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# Guest editorial: Immersive Telelaboratories for engineering designer education

## Abstract

This presentation tries to explain the background and the context of this Special Issue of Learning Technologies (SILT). It focuses on the usage of immersive telelaboratory to learn design expertise at a University-level and to create the relevant Knowledge. The end users addressed are Robot Control Engineering students (future designers) and skilled users of high-tech devices and systems. The immersive telelaboratory is meant as a telelaboratory in telepresence able to provide the richest perception of, and interaction with, the real laboratory devices and environment.

The contributions here collected come from organized research activities running and planned to run in this domain, both at Italy Country level and at a European level.

In Italy the TIGER Research Project (Telepresence Instant Groupware for higher Education in Robotics), co-funded by the Ministry of Instruction, University and Research (MIUR) and developed by a large number of Italian Research Groups, is running the final part of its programs. It aims to devise and realize a Web-based learning system able to efficiently represent and share the knowledge produced inside a traditional or advanced Robotics Laboratory.

This final part is now focusing on KM and social dimensions involved in small teams groupwork, in order to extend the domain of interest to Corporations working on complex artefacts (e.g., Air Traffic Control Radar Systems).

The project has received contributions and interest from the international community of Roboticians and from many researchers involved in Web-enhanced Learning and KM.

This scenario has recently led to the submission to the CEC of the RULE Project (Robotics' University Laboratories in Europe).

This SILT would contribute to give a synthetic picture of the immersive telelaboratory research state-of-art and related issues as emerged from these projects.

## Background

The original idea to which the topics here addressed are related was to allow both University students and working adults to be trained as control designers of robotic systems by operating in real laboratories from a remote site, according to experiential learning models [Kolb, 1984, Norman, 1993].

Robotic Control is an important topic for ICT and Engineering, some characterizing features of which are the complex skills required for devising and realizing artefacts, the mixture of complex formal and non-formal knowledge involved and the need for continuous retraining for people involved.

In this scenario the project of telelaboratory in telepresence is put, inside a framework of structured and/or continuing education: the focus was on providing *immersivity*, namely, as rich as possible perception of, and interaction with, the telelaboratory.

This is the case of Robotics (particularly of advanced robotics), where tasks have often features of exploration and recognition of an unknown environment, to define some intervention strategy on the environment itself. Beyond industrial manipulators, robotic systems comprehend mobile systems for underwater, spatial, terrestrial tasks, and co-operating (not only co-ordinated) systems. The operating environment is often unsafe, unknown and unpredictable; tasks may change within an assigned high level strategy according to the environmental constraints. This claims for a high 'human-like' decision level to be built-in the control module of robotic systems (evidences can be found in robotic systems for the assistance to disabled). Therefore the designer of robotic systems needs to perform "Learning by doing" in technologically advanced and expensive labs where tangible objects are operated.

To build, to maintain, and to use such advanced labs is difficult, sometimes even impossible for organisation problems, always expensive. The need arises of guaranteeing access to existing advanced labs to a wide population, surely wider than the users present on each laboratory site. Design methods and tools for developing "Learning by Doing" at remote labs in a framework of user telepresence appear to be needed, since simple simulation (i.e. virtual labs) cannot ensure the proper perceptive richness.

A relevant operation scenario is as follows:

The tangible objects are laboratories of advanced and/or traditional robotics. They should be equipped for the remote use ensuring the user telepresence, and grouped into clusters to allow the exploitation of their resources to other cluster members and to students enabled to access the cluster itself. The educational service is the access to remote experiments by single users and students groups, of course after suitable training on experiment operation and education on the involved methodological issues. This educational service finds its highest expression in co-operative works finalised to active self-learning performed remotely.

The experiments considered educationally richest should be captured during their performance, commented and edited with suitable tools for Learning Objects fast-prototyping, indexed and inserted in the Knowledge pool of the lab cluster. This requires the implementation of a technological infrastructure allowing operation both in local area and geographic networks. The Quality of Service was deemed a key issue, basically measured by the level of perceived synchronisation between the student and the operation environments.

The design of experiments and of connected learning paths has to be driven by the development of suitable pedagogical models, deriving from cognitive models tailored to the assigned learning goals, and based on ICT technologies and domain specifications.

In such a scenario, methods and tools for e-learning are key-issues. Available methods and relative pedagogical models, even the most innovative ones about active skill learning, appear rarely suitable, since they are mostly referred to abstract/symbolic more than to material domains. In the case of designers training the integration of Handling Skills and Strategic Knowledge, at the highest levels of professional ability (Evaluation level, according to Bloom's taxonomy) is deemed crucial.

Number of actors are in the background of the described scenario, whose relevance is tied to the large scale employment of the considered tools. They are the providers and the managers of the Application Services supporting the addressed educational method.

It is self evident that the issue can be faced only by a research team integrating number of heterogeneous disciplines, from ICT to pedagogy, from Robotic Control to cognitive psychology.

In Italy we had the chance of putting together experts of most of these disciplines and to launch a project named TIGER ( Telepresence Instant Groupware for higher Education in Robotics) inside which Partners come from heterogeneous fields of research and experiences, such as software engineering, robotic control engineering, pedagogy, psychology and cognitive science, technology-mediated learning research.

The research to be carried out in TIGER had three main objects, strongly interconnected to each other: The educational model, the Electronic Learning Environment (ELE) instantiating it in terms of ICT, multimedia and virtual reality technologies, the world where the learning experiences occur (the telelaboratory).

As far as the ELE was concerned, along with the related pedagogical models, most of that time existing experiences dealt with Corporate Learning. However relevant activities in the framework of Higher Education were developed in Europe by Open University [Laurillard, 2001], and, at a research level, by ARIADNE in Europe and EDUCAUSE in USA. It should be noticed that well defined models neither existed as far as high level Continuous Education is concerned, nor assessed methodologies for supporting high level cognitive skills did [see f.i. Collis, 2000].

The educational problem was that of designing educational models allowing, from an operation viewpoint, an easy access to resources different for content and methodology, and, from a pedagogical viewpoint, to induce autonomy in learning by stimulating motivation, building consciousness of educational needs and supporting a strategy development for satisfying such needs.

Due to its potential of satisfying these latter needs, e-learning had strong improvements with reference to both education in structured contexts and life-long learning. A number of research initiatives focusing on this issue have been, and currently are, active. Among them are particularly important those supported by CEC in the framework of the Fourth, Fifth and Sixth Framework Programme. An overview on some recent studies relative to these issues and their application in European educational initiatives can be found in [Restivo & Ribeiro, 2000]. Reported results show problems and potentialities. Among them, it was interesting for the TIGER project the discussion about the context-related aspects, i.e. the possibility of tailoring the educational proposal to the single user.

Due to the remarkable development costs of Learning Objects, attention has been devoted to the standardisation of the ELE components ( PROMETEUS Initiative, CEN-ISS-WS-LT, IEEE-LTSC, ISO JTC1/SC35, IMS consortium): Learning Management Systems; Content management; Learning support management; Competence management; Knowledge management.

In TIGER, the focus is on Content Management, with particular reference to rapid prototyping of educational contents, and to building and managing the Knowledge Pool. Some of the results obtained are referred into one of the contribution to this SILT: Corradini, Maiorano, Sammarco.

At the same time, the issues about the effective access of informative resources have not been neglected. With reference to this latter point, the recent studies about semantic web [see f.i. Berners- Lee, 2001] are of particular interest, together with the efforts made for the realisation of systems able to effectively include various educational resources adapting them to the user needs.

Some results are presented in this special Issue particularly for:

- definition and realisation of Learning Objects (LO) and related Learning Structures (supporting macrostructure which interconnect the LO according to educational strategies)- Buseti, Forcheri, Ierardi;
- modelling of the application requirements, finding out the different entities destinations of the application- Gobbo, Vaccari.

In such a framework, another important point is the learning evaluation for which, in spite of the high number of available studies, widely accepted methodologies for evaluating the benefits of e-learning w.r.t. traditional methods do not still exist. As a matter of facts, the evaluation of the learning efficacy is still an open problem, notwithstanding some relevant studies in the Corporate Learning area [see f.i. Kirkpatrick, 1999].

Another contribution to this SILT is concerned with the argument- Falsetti, Ramazzotti, Fabri, Leo.

With reference to the telelaboratory, the supporting technological infrastructure is electively based on the WorldWideWeb platform, due to its (and of related tools) widespread diffusion. Nonetheless, the telelaboratory has structural constraints which have rarely been taken into account in the current Web technology, like remote control, which claims for real-time responses.. The two-fold need arises of analysing and integrating the hw and sw components of remote control within the current reference infrastructure (the web).

It should be noticed that, after some diversion from the 'immersive' meaning given by the area pioneers [Jaron Lanier, 1989, 1990, 1992; Myron Krueger, 1983, 1991], [William Gibson, 1984] , current virtual reality (VR) experiences tend to soften the boundary between immersive and not immersive VR. A remarkable example comes from the telepresence concept adopted in telemedicine and telerobotics. TIGER is trying to address the issue regarding the remote manipulation of real objects present in a real, remote, laboratory operating Robotic Systems, based on number of preliminary experiences carried out at various participating research Groups. Some of them are reported in this SILT:

Casini, Garulli, Prattichizzo, Vicino; Boncagni, Tornambè, Zaccarian; Fiorini, Castellani.

In synthesis the results that were deemed realistically achievable by TIGER during its three-years life (starting from February 2003) are:

- Development of pedagogic learning models effectively supporting the training of designers in the field of traditional and advances robotics. This implies the flexible integration of educational paths which are peculiar of the knowledge domain (including experimental practice in the telelaboratory) in a unified learning environment, and the integration of different approaches to learning.
- The integration of open source software modules for assembling the Electronic Learning Environment ( ELE) best suited to the purpose to be achieved, highlighting:

- Modelling issues of web applications needed to include aspects tied to the Quality of Service (QoS). A key feature of QoS is the amount of user-perceived synchronicity between what is perceived by the remote user and what is going on in the remote lab.
- Quick development of Learning Objects and of the metadata needed for their re-usability.
- Development of a technological infrastructure web-compatible (the web is intrinsically asynchronous) accounting for the QoS requirements, which, on the contrary, has the perceived synchronicity as a key feature.
- Development of a number of telelaboratory prototypes, each satisfying some of the requirements about effective implementation of telepresence, and including the development of Learning Objects tailored to autonomous or co-operative self-learning, performed remotely.

It seems worth mentioning that the strong interconnection of the three main research fields of TIGER - the educational model, the ELE instantiating it in terms of ICT and multimedia technologies, the world where the learning experiences occur (the telelaboratory)-induced a relevant complexity for its logic and temporal organisation, and the need of a strong co-operation between experts in technological and pedagogical domains, to be exploited in a high level, integrated activity with co-operative features. In this framework, a relevant result has been some 'clarification' of terminology, in an effort of eliminating those ambiguities which frequently arise when languages typical of given domains, to be integrated for the sake of the project development, are used outside their original context.

## **Future trends and challenges**

In line with such a background, it has been quite natural to focus on Knowledge Management(KM), on the social dimension of learning and on the possibility of providing learners with a variety of distributed learning resources in a context of improved Learning flexibility.

The pedagogical framework continues to be deeply coherent with constructivist approaches.

The focus of Learning experiences is still on “immersive” experiments but the technological domain has been widened to other challenging and not yet experienced technological environments and the same idea of “immersivity” has been widened to comprehend the local use of hands-on devices together with the Web-based sharing of the relevant experiences.

We are considering a Trans European network of Universities using the system for educational purposes and the operation of a Corporation for effective world-wide maintenance and customer support of sophisticated high tech artefacts like Air Traffic Control Radar Systems. In both cases the end users will be small teams of adult learners committed at improving their professional competence and abilities and the Knowledge patrimony of the Organizations they belong to. These aspects are examined in one contribution to this SILT- Verdicchio, Felolo.

The foreseen system is aimed to implement the whole Knowledge cycle – creation, formalization, sharing and capitalization - by collecting and sharing learners’ experiences, experts’ advices and every other form of structured information that circulate within the system. We think about feasible implementation of the system, where the higher level trade-off between constructivist vision and practical feasibility of a running Knowledge Management and e-Learning system is pursued.

The operation scenario we are thinking about is as follows:

Experiential Knowledge is created by Learners, in a context of Learning-by-Doing, by accessing through the Internet real devices, processes, systems to be controlled/ manipulated/ managed during experiments. The status of the experiments will be perceived by the learner during its evolution through a number of multimedia interfaces, and depends on the decisions adopted by the Learners as well as on independent environmental changes. All these experiences will be performed in a rich knowledge environment providing access to well structured Knowledge repositories, troubleshooting support, online tutoring of experts. Moreover the role of non perceptual factors potentially important for creative presence experiences is planned to be explored and investigated.

The needed flexibility of the system is meant to have a threefold character:

- adaptivity to the present needs of Knowledge, information and advice and to the learning style of the learners.

- scalability of the learning contents according to different types of communication devices and channels and according to the different learning services required by the circumstance: desktop, PAD, mobile phones, Internet and cellular networks on one side and operational tasks support by means of learning material ranging from knowledge/information summaries up to complete explanation of complex technological topics on the other side.
- ability to capitalize the knowledge created by learners as it comes out in the context of constructivist approaches to learning.

In synthesis, the domains addressed refers to Cognition and Learning, to ICT technologies and to Cognition processes mediated by Technology.

To attain the foreseen results many steps have to be accomplished. In particular

- models of the involved organisations, of the relevant web applications, of domain Knowledge and of Learners, of the Learning Materials and of the related Learning processes, have to be defined;
- a suitable communication and information infrastructure has to be devised and implemented for the purpose;
- ontology, data structures, tools and engines able to support knowledge creation, formalisation, representation and sharing (synthetically Knowledge Management-KM) have to be devised and implemented;
- suitable Learning materials have to be devised, implemented, and indexed;
- the effectiveness of the system has to be tested and evaluated;
- models , design and the implemented system have to be modified and updated according to the system evaluation results.

The previous TIGER experience [see f.i. Fabri et al. ICRA 2004] is deemed to be fully exploitable.

However key elements as the “immersive” paradigm, the cognition, e-learning and instructional design issues are open to relevant extensions; moreover the KM issues, in view of a practical implementation in the high-tech domain, ask for improvements of the current approaches; the topics of cognition mediated by technology seem to require some more reflection w.r.t. the current state of the art.

As far as the Robotics education and the role of the Laboratories is concerned a deeper reflection has to be done. The paradigm of the Open Laboratory is discussed in one of the contribution to this SILT- Casals, Fernandez.

The cognition, e-learning and instructional design issues need more reflection too, notwithstanding the diffusion of number of experiences related to co-operative work and to re-using instructional material represented by Learning Objects [Eklund et al. 2003, Zhang & Numaker 2003].. In fact, once again, there are not well defined educational models as high level education and training nor consolidated methodologies aimed to support the development of high level cognitive abilities in complex domains are concerned; most of the known proposals are oriented towards the transmission of content, rather than towards the formation of competences [Kirschner 2005] and, for example, Gulikers and others (2005) recently questioned, on the basis of a study, the effectiveness and efficiency of so-called authentic learning environments.

Such a reflection led us directly on Knowledge Management (KM) issues.

In our case, we think about KM as “the identification and analysis of available and required knowledge assets and knowledge asset related processes, and the subsequent planning and control of actions to develop both the assets and the processes so as to fulfil organizational objectives “

Therefore there is the need of :

- to be able to *capture and represent* knowledge assets;
- to share and re-use knowledge for differing applications and differing users; this implies *making knowledge available* where it is needed within the organization;
- to *create a culture* that encourages knowledge sharing and re-use.

Traditional approaches to KM ranges between two extremes. On a industrial perspective KM is mainly conceived as a policy for providing access to knowledge: industrial solutions are mainly concerned with the creation of indexed repositories of documents and with the inductive processing of large data sets, which is the basis of the so-called “business intelligence”. On the other extreme, the academic research on automated Knowledge Based Systems ( KBS) tries to provide knowledge on the basis of complex user models.

In every case one important element for effective KM is to deal explicitly with the complexity of how people use their minds to perform their work. Therefore Knowledge Based Systems (KBS) aims to the implementation of efficient knowledge representation and inference procedures, matching the cognitive requirements of specific end-users.

It appears the need of composing some possible contradiction between knowledge management (top-down process) and Knowledge creation (bottom-up process). Knowledge is built by complex learning processes and results in highly individual mental models and associations frequently different from the source knowledge. Furthermore personal knowledge cannot be shared directly. Recipients make sense of the received information and become owners of a new knowledge that is their interpretation of the communication.

Sharing knowledge depends on many aspects: the nature of the knowledge, the cognitive processes, the users involved, etc. It isn't simply matter of providing the right information, it requires communication of processes, examples and abstract knowledge, showing how things changes depending on contexts, etc. Supporting knowledge sharing is therefore a complex task and requires focused solutions, involving accurate capture and accessible representation of knowledge assets. In particular "knowledge distribution systems" have to be accessible and comprehensible, for if knowledge re-use is difficult or frustrating, it is likely to be ignored in favour of knowledge re-invention.

Making reference to the Knowledge Cycle in figure 1, it can be said that design, marketing, management are typical examples of domains where knowledge is generated. Elicitation is the process of recording by tracing the knowledge creation events. Elicited (i.e. Dynamic) knowledge is stored as detailed records of the enterprise's activity, which are usually called cases. Selection is the process of refining and marking noteworthy cases and practices as part of the enterprise's reference knowledge. Mediators are the processes which transform and complement the reference knowledge so that it could suit specific tasks. Supporting knowledge is the result of the mediating processes. Finally, supports are the interfaces (i.e. applications) which provides supporting knowledge to end-users (e.g. the same actors that previously have generated it).

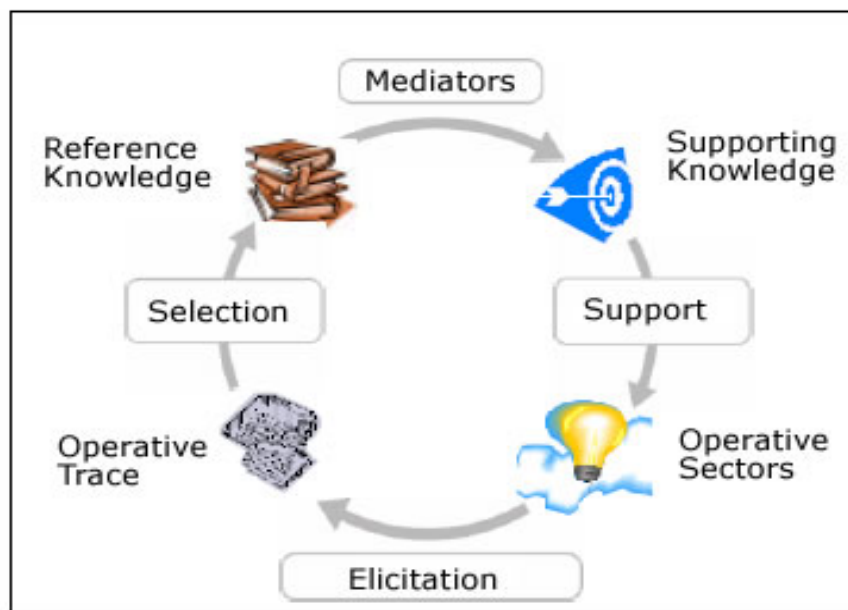


Figure 1 - The Knowledge Cycle

The scenario we have in mind asks for a careful implementation of KM. Providing services for accessing large repositories of expertise is a particular implementation of the expertise sharing scenario. In real cases expertise is contained both as explicit knowledge in a reference knowledge repository and as tacit knowledge in experts' mind.

An expertise sharing scenario can be drawn as follows: Users request for solutions posing problems to the front-end service. They are not perfectly aware of their needs and do not know completely the domain of interest. The front-end (i.e. expertise mediator) is an autonomous knowledge mediator which tries to find out the real customer's need on the basis of a "knowledge network" concerning the domain of interest. The mediator asks

questions to the customer and guides him towards the solution. This process is basically a diagnosis task. The solution is a state of the expertise repository which provides links to the domain processes and knowledge. In case the mediating process fails, the request is forwarded to human experts who provide the new solution. The selection process collects the new solution and put it in the reference knowledge repository. Notice that this way the expert is involved only when the knowledge repository is not able to provide the required solution, and that, once provided, the new solution is ready for future requests. Therefore we can say that the process capitalizes the expert knowledge.

This implies:

- • The use of a Knowledge structure who explicitly uses semiformal outlines formulated in order to allow a simple codification of expertise and a simple access;
- • The use of automatic systems (Knowledge Mediators) that assist the users in the search of the solution, biased by the users' operational context;
- • The possibility of shaping a sort of back-office fines level, perfectly integrated with the system automatic rifle, for the solution of critical cases.

In such a context the implementation of the concept of Open Laboratory (OL) is deemed a key issue for the creation and diffusion of the high- tech artefacts design expertise. The system based on the OL paradigm has to support institutions and small groups of users located in different Countries. The organizations have similar missions but substantial differences in their Country dependent regulations. Therefore we think to face a problem of different cultural environments more than a problem of different mother tongues.

The OL has to be supported by a suitable ELE. Hence having in mind the foreseen kind of users of the system, a pedagogical approach should be selected that helps students to integrate the development of specific methodological and content knowledge/abilities with capabilities of self-regulation, planning and control of learning, taking into account both collaborative and individual contexts of learning. Apart from previous experience [Busetti et al. 2005], the methodological indications aimed to support pedagogically driven approaches to e-learning present in the literature will be considered [Conole et al. 2004]. On this basis, a study environment aimed to support the construction of knowledge during the development of realistic task has to be built.

To foster the acquisition of competence, many aspects should be considered: prior knowledge; availability of relevant resources; use of a working method in which monitoring and reflection have an essential part; design of the task environment apt to generate problem situations as authentic and realistic as possible. Moreover w.r.t. collaborative learning, general indications can be found, that help to organise collaborative processes of conversational nature so that to make them productive; however, features that should be owned by telematics systems aimed to support this approach to learning are not completely clear [Coppola, Hiltz & Rotter 2001]. Finally, further work is needed to explore what kind of balance should be realised between the two aspects on the basis of the content [Rovai 2004, Williams 2004].

To build a study environment aimed to support the construction of knowledge during the development of realistic task, further attention should be paid to the potential of Learning Object technology as a basis to model, at least to some extent, educational processes aligned with the current pedagogical view [Busetti et al. 2004]. Therefore we think to have to face some interaction with existing standards and the implementation of some contribution to the standardization activities.

Moreover it is worth considering that the focus is on the creation of small communities (groups/teams) around the telaboratory core paradigm. The social context is the one of groups and teams structured in a definite way in the case of enterprises (one maintenance team has a definite composition and has hierarchical organization) and in a partially definite way in the case of Universities (students, even if belonging to different Countries, Universities and following different Courses will stay at a similar stage of their study trajectory) while the communities usually operating in the Net are constituted on the basis of a free and voluntary adhesion. Moreover the teams/ groups have to face tasks defined in an exogenous way. Finally these tasks are technological and do not refer to computer science nor basic sciences neither management. These are real situations pertaining to the organizations we consider, apparently not yet taken into consideration by the Organization psychology and/or sociology studies.

To try to manage such a complex matter, a large, pan-European pool with some participants coming from US and New Zealand, was established recently to develop a research project named RULE (:Robotics' University Laboratories in Europe) aimed to define, to devise and to implement a distributed, flexible Knowledge and e-



learning system with which small teams/groups of University students and/or Organization of professionals (i.e. Learners) will improve their ability in solving highly complex technological problems. The competences available in TIGER have been enlarged by the participation of groups involved in Cognition, its social dimension, KM, and in more technological issues. For instance other types of laboratories are considered and described in this SILT:-Zeiger, Schilling.

The goals pursued by RULE can be summarised as follows:

- to attain scientific advancements about competence enhancement;
- to develop methodologies for effective e-acquire skills and abilities;
- to develop methodologies for enhancing social skills utilization while acquiring competences/abilities;
- to increase the quality of efficiency - more than simple" performance"- of organizations dealing with advanced technological products and services;
- to test in real conditions and in a verifiable manner the feasibility of a pragmatic technology mediated constructivist approach and to appraise it vs. traditional teaching;
- to test and to verify the effectiveness of technology mediated Knowledge Management for education and acquisition of competences. This will be done on real scale pilots relative to Organizations with substantially different missions – respectively Higher Education and Production of complex high tech systems;
- to test and to verify how the improvement of competence/expertise of small teams/groups in charge of critical technological tasks will practically affect the quality of efficiency of the organizations in which the teams operate.

## Acknowledgments

It is my duty and my pleasure to thank the Editor of LT for offering the opportunity of preparing this Special Issue of Learning technologies.

Moreover, about the contents of this presentation it has to be stated that they come in large part from the contribution and the reflection of number of participants in TIGER and in the RULE proposal. In particular I would like to acknowledge the importance of the contributions by Paola Forcheri, Alberto Giretti and Silvia Viola.

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# The Open Laboratory paradigm for engineering education via e-learning

Learning on technical matters requires tackling theoretical and practical issues. The expected result of the learning process is for students to know how to solve problems, dealing with new situations, etc. Learning and teaching methodologies has changed drastically over the last three decades towards this goal. Students are having more prominence, acquiring knowledge through self-reasoning and experimentation.

Practical work is a key component in the learning process of technical matters. When practical work requires specialized equipment, it is carried out in an arranged room, the laboratory. Laboratory work has to focus on aspects more related to methodologies, work habitude, knowledge on equipment operation or experience, rather than the theoretical aspects covered in the classroom.

Being robotics a matter covering a wide field of topics based on complex theoretical foundation, it is not less evident the need of experimentation with real systems. Thus, practice constitutes a key element in robotics training [1]. Consequently, students of robotic courses, from introductory levels to specialized areas, must dedicate important efforts in laboratory practices. This fact makes the design of a training program as important as the study of theory. Unfortunately, the achievement of the practical training objectives requires a lot of lab time, working with expensive robotic equipment. This training process can even require the implementation of robotic elements, interfaces, etc.

The evolution of communication and information technologies has opened new possibilities in educational methods. E-learning methodologies make autonomous learning easier, by offering course materials and tools. While there is a wide offer of Course Management Systems (CMS) [2] that seem to cover adequately the e-learning requirements of theoretical issues, e-learning on practical issues, working with real equipment, is still an unsolved matter.

The purpose of this work is to advance on mixed learning methodologies. Mixed learning is understood as the combination of theoretical and practical activities, either in the classroom or in the lab, guided by the teacher (in-situ/contact activities), together with activities in the Internet (on-line/distance activities) that students carry out in an autonomous and supervised way (Figure 1).

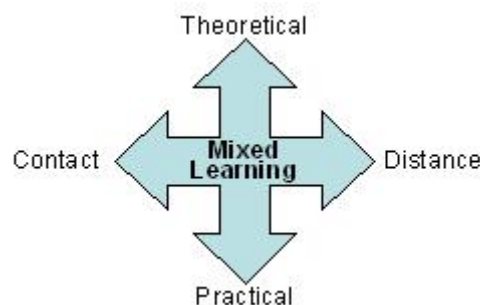


Figure 1. The mixed learning approach.

Therefore, this work relies on a web based system for the implementation of a robotics laboratory with didactic finalities. The laboratory is to be accessible indifferently and simultaneously, *in situ* or via Internet, aiming to provide any-X access to the laboratory (at any time, from everywhere, without space problems), paying special attention to safety issues.

## The Open Laboratory Paradigm

A *Traditional Robotics Laboratory* is equipped with several robots, sensors, robot scenarios, computers that facilitate the programming and interfacing with users, and a set of software tools for editing, simulating and for robot management. Usually all lab equipment and activities are arranged for contact learning, that is, students work under the guidance of their teacher.

On the contrary, an *On-Line Laboratory* contains a set of resources or equipment, having the entity of a full laboratory that can be accessed, controlled and supervised remotely [3][4]. An OLL is oriented to perform

activities (learning) remotely. Laboratory resources and space are arranged to be used, basically, through the Internet.

In education institutions the users of laboratories usually work on-site. Obviously, the experience of “touching” and working directly with real equipment is a significant part of a student training. Therefore, a laboratory, where on-site and on-line activities can be performed, would benefit from both approaches. In the mixed learning approach, on-line activities are complementary to contact activities, rather than an alternative.

For this purpose, an *Open Laboratory* contains a set of equipment and resources having the entity of a complete, multi workspace, laboratory [5]. It is available simultaneously for remote access and *on site* work. The laboratory arrangement and organization are oriented to mixed training, that is, to combine contact and remote learning activities.

The final interest is to merge the open lab in a CMS, therefore students can see both parts as a whole. The developed system consists of four main parts (Figure 2):

- A course web server that contains teaching/learning materials.
- A lab web server with the software that allows access to the open lab. The Web server is in charge of storing the user application projects, checking program syntax and validity, as well as translating, if needed, the user program to the target robot program language, as well as handling and checking the execution of commands and programs.
- Robot Server. This computer takes care of the physical communication between the user and the robot (programs, position files, commands, messages), the execution of a task supervision program, and sensor information acquisition (webcam or IP camera, presence and proximity sensors) for the automatic task supervision (in the robot server) and for remote user supervision.
- Robots. Mechanical structure and control unit connected to an interfacing computer (the robot server) by means of a serial port or an Ethernet bus. Robots can be either manipulators and/or mobiles indifferently.

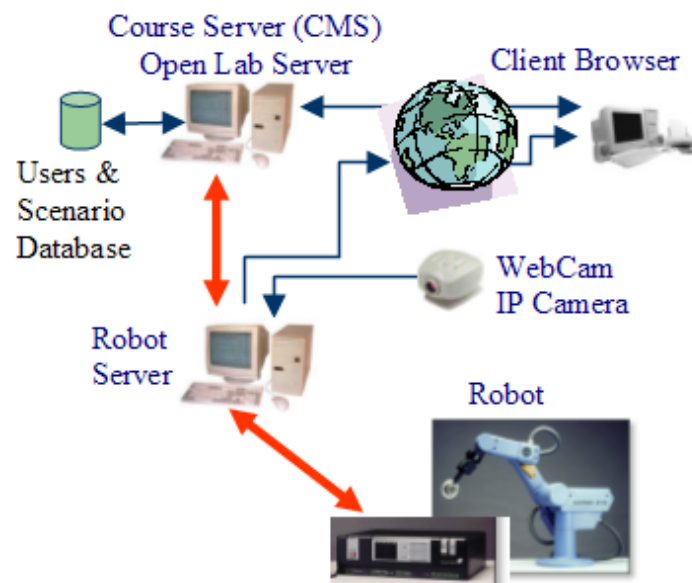


Figure 2. Structure of the open lab concept.

In conclusion, this mixed approach provides some comparative advantages since the sharing of equipment reduces cost, flexibility facilitates access to students promoting their initiative and autonomous learning, the system supervises the student work and equipment integrity. Additionally, the robots can be programmed using either their native language or a defined general purpose robot language. In this way, the same program can be executed in robots coming from different manufacturers.

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# On line perspiration: the laboratory experience via Web

## Introduction

An honest assessment of e-learning material available on the Web, and in particular of the material on technical subjects, would show that most of it is simply the Internet publication of standard printed formats [1]. In some cases, the presentation is enhanced by animated inserts showing various simulations [2], and, in few more cases, the theory is demonstrated with live experiments [3]. However, the experiments are pre-designed and the students have few choices available, either executing a prescribed experiment, or acquiring data, or trying various control parameters [4].

Clearly, giving access to laboratory hardware to remote users is a possible safety nightmare, and only carefully defined situations can be controlled remotely. Therefore, a completely free access to a laboratory experiment is, at the moment, impossible to grant. However, this may not be necessary in order to provide a remote student with the same emotional and cultural experience of a real experiment, in the same way sophisticated video games are able to excite and involve their users.

The Italian project Tiger (Telepresence Instant Groupware for higher Education in Robotics) [5] aims at producing a set of tools and teaching material that will replicate, within the limits of today's technology, the laboratory learning experience. The project will make accessible to remote students a network of robotics laboratories across Italy, each one focusing on a specific aspect of robotics to provide "remote" hands-on experience. Experiments will range from motion control, to obstacle avoidance, from basic control, to kinematics analysis. Since the robotics curriculum developed by the project aims at an experienced audience, similar to continuing education programs offered by US Institutions, the unit at the University of Verona decided to develop teaching and experimental material on sensor based control, to address the needs of working professionals who want to learn about new generations of robotic devices.

## The interactive experiment

The experiments proposed are on force control, to let the student get acquainted with the problems of force/torque sensing, data acquisition and processing, and control algorithm design. The range of tools that the students need to master to carry out a successful experiment is very broad and therefore we need to provide them with a carefully engineered environment that can guide them, but that can also give them the impression of enjoying a rather large freedom of action. To achieve these results, we have developed a software architecture expressly designed to support robot control and operator's interface. The necessity of developing yet another robot control architecture was dictated by the need of letting the users feel the emotions of real laboratory experiments without risking any damage to the hardware. We thought that we could achieve this result by a two step approach: a modular architecture that lets the users "plug and play", within limits, their custom designed force/impedance control algorithms, and an underlying position control layer that ensures safety while showing some of the negative effects of poorly designed algorithms.

The control schemes that we will let the students experiment with are shown in Figure 1 and 2, 3 representing impedance, force and hybrid control algorithms, respectively.

The internal position control will not be accessible to the students and will act as a supervisor of the experiment, executing the position profiles computed by the controllers, and implementing all the necessary safety checks. In order to give the student the impression of total freedom, and to let them understand what mistakes in the control algorithm can do, we need also to let the robot show some unstable and potentially danger behavior. Thus the challenge of these experiments is exactly this, simulating with enough realism a potentially unstable robot behavior.



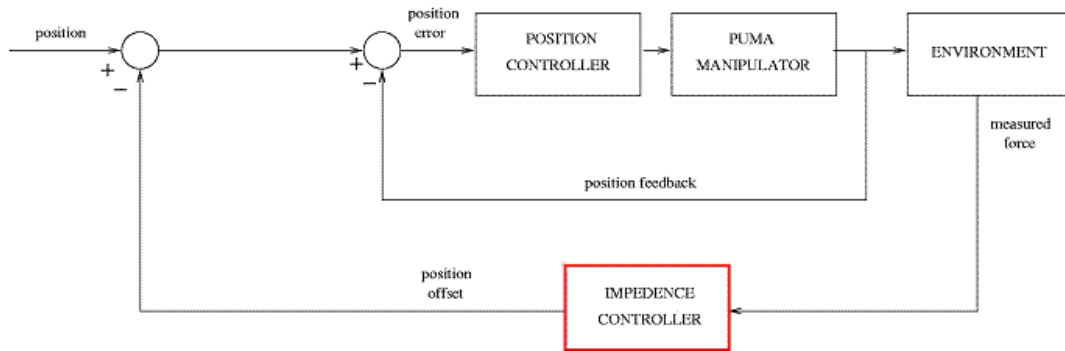


Figure 1: Scheme representing impedance control

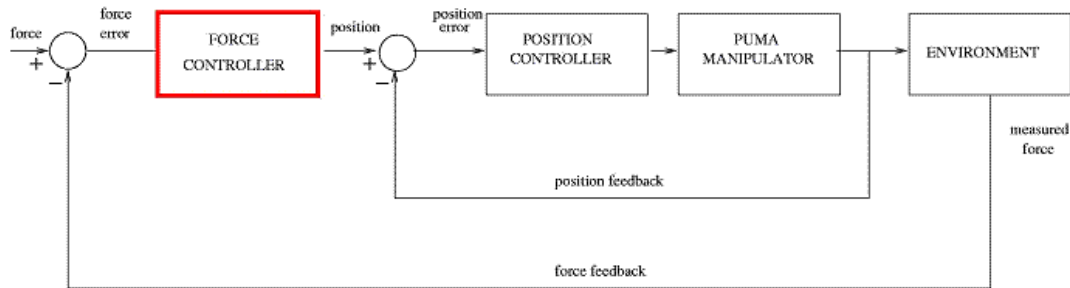


Figure 2: Scheme representing force control

## The safety protections

To achieve the goal of total safety during all the experiments, we rely on the modularity and flexibility of the software architecture that we are implementing, and on the time delay that the execution of a remote experiment implicitly includes. The architecture is based on a set of distributed modules, linked by a CORBA communication infrastructure, implementing various functions, such as operator's interface, graphical visualization, dynamic simulation, and control modules. This infrastructure lets us mix and match different functions depending on the needs of the current experiment. In particular, in the case of force control experiments, we are proceeding with two parallel approaches. The first one is a classical method: we use the standard set of safety procedures of the position control loop to ensure that the robot motion computed by the student control algorithm does not violate position, velocity, and acceleration limits. However, we are also implementing a more ambitious approach using an on-line simulation of the robot behavior before executing the experiment. In this second case, we use the delay of the remote laboratory, to simulate the experiment and memorize position and velocity data computed by the simulation. These data will then be "played back" by the position controller, duplicating the motions computed by the simulation, rather than using the student designed force controller. The differences between the two methods are basically on the length and realism of the experiment. In the first case, the experiment will be "real", however the safety locks will stop it immediately without giving the student enough time to understand the event or even to be afraid of his/her own mistakes. In the second case instead, the system will be playing back a carefully edited version of the simulated experiment, limiting excessive velocities and eliminating out-of-range motions, thus giving the student time to appreciate the extent of unstable motions. We plan to carry out experiments to verify whether the students are able to distinguish between the real and the simulated experiments and to ask them to grade the realism and the effectiveness of this approach.

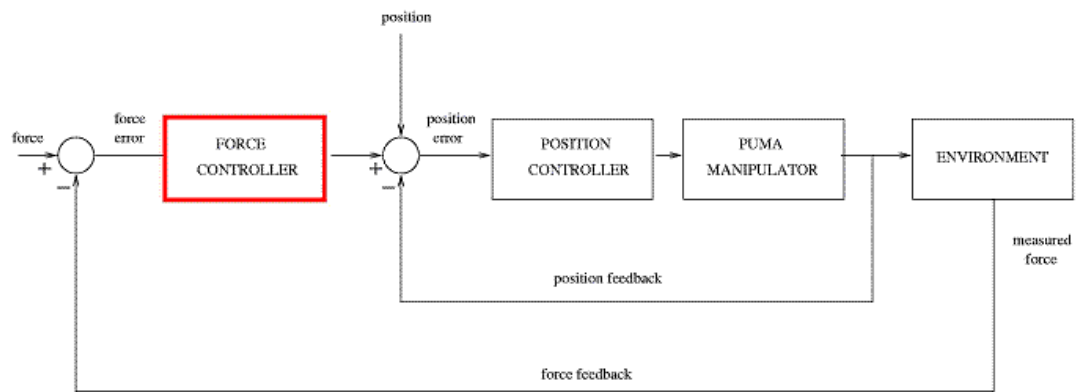


Figure 2: Scheme representing hybrid control

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# Learning Objects design for supporting e-learning by Immersive Telelaboratory

## Abstract

The approach followed in the design of Learning Objects (LOs) used in the TIGER (Telepresence Instant Groupware for higher Education in Robotics) environment is outlined. By devising a suitable typology for LOs, the proposal aims to render them a tool apt to model the pedagogical intentions of a teacher who acts as initiator of constructive learning processes.

## 1. Pedagogical approach

In TIGER, Learning Objects (LOs) are conceived so as to reflect the articulated organization of educational materials and activities that experienced teachers usually employ in their work.

We start from observing that teachers, while preparing some educational activity, devise the overall learning experience, based on contents to be learnt and abilities to be acquired, as well as on previous educational work. Then, they organise the overall path in a number of learning modules, focused on specific topics or activities, which work as initiators of learning experiences and hence include a specific educational objective and a pedagogical approach. These modules can make use of general-purpose auxiliary material and resources, aiming to complete and differentiate the orientation of the learning process hypothesised. The use of the resources is organised so to be functional to work development and to the interactions among the actors of the educational experience. Our pedagogical framework reflects this organisation.

## 2. Realisation

Learning modules are realised by means of LOs apt to structure and guide an articulated educational activity. These LOs are designed so that they can make use of, or refer to, other LOs, with a different structure, corresponding to possibly necessary auxiliary materials. Moreover, they support the use of the tools that the environment puts at students' disposal for manipulating, sharing and representing knowledge. Figure 1 summarises the realisation in the TIGER environment of this conception of learning module.

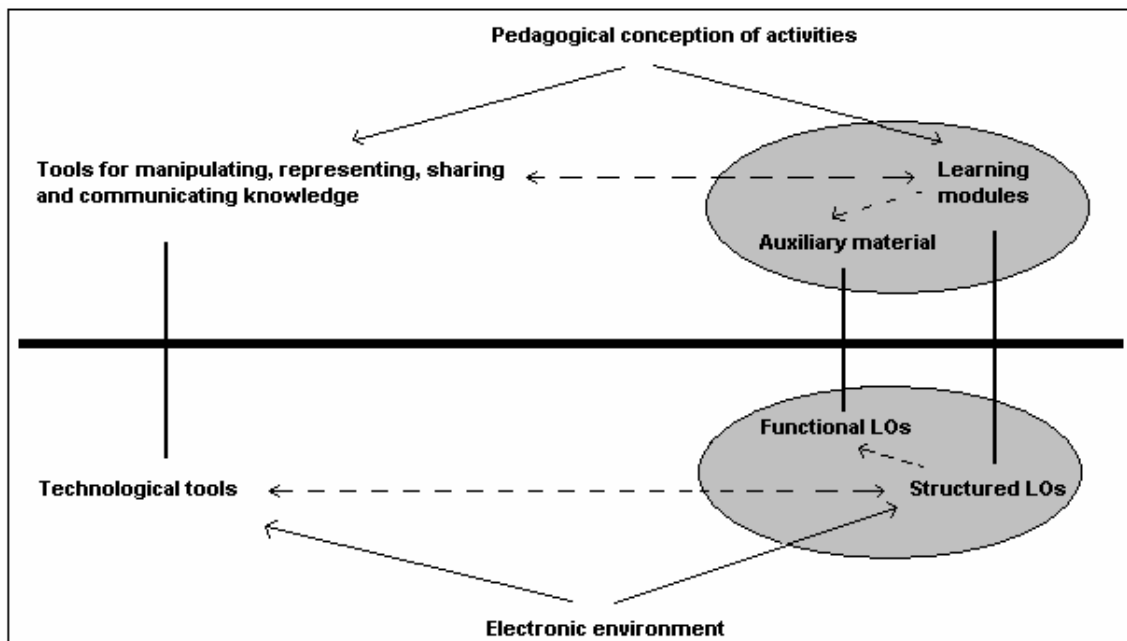


Figure 1. Organisation of an educational activity and its representation

This organisation implies having at disposal LOs of two different types: 1) *Structured LOs*, based on a precise educational objective, characterized by a type determining their structure and didactical function; 2) *Functional LOs*, which have a general-purpose or context-related function, such as Glossaries, Reference material, Forms to fill in, and so on.

These two types of LOs are divided into different subtypes, according to their structure and function. Here we briefly characterise *Structured LOs*, referring to [ICWL 2005] for a more complete description.

*Structured LOs* can take different forms, depending on the objective of the correspondent modules (see Figure 2):

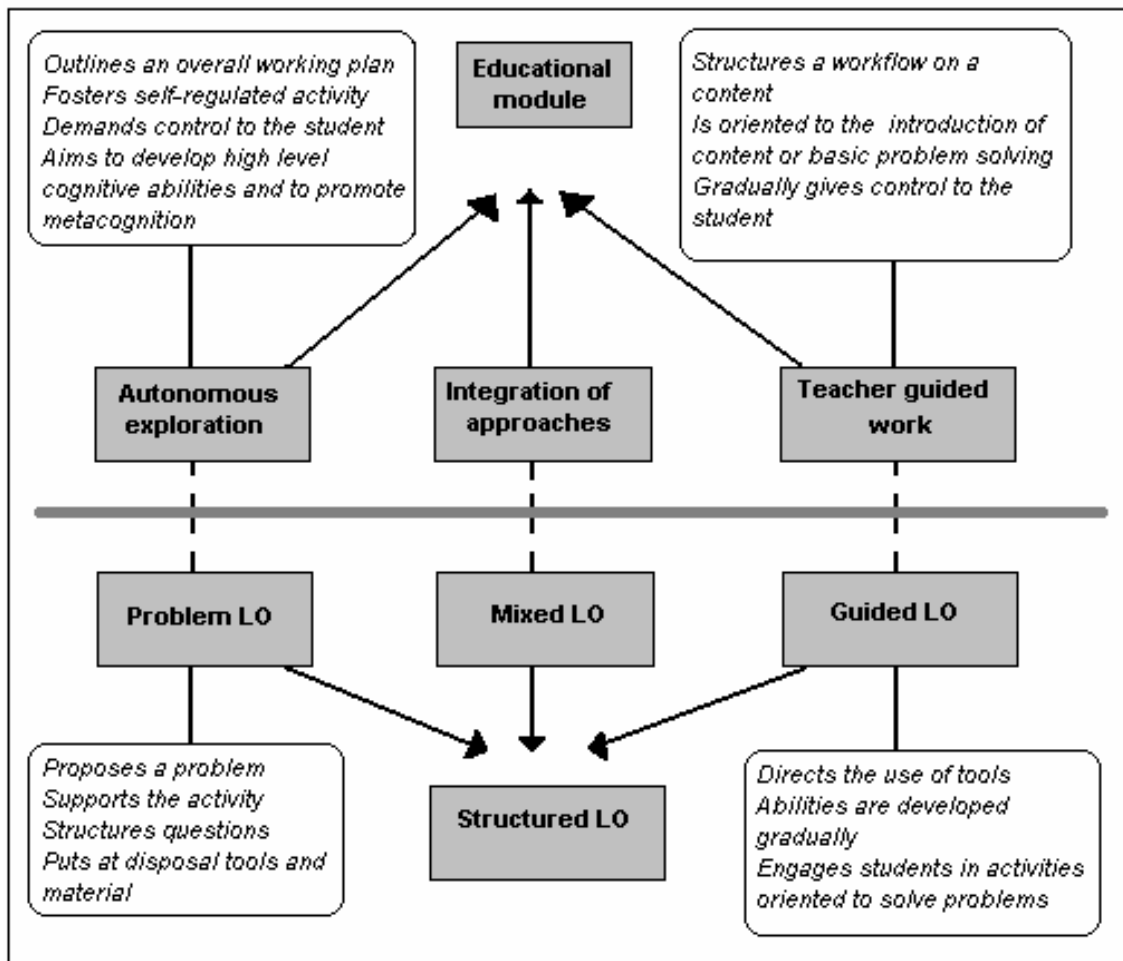


Figure 2. Parallelism between learning modules with their specific learning approaches and *Structured LOs* with their subtypes

- • *Guided LOs*, devoted to introduce some topic under planned guidance, are suitable for leading inexperienced students in the initial exploration of some new topic. Such LOs introduce content knowledge or some basic approach to problem solving. Teaching and learning are structured and aim to stimulate autonomous reflection, as well as control, evaluation and comparison of the work done.
- • *Problem LOs* leave students space to use their ability and creativity on topics where they already have some experience. Here, a problem situation is proposed. Questions leading towards activities necessary to solve the given problem, as well as materials and tools relevant for the assigned task, are included. This approach aims to develop high level cognitive abilities and to support metacognition and autonomous learning.
- • *Mixed LOs* are based on a combination of these two types.

### 3. Examples of structured LOs

Both a *Problem LO* or a *Guided LO* may be suitably used on a same topic, but with different pedagogical aims. Let us see, for example, LOs of different type, guiding to analyse the unexpected behaviour of a robot.

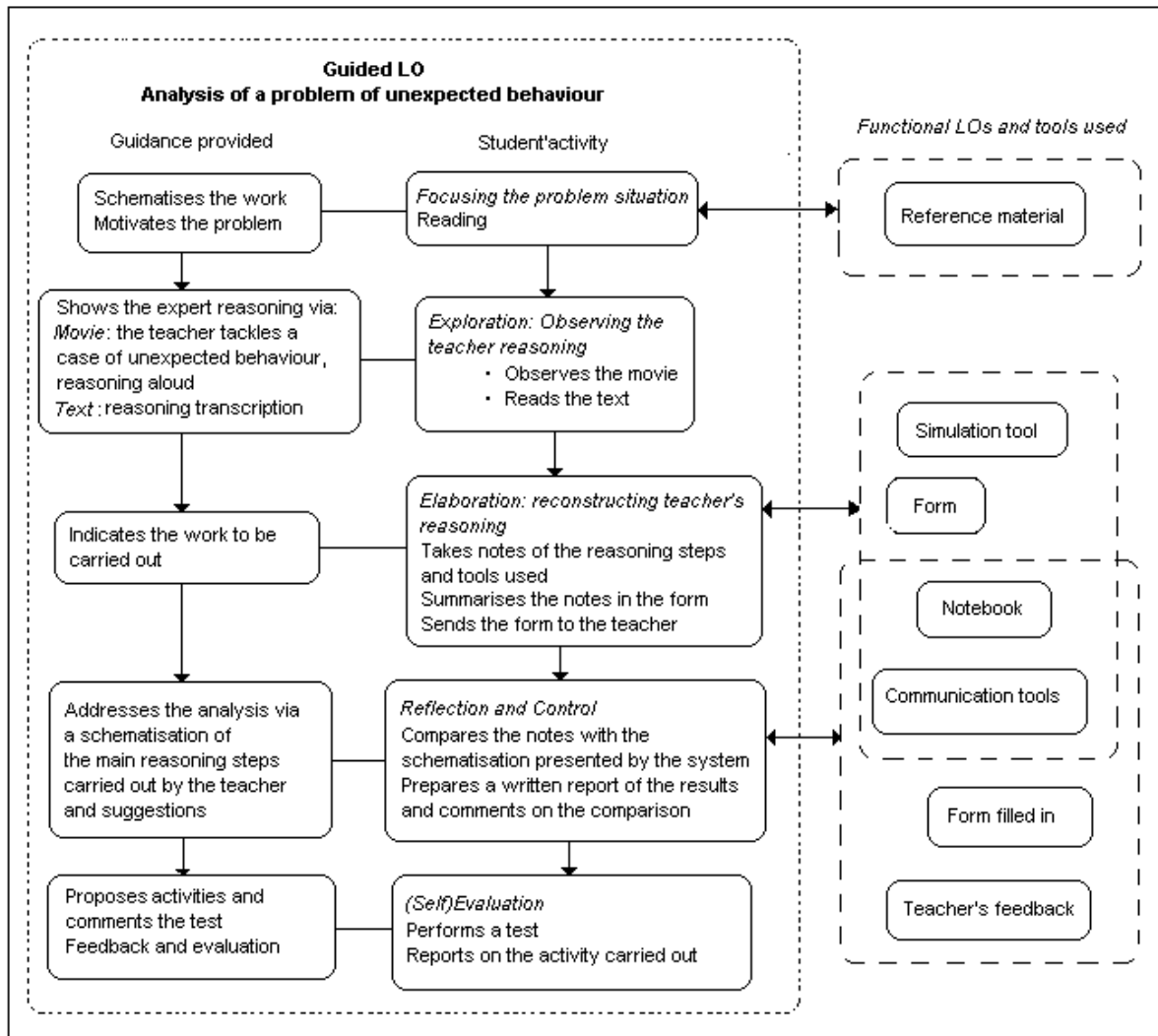


Figure 3. The structure of a *Guided LO* on an 'unexpected behaviour' problem and examples of resources used

If the students are beginners with limited practical experience, teacher's guidance is necessary to help them learn how experts reason on such problems; hence, a *Guided LO* will be used. Figure 3 shows the structure of this *LO*, outlining the kind of support it provides to the planned student's activity, and the mediation it offers to the use of functional LOs. This proposal is characterised by: 1) central presence of the teacher, who tackles the problem and reasons aloud while trying to determine the causes of the unexpected behaviour; 2) strict interconnection between teacher's interventions and students' activity; 3) proposed activity, aiming to guide the students to gain understanding of the expert's reasoning and to reconstruct such reasoning in real situations.

Figure 4, on the other hand, shows the structure of a *Problem LO* on the same topic. From a pedagogical point of view, the proposal is similar to a working proposal presenting the problem and the goal to be reached, together with a number of suggestions on the choice and use of tools, as well as recalls on conceptual work organisation. The problem's solution is left to the student, as well as planning, controlling and self-evaluating the activity.

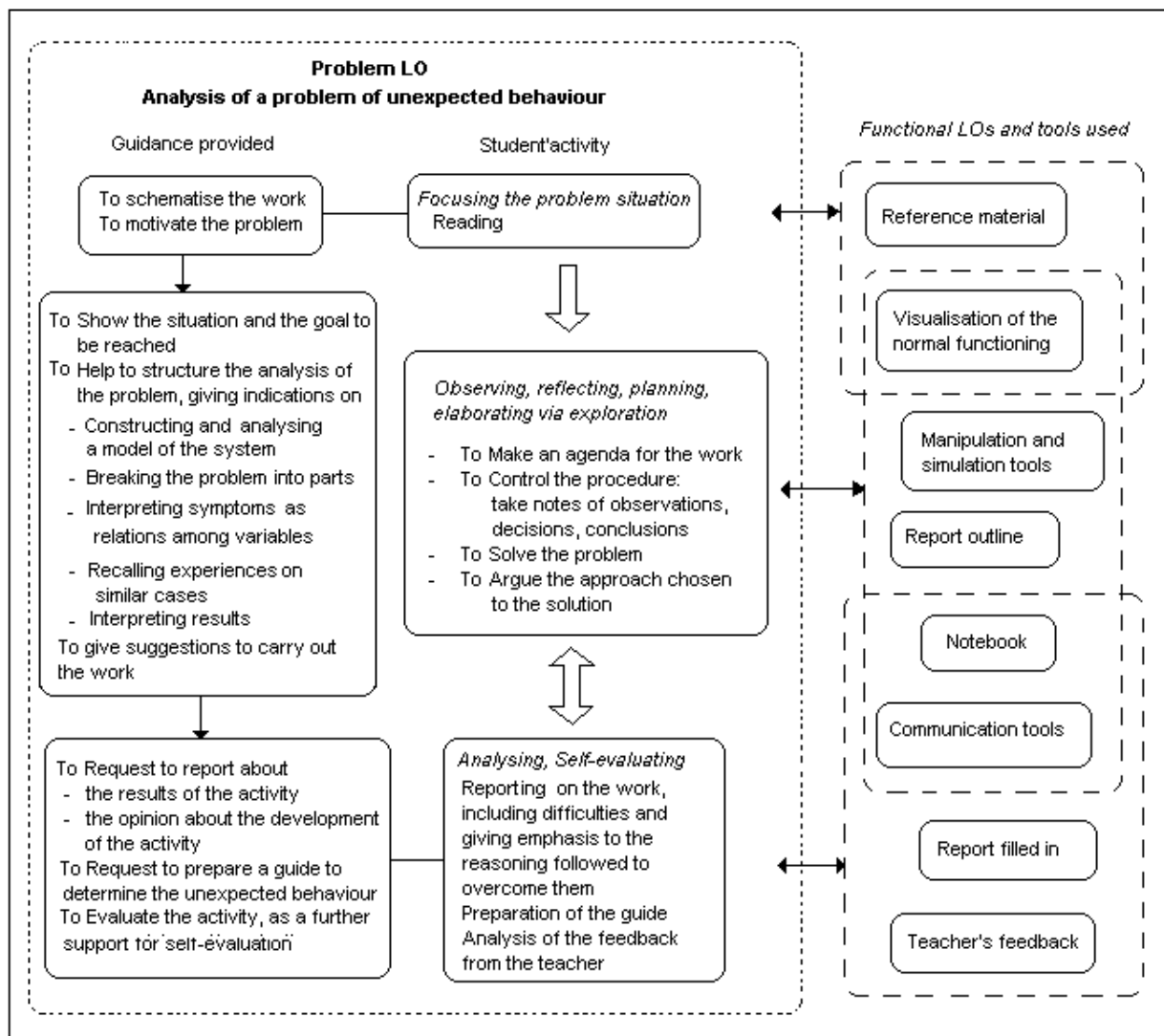


Figure 4 The structure of a Problem LO focusing on a problem of “Unexpected behaviour”, together with examples of resources and functional LOs used

## Concluding remarks

We propose a teacher-oriented approach to the design of learning objects aiming to use this technology to realise educational proposals based on the current educational orientations. Our approach has several educational advantages: it gives an operative tool to help the teacher gain familiarity with the concept of LO; it enriches the expressive power of LOs by representing not only learning materials but also pedagogical approaches; it gives indications on a possible way to create constructive LOs, hence capturing the essential nature of the didactical process, which is constantly in evolution.

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# Learning Evaluation in a Context of Immersive Telelaboratory

## Abstract

Learning Evaluation of students using an Immersive Telelaboratory represents a relevant and complex point at the same time. The aim of this work is to evaluate the effectiveness of a remote immersive laboratory on students learning aimed at acquiring project competences on Robotics.

## 1. Introduction

This work describes our plans and preliminary results for the learning evaluation of students involved in the project TIGER, Telepresence Instant Groupware for Higher Education in Robotics, (<http://www.del.univpm.it/tiger>). TIGER wants to train control systems designers in the context of university and professional education on Robotics by using Immersive Telelaboratory (<http://www.del.univpm.it/it>). The test bed is a process which simulates the behaviour of an helicopter. The students have to set a industrial regulator with Ziegler and Nichols technique. Number of perceptive channels like audio, video and force measure relevant for control are available. Appropriate constructivist [Flavell, 1979] learning models have been defined to manage learning in such an environment.

## 2. Approaches to evaluation

The evaluation of learning is at the attention of the scientific community. Several general approaches [Stufflebeam et Shinkfield, 1985] [Stake, 1975] have been developed on this subject. We focus on the evaluation based on goals (or objectives) [Tyler, 1949].

In particular we refer to the model developed by Kirkpatrick. This model [Kirkpatrick, 1975] is widely used for evaluating training programs in corporate learning and is divided into four levels, corresponding each to a group of results of a training program: *Reaction*, *Learning*, *Transfer* and *Results* (see Picture 1).

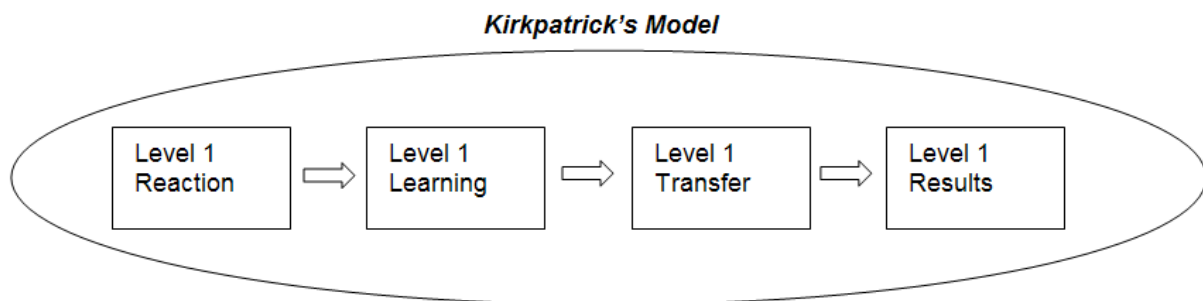


Figure 1. Kirkpatrick's model

In our experimentation we adapt it to the higher education context and we refer to the first two levels.

1. Level of *Reaction*, which aims to measure the reaction of students to learning resources in terms of interest, satisfaction with the trainer, usefulness and importance perceived. This level refers to motivation of students. The reaction is often measured through a final questionnaire.
2. Level of *Learning*, which measures the change of attitude, the new knowledge acquired and the increased abilities of students through quantifiable indicators.

This level aims to validate the effectiveness of the course. Measures of learning can be in general obtained through summative evaluation (tests, reports, projects...).

### 3. Objectives and methods of evaluation in the experimentation of an immersive telelaboratory

The purpose of the evaluation is to assess quality to the work done and to allow possible improvements. As it is expected that TIGER project instructs control designers of Robot; among the most important purposes of evaluation there is to check if telelaboratory improves design competences. These are meant to be operative abilities, cultural knowledge and relational skills.

According to the Kirkpatrick's model we considered reaction and learning as follows:

#### reaction

- Student's learning expectation towards the knowledge of the subject, the planning skills and the use of the telelaboratory.
- Students' expectations towards cooperative work
- Students' satisfaction level
- Personal motivation and interest of the student

#### learning

- How much has the student employed the instruments of collaboration (has collaborated)
- How much has the student effectively taken part to the didactic activities proposed
- How have the didactic goals been reached
- How has the student been able to evaluate critically the results obtained.

Due to the novelty of the TIGER learning system, evaluation tests have been issued in an experimental way. This experimentation is made by the following steps:

- step 0: questionnaire informing the connectivity and functions of data elaboration
- step 1: face to face presentation of the system to the students;
- step 2: enrollment of students and presentation on line of the metacognitive framework;
- step 3: preliminary online questionnaire about user's expectations and entry level;
- step 4: start of the telelaboratory activity;
- step 5: questionnaire for the student's self-evaluation of learning on theoretical aspects regarding the telelaboratory;
- step 6: reservation of the processes under test and management of the authorizations;
- step 7: guided activity and development of experiments; Report of the group with a series of individual remarks;
- step 8: final questionnaire to collect users' evaluation of the experience.

### 4. Preliminary results and future works

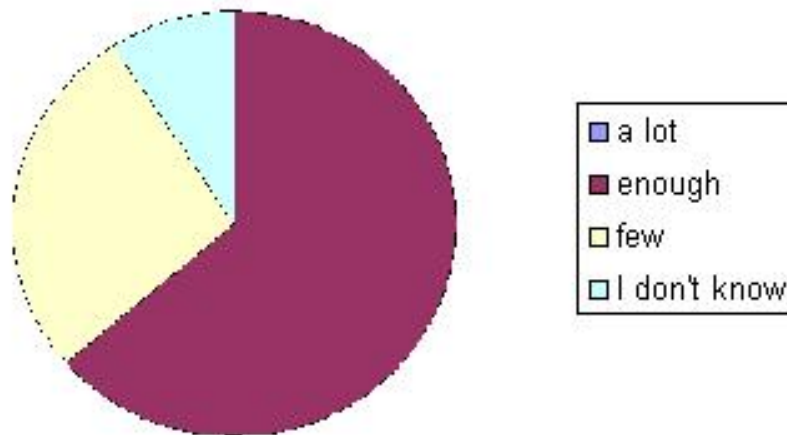
The experiment has been executed on two groups, the attention has been focused on didactic and learning aspects. In both groups, techniques of discussion and forum management have produced the following results: the forum gives information and creates sharing and interest and in particular the forum was effective when the moderator posted discussion items related to the study subject; besides a collaborative and active e-learning mode doesn't reduces time costs for the students. Regarding to the problems related to experimentation, we noticed that our telelaboratory creates problems of time to the students because it is used at the end of the course and during the preparation of the exams.

With the second group, bigger than the first, the problem arised is the difficulty of the students for forming collaborative groups because they don't know each other. Nevertheless once the groups are formed the collaborative work becomes easier and appreciated by the students. Some relevant answers to the questions of the preliminary questionnaire are:

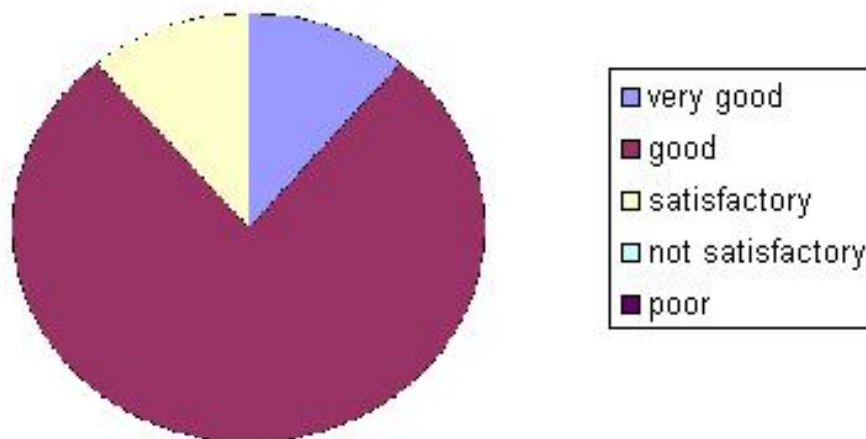
For the future works, we will develop further didactic and learning objects in order to start the telelaboratory activities at the beginning of the course and we will improve the discussion management of the forums. Moreover the telelaboratory will be used by students of universities involved in the TIGER project.



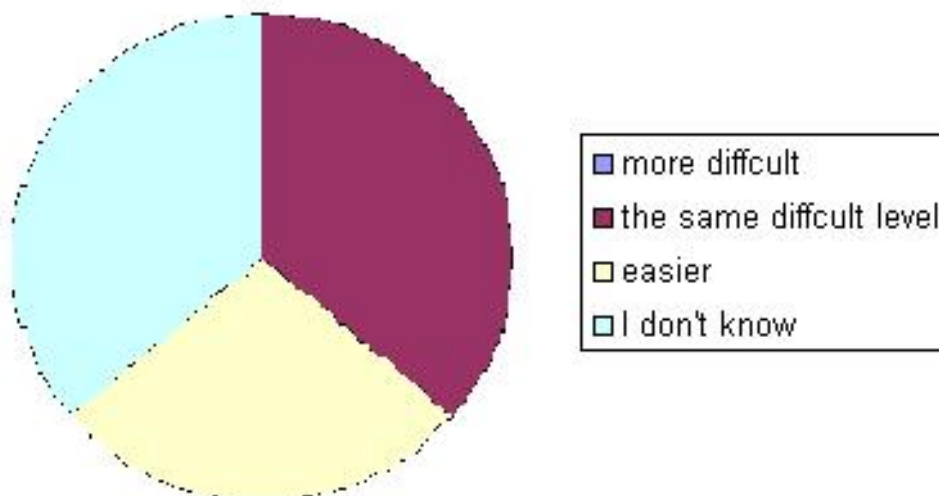
Using the Tel-elaboratory, you can increase your ability to solve real problems



The Tel-elaboratory is a .... tool in order to acquire design ability



Studying online is .... than traditional studying?



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# VLR: a novel approach for the effective learning of robotics on the Web

## Abstract

In the present work, an educational tool called *VRL*, used as a support for active learning of robotics in a web-learning environment, will be described. *VRL* guarantees forms of flexible learning, and couples virtual reality experiments, obtained through the integration of Matlab and Shockwave technology, and remote lab experiments, in order to allow a preliminary verification of theoretical concepts without the risks of damaging the remote experimental device.

## 1. Introduction

A consequence of the continuous advances in information technologies is that educational models emphasizing collaborative and active learning have been more and more claimed for in university courses. University curricula for control engineering courses have been substantially modified during the last years, to include modern techniques for analysis and design as well as novel learning tools based on the Web. In face of continuously evolving programs, yet the recognized need for laboratory experience in the curricula is a constant issue: "More and more educators recognize the importance of a complete educational experience involving theory and practice" (Yorkovich and Passino, 1996). In educational terms this corresponds to the need of learning skills. In the Control Engineering domain, an important category of skills is the ability of capturing the experimental richness of the real physical processes, and to abstract from it the approximate models suitable for an effective control. This would imply the availability of large laboratory resources, which is instead limited due to economic factors. The need of integrating traditional classroom lectures with some kind of "experimental practice" is often addressed using simulation tools, but the richness of physical realities is inevitably omitted. Distance learning can be effectively used to overcome these problems.

## 2. VRL

This paper describes a program which is being carried out at the University of Lecce in the framework of the project "TIGER" (Telepresence Groupware For Higher Education in Robotics). The developed tool VRL (Virtual-Remote Lab) is a flexible and dynamical educational tool aimed at coupling experimental training and active learning in the field of Control Engineering Courses. The novelty of VRL consists mainly in the definition of a flexible and user-tailored learning path, containing also some experiments on a virtual reality set-up, which the user has to follow before being allowed to access the remote physical devices available. This latter choice stems from the fact that obvious safety reasons usually hinder, de facto, the effective use by students of classical remote labs. In VRL active learning is achieved by the use of learning "elements" (tests, exercises, design) which can be executed according to a totally flexible, user defined order, still maintaining complete interactivity with the system.

A further remarkable issue of VRL is the definition of a dynamically updated "learning coefficient", associated to each user, which formalizes the degree of successfulness in learning of the user according to his/her individual learning pathway. Therefore, not only the sequence of the learning elements varies with the user, but also their number and type, according to the learning "performances" of the user itself.

The availability of virtual reality experiments in VRL, obtained through the integration of Matlab and Shockwave technology, allows the user to integrate theoretical concepts with a preliminary practical verification, without the risks of damaging the experimental device. The user can check his/her controller again and again on a virtual version of the selected device and, when the virtual control experiment is successful, he/she gains access to the physical device. It is worth noting that the virtual device can be accessed simultaneously by more students, while the experimental device can be accessed only by a user at a time. The currently available version of VRL contains the virtual version of the inverted pendulum by Feedback, whose picture is reported in Fig.1. The same device is also available as remote device through the remote lab interface.

With reference to the VRL user interface, it has been designed according to the well known issues of usability and accessibility. Easy graphics and smooth colors have been used, structuring the information to be delivered to the user with the aid of cards, which separate the site into multiple environments, each of which is associated to a color. Still retaining a pyramidal structure, the site can be easily navigated (since from a page the user can access almost all the other pages, according to the issue of navigability of a hypertext).

### 3. Architecture of VRL

From an architectural viewpoint, the key issue is the use of Matlab Server (to avoid the use of applets or software to be downloaded by the user) and the presence of a dynamical database which underlays the entire system. The structure of VRL is reported in Fig.2. The so called Robotic Cell contains four devices (Inverted pendulum, Magnetic Levitator,

Servomotor, Helicopted, all of them commercialized by Feedback) each of which is controller by a server. Each server is connected by intranet to a General Web Server (GWS) which, along with a Matlab Web Server (MtWS) and a Data Base Server (DBS) constitute the VRL Core). It follows that the web based architecture is based on the following five levels:

- Web Clients: The set of machines on the Web requiring access to VRL;
- VRL Core: it contains GWS (General Web Server), which manages the communication among the Web Clients Web and the devices in the Robotic Cell, MtWS (Matlab Web Server) which is devoted to matlab computations on the Web, and DBS (Data Base Server) which manages the dynamic database governing the infrastructure;
- SGrab (Servers Grab), which manages data from the webcam;
- CSD (Control Servers Device) controlling physical devices (PLD);
- PLD (Physical Learning Devices): the set of devices available for remote access.

The advantages of the above architecture can be summarized as follows:

- Protection against external accesses. Since access to VRL can be gained by the web site and the https protocol, complete control on users is ensured;
- Usability and navigability. In particular, the web pages are designed as to integrate what the user needs for its task, leaving computations, controls, storing, etc. to other subsystems;
- Modularity of the architecture. VRL has an open structure, hence adding new devices and/or new learning objects is always possible and easy;
- Realization of a user tailored learning path, based on the dynamic architecture, which is traceable at each stage of the learning process;
- Safety of shared devices, hence real possibility by the user of
- performing remote experiments. One of the aims of VRL is the coupling of theoretical issues with experimental practice, joined together through the availability of preliminary test on virtual versions of the same devices available for remote experimentation;
- Effective interaction with the physical device (by feedback given by a webcam) and with experiment results

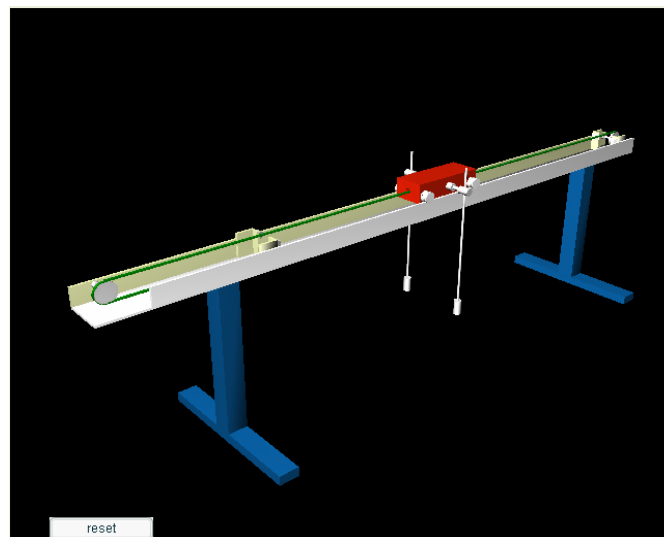


Figure 1. The virtual inverted pendulum in VRL

# VRL

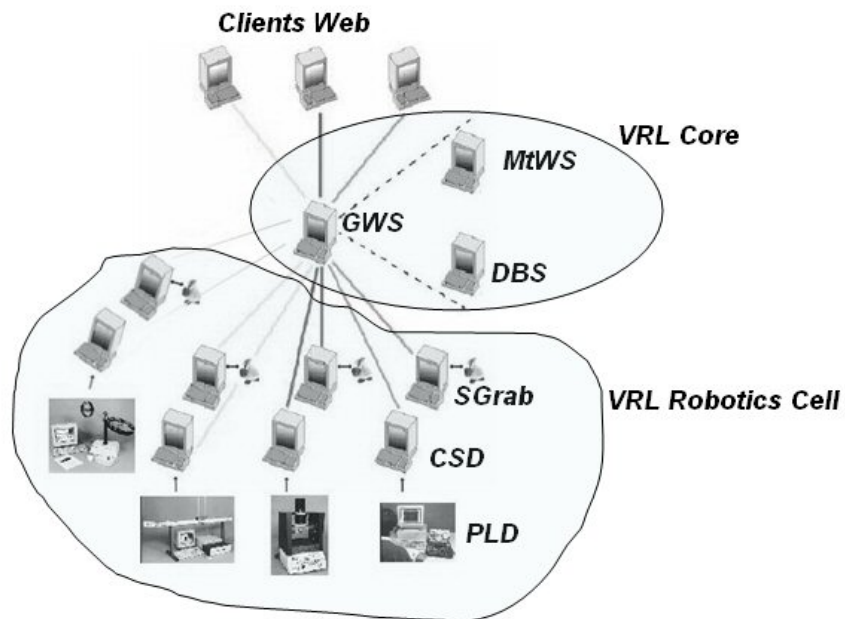


Figure 2. The architecture of VRL

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# Open Standards for Higher Education in Robotics by Immersive Telelaboratories

## 1. Introduction

Immersive telelaboratories for higher education in robotics involve new technological challenges. A telelaboratory is a laboratory where remote access to laboratory hardware is provided. A telelaboratory provides three separate access modes: *proximal*, *remote* and *simulation*. In particular, *immersive* telelaboratories aim to minimize the experience gaps between the three access modes, i.e. audiovisual experiences throughout simulation and web-based remote access modes should be very similar to the proximal one. Towards this end, we need quasi-real time communication, i.e. users ought to perceive changes to the laboratory environment as soon as they occur. Students and educators can access laboratory resources anytime and anywhere; more, institutions may share rare and expensive laboratory hardware, so that each institution may offer a broader range of lab experiences. The immersivity requirement is the key feature, making remote access almost as useful as the proximal one.

In this paper, we describe how an architecture of immersive telelaboratories based on open standards may act as a facilitator for educational purposes.

## 2. Architecture

A telelaboratory may be analysed in four components: the Lab Server, the Simulator, the Repository and the Web Server. Users (educators and students) connect to the telelaboratory via a Web Client, i.e. a browser.

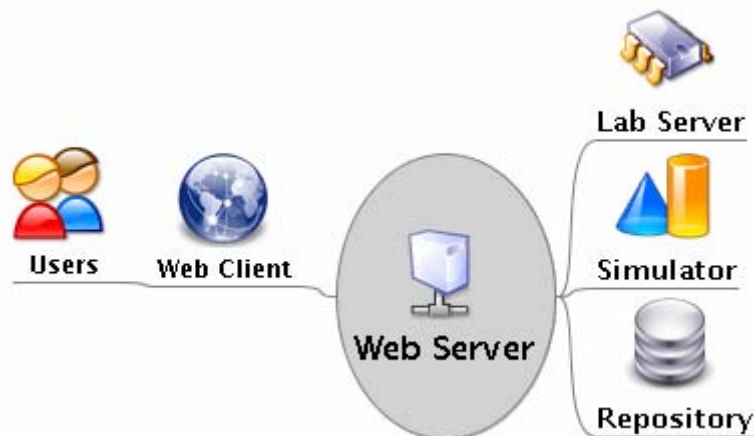


Figure 1. Architecture

The *Web Server* should comply with whatever protocol and language is used by each *Lab Server*, which controls the laboratory hardware. This concern can be dealt with adopting a plugin-based architecture: integration of different protocols should be a matter of developing an appropriate plugin module. The Web server also provides a convenient Learning Management System (LMS) to the *Repository*, which is a database of Learning Objects (IEEE 1484.12.1–2002) of experiments in advanced robotics, and their developments made by the students, ordered along quality indicators. Until now, far less attention has been given by now to open source LMS platforms (see Avgeriou et al., 2003), although they may be easily customized for educational purposes. Finally, the *Simulator* is a web application, i.e. a software module that simulates the lab's physical process as closely as possible in the web. The Simulator will be the main environment to construct and develop a variety of simulated experiments as Learning Objects.

### 3. Developing Software for Telepresence

The Web Server should be an effective information broker for users. Brokerage effectiveness may be divided in three requirements: accessibility, compatibility and immersivity.

*Accessibility requirement.* Web-based applications should deliver a good quality of interaction with the broadest range of hardware and software without relying on the presence of special software on the user's computer, other than a standard compliant browser (Zeldman, 2003). Moreover, standard web technologies respect accessibility special requirements for people with disabilities (W3C, 2002).

*Compatibility requirement.* Most modern web applications rely on JavaScript, as the client-side scripting language, which is able to manipulate the objects in the web pages without having them to be fully reloaded. This method permits to perform operations without information pull from the server, and avoiding unnecessary network round-trip delays, and recently it has been dubbed 'Ajax', i.e. 'Asynchronous Javascript and XML'. The Ajax method has become widespread, e.g. web services by Google (Gmail, google Suggest, Google Maps) follows this philosophy (Garrett, 2005). As it does not require any additional plug-ins to common browsers, the Ajax method is well suitable for quasi-real time needs.

*Immersivity requirement.* Live video images of the laboratory hardware may be put on the web using the MJPEG protocol (Casey, 2004): many readily available surveillance cameras are able to generate such a video feed with no additional hardware or software, and every common browser can display an MJPEG feed.

We should also care providing an animated drawing or diagram of the lab state. This has significant advantages over a plain video image in terms of less bandwidth: we need only to transmit an array of numbers that represent the state of the system; in case of network delay, the lost frame may be interpolated in a precise way, by using a mathematical model of the physical process.

A third important point is that the same animated diagram can be used to display the state of the Simulator. This makes it possible to make a smooth transition from the simulated experience to the real experiments. We decided to use the Scalable Vector Graphics (SVG) standard, which is going to be almost universally available (Hicks, 2005), and it may also be coupled with client-side JavaScript to build animations, following the Ajax method.

### 4. Conclusions and further works

Work is underway to build a prototype of immersive telelaboratory for higher robotics education, as described above. Our further directions is to develop a framework for construction of experiments in advanced robotics as Learning Objects. We are going to extend an open source LMS with a software module *ad hoc*.

### Acknowledgements

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# Remote Laboratories on Mobile Robotics

## I. Introduction

Remote laboratories enable via internet for students the access to hardware experiments, physically located at distant locations. This offers a more efficient use of hardware resources as well as more flexibility for the students regarding schedule and location [1]. Telematic techniques [5] provide appropriate methods for the necessary remote sensor data acquisition and tele-operation infrastructure. This contribution presents exemplary learning units for self guided learning, including tutorials, feedback on learning progress, integrated simulations, and remote access to experiment hardware in the field of robotic vehicles with respect to kinematics, dynamics and sensorics [4], [2], [6].

While first developments on robots on the web started in our laboratory in 1995, these experiments on mobile robots are now offered in the “Virtual University of Bavaria” for 24 hours a day, 7 days a week. This is based on

- robust rover hardware like the MERLIN (Mobile Experimental Robot for Locomotion and Intelligent Navigation [3]), a robot of 50 cm length (Figure1),
- supporting infrastructure to minimize administrative efforts and to allow unattended operation during the night or over the weekends.

A powerful infrastructure allows the management of 100 students per semester with a reasonable effort.

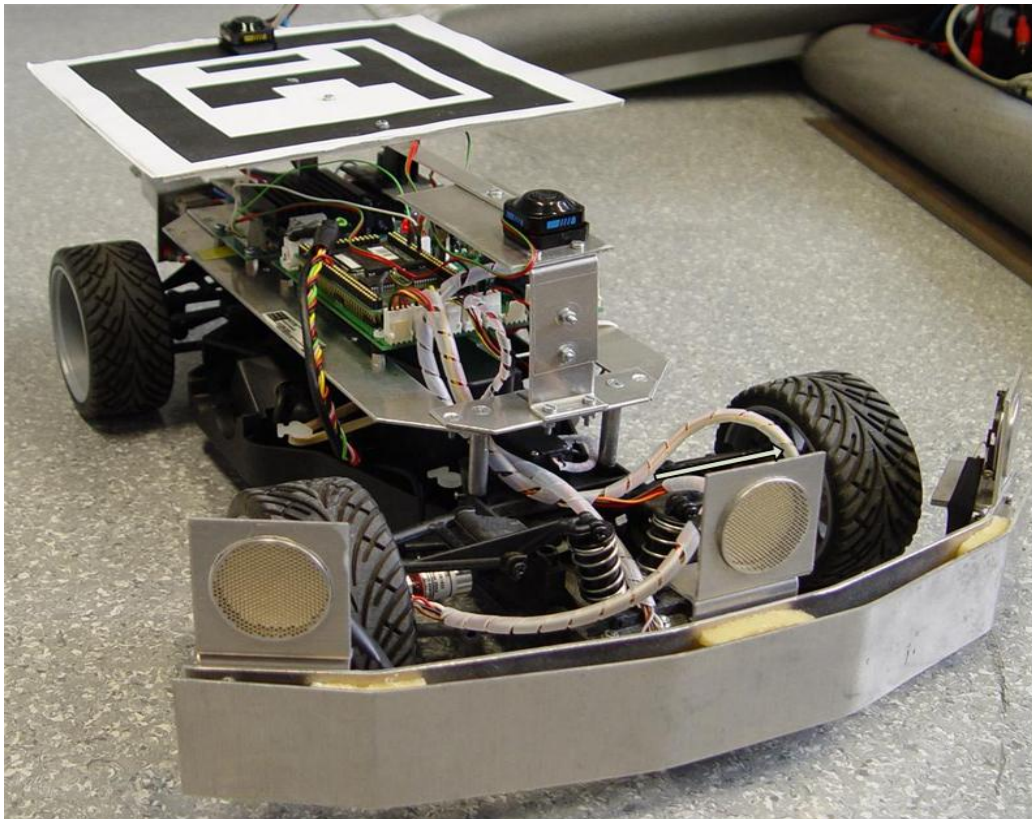


Figure 1. The four wheeled test vehicle MERLIN with fixed rear wheels and steerable front wheels; on top optical localization markers are attached

The modular design of the architecture presented in the following sections and the unified experiment procedures allows an efficient operation of this remote lab.

## II. Infrastructure

The required infrastructure (cf. Figure 2) consists of three main hardware components: the mobile robot, external reference sensors for localization, and web services [6].

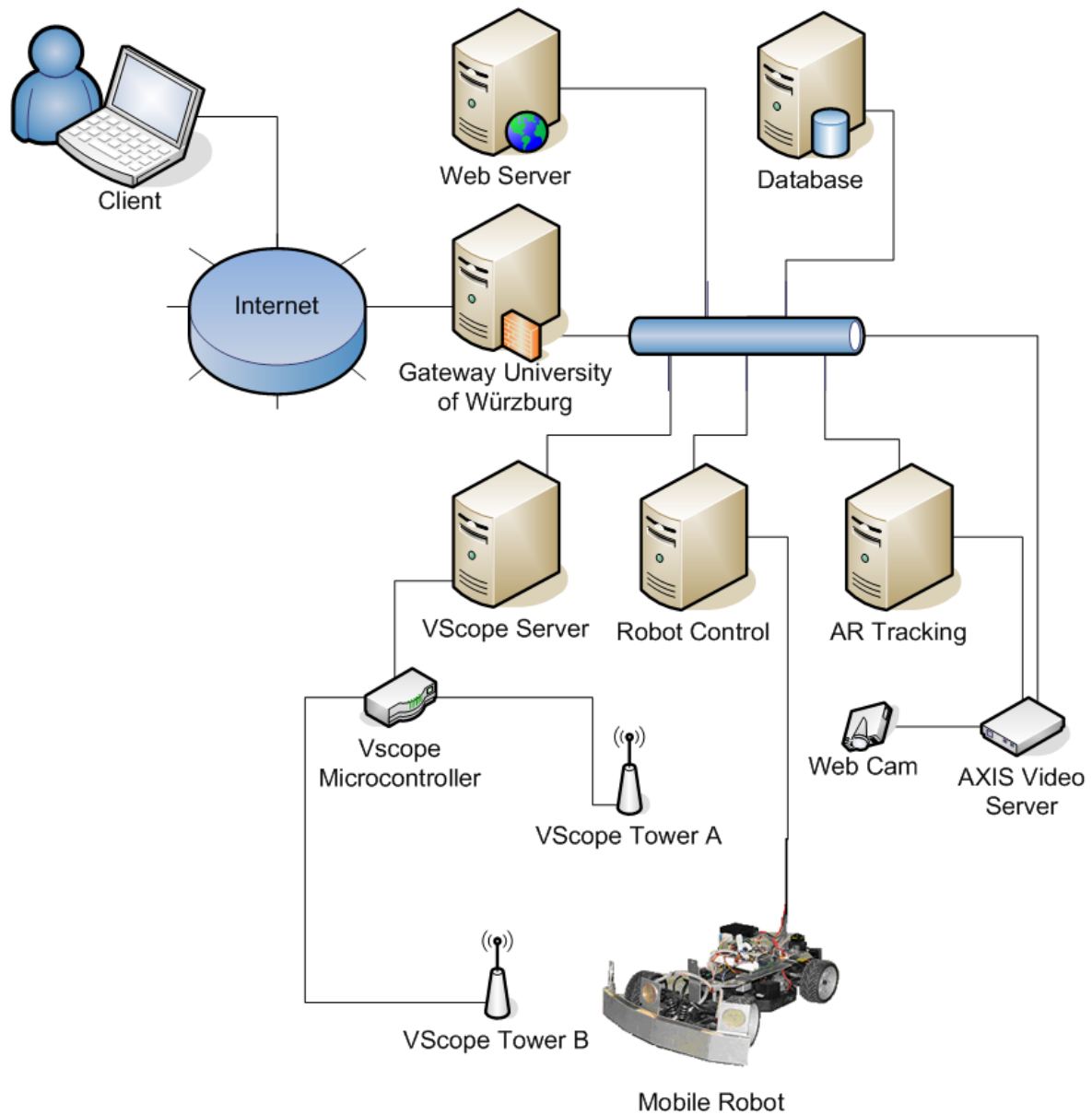


Figure 2. Remote Experiment Architecture including vehicle, reference tracking system (VScope) and webcam

The MERLIN robot was developed over 10 years in our team to provide a robust test platform, being stable and reliable enough for tele-education. The external sensors are mainly used for a position estimation of the MERLIN. Here tracking systems are employed, based on triangulations using ultrasonic/infrared distance measurements (like VScope) or optical tracking principles (like ARTS [2]). The components tracking system, robot control, database, and web portal are connected via TCP/IP to the internet. Time synchronization is inevitable to run this configuration. To cope with the amount of users, all web services are distributed [6]. The web server hosts a web portal to manage the experiment access. The database server controls user, resource, and schedule management. These modules coordinate access to the JAVA applets for operating the robot.

In the software architecture, a client-server approach is used to provide reliability, scalability, and security. The web server and the database server are secured. The VScope Server and the ARTS server are decoupled from the internet and can only be accessed inside the University's intranet. The robot control server is protected by

firewall services allowing access to necessary ports for the robot control. Furthermore, a monitoring system is used for supervising the activities of these computers. To provide scalability and reliability, the web portal is a large php-based dynamic webpage combined with a MySQL database for user-, resource-, and schedule management. The use of several MySQL databases reduce the necessary administrative tasks to a minimum while providing dynamic, personalized views and an overview of the learning progress to the students and tutors. The students can book resources and timeslots for the experiments directly. Reports for each experiment are submitted by the students on-line, as well as questionnaires to characterize experiences with the remote experiment. The final registration of users, the review of the reports, and the evaluation of the questionnaires require a tutor. In addition a chat facility for students is offered, to provide feedback to questions, arising while performing experiments.

### III. Conclusions

Two robot types, a differential drive robot and a non-holonomic vehicle with Ackermann steering are used for the remote rover laboratory, offering access to about 100 students per semester to perform 6 experiments for an average period of 4 hours each. From the educational side motivating, interactive remote experiments are to be provided, while from the technology side interdisciplinary mechatronic systems in combination with telematic techniques are to be implemented. According to our experiences in applying such remote experiments for more than 5 years in regular classes, these remote laboratories can in appropriate areas well complement traditional hands-on experiments. Thus students appreciate to use this way modern telematics methods in parallel to learning the robotic lessons.

Actual research topics address augmented/virtual reality approaches [2] in order to operate these tele-experiments at conditions of limited bandwidth availability to the tele-operator. This telematics approaches offer interesting impact far beyond tele-education also for industrial telemaintenance and telediagnosis of defects.

### Acknowledgements

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# Remote Identification and Control Experiments on a DC Motor

## 1. Introduction

Remote laboratories are surely one of the most important tools for distance learning in the Automatic Control field [1, 2]. In this paper, a case study involving remote identification and control experiments on a DC motor is reported. Students are required to find a suitable model of the physical system, and to design a controller which achieves some requirements. All these tasks can be carried out remotely. The DC motor along with other processes are part of the “Automatic Control Telelab”, a remote lab developed at the University of Siena.

## 2. The Automatic Control Telelab

The Automatic Control Telelab (ACT) is a remote laboratory developed at the University of Siena. It is mainly used for educational purposes, and since 1999 it has been used in control systems and robotics classes [3]. The aim of this project is to allow students to put in practice their theoretical knowledge of control theory in an easy way and without restrictions due to laboratory opening times and process availability. In fact, the ACT is accessible 24 hours a day from any computer connected to the Internet by means of any common Internet browser.

Through this lab, students can run control and system identification experiments. A key feature of the ACT is that students can design their own controllers by using the Matlab/Simulink environment. Since Matlab/Simulink is a standard tool in control system classes, students can design their own controllers in an easy way as a Simulink model similar to those commonly used to run simulations. During a control experiment, students can change controller parameters and reference signals, observe the signals of interest and a live video of the process. At present, five processes are available for remote experiments: a DC motor, a water tank, a magnetic levitation system, a 2-DOF helicopter and a Lego mobile robot (Figure 1). In the following we will focus on the DC motor experiment. The ACT home page is: <http://act.dii.unisi.it>.

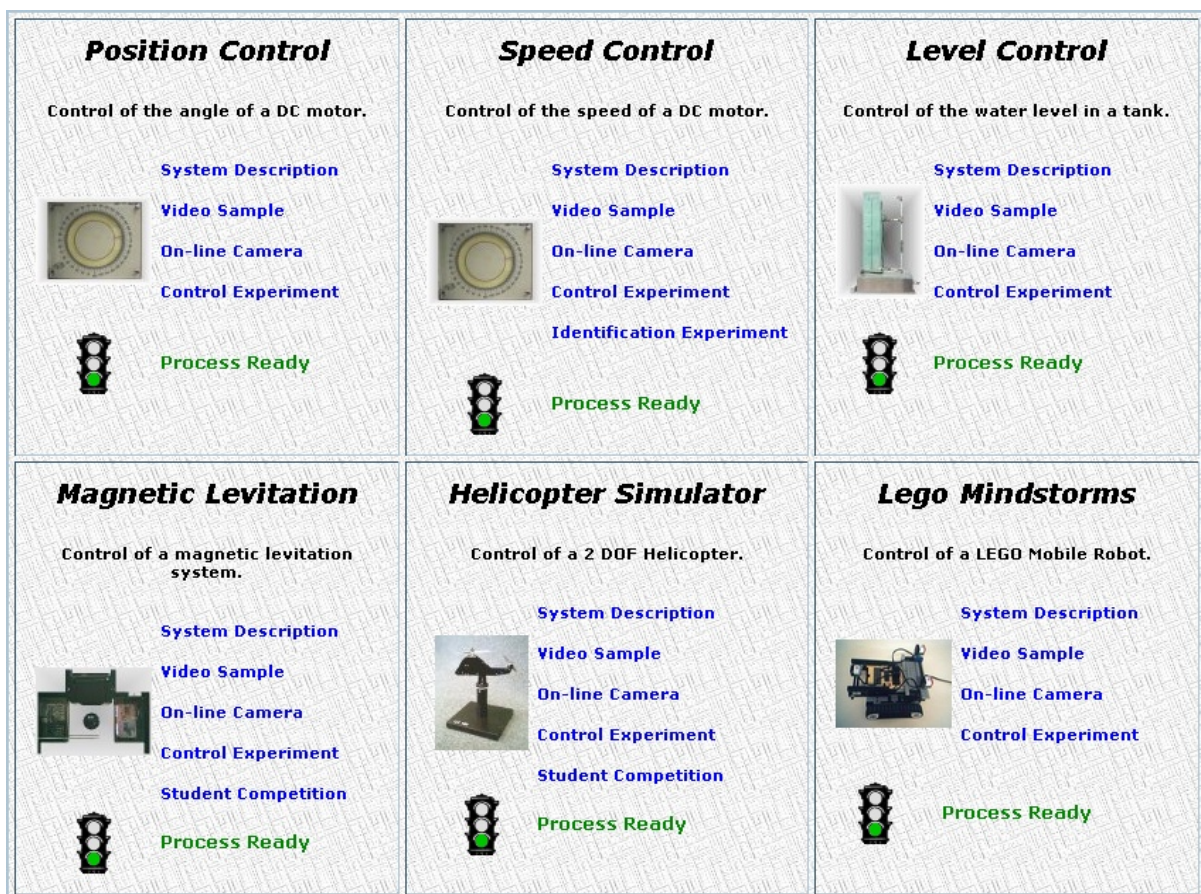


Figure 1. The processes available for remote experiments

### 3. Remote experiments on the DC motor

In this section, some experiences based on the DC motor are reported. The motor can be used to perform position control experiments as well as speed control experiments. In the following we focus on the speed control experiment. Students are committed to perform two experiments:

- **Identification experiment:** students must build a mathematical model of the process by performing remote experiments. Students can choose the input signal to apply to the system and run the experiment. Once a set of input/output data has been gathered, a special interface (Figure 2) allows them to choose the desired model structure and the related order. Moreover, it is possible to remove mean and trend as well as choose which data can be used for identification and which for validation purposes. It is possible to perform remote identification through statistical as well as set-membership techniques [4]. Once a model has been obtained, some benchmark functions and plots are reported, so that, if the model is satisfactory, it is possible to use it to design a controller.
- **Control experiment:** students have to design a controller in order to achieve some performance requirements. They can use the estimated model obtained in the previous step as nominal model for design purposes. Several kinds of controllers can be designed, such as PID controllers, lead-lag controllers, nonlinear controllers, etc. All these controllers are Simulink models which students can upload to the ACT server and run on the remote process. When the experiment is in progress, a graphical interface allows them to see all the relevant signals as well as change online the reference input and the controller parameters (Figure 3). At the end of the experiment, all data can be downloaded and used to verify if the requested specifications have been achieved.

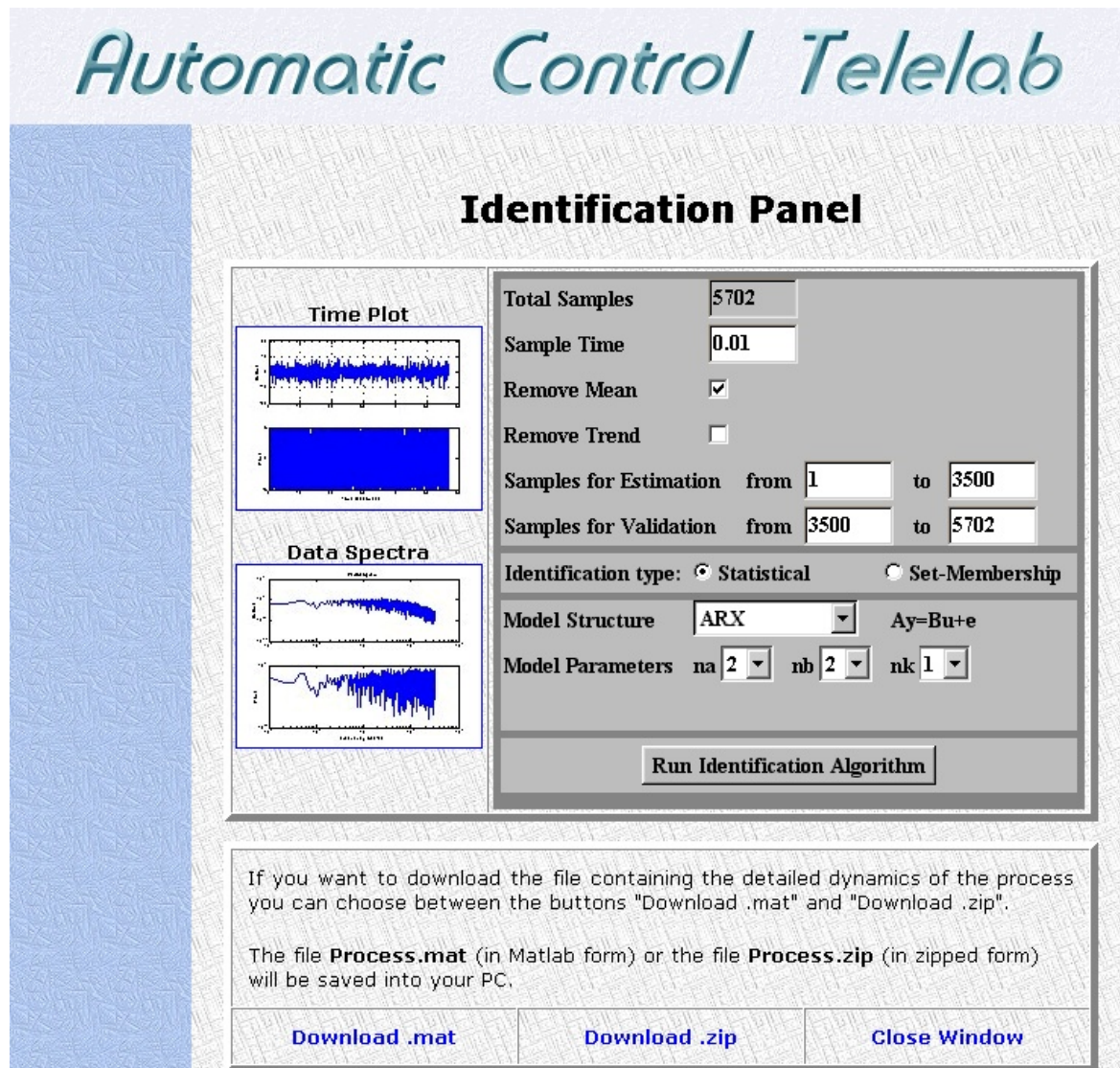


Figure 2. The interface which allows the real execution of remote identification experiments



Student feedback is in general very positive, especially for the possibility of performing experiments at any time and from any location. So, they can organize their time in a flexible way, without constraints due to laboratory opening times. One more positive aspect is the easiness to put in practice their theoretical notions; in fact, they already know the Matlab/Simulink environment, so they have no problems regarding the software aspects of controller design.

In addition to the previously reported exercises, some other experiments guided by the lecturer are executing during a class. In these experiments, it is possible to practically explain the concepts of time and frequency performance requirements, asking students to perform suitable experiments in order to evaluate such specifications.

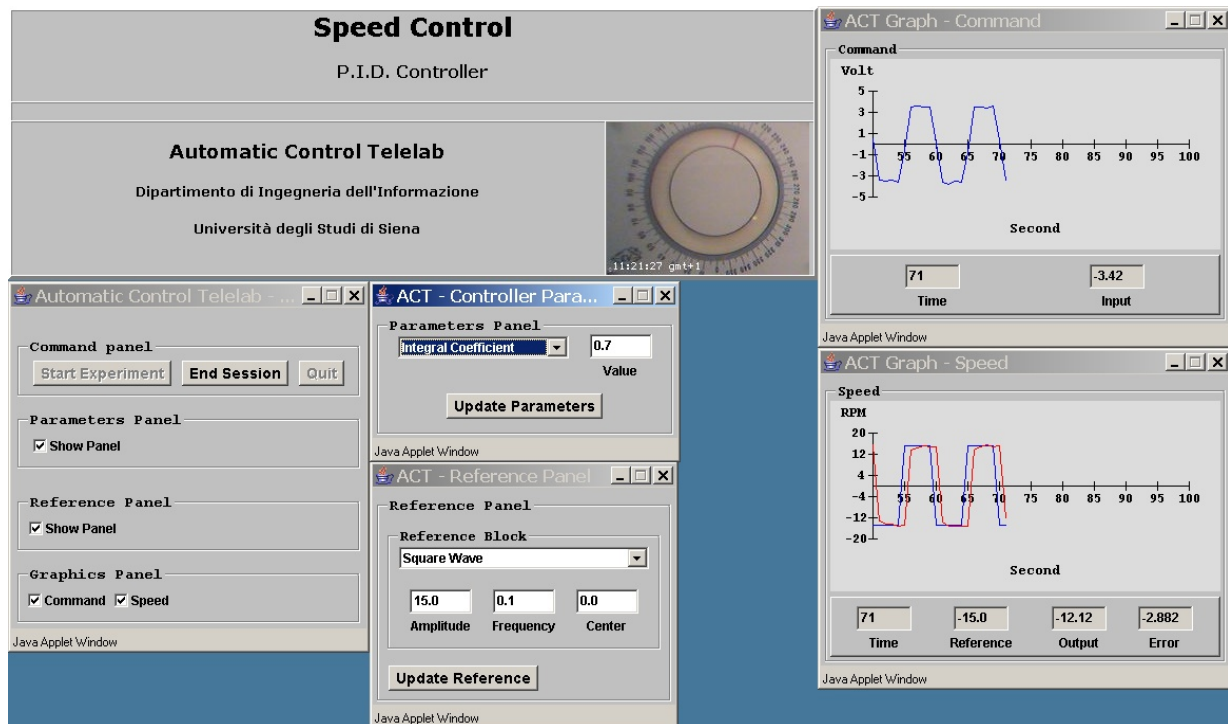


Figure 3. The interface for remote control of the experiment

## 4. Conclusions

In this paper, a set of remote experiments based on a DC motor are described. In particular, students have to perform remote system identification experiments in order to find a mathematical model of the process. Once a suitable model has been obtained, they are asked to design a controller in order to achieve some performance specifications. All these tasks can be executed remotely at any time and by any computer connected to the Internet.

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# On Job training in immersive environments

## Abstract

Support and maintenance activities on a complex system can gain greater effectiveness from web technologies and e-learning in terms of skills acquisition and cost reduction via minimization of expert interventions on site. The paper outlines a possible scenario and some features with respect to the limits of available technologies.

## 1. Introduction

Immersive environment can be considered the forefront solution in customer support activities for those manufacturing companies that produce complex electronic systems (like radars), supply and install them worldwide. In fact it allows to fulfil the need of suitable personnel training, above all when customer is in charge for maintenance and with limited skills: the user has usually to operate in field and/or in non optimal conditions (e.g. on sensor platform, aboard a ship etc) and needs support from a remote expert. The “expert” can be viewed either as remote guidance in task execution for installation, setting up, maintenance etc or e-learning for training activities when not operating on the system. To fulfil these needs in the particular operating conditions, the user would require peculiar displaying devices to apply in real time the obtained information (e.g. “hand free” communication equipment) and a clear comprehension even in noisy and uneasy environments; on the other side, the remote expert requires a clear knowledge of the user actual operating environment.

## 2. Remote on job training

Immersivity lays at the teacher’s side more than at learner’s one, since he needs a punctual perception of field situation and to monitor site activities (e.g. system operating parameters) in order to give proper support to the user and to control correctly on site test equipment and other tools.

Another challenging issue is the management of every man/machine interaction in order to accumulate the knowledge generated in each support action and to make it available to the other connected users. In this perspective, an important role is played by content management, since relevant topics about system operation, test and maintenance should be made available in a distributed way and integrated with the knowledge repository that is created and updated during system life; this amount of information is also a suitable tool for task briefing and, due to its versatility, it is able to improve the “on demand” capabilities of the entire support system as it makes possible a more direct application of the acquired knowledge.

So far we are thinking of an e-learning context in which the student is the operator on site and the teacher is the remote expert. The former needs instruction to improve his own knowledge and skill on the system or guidance in executing some task, the latter needs the immersive knowledge of the remote site in order to give effective support; this interaction results in a knowledge generation process whose benefits are to be shared between the actors (connected users and remote experts).

The described capabilities allow the customer technical personnel to develop and consolidate their theoretical training, to gain a better understanding of system principles and improve the execution of associated maintenance tasks.

As a result, On Job Training will be integrated into an interactive system aimed to:

1. Establish and implement a tutorial program to consolidate theoretical training on the elements of the system;
2. Brief personnel on the purpose of the preventive maintenance tasks as they are performed;
3. Interactively provide guidance in the performance of all maintenance tasks as they are carried out;
4. Interactively develop skills in use of strategies to isolate faulty LRUs (Line Replaceable Units) and basic technical fault conditions;
5. Provide practical guidance in the use of test equipment and interpretation of measured parameters;
6. Provide guidance in the use of Flow Charts, Key Test Points, and BITE (Built In Test Equipment) to aid in efficient fault location;
7. Provide guidance in the update and management of all technical documentation (user and maintenance manuals).



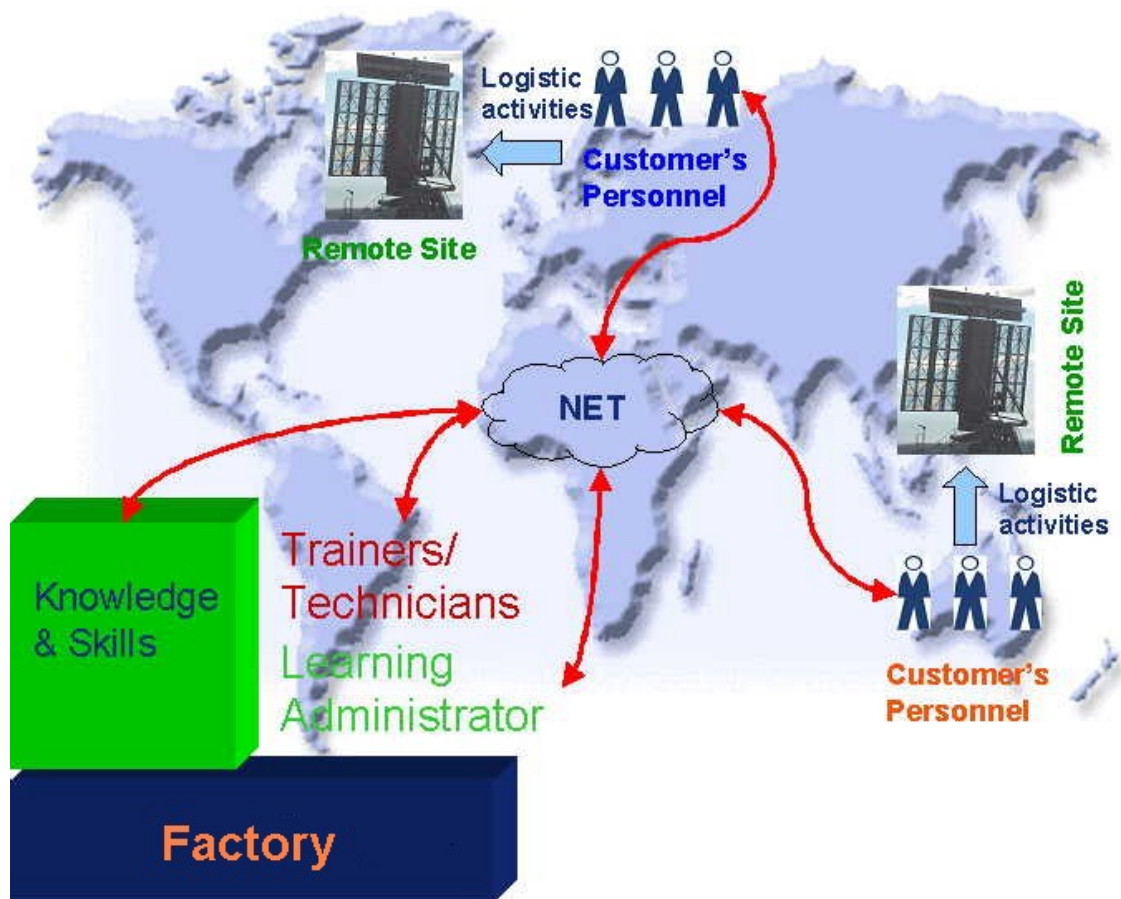


Figure 1. In principle scheme for remote on job training

### 3. Conclusion

This being the scenario, several requirements have to be fulfilled. In particular, training has to migrate from a “class” format to e-learning, thus needing a great effort in terms of definition of learning models and contents management; suitable tools and protocols have to be defined in order to properly collect, exchange and display the great amount of information needed to guarantee the immersivity of communications to both remote and site operators, since site is usually a rapidly changing environment; a feedback process has to be implemented in the scope of the knowledge management architecture to spread the acquired experience among factory designers and users.

An effective solution of these requirements would mean a significant innovation in technology. In fact available technologies like videoconference and telephone (for communication) or Customer Support Web Desk (CSWD, for remote assistance - FAQ management) and common training management do not fit the proposed scenario, as they are all static, time consuming and skill requiring approaches.

In particular, videoconference, due to its technical features, does not adapt to dynamic situations or a “learning by doing” context, as the one required for tele-laboratory or real time customer support, nor telephone is able to give the needed guidance in executing maintenance tasks on a system. Web technology (partially used within the web desk service) would advantage of an enormous improvement to properly handle with training and learning management and knowledge dissemination between factory and customers.

Real time interaction among actors (factory experts and technicians, customer personnel) means also a significant reduction of service time, due to the automatic features of the system in generating and collecting knowledge, and results in an increase of system availability as far as the needed know-how is obtained on demand and is made available for all the customers.

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# ScorNet: a tool for remote experimentation on educational manipulators on the World Wide Web

## Abstract

In this paper we describe the first implementations of remote experimentation tools within a robotics class. The tool, developed in Java and C languages to allow remote communication to an experimental system through a browser, is tested within the context of a classroom and feedback from the students has been reported via the compilation of a questionnaire.

## 1. Introduction

Since the early 1990s, the Robotics and Automation student laboratory of the University of Rome, Tor Vergata is equipped with educational manipulators having five rotational degrees of freedom. In the early days of this class, the laboratory served approximately 20 students at a time and this corresponded to a feasible task to accomplish having full availability of an experimental setup for each group of two or three students. The number of students has increased to 100-150 in recent years. This oversized situation has been temporarily addressed by reducing the laboratory time available to each working group, thereby resulting in a decrease of the effectiveness of the class. To propose an innovative solution to this problem, the underlying real-time software controlling the robots has been ported from a DOS environment into a Linux-RTAI environment. The Linux-RTAI environment, in addition to being more appropriate for the current technology in real-time control systems, allows to embed in the robots operation all the functionalities available to Linux by default, such as the network connectivity, the graphical capabilities. We report here on the initial feedback received by the students after their experience with a remote experimentation tool called RobotNet, developed at our university. This tool allows to gain a good understanding of the operational capabilities of the robot via a network connection, thereby allowing the concurrency of more than one student in learning from the experimental setup.

## 2. The ScorNet system

The ScorNet system is a client/server framework for the remote experimentation on a robotic system. The first experiment made available to the system via a dedicated software is the connection to the educational robot Scor-TEC via a user-friendly interface which runs within an applet in any browser. The applet is distributed to the client computer by the same host that is physically connected to the robot, so that a single computer is sufficient on the laboratory side. A snapshot of the applet is reported in Figure 1, where an image captured by a webcam (via UDP) is reported on the left and a VRML reconstruction of the robot motion based on the measurements of the joint angles (transferred via TCP) is reported on the right. The lower panel provides tools for the user to modify the robot position. Figure 1 reports the external aspect of the applet when using a Linux environment (with Mozilla as a browser) but the application has been developed and tested also under the Windows and MacOS operating system.

The internal architecture of the remote educational system is reported in Figure 2. On the left side we have the software running in the client, which serves as client side of the ScorNet connection. The client connects to a class server by way of the browser and receives an applet hosting three main parts: the two reconstructions (the webcam image and the VRML applet) and the control panel. The rest of the software runs on the server connected to the robot which communicates to the client via RMI functionalities and via UDP between the RTP transmitter receiving images from the webcam and the RTP Player applet. The remaining blocks on the server side are devoted to the cross communication between the Java software, which receives and sends data to the client, and the C software which communicates with the real-time process controlling the robot movements at the lowest level. Based on this architecture, the remote student can send the request for a joint movement and the robot reacts to it as if the request was made directly on the experimental system.

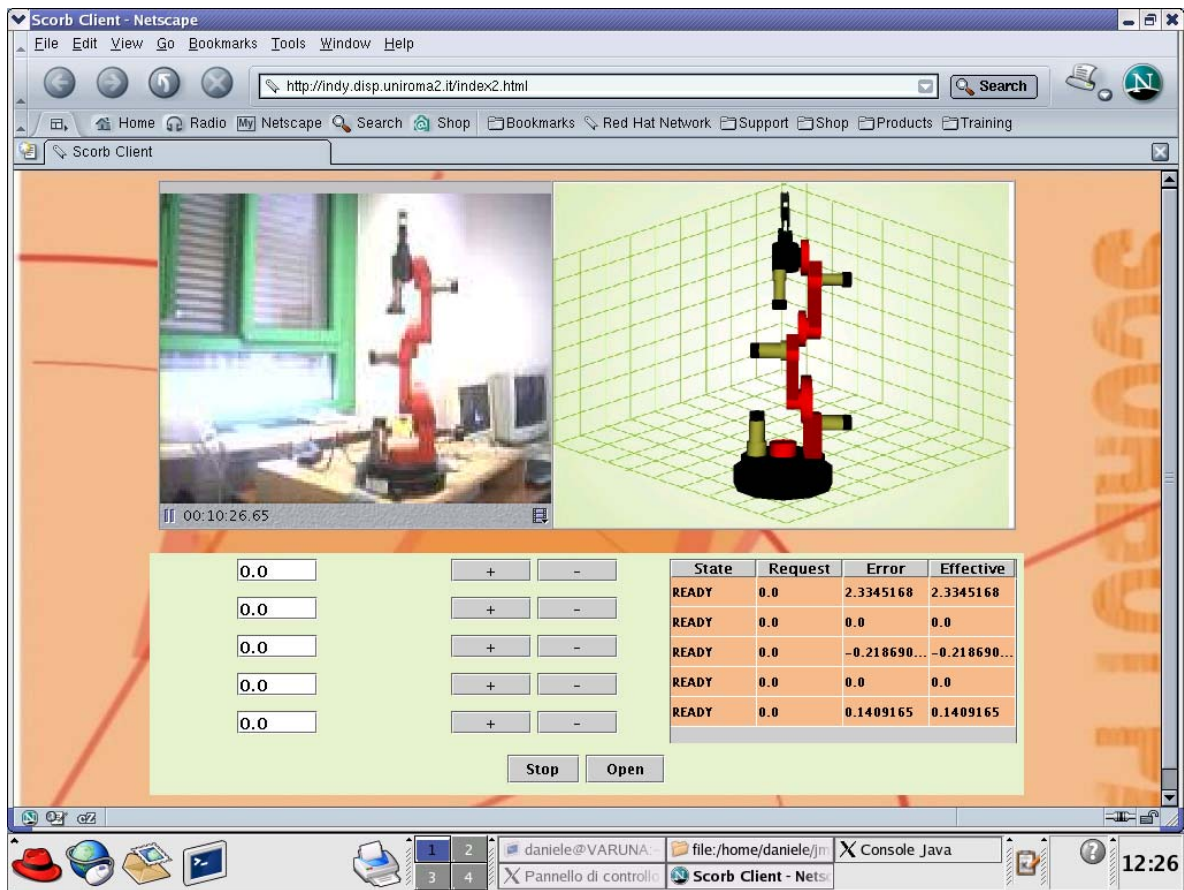


Figure 1. Snapshot of the ScorNet applet

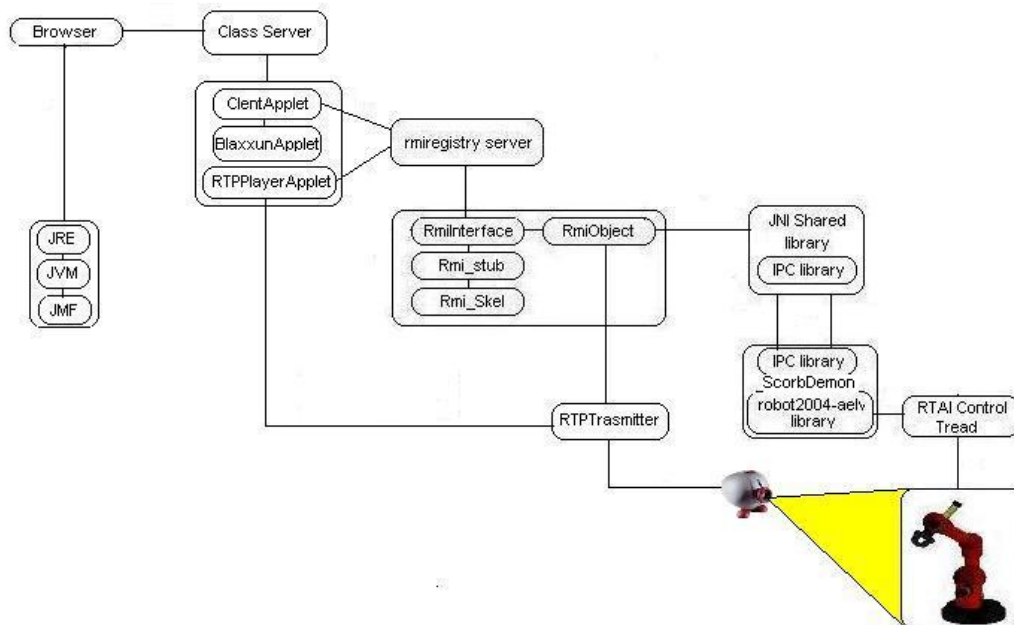


Figure 2. Schematic diagram of the ScorNet software

### 3. Learning experience

The ScorNet system has been tested in a classroom with 75 students attending the Experimental Robotics class at the University of Rome, Tor Vergata. Within the class each student used the remote experimentation system to be able to appreciate the kinematics problems associated with the ScorTEC robot manipulators. By way of suitable buttons the students were able to move each joint of the robot and by way of input fields they could require a specified angular position for all joints. Moreover, by drag and drop techniques, the students could also enforce a movement on the robot by interacting with the VRML implementation of the manipulator. The robot motion was monitored from the webcam image, from the VRML animation of the robot and from the numerical information reporting the angular positions of the joints. This learning experience results in the appreciation of the constraints arising from the kinematic structure of the manipulator and the difficulty in imposing a certain end effector position, given certain angular positions of the joints.

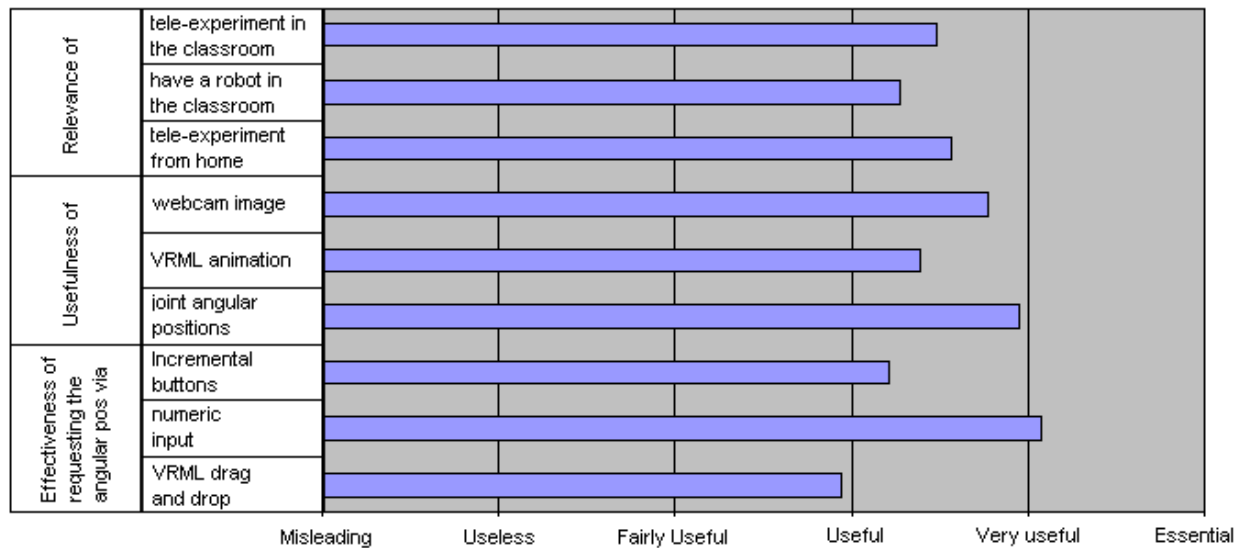


Figure 3. The average evaluations by 75 students

After the interactive class, each student compiled an evaluation form commenting on his opinion about the relevance of the experience carried out and about the usefulness of its possible extensions to a higher level of remote accessibility (including, e.g., the possibility of remotely running C code on the server). The outcome of the questionnaire is reported in Figure 3, which indicates a high success of the experimentation and the need for generalizations and extensions of the remote experimentation architecture which will allow increasingly sophisticated remote learning experiences.

### References

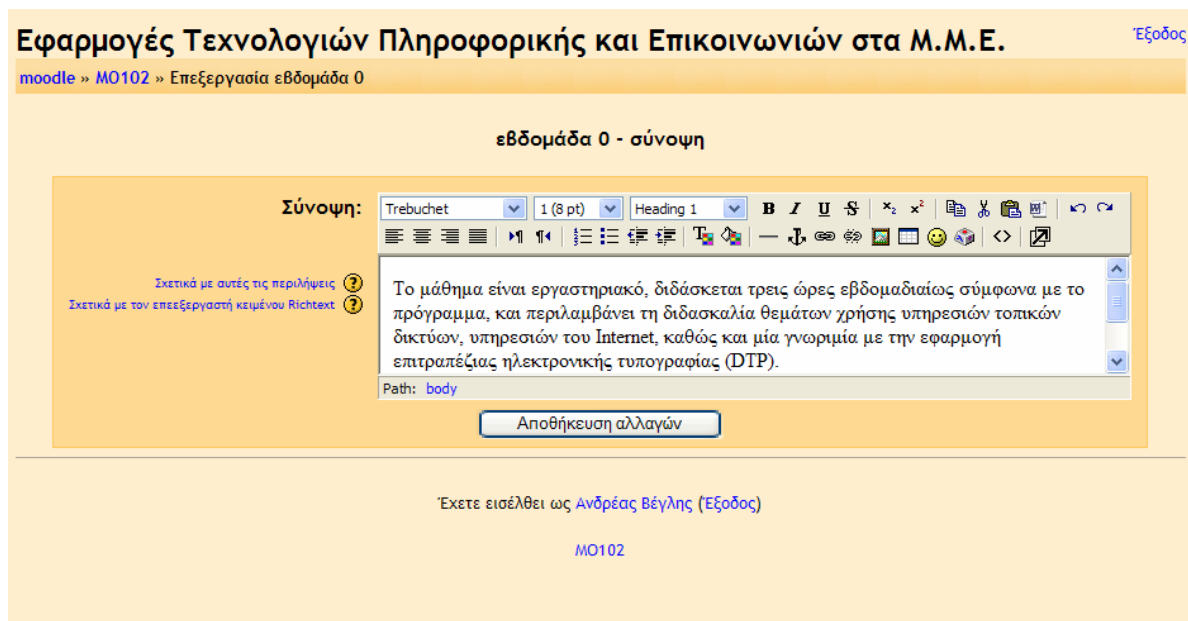
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Except HTML files other kind of files may be used to offer educational material in a Course Support Environment. PDF format is a very popular format. PDF are highly compressed, completely portable and platform-independent. They are recommended for giving the students extended or supplemental material.



HTML editor in Moodle

Some instructors usually include Word files in a Course Support Environment. If these files are supposed to be accessed online, this may not be a good idea. The operating system of the student's computer, automatically loads the Word application and this might result in the degradation of its performance or may disorientate the student. All three platforms can handle the above file formats.

## Multimedia files

Depending on what we want to accomplish there is a big variety of types of multimedia files we can include in the Course Support Environment. Starting from the static graphics files we can use GIF or JPG format. These formats are best suited for the WWW and they do not require special plug-in, in order to be visible.

Video and audio files are also an option, although we must use them only when it is absolutely necessary (especially in the case of the video file), due to their extended size. The format may vary, but Windows Media Player seems to be able to play the majority of them. Of course the download time is a crucial parameter, when deciding if to include long movies in the educational material.

Flash animation is another tool when we require exhibiting to our students a certain procedure. All the latest versions of the browsers play the Flash animations without the need of a plug-in. But always have in mind that we only use animation if it is absolutely necessary for the educational procedure and not in order to make our Course Support Environment more attractive to our students. Some instructors are tempted to supply course material in Flash animations with navigation buttons and internal hyperlinks. Although this solution may be suitable to some rare situations, it is not recommended for general because the material is not printable and we can not guarantee the same appearance of the Flash animation on the student's computer screen. Of course Flash animations may be used to create quizzes and self-assessment exercises that can further enrich the educational procedure.

## Text and multimedia files

The existence of the multimedia files does not guarantee the support of the educational procedure. Very important role plays the way that the multimedia files are embedded with the text. Students and generally WWW surfers prefer mixed text and graphics HTML files (Oliver et al, 2000; Collis, Winnips and Moonen, 2000). We

must always try to offer all the necessary data with the minimum number of steps. Table I summarizes the ways the three Course Support Environments support embedding multimedia files with text.

From the Table 1 it is obvious that all platforms offer similar capabilities. Only Blackboard does not offer a build-in HTML editor but this is not a significant problem since we can always download many freeware reliable HTML editors from the WWW. From our experience in using all three platforms Blackboard seems to be more user friendly and usually offers two ways in creating / uploading content, basic (where only the basic parameters are visible) and advanced (where we can make a lot of modifications).

Table 1

	<b>BlackBoard</b>	<b>Moodle</b>	<b>E-Class</b>
Plain text	✓	✓	✓
HTML	✓	✓	✓
HTML editor		✓	✓
Create a link to a graphics file	✓	✓	✓
Display media file within the file	✓	✓	✓
HTML with the graphics embedded in the text	✓	✓	✓

## Organizing the content

The problem is what kind of organization we can create in a Course Support Environment. All three platforms offer about the same capabilities. We can create a lesson or a series of courses that students can access sequentially (based on chronological order) or directly (a student may be interested only for a particular course) (Lynch and Horton 2002). In each course we can organize our material in folders in the same way as in the local disk. The problem is that we can not make hyperlinks from one file to another. Thus the students can access the content only by following the organization of the site, based on the navigational structure that the Course Support Environment offers. Simple text descriptions should be added at the entrance of each folder in order to inform the student about the content of the folder. Thus the student can have a general idea of the content of each folder without needing to browse them. Another helpful tip is to use the same organization of the educational material in all courses.

## Conclusions

Based on the findings we can conclude that there are no significant differences of what the three platforms offer. One thing is certain Course Support Environments limit the way instructors can organize the educational material. It is time for the developers to give the instructor more tools, to enable them to use all the characteristics the WWW offers in the educational process.

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## ***Regular article: Possibilities for Inclusion of Simulations in current Standards for e-learning***

Although the “true e-learning” implies the use of interaction and simulation to provide an effective and stimulating learning experience, the inclusion of simulations in e-learning systems compliant with the current standards still represents a great challenge. In this work we present the results of a study about the possibilities for inclusion of simulations in SCORM. An investigation was made about different approaches and proposals that allow an interoperation between simulations and SCORM employing different architectures and mechanisms.

A first possibility considers the LMS and the simulation as two independent systems and provides mechanisms to permit the exchange of data between them. As representatives of this first approach we found three prototypes that were developed by different institutions. The prototypes are: The Boeing Company’s SCORM/HLA Prototype [1]; SCORM/HLA SITA Prototype, constructed by the Joint ADL CoLab and Intelligent Automation, Inc. [2]; and the civil support team trainer Prototype developed by the Joint ADL CoLab, the Army Research, Development and Engineering Command, and the National Guard Bureau, Engineering & Computer Simulations, Inc. (ESC) [1].

The three works connect a LMS with a simulation platform such that data can be interchanged between them. Two of the three prototypes connect to HLA (Standard for connecting several computer-based simulation systems [3]) - based simulations; the third uses a commercial off the shelf 3D game engine, called Gamebryo. All the three prototypes examine methods for interchanging learner performance information from the simulation environment to the LMS, in order for the LMS to provide appropriate and relevant instruction. These prototypes use a Sharable Content Object (SCO) that functions as an interface between the LMS and the simulation, for the interchange of information.

They also send information from the simulation back to the LMS by mapping the simulation state to the LMS’s data model. This mapping process could be the hardest part for the integration of the environments; if there are a large number of scenarios it could become complex, and a great amount of time must be invested for developing instructional strategies that use this information.

None of the three proposals report the way in which the LMS can restore or initialize the simulation state, in case the learner has not reached the learning objectives and he has to repeat again the simulation, backing to a specific state of simulation. It would be necessary to initiate the simulations and save their state for a later use, but here we find another problem, since to date SCORM lacks an adequate mechanism for persistence.

A possible solution is the use of the Sharable State Persistence (SSP) specification [4], which was developed by the IMS Global Learning Consortium. It defines an abstract service that enables content objects to declare and access *data buckets* (places to store and share arbitrary data). State storage requirements are explicitly defined for a SCO by associating one or more *<bucket>* elements with the SCO’s resource. In the context of a SCORM Content Package, this is accomplished by including *<bucket>* element (s) within a *<resource>* element. The SSP Information Model defines a data model (buckets) and the means (abstract API) to access the communication mechanism in SCORM (Run-Time API). All operations defined in the SSP abstract API must be bound, to the Run-Time API SCORM.

As an illustration of this approach we present figures 1, 2, 3 and 4 that represent different possible scenarios of the interchange of data between SCOs and the LMS, and between the LMS and the simulations employing the SSP specification.

In the figures it can be appreciated that with the implementation of SSP it is possible that SCOs store and share information of their state, independently of the type of their content (static, simulation, etc.). However, this interchange of information must be sequential, since SCORM currently doesn’t permit that two SCOs are active at the same time.

The works mentioned before propose an interoperation between simulations and SCORM employing different architectures and mechanisms. However, they all focus on enabling the communication between a simulation and a LMS compliant to SCORM, **both working separately**.

An alternative path would be to obtain a true integration of simulations with SCORM, where the simulations become common SCOs in e-learning systems. For reaching this, it is still necessary to give some steps forward in the development of contents and extensions to SCORM. Our proposal is to reach this objective by following the next steps:

- To establish a categorization of simulations.
- Based on this categorization, to identify and classify the relevant information of each kind of simulation.
- The simulation state information would be stored in an external data base, which would be continuously updated according to the interaction of the learner with the simulation, and that information could be used by another SCOs.
- To define an extension to the elements of the Runtime SCORM data model, to include new parameters for the reception of simulation data.
- To propose guidelines to decompose a simulation into different types of Learning Objects depending on its classification using the defined categorization.
- To enable a different sequencing model for SCOs, such that it would be possible to have in a same session different content objects active simultaneously, and to interchange data between them.

The advantages that can be obtained from following the second alternative are: 1) To obtain a continuous feedback between the LMS and the simulation, where the LMS has the control of the simulation while the learner is interacting with it; 2) to promote a new mentality for simulation design, oriented to reutilization.

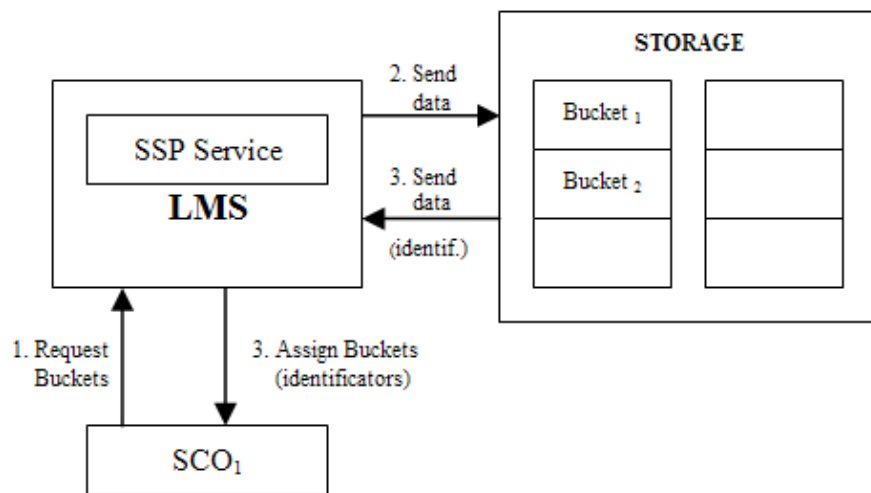


Figure 1. Request of Buckets assignation

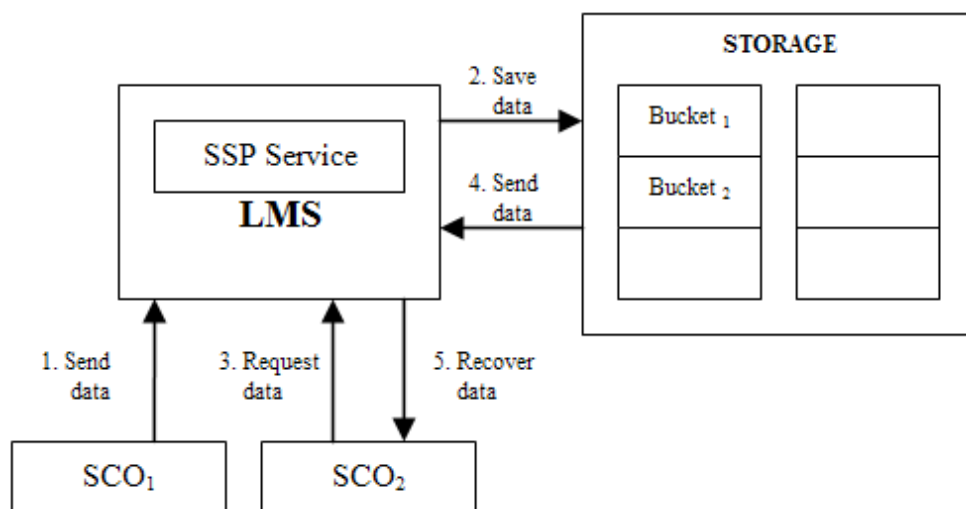


Figure 2. Interchange of data between two SCOs

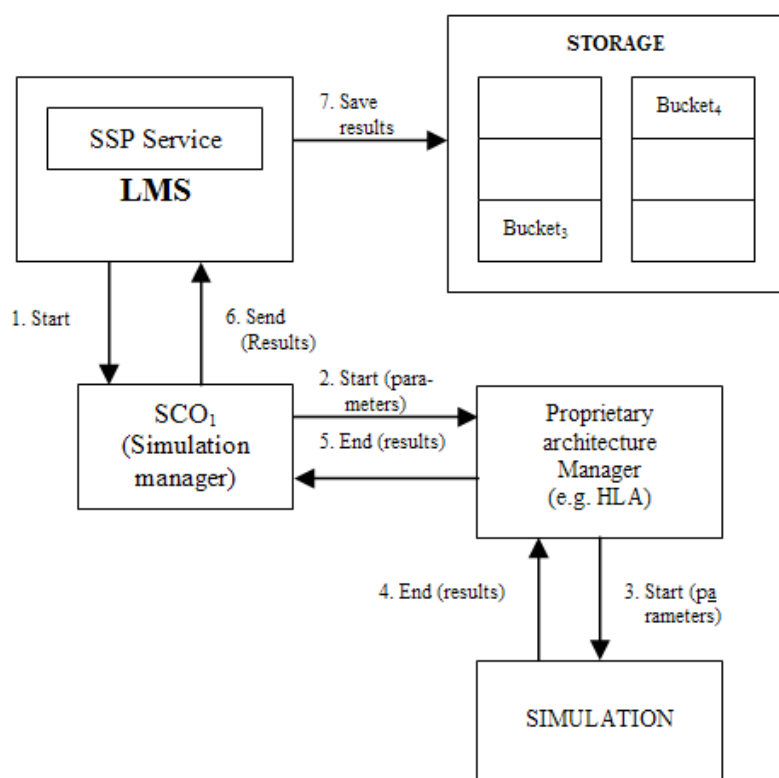


Figure 3. Storage of simulation state data

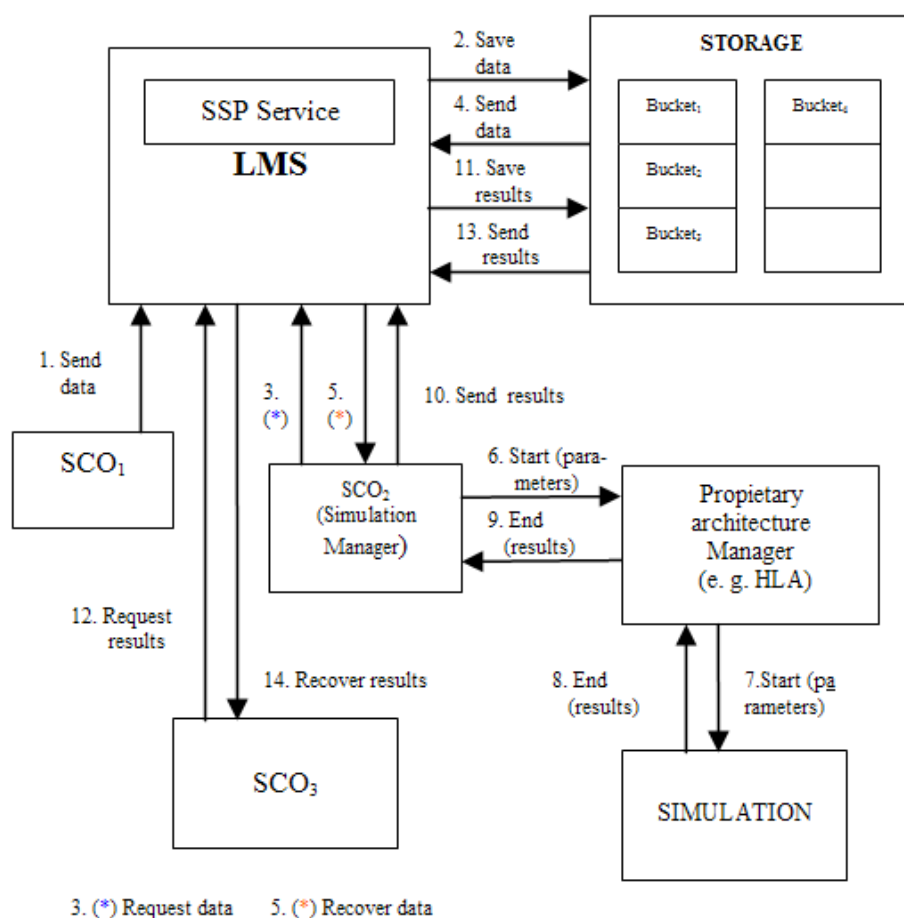


Figure 4. Interchange of data between SCOs and a simulation

## Conclusions

There are various solution alternatives for the use of simulations in e-learning systems, which are mainly directed along two paths: On one side, there is the interoperation between simulations and the SCORM LMS, working separately; and on another side we propose a true integration, by developing a classification of simulations and defining the necessary extensions to SCORM Runtime mechanisms and other components (Content Aggregation Model, Sequencing and Navigation). We consider that the last alternative is the best solution for achieving a standardized inclusion of simulations in the e-learning systems.

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