Team Teaching for Web Enhanced Control Systems Education of Undergraduate Students

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Abstract— **The present work focuses on the didactic approach for the HE in technical-scientific domains, namely Control Systems undergraduate courses, via blended e-learning. Material knowledge has to be learnt. So, tools to be integrated in Moodle to manage related didactic variables have been developed, such as an Immersive Telelaboratory. In such a context a team approach to teaching was adopted. It seems useful to summarize such experience putting into evidence its potential and some critical aspects related to the implementation of the approach.**

Team Teaching, Material Knowledge, Immersive Telelaboratory, e-Learning

I. INTRODUCTION

Engineering designer education involves training students to master complex physical phenomena, to acquire competence in the analysis of complex systems in several application domains and to become able to develop proper design processes. The focus should be on acquiring the competencies and abilities of an expert designer. One among them is "Material Knowledge" (MK).

According to [1] Material Knowledge is the Knowledge relative to the real operation conditions of engineering complex systems. Mains features of MK are: its owners are experts; it is compiled and implicit, and can be described as intuitive; it is empirical, i.e. the novice has to learn more "how to do" than "what it is". To try to teach MK asks for active, experiential and collaborative learning in a supervised way.

For such purpose laboratory activities are practiced Face to Face (F2F), with a limited number of students. In traditional laboratories (as part of institutional courses at the University) students have the possibility to practice real or realistic experiences under teachers' and tutors' guide. In this way they can match the theoretical aspects learnt during the lectures and practical experiences.

To build, to maintain, and to use such labs is difficult, sometimes even impossible for organization problems, and it is always expensive. A didactic laboratory is a costly installation exposed to a concentrated use at certain times of the year. The need arises of guaranteeing the access to existing labs for a wide student's population, surely wider than the users present on each laboratory site. This need is apparent both at a local level – more students belonging to the same University - and, in principle, at a University system level - students belonging to different Universities could use laboratory settings not available at their own University on a reciprocity base [2].

For these reasons, having many students that could profit of it at our University, an Immersive Telelaboratory (IT) accessible by the net is used.

Immersivity is specified as follows: remote users experience the operation within the real environment – a laboratory – by means of a rich perceptive Internet-based bi-directional interaction comprehending vision, hearing, and perception of current modification of physical quantities [3]. No haptic interfaces are required.

Compared to an experience of Virtual Reality (VR) [3], Immersive Telelaboratory allows being in touch with MK. In general terms VR is a technology that allows a user to interact with a computer-synthesized environment, be it a representation of the real or of an imaginary world, and in every case it is based on a model. It is exactly for this latter character that these solutions don't provide the richness of experiential elements implicit in a real laboratory practice, related to the acquisition of MK. The immersive experience of the laboratory, even if based on a didactic approach with some simplifications, involves the elimination of the significant simplifications intrinsic to the VR model.

The laboratory experience is scaffolded in a context of training and gradual activities (Tutorial, process analysis, clarification of the issue of control), comprehending documentation and reflection on the experience performed.

To try to verify in an empirical study the previous statements, an undergraduate Control Systems course has been given following a Team Teaching approach (TTa). According to [4] usually TTa involves a team of teachers, each devoted to different tasks, in synchronous/asynchronous blended learning. In our case it has been used in a F2F/online blended modality. The focus is on pooling different competences more than on reducing the cognitive workload of the teachers. This second objective appears to be prevailing in asynchronous/ synchronous blended learning.

II. EUCATIONAL DESIGN OF THE COURSE

We refer to an undergraduate course of Automatic Control, compulsory for an Information Engineering curriculum, having many students (around 300), delivered in blended e-Learning.

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Blended means a suitable mix of F2F lectures/numerical case-study presentation and on-line activities both tutored and untutored.

A. The Syllabus

In order to promote an active and collaborative learning an online course was devised. The course design required the definition of a detailed Syllabus. Main components of the Syllabus are:

Aim: the course will provide students with fundamentals of the theory and techniques of analysis and design of linear time invariant control systems single input single output. The control is usually feedback control.

Theory and techniques deal with a particularization of the Theory of Linear Dynamical Systems. In comparison with the international approaches to engineers training this course corresponds to courses named Linear Control Systems or Feedback Control of Dynamical Systems.

Learning Objectives: at the end of the course the student is expected to be able to explain to others the declarative knowledge learned in a clearly and compelling way and to apply operational skills in a competent way.

Course Description: the learning materials are learning objects (LO), which are collected in self-contained learning units (LU). A LU covers a topic autonomous from the didactic point of view, even if logically related to several others. In order to enable learning, the course also suggests many activities to be conducted alone or in small groups. All activities are always meant to take advantage from the discussion Forum where students, teachers and tutors are in touch.

Learning Objects (LOs): three kinds of LOs were developed.

1 Learning Objects related to declarative knowledge.

Declarative knowledge of the course is composed by definitions, conditions and theorems. These elements are available as downloadable documents that can be printed and studied offline. These documents are presented by synthetic introductory web pages.

2 Learning Objects that provide operational abilities. Learning operational skills is based on a number of examples and exercises, some of which are completely carried out and/or solved and others have to be played by the student. For this purpose, an Open-Source package SW – SCILAB™ - is made available and downloadable [5]. This package allows performing the calculations necessary to deal with a realistic example without facing with paper and pencil large sized computational problems, which would require a high amount of time and would be easily exposed to the risk of calculation errors.

The discussion of examples of this type is always preceded by exercises of limited computational complexity, which can be tackled with pencil and paper. Each student is asked to solve them and to post the solution on the forum. The review of these exercises is done by an online tutor. The tutor timely sends comments to help students to understand the reason for errors.

Each student is asked to address the more complex examples only if he/she has solved the simplest exercises correctly and safely.

3 Learning Objects for self evaluation test: aimed at verifying what students learned declarative knowledge and operational abilities.

Learning Objects of this type are inserted into each LU. They are composed of exercises, examples and a section of self-assessment test with score. The score is simply a tool for self assessment of student learning. It provides a measure of appropriateness of learning that the student has attained up to that point. It gives the tutors the possibility to monitor the evolution of learning in the class.

Course Outline: the course contents are organized in 8 LUs.

LU 1: Introduction to the control issues;

LU 2: Mathematical Models in an Information Rich world (state space models);

LU 3: Analysis of oriented abstract systems, differential linear time invariant, finite-order, lumped parameters, real constant coefficients;

LU 4: Introduction to feedback control systems;

LU 5: Poor information models Analysis (Input-output models);

LU 6: Solution to the control problem with poor models 1 (Industrial Regulator tuning);

LU 7: Solution to the control problem with poor models 2 - Servo-systems design in the frequency domain;

LU 8: Solution to the problem of control with poor models 3 - Servo system design with root locus method.

Learning Activities: the course offers different learning activities. These are delivered in asynchronous and synchronous way and refer to different pedagogic models. Most of the online activities are asynchronous and are based on students' self-learning and self-evaluation. The LUs from 3 to 8 comprehend the suggestion and the availability of Immersive Telelaboratory activities. These can be considered in some way synchronous activities for the apparent real-time interaction with the experiments to be performed. The laboratory experiences are meant to involve the students in collaborative, experiential and reflective activities, supported and enabled by a proper didactic context and suitable tutoring.

Didactic context is constituted by:

- tutorials describing the physical process under study, the assumptions made to define the related mathematical model, the difficulties for building up such a model, the real world aspects cut away to obtain a viable model, the characters of the physical devices involved in the experiment;
- summaries of the control theory relevant for the problem under study;
- a simple VR environment where the students can observe the representation of real experiments performed on the given physical process. It is a VR environment where the avatar of the physical process is driven by data and signals collected on the physical process itself;

- a GUI, where the student can specify the experiment he/she will perform and its main parameters;
- tools for the interaction with the Laboratory administrator and with the colleagues belonging to the group involved in a given experiment;
- a simplified e-portfolio space where results deemed significant (both satisfactory and unsatisfactory) can be stored by the students together with their reflections on the experiment performed.

It is self evident that these activities involve a certain level of organization complexity in case of large classes following compulsory courses. Complexity refers in particular to time management and to the proper level of cognitive load required to students. Time management will be discussed in the context of the architecture of the Immersive Telelaboratory.

As far as the cognitive load is concerned, recent theories take into account learning design implications of the human cognitive architecture. It is well recognized that the subjective measure of the cognitive load is related to the student' cognitive resources directed towards achieving certain learning objectives [6], [7]. The IT in the context of a compulsory course for undergraduate students is aimed at the attainment of a medium-high level of competence. This one cannot be considered the learning objective of all the students, neither of a majority of them that could be interested only in obtaining the credits associated to the course. For these students the cognitive load related to IT will appear too large and therefore it could be an element hindering the attainment of a reasonable mastery of the operation solution of the problem. This level of mastery is somehow higher with respect to the learning objectives of the whole course. Therefore such an activity is offered to the interested students to be freely undertaken, while the other on-line activities are considered essential part of the learning process.

For the interested students the constitution of small groups is suggested. Three to five people constitute the group. Schedule of the activities is usually arranged on a weekly base. The roles and tasks within the Group are the following:

- *Coordinator*: early in the week he/she sends the first message to the group in the forum with details of roles, general organization and agenda of the week; he/she cares the management of eventual meetings in presence, and the management of potential conflicts. He/she acts also as moderator, animates the communication in the forum with the support of the tutor, organizes and creates new categories for better organization of the Forum.
- *Editor*: publishes within 24 hours to the deadline, the diary of the week (five lines about what really happened in the group during the week); he/she is in charge of editing the final presentation of the group work.
- *Researcher(s):* each week he/she finds and provides to the group at least two significant references (websites or papers).
- *Devil's advocate:* he/she is a critical observer. The duty is to weekly express criticisms and suggestions on the product developed.

The group autonomously decides the roles. The groups have to interact with a teacher competent in the laboratory practice and capable to enable their activity (Laboratory Administrator).

Evaluation: the summative evaluation is carried out by a F2F exam where the students have to answer three questions. One of them is specifically relative to operational abilities and has to be answered in writing. The participation on Telelaboratory activities is not a matter of the summative evaluation. If satisfactorily undertaken it provides a bonus that will be added to the exam score.

Pedagogical models: F2F lessons and information materials follow a substantially directive approach. In synthesis the teacher supervises and directs F2F activity. Lectures and exercises are accompanied by self-assessment tools designed to assist students in the understanding and acquisition of the theory and of operational skills. In this case a constructivist approach is explicitly followed [8].

The Telelaboratory activity follows a constructionist approach. It is an experience built in relation to a problem well defined in a theoretical way that puts the student in touch with aspects of the problem not explored during lectures and numerical exercises. These aspects deal with the real operation conditions of an engineering system asking for proper control to attain a performance aligned to given requirements (MK).

As already mentioned the laboratory experiences are meant to involve the students in collaborative, experiential and reflective activities, supported and enabled by a proper didactic context and suitable tutoring.

B. Team Teaching Approach and Teacher Roles

Different kinds of knowledge and different pedagogical approaches are tackled in the delivery of the course. Therefore it could be self evident that different teachers with specific competences should be involved to attain the required learning/teaching efficacy. At a first glance a three teachers model would be appropriate. According to this model the roles of the teachers would be complementary: the coordination and the most directive activities are in charge of the responsible of the whole course, the F2F activities promoting active participation of the students (numerical case studies) are in charge of another domain expert, the on-line management and support for Immersive Telelaboratory are in charge of a laboratory technology and operation expert.

The asynchronous online discussion is promoted by the use of some Forum. Two kinds of Forum are available:

- a General Forum for the interaction with the first two teachers of the course; Questions and Answers relative to theory and numerical case studies are meant to be posted in this Forum. A fixed time limit for answering is guaranteed by the relevant teachers;

- a Collaboration Forum with discussion spaces for small groups of students (3 or 4 people), is foreseen. It is moderated by the third teacher (the one dealing with MK involved in IT activities).

According to a constructionist approach the aim of this interaction is knowledge sharing among the students and with the expert. For this purpose mentoring is a critical point. Mentoring has to be the duty of the expert of the relevant MK. In fact the success in learning MK is heavily related to the availability of an expert showing it in a perceivable manner. However the contribution of the other two teachers is deemed necessary. These are domain experts, namely Control Systems analysis and design theories and techniques experts, the third one has to be expert of physical process and physical implementation of control devices and apparatuses. This latter has to provide arguments for the reflection, the other two have to assist in the development of the reflections, by giving suggestions and asking questions that help the students to integrate in their cognitive models theory, operation and MK. The aim is to reflect together in a specific tutored forum and to produce an essay collecting the student's reflections on the experiments.

It is evident that such an approach is useful and significant not only to improve students' learning, but also to enrich the teachers competencies, in particular in case of young teachers with experiences limited to specific sectors of a very broad domain like Control Systems.

III. The Architecture of The Immersive Telelaboratory

To overcome the organization, structure and cost involved in providing laboratory facilities for a potentially large number of students, an IT has been implemented and integrated within the University Moodle Learning Environment.

The architecture of the whole LE is illustrated in figure 1.

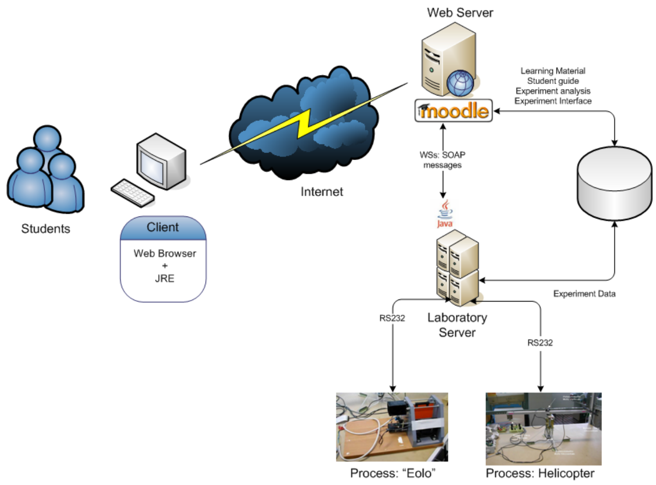

Figure 1: The architecture of the Immersive Telelaboratory

A module named MoodleLab has been developed and installed in Moodle.

With this new module, the integration of different functions in one collaborative Virtual Learning Environment (VLE) has been made possible: the learning materials, the tutorial for the conduction of the experiments, a reservation system, tools for remotely running experiments, tools for the analysis of experiment's data and some collaborative tools such as forum and chat is the whole set of tools made available. They allow the friendly implementation of the three main categories of Didactic Variables [9] relevant for an institutional course in technical scientific domains: What to learn, How to learn, and the time schedule of the learning process.

Main characters of the implemented module are:

1) The authentication of enrolled students follows standard procedures already present in Moodle. As far as the Roles considered in Moodle are concerned, the role of "Lab Manager" has to be defined for management of the experiment. To manage the experiments running it has been necessary to add to the MOODLE DB some important tables, including those relating to the accreditation of test and data collection.

2) The students access the Telelaboratory through a specific booking system. The student must choose the time period and the type of experiment among those offered during the course. The booking management is made through the LCMS MOODLE by the integration of the MOODLELAB module with the BOOKING module. This is a key issue with respect to student's time management.

3) During the booked period, the students connect to the chosen activity of Telelaboratory. The Laboratory Manager authorizes the execution of the experiment. Once enabled, the student invokes a Web Service through a specific Java applet for the experiment previously chosen. The application that manages the experiment will interface directly with the LCMS.

4) The student enters the data, starts the experiment, can display the output data through continuous or segmented charts, and can view the process by a WebCam that allow the real time vision of the physical devices.

5) After each session, the data relative to input, output and selected parameters are recorded, if confirmed by the user, in the DB "MoodleData" connected to the LCMS Moodle.

The students can perform different experiments on different physical processes: helicopter, fan-plate and robot mobile.

Figure 2: The processes of the Immersive Telelaboratory

The process called "helicopter" is a system with two degrees of freedom – pitch and rotate -, simulating the operation of a helicopter. The regulation of the process attitude has to be attained in presence of disturbances. The second process, called "Fan-Plate or EOLO" is a system with one degree of freedom. The attitude of a plate exposed to an air stream produced by rotating wings has to be controlled. There is a third process, constituted by an autonomous vehicle that has to be driven in a partially structured environment. It is not offered to the students of the Course here considered, because of the involvement of further methodological issues.

For each process, different experiments can be executed, ranging from the elicitation of the process output in response to standard inputs (open loop experiments) to the tuning of regulator parameters in various operation conditions (closed loop experiments).

The general rules, established in the official documentation of Moodle [10] have been followed for the development of the code. In the same module the database that interfaces with Moodle and with data coming from the laboratory was developed in XML [11], according to the indications given by the Moodle documentation.

It appears that in the learning environment, built up in this way, the Moodle platform plays the role of the Web Service client; the Web service at the server side is implemented by Java applets that interface with the microcontroller driving the motors propelling the devices.

The client has been implemented via a suitable Php function.

The server-side application has been implemented in Java language. It allows at one side the communication to and from the microcontroller, and at the other it manages trough a Web Service the data coming from the client for the activation of the applet.

The application has been implemented on a Linux server with Fedora distribution, with the Apache Web server, for the interpretation of PHP, Tomcat, to run the WSS, and the MySQL DBMS for managing data have been installed.

One important feature of the IT integrated in Moodle is the Portfolio of the experiments, in which each student group can save the work performed, can retrieve the input values, view charts, reproduce the behaviour of the process in a virtual environment fed by the real data.

A. Reflexes on Team Teaching

As mentioned in the previous section, course and courseware design, implementation and delivery followed a three-teacher model [13]. The responsible of the whole course has the coordination and most directive activities, numerical case studies are in charge of another domain expert, a technology expert gives on-line support for MK management. Given the relative complexity of the IT architecture and of the whole Learning environment, it is apparent the need of a fourth teacher managing the LE use and IT access administration.

It appears that a four teacher team would be ideal for the described experience. In particular the MK owner seems essential for the IT proper exploitation in order to provide the students with design competences.

The smooth operation of such a team can be a critical argument, due to the different and possibly conflicting commitments that the teachers can have in their professional activities. In fact, when teachers are expected to work together in one class criticalities related to practical or interpersonal issues, rather than to clashes in ideology or personality, can arise and serious difficulties can be encountered [14].

IV. STRENGHTS AND WEAKNESSES OF THE EXPERIENCE

The experience conducted has so far shown some strength mainly related to the improvement of teaching/learning effectiveness and to the openness to innovative teaching strategies. Notice that the experience has been performed in a not completely systematic way, so that the positive attained results about the quality of learning cannot be considered sufficient for an empirical study. A structured empirical study is planned for the coming Academic year. It will involve a structured monitoring activity relative to both the smooth delivery of the course and the student's and teachers satisfaction appraisal.

The main points we already experienced and we would put into evidence are:

- Instructional design becomes a critical issue, especially as it applies to the development of instruction for novices. In fact, within the presented learning scenario students can be considered to be novice designers who do not yet possess the underlying mental models [15]. In this case, a teaching approach which moves from a more directive approach towards facilitating and mentoring seems to provide effective results.
- With respect to the IT, maintenance and supervision of the physical devices into the lab and level of students'

awareness of the MK involved in its proper use are also critical issues. The extension of the Team Teaching model to the four teacher's team could have important effects on the teacher's time management problem and on the effective coordination of the work. When it finds a satisfactory solution the quality of learning is significantly improved. Moreover it appears that the use of synchronous online tutor-students interaction could greatly improve student awareness of MK.

- Team teaching could be an essential experience both for teachers and for students. From the teacher's point of view, it is important a clear definition of activities and then the choice of the proper pedagogical model. A clear definition of an (inter)relations' model among actors is also needed to support teachers' coordination and leadership management. At this step, to analyse teachers' profiles and to clearly define roles is a fundamental task.

The modalities with which this interaction can be improved can be further investigated, as well as the students' reactions to the proposed team teaching model, in order to be able to facilitate learning and to improve interaction with the different teachers in future. In particular, it would be interesting to investigate in deep the students' reaction to the presence of different teachers, how the different roles are perceived and if they are perceived and, finally, how they can be better perceived by the learning group in a team teaching context. In fact, some students may feel frustration and discontent about having more than one teacher.

Nonetheless, team teaching seems to represent a great opportunity for the personal and the professional development of teachers, who are required to make a step forward and to develop new competences and new work practices, requiring cooperation and interaction with other colleagues. Collaboration is a process that happens if particular instrumental abilities subsist, not only related to the domain of expertise. Behavioural aspects of collaboration and communication are also important.

Team teaching requires the most mutual trust and respect between teachers and requires that they are able to mesh their teaching styles [16]. The creation of a community of practice [17] [18] to support teachers within the educational institution may help. It could happen in either informal or formal manner, but the support of the management is crucial.

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