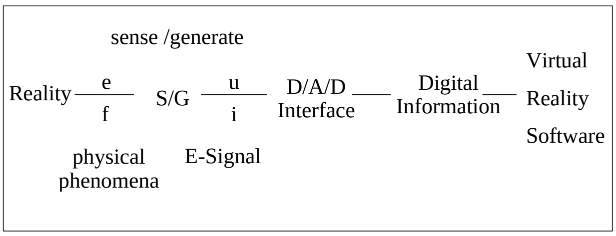

Fig. 3: Hyperbonds

5. Experiments with laboratories

The European project entitled 'Distributed Real and Virtual Learning Environment for Mechatronics and Teleservice' (DERIVE) used the concept of hyperbonds to describe electropneumatics (Bruns et al, 2002) in a unified and didactically expandable way, and to establish links to several powerful simulation tools supporting bond graph modelling. DERIVE provides a new learning environment, named *deriveSERVER*, that helps engineering colleges to deliver mechatronics courses. The learning process is supported by a progression from local/real to local/virtual to remote/virtual to remote/real, taking the student from basic knowledge to full implementation in industry.

The telecooperation functionality embedded in the learning environment allows enterprises to use remote laboratories for further training of their employees. With new equipment being more and more complex and requiring increasingly complex maintenance, training needs among engineers and workforces in general are on the increase. The new training environment allows groups of employees at remote locations to take part in the same training course, using the same equipment (either simulated or real). Employees undergoing training are able to work collaboratively to solve problems and explore learning situations. This new kind of interaction allows systematic support of skilled workers and engineers. In addition, the DERIVE learning environment is an appropriate tool for project-based technical training, providing a platform for self-managed and collaborative learning.

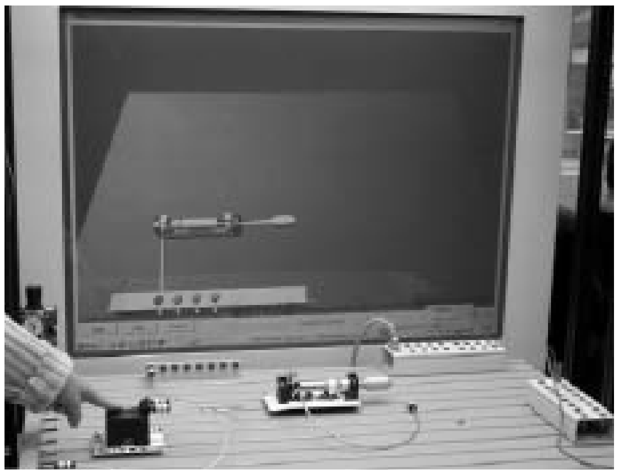

Fig. 4: Pneumatic equipment similar to that in Figures 1 and 2, split into reality and virtuality (single-acting cylinder)

In the DERIVE project, a mixed-reality human computer interface was developed (figure 4). If adequate technological and educational concepts for eLearning in future technical training are to be developed, it is essential to analyse user needs in depth. The needs and requirements of different user groups (students, teachers, employees) were described and consolidated. Acting in an environment in which real-world objects and IT technologies are applied simultaneously requires new concepts for supporting local and distributed learning groups engaged in collaborative learning. The scientific challenge is to handle physical as well as virtual presence and awareness without producing confusing side-effects for users. DERIVE evaluated the user-friendliness of the developed software, analysed behavioural findings in respect of communication and telecooperation, and identified the learning benefits of the prototype developed.

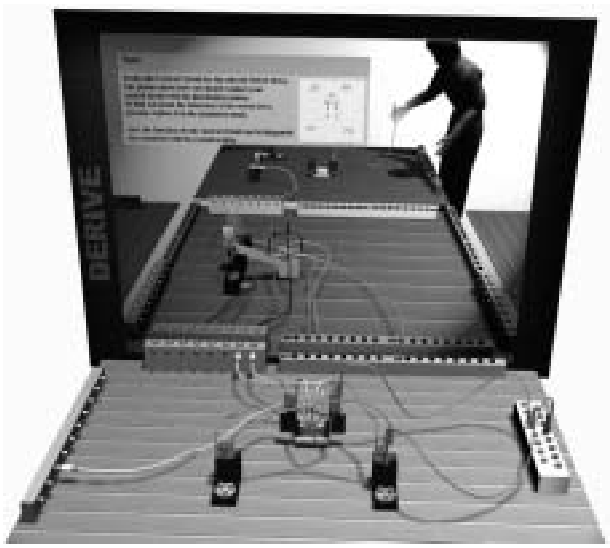

Fig. 5: Real and virtual training environment in electropneumatics. Objective: to control a robot arm

DERIVE developed a mechatronic system in which on-site and remote components are merged into a cooperative learning process. The system allows users to work together on complex real and virtual mechatronic systems, and consists of parts that may be remotely distributed. The learning environment includes support from a web database, with multimedia learning sequences providing theoretical background, exercises and assistance with training assignments. It seamlessly integrates equipment and supports hardware-in-the-loop functionality, thus enabling real mechatronic systems to be created as subsystems of complex virtual systems (Figure 5).

The environment was evaluated in 3 European vocational schools and colleges, and at one industrial site. The result, based on a prototype which was not yet very stable, encouraged subsequent development of a broad learning-landscape using both concrete and symbolic representations A comparative evaluation was made of:

- traditional teaching with blackboard and teacher-learner interaction;
- support from simulation only (FluidSim software from FESTO AG, Germany);
- support from real complex system only (Modular Production System/MPS from FESTO AG, Germany), and
- support from real and virtual media (DERIVE).

In 20 course hours in mechatronics, Grund and Grote (2001) found some indications that students/apprentices being trained with DERIVE showed good achievements in constructional assignments and fault finding, with no significant differences being observed with respect to factual knowledge.

MARVEL benefited from the outcomes of DERIVE, in that the learning environment developed in DERIVE was tested and used in MARVEL as well. Accordingly, we were able to demonstrate how learners can access the DERIVE laboratory facilities remotely and use them to solve typical engineering tasks involving electropneumatics and remote services (Müller, D., Ferreira 2005).

Lab@Future (2005) is an ongoing European project in which four different types of laboratories are integrated in a single multi-user communication and action platform for conducting experiments in fluid dynamics, geometry, history and ecology. Although significant progress has yet to be made with regard to platform independence, simplicity of installation and access, quality of service via Internet, organizational structure of distributed laboratories and stability of the interface, courses already held with students of mechatronics and computer science suggest that this type of laboratory work can provide a number of interesting benefits (Totter et al 2004). Rather than present quantitative results from our evaluation, we describe below a typical experimentation session in this type of laboratory.

6. Experimentation session

Modelling Task

1. Build a circuit for a welding operation: First activate a clamping cylinder with the push of one button. When this first cylinder has reached its end position (clamping a workpiece), a second cylinder, the welder is automatically activated. On pressing another button, the process is terminated and the clamping and welding cylinders move in, releasing the workpiece and stopping the welding process. Solve the task by using virtual parts and real parts of the platform at the remote lab as preferred. Consider how to define the problem definition and suggest improvements.

2. Use in virtuality:

- Double-acting cylinder with magnetic proximity switch
- Single-acting cylinders
- 3/2-way valves with push button, normally closed
- 3/2-way solenoid valve, normally closed
- 5/2-way solenoid valve
- Sources of pressure and voltage
- Hyperbond connectors between virtual and real
- Tubes and wires
- You can use these elements in reality, observable by video camera:
- Hyperbond connectors between real and virtual
- Single-acting Cylinders
- 3/2-way solenoid valve, normally closed
- Tubes and wires

The virtual solution could look like figure 6, with a double-acting cylinder1 (upper half), a 5/2 way solenoid valve, (figure 7, next page), a single-acting cylinder 2 (bottom right) and two 3/2 way valves (left). After verifying the expected behavior in virtuality (figure 8, next page), use the remote real laboratory whose available components can be observed in a video window and can be accessed via the hyperbond using the corresponding virtual-real connectors.

3. Now export virtual parts into reality: Connect a virtual pressure valve via hyperbond (first pneumatic connector on the right) with a real cylinder seen at the top right of the video image (figure 9, next page). Press the virtual push-button and see the single-acting cylinder moving out as long as the button is pushed (figure 9). On releasing the button, the air flows back from reality into virtuality and the cylinder moves in. In figure 10 (next page), most virtual parts are exported. Pushing the virtual button highlights active connectors in virtuality and moves real cylinders.

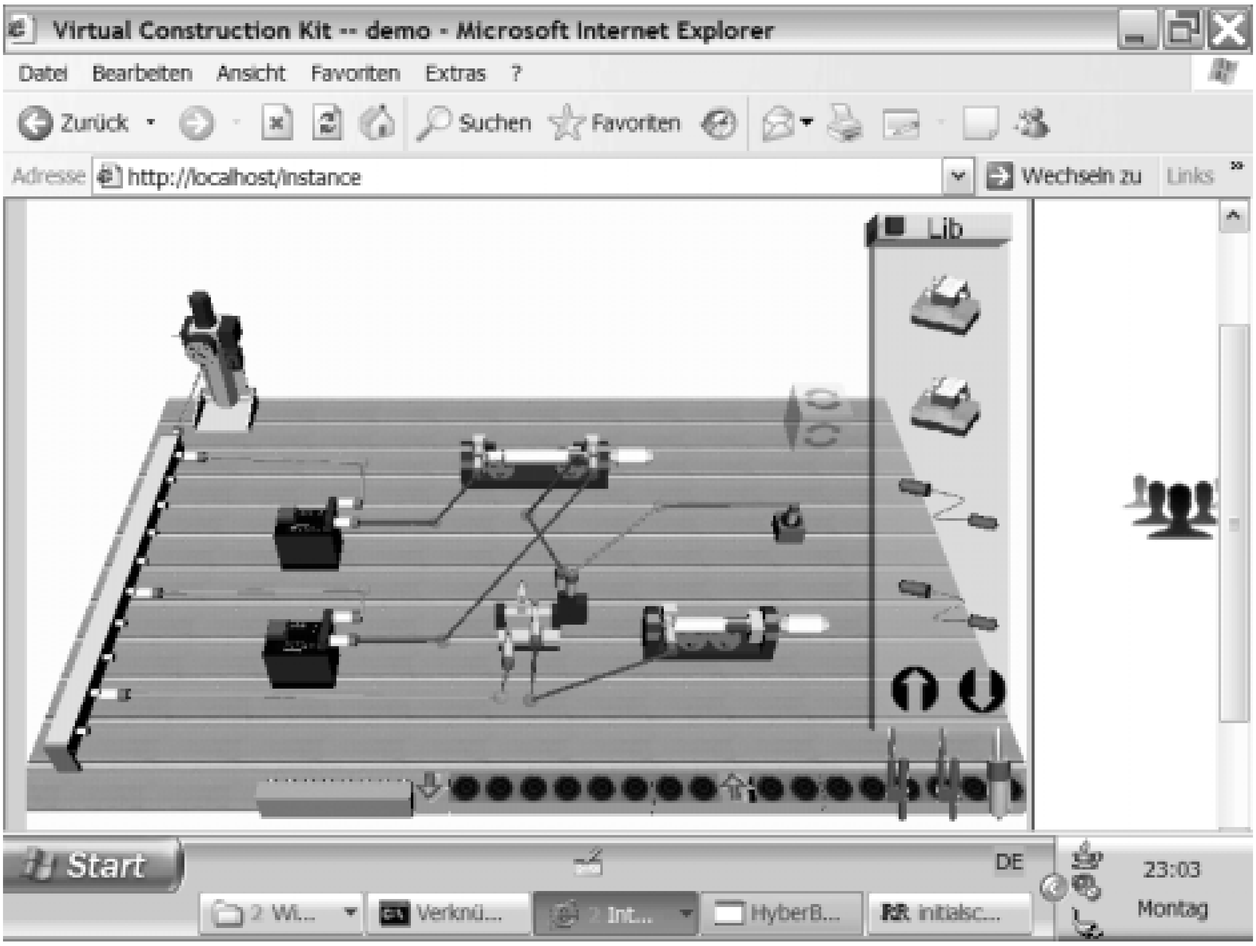

Fig. 6: Simple sequence of cylinders connected via 5/2-way solenoid valve

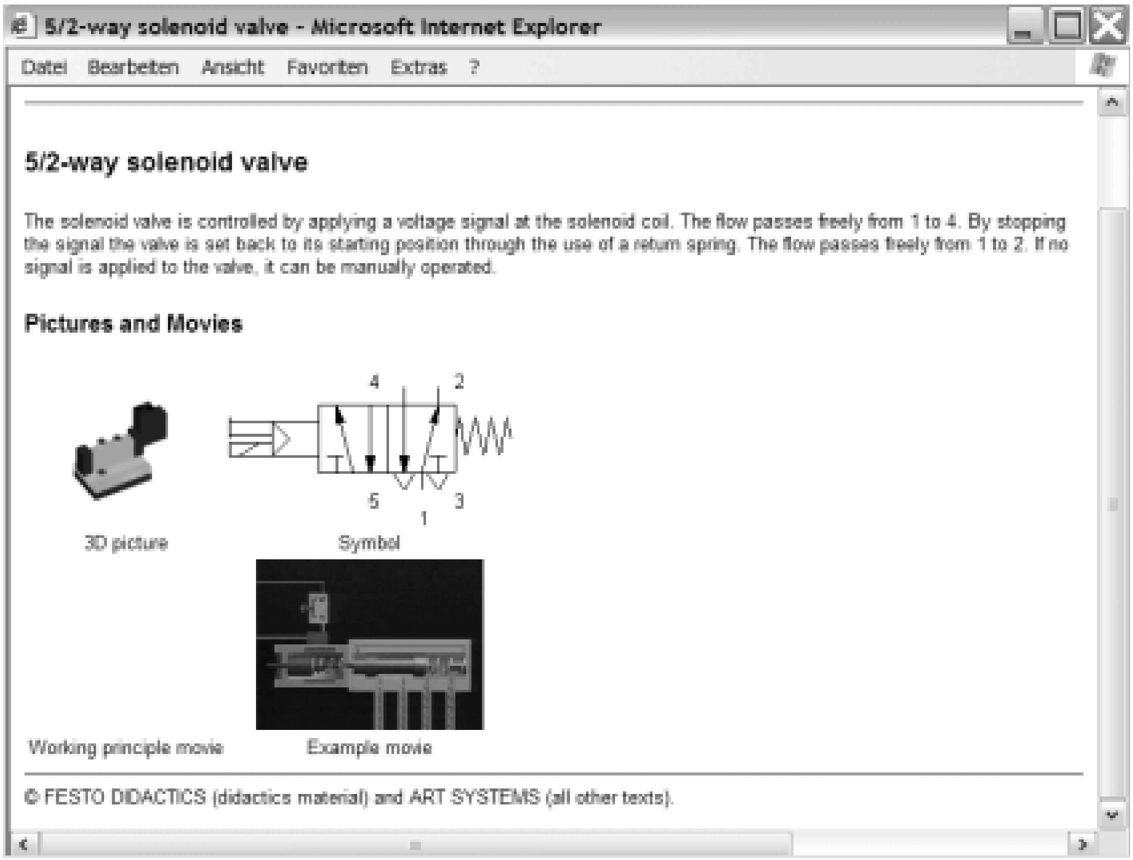

Fig. 7: Description of a 5/2-way solenoid valve, accessed using the Help function

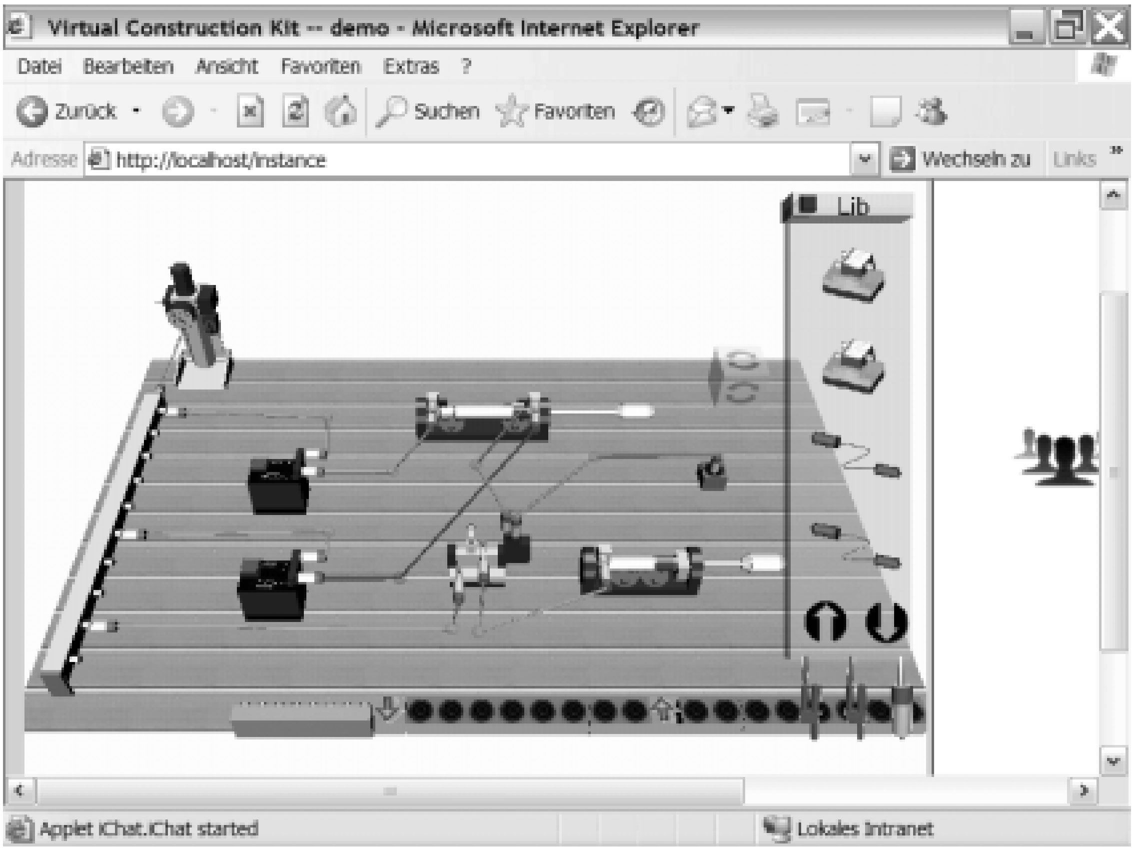

Fig. 8: Upper double-acting cylinder with magnetic proximity switch activated, activating 5/2 way solenoid valve, activating single acting cylinder

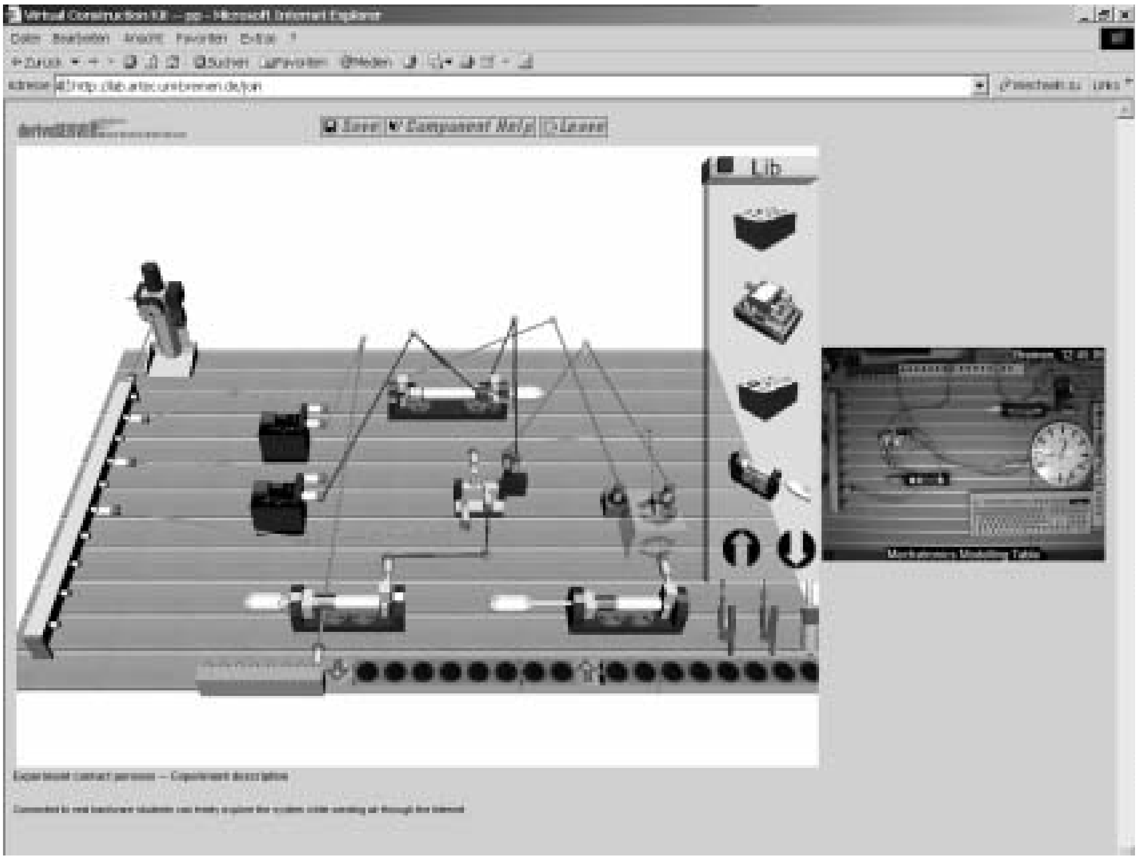

Fig. 9: Exporting pressure via hyperbond into reality, pushing real cylinder (top right) out

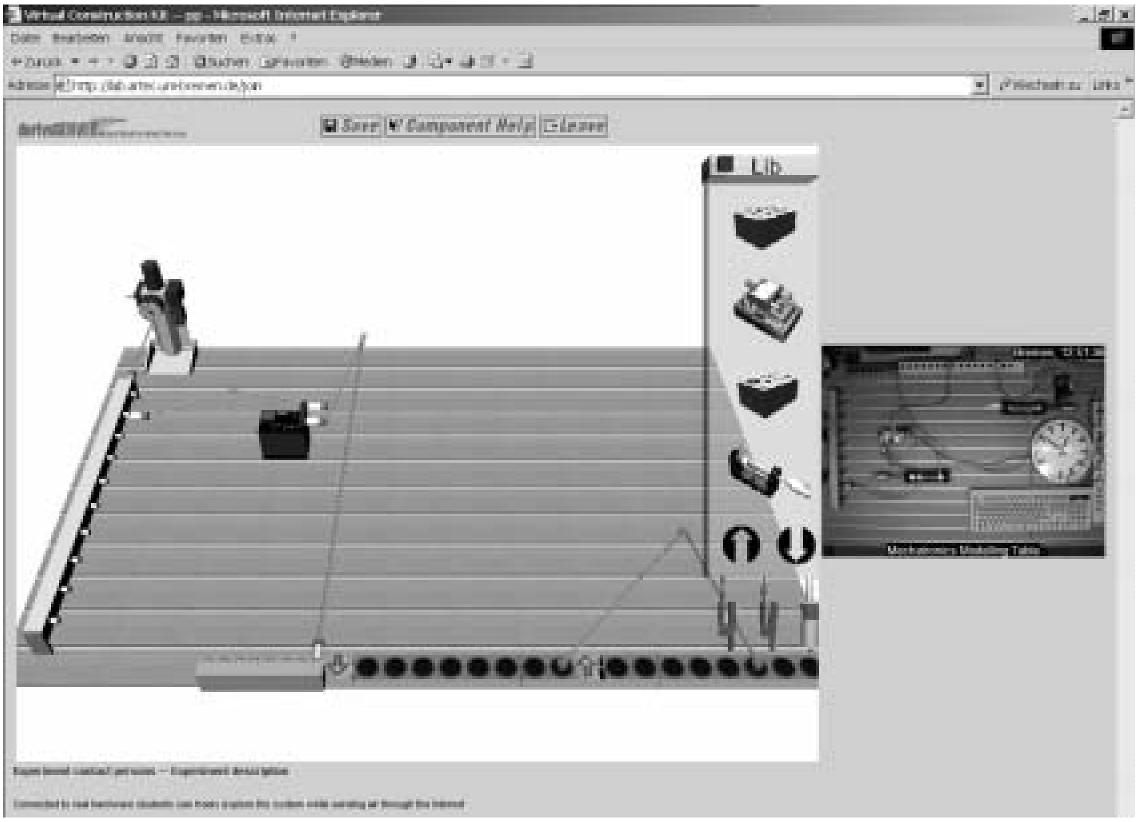

Fig. 10: Most parts being exported into reality

7. Didactical aspects

We consider several aspects of engineering training to be important here:

- thinking in abstract structure-behavior-function categories, searching for alternative concrete instantiations (e.g. various structures for a given function, or various functions of a given structure)
- thinking in information-control-work process categories and their realisation
- searching for unified views of systems dynamics (e.g. Petri nets and bond graphs) for analogous physical phenomena (electricity, pneumatics, force-momenum mechanics ...)
- judging the adequacy or deficiencies of simulation models versus real systems.

A theoretical framework for this didactic approach requires more insight into how individual learning styles use individual learning media and paths to develop meaning and concepts from basic experience with natural and technical phenomena. However, the development of learning environments should not wait for such a foundation to be established. Instead, we suggest some iteration between the development of learning environments and theoretical derivations based on empirical studies. In several research projects, we found suggestions for further extensions of learning theory and practice.

Task- and problem-solving in mechatronics requires cognitive and operational knowledge and practical experience in building systems, and in diagnostic and maintenance techniques. However, a significant challenge here is that these tasks are essentially characterised by the use of telemedia systems. Service staff in the professional field need to be able to achieve their aims in (tele-) cooperation with others, and they should be able to cooperate in virtual and supranational forms of organisation. Until now, no concepts have been elaborated for the educational, technical and organisational aspects needed to meet these requirements in education and training. Cultural differences and similarities in learning and collaboration styles can be noticed, but have not been sufficiently integrated into curricula, courseware and teaching methods.

Enterprises have come to realise that employee expertise is a vital and dynamic resource. The desire for employee expertise is meaningless unless an organisation (enterprise) can develop such expertise in ways that respond to its business needs. Many enterprises rely on off-the-job training (formal learning) without considering its suitability for the learning tasks at hand. On-the-job training (informal learning) has a substantial advantage: it is closer to the problems to be solved and it can be organised in a cooperative way, crossing the boundaries between different professions that are involved in a project in order to fulfil a customer order. However, on-the-job training is often unplanned and therefore ineffective in most cases. Applying a structure, using well-developed training materials that can be used at the workplace, and facilitating external support for cooperative learning makes on-the-job training a powerful tool (Jacobs and Jones 1995). The advantages of structured, on-the-job training are obvious and manifold, because employees

- work in projects (small groups of different professions) to solve problems,
- learn how to learn and think critically,
- identify the skills needed to meet the requirements posed by current work,
- develop a personal theory of management, leadership or empowerment.

What enterprises need is a culture of expertise, for the good of both the enterprise and the individuals in it. Employees should be encouraged to engage in continuous learning activities – but not forgetting that learning and doing go hand in hand. Learning by itself does not lead to enhanced productivity, yet expertise can be attained only through learning. Having a learning culture is a prerequisite for fostering expertise. Analysing a task to be learned often produces insights into ways of performing a task. Training modules can be used as a way of documenting and storing task information for purposes other than training. Collecting case studies of solved problems in manufacturing and service could help to solve new tasks. If they are published and available in electronic format, preferably via Internet, they can be a powerful instrument for workplace learning. It is also possible, via the Internet, to use training material and remote labs offered by training institutions.

8. Conclusions and future work

Experience gained in the aforementioned projects, such as DERIVE, Lab@Future and MARVEL, has demonstrated how future laboratories might be structured. The laboratories envisaged allow users to work with complex and simple, real and virtual systems, isolated or embedded parts, and local or distributed components. Several key features of tomorrow's laboratories can be identified, including:

- support for freely exploring a phenomenon and its appearance in various applications and contexts,
- bridges and means for interweaving real concrete and virtual abstract phenomena and objects,

- means for operating on virtual objects in a physically adequate way,
- cooperation on objects and phenomena in a multi-modal, multi-user way,
- cooperation on distributed objects,
- communication related to operations via Internet.

To solve the problem of physical-digital continuation and vice versa, a theory of hyperbonds has still to be developed further. So far, we have only been able to gather some initial experience with low-frequency coupling and discrete real systems. Further applications of control theory in this field seem promising.

References

Bruns, F.W. (2001): Hyperbonds - Enabling Mixed Reality. artec paper 82, Bremen.

Bruns, F.W. et al (2002) : DERIVE, Final Report. artec-paper 102, Bremen.

Engeström, Y. (1987): Learning by Expanding. Helsinki.

Grund, S. and Grote, G. (1999). Auswirkungen von gegenständlichem Lernumfeld auf Wissen und Problemlösen. In: Zeitschrift für Arbeitsforschung, Arbeitsgestaltung und Arbeitspolitik, Heft 3/1999, Westdeutscher Verlag, Leverkusen, pp. 312-317.

Grund, S. and Grote, G. (2001): Multimediales Lernen: Wie wichtig ist die Gegenständlichkeit? In: Kongressband Mensch & Computer 2001, Bonn.

Jacobs, R.L., Jones, M.J. (1995): Structured On the-Job Training. Berrett-Koehler Publisher, San Francisco.

Karnopp, D. C., Margolis, D. L., Rosenberg, R. C.(1990).: System Dynamics – A unified Approach John Wiley, New York.

Lab@Future (2005): School Laboratory anticipating FUTURE needs of European Youth. [http://www.labfuture.net/showcase/index.php].

MARVEL (2005): Virtual Laboratory in Mechatronics: Access to Remote and Virtual e-Learning. [www.marvel.uni-bremen.de].

Mostermann, P. J. (1997): Hybrid dynamic systems: A hybrid Bond Graph Modeling Paradigm and its Application in Diagnosis. Dissertation, Vanderbilt University, Nashville, Tennessee.

Müller, D., Ferreira, J. M. (2005): Online labs and the MARVEL experience**.** International Journal of Online Engineering. Vol. 1, No. 1, 2005.

Paynter, H. M. (1961): Analysis and Design of Engineering Systems, MIT Press, Cambridge, MA.

Totter A., Grund S., Grote G. (2004): Lab@Future: A Methodological Approach to the Evaluation of e-Learning Technologies. ED-MEDIA 2004, World Conference on Educational Multimedia, Hypermedia & Telecommunications. Proceedings p. 4392-4397. 21-26 June 2004, Lugano, Switzerland.

Vygotskij, L. S. (1987): Unterricht und geistige Entwicklung im Schulater. In J. Lompscher (Ed.): Lew Wygotski. Band 2. Arbeiten zur psychischen Entwicklung der Persönlichkeit (p. 287-306), Köln.

GLOSSARY

Assessment – the process used to systematically evaluate a learner's skill or knowledge level.

Assignment – a task or series of tasks that covers all or some of the requirements of a unit of study. It may also provide evidence for some requirements of another unit or for a key skill qualification.

Blended learning – term used to describe learning or training events or activities where e-learning, in its various forms, is combined with more traditional forms of training such as "class room" training.

CUseeMe-technology – a videoconferencing tool that utilizes the Internet to transmit audio and video signals.

CAVES – an acronym for Computer Automatic Virtual Environment. A virtual reality system that uses projectors to display images on three or four walls and the floor. Special glasses make everything appear as 3D images and also track the path of the user's vision. CAVE was the first virtual reality system to let multiple users participate in the experience simultaneously (immersive environment).

Collaboration – Collaboration involves the "... mutual engagement of participants in a coordinated effort to solve the problem together" (Roschelle and Teasley).

Collaborative learning – an instruction method in which students work together in small groups toward a common goal.

Constructivism – a theory wherein learning is seen as an active process of knowledge construction.

Cooperative learning – an instruction method in which small teams of learners use a variety of learning activities to improve their understanding of a subject, almost always under the guidance of an instructor.

Course trial – A full length course conducted in a target environment (facilities, instructors and students) using the curriculum as well as supporting training tools and materials prepared for that course. Its purpose is to validate a targeted learning environment. Also called 'pilot course'.

CPCI (Compact peripheral component interconnect or CompactPCI) – an adaptation of the peripheral component interconnect (PCI) specification for industrial computer applications requiring a smaller, more robust mechanical form factor than the one defined for the desktop. CompactPCI is an open standard supported by the PCI Industrial Computer Manufacturer's Group (PICMG). CompactPCI is best suited for small, high-speed industrial computing applications where transfers occur between a number of high-speed cards.

CSCL – Computer Supported Collaborative Learning.

CSCW – Computer Supported Cooperative Work.

CSILE – Computer Supported Intentional Learning Environment.

Curriculum – the aggregate of courses of study given in a learning environment.

Distributed environments – virtual environments that are shared by multiple participants at the same location or across networks.

eDocs – stands for electronic document (e.g. PDF, HTML, animations).

eLearning (e-learning, electronic learning) – The use of information technology (IT) and the Internet to support learning by facilitating access to resources and services as well as remote exchanges and collaboration. eLearning is a term that covers a wide set of applications, processes and tools, such as web-based learning, computer-based learning, virtual classrooms, and digital collaboration. It includes the delivery of learning content via networks (Internet, Intranet), CD-ROM, interactive TV, satellite broadcast, and more.

eMaintenance – see RRDM (Remote repair, diagnosis and maintenance).

Experiential learning – a learning method that emphasizes (1) hands-on experience, (2) processing that experience through reflection, and (3) applying the knowledge gained to 'real life' situations. Makes the learner undergo practical training in addition to or instead of classroom lectures.

Experiential learning cycle – developed originally by David Kolb, the concept of experiential learning explores the cyclical pattern of all learning from experience through reflection and conceptualising to action and on to further experience.

Hyperbond – an interface technology that provides a mechanism to combine real and virtual worlds freely.

ICT – Information and Communications Technology

Interface – a set of devices, software, and techniques that connect computers with people to make it easier to perform useful activities.

Laboratory – a laboratory is where experiments are carried out. New approaches and combinations are tried and the results observed. Different system elements and physical or technical parameters are combined and tested.

LabView – a specialized commercial software for measurement and data acquisition as well as virtual instrumentation (www.labview.com).

Learning environment – a physical or virtual setting in which learning takes place. The learning environment is determined by social, technical, spatial, and time factors. In the eLearning context, the term learning environment refers to specifically designed or selected tools and media.

Learning environment – the physical or virtual setting in which learning takes place.

Learning scenario – a learning scenario is both a case study and a role-playing activity. You are given an identity to assume and a problem-solving mission to accomplish; the mission is subdivided into tasks. Every learning scenario should provide all means for students to perform real world tasks.

Learning space – an imaginary geography in which learning takes place.

Learning style – refers to the preferred way(s) by which learners construct knowledge and acquire skills across the three domains of learning: cognitive, psychomotoric and affective. Common learning styles include visual, auditory, and tactile (hands-on).

Learning venue – in technical education and training, traditional learning venues are technical colleges, universities or the workplace itself. Through the Internet, new learning venues beyond the traditional institutions became popular, because they offer independence of place and time.

MARVEL – stands for Virtual Laboratory in **M**echatronics: **A**ccess to **R**emote and **V**irtual **eL**earning.

Mechatronics – mechatronics is the synergistic combination of precision mechanical engineering, electronic control and information technology.

Mixed reality – a concept in which virtual information generated by computers is mixed with the real environment (as perceived by humans).

Mixed-reality environment – refers to environments that merge elements of virtual reality and the real world.

Mixed-reality laboratory – a lab environment that consists of coupled virtual-digital and real-physical lab components. The whole system builds a functioning lab environment. Mixed reality labs try to combine the advantage of real-life-systems, remote labs and virtual labs (simulations). In a mixed reality laboratory simulation models interact with real devices and equipment.

Moodle – a course management system (CMS) – a free, open source software package designed using sound educational principles to help educators create effective online learning communities (www.moodle.org).

.NET Remoting – a system for application communication. The applications can be located on the same computer, different computers on the same network, or even computers across separate networks.

Online – connected to the Internet or another computer.

Online community – a meeting place on the Internet for people who share common interests and needs. Online communities can be open to all or membership only, and may or may not be moderated.

Online laboratory – a web site that enables an individual (alone or as part of a team) to carry out a laboratory experiment. Online labs cover a wide spectrum that goes from pure simulation (virtual labs) settings to remote laboratories where all devices and equipments are real.

Online Learning – a method of learning, in which some or most of the interaction take place via the web or other electronic means. See web-based training and Internet-based training.

Online Training – web- or Internet-based training.

On-the-job training – formal training for learning the skills and knowledge to perform a job that takes place in the actual work environment.

Programmable logic controller (PLC) – is a control computer for process control. PLCs are often RISC based and are designed for real-time and rugged industrial environments. PLCs are typically programmed in IEC 61131 programming languages and often categorised by the number of I/O ports they provide.

PXI – an industrial computer architecture that uses CompactPCI (see CPCI) for measurement and automation.

Real time – the actual timing of an event or process. For example, if a video of an manufacturing process is displayed on the web in 'real time', this is the actual length of time over which the process took place.

Remote engineering – remote engineering is a relatively new concept in industry namely in relation with mechatronics systems and plants. It refers to technologies that let technicians and engineers remotely monitor, maintain, control, and diagnosis machines and systems (e.g. production lines) using the Internet or a company's Intranet.

Remote experimentation – an activity in which an individual (alone or as part of a team) uses a communication network to carry out a laboratory experiment that involves the use of real devices and equipment. Remote experimentation can also support the development of important engineering skills such as remote operation, diagnosis, and maintenance (see RRDM)

Remote laboratory – a remote laboratory provides access to experiments controlled by a computer (the lab server) that is linked up via a local area network to the actual laboratory devices and equipment. With a remote laboratory students can gain 'hands-on' experience via web-based remote control of physical experiments. Web-based remote controlled laboratories differ from 'laboratories' by the fact that the students conducting an experiment are controlling a physical apparatus over the internet. Schools, research institutions, technological suppliers and companies may share resources and rationalize costs by setting up networks of remote facilities in their areas of activity. Remote lab-based courses offer the opportunity to use facilities from remote sites, without replicating expensive lab equipment at all teaching institutions.

Remote workshop – a workshop which can be carried out in one location and be followed by people in other locations. This can be achieved via teleconferencing, web or any other form of telecommunication.

RRDM (Remote repair, diagnosis and maintenance) – RRDM is a broad term that incorporates various technologies and applications. At its most basic, it can be a phone call for simple troubleshooting support. At its most complex, it consists of fully integrated computer and network applications that automatically monitor performance, diagnose problems, and request attention from service technicians for specific problems.

SCADA – an acronym for supervisory control and data acquisition, a computer system for gathering and analysing real time data. SCADA systems are used to monitor and control a plant or equipment in industries.

Simulation – a technique of imitating (modelling) the behaviour of a system or some situation (Mechanical, Economic, etc.) by means of an analogous model, situation, or apparatus, either to gain information more conveniently or to train personnel. The modelled system is usually made simpler than the original system so that only the aspects of interest are mirrored. Simulations are commonly used to learn more about the behaviour of the original system, when the original system is not available for manipulation. It may not be available because of cost or safety reasons, or it may not be built yet and the purpose of learning about it is to design it better. If the purpose of learning is to train novices, then cost, safety, or convenience are likely to be the reasons to work on a simulated system. Accordingly simulations enable the learner to practice skills or behaviours in a risk-free environment.

Simulation tool – an interactive applications that allow the user to model or role-play in a scenario.

Social constructivism – refers to a learning paradigm where the students carry out collaborative activities that lead to the acquisition of knowledge in an exploratory manner.

Solar energy laboratory – a laboratory that is fully equipped with equipment, instrumentation, control and measurement devices needed to perform experimental investigations in the field of solar energy.

Synchronous versus asynchronous communication – synchronous communication takes place when the participants interact at the same time (e.g. using MSN Messenger). Asynchronous communication takes place when the exchange of information is done at different times (e.g. via email).

Technical or vocational training – training that is designed to prepare technicians, middle management and other skilled personnel for one or a group of occupations, trades or jobs.

Telematics – a term referring to an industry based on the use of computers and telecommunications systems to carry data.

Telerobotics – robotic control of distant objects.

Teleservice and telemaintenance – a broad term that incorporates various technologies and applications. At its most basic, it can be a phone call for simple troubleshooting support. At its most complex, it consists of fully integrated computer and network applications that automatically monitor performance, diagnose problems, and request attention from service technicians for specific problems. See also eMaintenance.

TestPoint – a specialized commercial software for measurement and data acquisition applications (http://www.test-point.com).

VET – Vocational and Training. Study and training that develops the skills and knowledge that people need for employment.

Virtual – not concrete or physical. For instance, a completely virtual university does not have actual buildings but instead holds classes over the Internet.

Virtual classroom – the online learning space where learners and instructors interact.

Virtual environments – realistic simulations of interactive scenes. Virtual Environments (VR) are based on interaction devices, dedicated computers or hardware, and software which allow to develop or interact in VR application.

Virtual laboratories – are computer-based simulations of physical or other real-life laboratories.

Virtual learning – the process of learning over the Internet without having face-to-face contact. Also learning with virtual media and tools (e.g. computer based simulation).

Virtual learning environment – a generic term for virtual environments which are used in learning situations.

Virtual Learning Environment (VLE) – a browser dependant software system that enables online interaction between learner and tutor. It combines methods of online communication with the ability to deliver learning materials (such as documents, articles and assessments).

Virtual reality – an immersive, interactive computer simulation of realistic or imaginary environments. With Virtual Reality (VR) a human user can perceive and interact with data in a virtual world or environment by means of computerised systems. Users can walk through structures or interacting with objects in the VR environment.

VLE – see Virtual Learning Environment.

Web-based learning – see Web-based training.

Web-based training (WBT) – delivery of learning content via a web browser over the public Internet or a private Intranet.

Web services – the term Web services describes a standardized way of integrating Web-based applications using the XML, SOAP, WSDL and UDDI open standards over an Internet protocol backbone.

WinCC – a specialized commercial software for supervisory control and data acquisition (SCADA) from Siemens (http://www.siemens.com/wincc).

Work process-oriented learning – a learning methodology which closely combines learning and work, and builds up key qualifications that equip employees to cope with open work assignments and the rapid pace of change.

Work-based learning – learning acquired in the work place, normally under the supervision of a person from the same company as well as a professional teacher from outside the company.

MARVEL PUBLICATIONS

1. Papers and articles

The following papers and articles (conference and workshop papers, chapters in journals or books) have been published during the MARVEL project:

1. Bruns, W.; D. Müller, D. (2002): Hyper-Bonds - Multimodal Interfaces for Collaborative Workspaces of the Future. Future_WorkSpaces Technology Challenges Workshop. October 10th - 11th, Stuttgart, 2002.
2. Ferreira, José M. Cardoso, António M. (2005): A Moodle extension to book online labs. 2nd Remote Engineering and Virtual Instrumentation International Symposium (REV'05). Brasov, Romania, 30 June – 1 July 2005.
3. Ferreira, José M., Müller, D. (2004): The MARVEL EU project: A social constructivist approach to remote experimentation. 1st Remote Engineering and Virtual Instrumentation International Symposium (REV'04), Villach (Austria), 28 - 29 September 2004.
4. Michaelides I., Eleftheriou P. (2004): The HTI e-learning platform – A remotely accessible solar energy laboratory. HTI Review, No 33, 33-36, (2004).
5. Michaelides I., Eleftheriou P., Economides K (2005): HTI e-learning Laboratory –Remote Experimentation over the Internet. 2nd International Conference on Remote Engineering and Virtual Instrumentation (REV2005), Brasov, Romania, 30 June – 1 July 2005.
6. Michaelides, I., Eleftheriou, P., Müller, D (2004): A remotely accessible solar energy laboratory - A distributed learning experience. 1st Remote Engineering and Virtual Instrumentation International Symposium (REV'04), Villach (Austria), 28 - 29 September 2004.
7. Müller, D. (2002): Teleservice in Industry: Requirements and Recommendations for Vocational Education and Training. artec paper 86, Bremen.
8. Müller, D. (2004): Mixed Reality Learning and Working Environments - The MARVEL approach. Proceedings of the 12th European Conference for Educational and Information Technology (Learntec 2004), Karlsruhe 2004.
9. Müller, D. (2005): Zwischen Realem und Virtuellem - Mixed-Reality in der technischen Bildung. In K. Lehmann & M. Schetsche (ed.), Die Google-Gesellschaft. transcript-Verlag: Bielefeld.
10. Müller, D., Bruns, F. W. (2003): Arbeiten und begreifen: Erfahrungshandeln in virtuellen und realen Welten. In: Oberliesen, R./ Günter Reuel (Hrsg.): Schule zwischen materieller und virtueller Lernkultur. Hohengehren 2003.
11. Müller, D., Bruns, F. W. (2005): Arbeitsprozessorientiertes Lernen in Mixed Reality Umgebungen. In: Pangalos, J.; Spöttl, G.; Knutzen, S.; Howe, F. (Hrsg): Informatisierung von Arbeit, Technik und Bildung.
12. Müller, D., Bruns, F. W. (2005): Experiential Learning of Mechatronics in a Mixed Reality Learning Space. Paper to be presented at the EDEN 2005 Conference, Helsinki University of Technology, Finland. June 20-23, 2005
13. Müller, D., Bruns, W. (2004): Arbeitsprozessorientiertes Lernen in Mixed Reality Umgebungen. In: Pangalos, J. / Knutzen, S. / Howe, F. (Hrsg.): Informatisierung von Arbeit, Technik und Bildung: Kurzfassung der Konferenzbeiträge; GTW-Herbstkonferenz, 04./05. Oktober 2004. triass druck & media KG, Hamburg 2004, S. 184-188. (PDF german).
14. Müller, D., Ferreira, J. M. (2003): MARVEL: A Mixed Reality Learning Environment for Vocational Training in Mechatronics. International Conference on Technology Enhanced Learning 03 (TEL'03), Nov. 2003, Milano, Italy.
15. Müller, D., Ferreira, J. M. (2005): Online labs and the MARVEL experience. International Journal of Online Engineering. Vol. 1, No. 1, 2005.

2. Presentations

The following presentations (on workshops and conferences) have been published or held during the MARVEL project.

1. Alan, B. (2004): MARVEL presentation to the conference PassIT, Glasgow (04. December 2002).
2. Ferreira, J. M.; Cardoso, António M. (2005): A Moodle extension to book online labs. Presentation at 2nd Remote Engineering and Virtual Instrumentation International Symposium (REV'05). Brasov, Romania.
3. Ferreira, J. M. (2003): Guest lecture presented at the opening of the I. International Workshop on Remote Experimentation (title: A Experimentação remota servirá para alguma coisa? What is remote experimentation useful for?) Florianopolis, Brazil. (30.July – 1. August, 2003).
4. Ferreira, J. M (2004): Invited talk: "The lab of the future: Learning model, remote / virtual workbenches, collaborative tools", UNIGUAÇU and UNIMEO, Paraná, Brazil, 31. July 2004 [in Portuguese].
5. Ferreira, J. M. (2004): O Laboratório do Futuro: Bancadas remotas / virtuais, modelo de aprendizagem. Talk at Parana University, Brazil.
6. Ferreira, J. (2004): Remote Electronics Workbench - Taking the Lab Home. Presentation at the INCOM 2004 - 1th IFAC Symposium on Information Control Problems in Manufacturing. S. Salvador, Brazil. (5.– 7. April, 2004).
7. Ferreira, J. M., Müller, D (2004): The MARVEL EU project: A social constructivist approach to remote experimentation. Presentation at 1st Remote Engineering and Virtual Instrumentation International Symposium (REV'04), Villach (Austria), 28 - 29 September 2004.
8. Hoell, W. (2005): Prozesssteuerung und -überwachung einer Solaranlage über das Internet. Presentation at "Ausbildungsleitertreffen des Allgemeine Arbeitgebervereinigung Hannover und Umgebung". 15. June 2005 [in German].
9. Karlsson, P. (2003): Presented MARVEL to an invited committee of Greek Ministry of Education during an e-learning workshop organized in ZENON. Location: ZENON, Athens / Greece. September 2003.
10. Karlsson, P. (2003): Presented MARVEL to VOCATIONAL TRAINING SA (subsidiary of the Greek Organization of Manpower). VOCATIONAL TRAINING S.A, Athens / Greece. December 2003.
11. Marvel exhibition stand at eLearning Conference "Towards a Learning Society". The European Commission is organising a conference on eLearning which will take place in Brussels on 19-20 May 2005.
12. Michaelides I., Eleftheriou P., and Economides K. (2005): HTI e-learning Laboratory – Remote Experimentation over the Internet. Presentation at 2nd International Conference on Remote Engineering and Virtual Instrumentation (REV2005), Brasov, Romania, 30 June – 1 July 2005.
13. Michaelides, I. (2004): HTI Solar Energy e-Learning Lab. Presentation at Aristotle University of Thessaloniki (AUTH), Greece. 16. November 2004.
14. Michaelides, I.; Eleftheriou, P.; Müller, D (2004): A remotely accessible solar energy laboratory - A distributed learning experience. Presentation at 1st Remote Engineering and Virtual Instrumentation International Symposium (REV'04), Villach (Austria), 28 - 29 September 2004.
15. Müller, D. (2004): Marvel: Virtual Laboratory in Mechatronics. Presentation at 1st PROLEARN Thematic Workshop 4/5 November 2004 – Hannover.
16. Müller, D. (2004): Mixed Reality Learning and Working Environments (MARVEL project). Talk on Learntec 2004, Karlsruhe.
17. Müller, D. (2004): Virtual Laboratory in Mechatronics. Talk on "E-Learning - Wie lernen wir die Zukunft?" Nutzung von realen Welten in virtuellen Lernumgebungen, Lüneburg.
18. Müller, D. (2005): eLearning in Mechatronik. Presentation at Koblenzer eLearning Tage. Koblenz 26. - 28. April 2005.
19. Müller, D., Bruns (2004): Arbeitsprozessorientiertes Lernen in Mixed Reality Umgebungen. GTW-Herbstkonferenz 2004, Hamburg, 4.-5. Oct.
20. Müller, D.: Das Projekt MARVEL. Presentation at "Ausbildungsleitertreffen des Allgemeine Arbeitgebervereinigung Hannover und Umgebung". 15. June 2005 [in German].
21. Müller, D., Bruns, F. W. (2005): Experiential Learning of Mechatronics in a Mixed Reality Learning Space. Presentation at EDEN 2005 Conference, Helsinki University of Technology, Finland. June 20-23, 2005.
22. Müller, D., Ferreira, J. (2003): MARVEL: A Mixed Reality Learning Environment for Vocational Training in Mechatronics. Presentation at International Conference on Technology Enhanced Learning 03 (TEL'03), Nov. 2003, Milano, Italy.
23. Müller, D., Pundt (2004): Virtual Laboratory in Mechatronics: Access to Remote and Virtual e-Learning. Auditorium presentation on Learntec 2004, Karlsruhe.

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LEONARDO DA VINCI is the action programme for implementing the European Community's vocational training policy. The second phase of the programme, LEONARDO II, with a total budget of € 1.15 billion, was approved by the European Council on 26 April 1999 and will run for seven years (2000 – 2006).

LEONARDO DA VINCI supports and supplements the vocational training policies of the Member States. Its aim is to use transnational cooperation to enhance quality, promote innovation and support the European dimension in vocational training systems and practices, and in this way to enhance the performance of the Member States.

The German Federal Ministry for Education and Research (BMBF), as the ministry with policy responsibility, has commissioned the National Agency - "Education for Europe" at the Federal Institute for Vocational Education and Training (NA at the BIBB) to operate the LEONARDO DA VINCI programme in Germany.

The 'impuls' series is published by the National Agency at the BIBB as a means of presenting the outcomes of LEONARDO DA VINCI projects, showing and disseminating innovations and advances in vocational training, and initiating extensive exchange of opinions and experience in this field.

MARVEL – Virtual Laboratory in Mechatronics: Access to Remote and Virtual e - Learning

The MARVEL project developed novel concepts for learning communities and inter-site cooperation in which the stakeholders involved (e.g. vocational colleges, training enterprises, universities) can share and use costly mechatronics plant and laboratory facilities via the Internet. This publication presents some specific outcomes of MARVEL. It highlights innovative concepts, practices, and recommendations that describe the use of 'real worlds' in virtual learning environments in order to accelerate the deployment of work process-oriented training with real-life systems in mechatronics.

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