EMERSION: A NEW PARADIGM FOR WEB-BASED TRAINING IN ENGINEERING EDUCATION

Denis Gillet [1], *Georgios Fakas* [2]

Abstract *¾ The eMersion project aims at promoting a pedagogical trial-and-error paradigm by enhancing the opportunities for engineering trainees to carry out extensive experimentation in their education curriculum. The proposed approach relies on the benefits to be gained from alternative means of experimentation that allow the students to reinforce their understanding of physical phenomena. In addition, dedicated solutions are provided to enable a flexible access to hands-on experimentation resources using the Internet. Specific pedagogical scenarios developed for the teaching of automatic control, fluid mechanics, and biomechanics are presented. New learning-technologies resources enabling the eMersion paradigm are introduced, i.e., facilities to experiment through Web-based simulations or remote manipulation of laboratory setups. Key components introduced to sustain the experimentation include XML-based documents describing the experimental setups, the experimental protocols to be followed, cockpit-like GUIs for running the experiments in a highly interactive manner, and also an electronic journal shared by a team of students that collaborate to fulfill the hands-on sessions requirements.*

Index Terms ¾ Knowledge Engineering, Flexible Learning, Distance Learning, Collaborative Learning, Web-Based Experimentation.

INTRODUCTION

Rapid developments in the domain of networked computers and of the Internet during the last decade have provided a feasible basis for the design and implementation of distributed and collaborative applications. One of the areas that has benefited from such technologies is engineering education, where significant efforts have been directed towards the design and implementation of asynchronous learning network environments for distance and flexible Web-based learning [1]. Nowadays, the trend is to expand the diversity of educational resources by providing virtual and real experimentation facilities. Such an addition relies strongly on the availability of synchronous Internet services, and is highly demanding from both the user-interaction and user-perception points of view. Reusability of educational content is also becoming a question of great concern, but fortunately this issue can be handled effectively thanks to advanced document engineering approaches. When considering the deployment of Web-based experimentation solutions, the necessity of providing tools for supporting collaborative work appears to be a key point to realistically sustain the learning activities. This set of requirements represents a strong challenge in new learning technologies, therefore inspiring leading-edge research activities in pedagogy, information technologies, and knowledge engineering.

As far as Web-based simulation is concerned, one can observe an increasing production of dedicated Java applets used to illustrate physical phenomena in a visual manner. While interesting for educational purposes, this trend is not efficient at all as a technological solution. Component-based implementation is in fact a preferable approach [2]. Moreover, numerically intensive simulation applications that are highly demanding in computing resources (such as those required to illustrate fluid mechanics) still cannot be executed sufficiently fast on personal computers. In order to address these issues, the *eMersion* project described in this paper makes use of a single interface developed using Java technologies that permits communication with a number of computers and supercomputers distributed throughout the campus, which in turn run at great speeds existing simulation codes and commercially available simulation packages.

Regarding remote experimentation activities carried out for educational purposes, the few existing dedicated environments are simply remote instrumentation facilities designed to monitor distant laboratory setups [3], [4]. It is only recently that the specific requirements for sustainable remote experimentation [5] and the identification of the necessary components to carry out entire hands-on sessions [6] have been fully characterized. Such integrated environments include documentation, experimentation protocols, as well as computer simulation capabilities and implementation interfaces; however, the available systems are restricted to be used by one user at a time.

In order to develop a multi-users perspective, a basic collaboration scheme has been proposed [7] to enable the simultaneous monitoring of a remote experiment by one or more *observers*, while a single *master* operator controls the real setup. This scheme meets the minimal requirements for a teacher interested in carrying out demonstrations that can be observed simultaneously by several remote students, or conversely, for remote students who are directed to working together on a single project. In spite of these advances, the simultaneous observation of an ongoing experiment is still

[1] Denis Gillet, Swiss Federal Institute of Technology Lausanne (EPFL), Switzerland, Denis.Gillet@epfl.ch.
[2] Georgios Fakas, ERCIM Fellow, Swiss Federal Institute of Technology Lausanne (EPFL), Switzerland, georgios.fakas@epfl.ch

not sufficient to carry out effective collaborative learning activities because key student-to-student interactions are missing. In the Basic Support for Cooperative Work (BSCW) environment [8], the underlying idea is to provide the cooperating partners with a shared workspace on the Internet that they can use to perform their activities. However, BSCW does not emphasize the need to fragment the project into specialized tasks that are to be performed by different students working within a single group. It is therefore necessary to provide additional synchronous and asynchronous interaction capabilities in order to mimic as efficiently as possible the teamwork of traditional students, such as the kind of teamwork carried out on campus during laboratory sessions.

The objective of the *eMersion* project is to define and validate approaches and resources that enable sustainable interaction and collaborative work in the framework of web-based simulation and remote manipulation of physical experimental facilities. The idea is to reproduce in a flexible way an environment that promotes a pedagogical trial-and-error and discovery-learning paradigm [9]. We have designed and developed prototyping tools that support such an environment.

The maintenance of information documenting laboratory experiments and the implementation of the Internet-based communication process make use of XML (Extended Markup Language) [10] and of Java technology [11]. Using these technologies it becomes rather simple to structure the experimentation information in such a way that it makes it reusable through the users (related theory, protocols, bibliography, collecting and sharing data from experiments, synthesizing reports through structural transformations, etc.). The client software developed to support the remote experimentation on physical setups over the Internet is implemented as a series of Java Applets.

The rest of the paper is organized as follows. In the next section we introduce the three online courses that are supported by the *eMersion* effort. The following section describes the *eMersion* environment and its components. The paper ends with concluding remarks.

PEDAGOGICAL SCENARIOS AND COMPONENTS FOR PILOT-COURSES

The *eMersion* environment currently supports pilot-courses in automatic control, fluid mechanics, and biomechanics. These courses are taught to students from several engineering majors at the Swiss Federal Institute of Technology Lausanne (EPFL). Traditionally, each of these courses is partitioned into theoretical and hands-on experimentation sessions, *i.e.*, lectures and (virtual or real) laboratory exercises. This partition, as well as the usually fixed schedule for the hands-on sessions, is simply a consequence of school policies and logistic matters. In fact, there are strong pedagogical reasons to avoid the decoupling of the lectures and the hands-on activities, as well as to avoid fixing the date, time, and place of experimental activities.

The aim of applying the *eMersion* paradigm in engineering education is to add flexibility to the students' experimental work and to better integrate complementary activities, such as lecture, exercises and laboratories. Special *modules* describing hands-on experimentation packages are provided online as complementary support to the lectures. Each module includes the necessary components to carry out a complete laboratory session. Figure 1 shows the Web portal for accessing the modules that complement the expositive content of the automatic control course. This mandatory course is taught at the EPFL to students from mechanical, electrical, and mechatronics engineering. The portal shows five modules as available, labeled from M0 to M4. The requirement in terms of the specific modules to be completed by the students varies from one major to another depending on the curriculum adopted by each discipline.

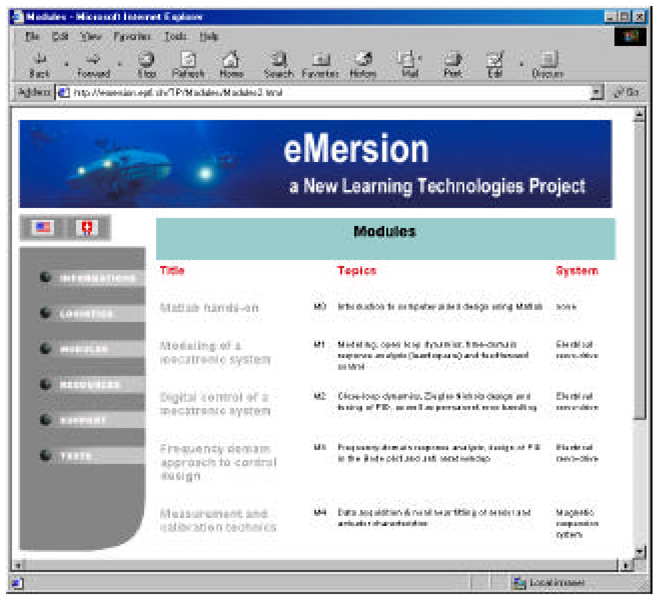

FIGURE 1.
THE *EMERSION* ONLINE MODULES FOR AUTOMATIC CONTROL

As discussed in the next section, the *eMersion* environment allows students to execute the tasks of any given module remotely. Hence, the students have the possibility to carry out an experiment at a time and from a location of their choosing, and therefore benefit from a more effective cognitive experience. It is worthwhile to note that for the regular students at EPFL, *i.e.*, those located directly on-campus, there is no formal requirement that they use the resources from locations away from the campus. In the spirit of flexible learning, the students are in fact also allowed to carry out the experimental work directly on the campus premises; however, access to the facilities is restricted to a number of specific time slots. Consequently, the experimentation modules have been designed to ensure that they are equally helpful to local and to remote students.

The modules introduced into the different pilot-courses have been carefully designed and the pedagogical scenarios of the courses have been revised and adapted in order to maximize the benefits realized via the integration of the online modules. The way this adaptation has been carried out is described below for three different cases.

- In **automatic control** the challenge has always been for students to link the highly mathematical analysis and design methods introduced during the lectures with the actual implementation of feedback loops. To facilitate this cognitive association process, an inverted pendulum as well as an electrical drive is introduced **as physical experimentation setup**. The former is used by the teacher for demonstration purposes, and the latter by the students for hands-on experiences. Instead of devising a single online module for each of the former "classical" experimental sessions, it was decided to offer a larger number of modules which in turn were shorter in required execution time, and also more focused in terms of the objectives. Care is taken to ensure that the modules allow the students to learn one topic at a time, rather than being overwhelmed with a large number of concepts during a lengthy session. Another key change in implementing the *eMersion* paradigm has been the complete decoupling of both the teaching-assistant support and the evaluation task from the experimentation activities. Tutors now replace the teaching assistants that used to grade the students' work under the previous scheme. The students either can contact the tutors directly during office hours, or asynchronously using the Internet. Currently, no grades are given for the timely completion of the modules during the term. The only constraint for the students is to successfully fill a *prelab form* that poses technical questions that must be answered to gain permission to access a given module. This requirement has been introduced to ensure that students have the necessary prior knowledge to benefit from the experience, and to motivate them to do preparatory work on their own. A grade is given only at the end of the term, when every student is assigned a randomly selected module that they are required to execute within a pre-specified time. A grade is then given based on the degree of completion of the deliverables accomplished by the student. The existence of a test module at the end of the semester is, in our experience, a strong motivating factor to induce the students to learn as much as possible during the term, and to develop a thorough understanding of all the freely accessible modules.
- In the **fluid mechanics** course both the phenomenological behaviors of flows and the simulation techniques are studied. Consequently, it is essential to provide the students with virtual experimentation setups to illustrate these two subjects. A **virtual wind tunnel** as been designed for this purpose. Different features can be selected as the course progresses during the term. The options include various wing profiles and alternative simulation algorithms. The basic wind tunnel simulates 1D phenomena, while the advanced version enables the study of 2D flows or shockwave propagation. The virtual wind tunnel is uses as a common resource all along the course, either as a demonstration tool for the instructor or as an experimentation platform for the students.
- In the **biomechanics** course the objective of the experimental work is to exercise the standard test procedures that are applied on biological tissues. The tests concern the rheology of tissues for which the intuition that students have gained working on classical material traditionally exploited in engineering are not valid anymore. This is due to the fact that bones, for example, deform differently depending on the direction of the applied stress. In order to support the students' efforts to synthesize a new intuition regarding the behavior of biological tissue under external constraints, a combination of **graphical animation** and numerical simulation tools is proposed to the students as an experimentation platform for deformation analysis. The resulting virtual test bench is loaded with samples of randomly selected biological tissues that the students are asked to test. Once a new phenomenon has been described in the course, the students are asked to illustrate the corresponding tissue behavior on their own sample. This virtual test bench is introduced in the mechanical engineering curricula at the EPFL, as well as in a continuing-education program offered to engineers and medical doctors jointly by the EPFL, the University of Geneva and the University of Lausanne. This shows an additional degree of flexibility that is provided in the deployment of experimentation resources. The same experimental facility can be used to illustrate different subject matter without any modifications, with the exception of the proposed experimentation protocol.

THE *EMERSION* ENVIRONMENT

All engineering students have to perform a number of *Experimentation Modules* (EM), *i.e.* lab exercises, for the practical part of their courses. The *eMersion* environment supports the remote execution of the EMs over the Internet. A *Cockpit* metaphor has been introduced as a graphical user interface (GUI) to integrate all the components necessary to complete successful **interactive experiments** and to sustain **collaborative activities** between the students. As an example, Figure 2 shows the cockpit that is available to complete an experimentation module in automatic control. In this case the EM is dedicated to the control a real electrical drive that is visualized within the central video frame of the cockpit.

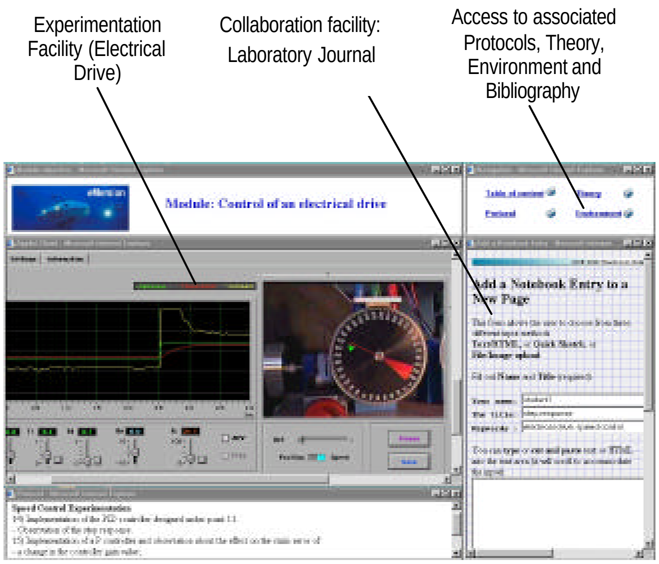

FIGURE 2.
THE *EMERSION* COCKPIT FOR THE CONTROL OF AN ELECTRICAL DRIVE

In the *eMersion* environment, the **interaction** mainly relies on changes made by the students in the configuration algorithms or parameters (actions on the virtual broomstick) that induce modifications in the real or virtual experimentation facility. The modifications are graphically display as soon as possible in the cockpit (perception through the porthole or using panel instruments).

The part of the cockpit dedicated to **collaboration** is referred to as the *Laboratory Journal* (area located on the right-hand side of Figure 2). It has been designed as an electronic and extended version of the traditional notebook used by students to document heir practical work. The laboratory journal lets students access their preparatory material (such as that required in the prelab form), store their experimentation results, post-process them, as well as pursue analysis activities and write reports. Since the EM is usually completed by a team of students (usually a pair), the laboratory journal is designed as a shared space. The design emphasizes the fact that the authors first agree on the document structure and on the task allocation, and then work individually on their own parts of the document. The students can also use the laboratory journal to submit their results automatically.

In order to offer to students a self-contained environment, a comparative study has been conducted to define specific supplementary information that is typically required for the completion of an EM in any of the pilot-courses. This set of dedicated information includes the following components:

- a clear statement of the module's **objective;**
- relevant **theory**, such as short reminders or links to theoretical references;
- an experimental **protocol**, which corresponds to the step-by-step procedures required to perform the EM;
- a description of the **environment**, including the experimental facilities (real or virtual) and the dedicated cockpit features.
- a **bibliography**, which includes a set references related with the EM.

These components have been integrated as tags in XML documents. The XML technology allows flexible and easy reuse of information. Because of their structured nature, XML documents can easily be retrieved, in the same fashion as data is retrieved in databases. The XML parsers check the document type validity using a document type definition (DTD), and also process the documents for a target application (such a Web browser, a generator of pdf files, a Java applet, etc). In addition, XSL (eXtensible Style Language) documents can be used to dynamically specify the style of XML documents.

CONCLUDING REMARKS

In this paper we propose the *eMersion* project as a paradigm introduced in engineering education at the EPFL to enforce hands-on learning activities and to add flexibility in the curricula. Its associated online environment integrates remote access to experimentation facilities and Web-based simulation capabilities. These resources are provided along with a set of necessary documents that discuss the objectives, theory, protocols, and bibliography needed to complete the experimentation modules. The environment also includes a laboratory journal facility, which supports the collaboration between the group members committed to complete the experimentation modules. Currently, *eMersion* supports three courses taught to engineering students, namely, automatic control, biomechanics, and fluid mechanics.

ACKNOWLEDGMENT

The *eMersion* project is funded by the Board of the Swiss Federal Institutes of Technology in the framework of its New Learning Technologies (NLT) program.

REFERENCES

[1] Latchman, H. A.; Ch. Salzmann, S. Thottapilly, and H. Bouzekri, "Hybrid Asynchronous and Synchronous Learning Networks in Distance Education", *International Conference on Engineering Education*, Rio de Janeiro, Brazil, 1998.

[2] Roschelle, J.; *et al*., "Developing Educational Software Components", *IEEE Computer Magazine*, September 1999, pp. 50-58.

[3] Bhandari, A.; and M. Shor, "Access to an Instructional Control Laboratory Experiment through the World Wide Web", *American Control Conference*, Philadelphia, 1998.

[4] Overstreet, J. W.; and A. Tzes, "Internet -Based Client/Server Virtual Instruments Designs for Real-Time Remote-Access Control Engineering Laboratory", *American Control Conference*, San Diego, USA, 1999.

[5] Gillet, D.; Ch. Salzmann, H. A. Latchman, and O. D. Crisalle, "Advances in Remote Experimentation", *American Control Conference*, Chicago, USA, June 28-30, 2000.

[6] Junge, T. F.; and C. Schmid, "Web-based Remote Experimentation Using a Laboratory-Scale Optical Tracker", *American Control Conference*, Chicago, USA, June 28-30, 2000, pp. 2951-2954.

[7] Gillet, D.; Ch. Salzmann, R. Longchamp, and D. Bonvin, "Telepresence: An Opportunity to Develop Practical Experimentation in Automatic Control Education", *European Control Conference*, Brussels, Belgium, July 1997.

[8] Klockner, K.; "BSCW - Educational Servers and Services on the WWW: How shared Workspaces Support Collaboration in Educational Projects", *International Distance Education and Open Learning Conference*, Australia, 2000.

[9] Armstrong, B.; and R. Perez, "Control Laboratory Program with an Accent on Discovery Learning", *IEEE Control Systems Magazine*, February 2001.

[10] Harold, E.; *XML Bible*, *IDG Books*, USA, 1999.

[11] Morrison, M.; *Java 1.1 Unleashed*, Third Edition, MacMillan Computer Publishing, 1997.