A framework for sustaining the continuity of interaction in Web-based learning environment for engineering education

Anh Vu Nguyen, Yassin Rekik, Denis Gillet
École Polytechnique Fédérale de Lausanne (EPFL), Switzerland
{anhvu.nguyenngoc, yassin.rekik, denis.gillet}@epfl.ch

Abstract: This paper presents an innovative approach that can facilitate Web-based collaborative hands-on activities in engineering education. We present a framework that helps to sustain the continuity of interaction in flexible learning. The proposed approach is based on Activity Theory and focuses on the mediation role of collaboration artifacts within a learning community in Web-based experimentation environments. The artifacts serve both as a medium and as a product of the collaboration process in the community. We have developed the eJournal as an implementation of collaboration artifacts to support knowledge acquisition and reinforcement in a collaborative way. The eJournal is integrated into the eMersion environment, which is currently used to supply online experiments for various practical courses offered by the School of Engineering at the École Polytechnique Fédérale de Lausanne (EPFL). The paper also presents two case studies and some evaluation results.

Introduction

Computer supported collaborative learning (CSCL) is a new trend of learning and education in which technology is used to enabling constructive approaches to support collaborative learning. Pedagogical approaches to collaborative learning treat the learner as an active and reflective participant of a collaborative community (Fjuk 1998). According to the socio-constructivist theory (Piaget 1929), previous experience plays an important role for learners to develop knowledge. In fact, this point is extremely important in engineering education where hands-on activities are best supported by resources that embody knowledge. In engineering education, the hands-on activities are as important as the theoretical ones. The hands-on work helps students to reinforce the knowledge obtained from the theoretical lectures, to improve the professional competences and the personal development, including the necessary skills for teamwork, since hands-on activities are usually conducted in groups. In his socio-cultural theory, Vygotsky stated that social interaction is a fundamental factor in the development of cognition (Vygotsky 1978). The collaboration between students working actively in small groups can help them to work more productively in the laboratory and also learn more easily, especially in a flexible context where students can follow different learning modalities to perform multi-session experiments. It may also have a significant impact on learning outcomes (Berge & Collins 1995).

Recognizing the importance of hands-on activities in engineering education (Ogot 2003), several institutions have developed remote experimentation resources (Böhne et al. 2004, Sepe & Short 2001), most of them are based on Web infrastructure, as a supplement to the face-to-face learning and teaching activities. However, from a constructivist point of view and in order to be effective, a Web-based learning environment for engineering education should allow the integration of different tools and services that (i) support hands-on activities, (ii) permit saving and reconstructing the experiments, i.e. allow to benefit from the previous experience, and (iii) facilitate collaborative activities. However, the development and deployment of such environments for flexible engineering education has raised many issues to be addressed.

This paper presents our study on the concept of the continuity of interaction, which is quite important in the context of flexible hands-on activities. The discontinuity of interaction prevents students from getting the sense of dealing with ‘reality’, which is normally well supported in face-to-face learning modalities. In fact, flexible pedagogical scenarios introduce many sources of discontinuities of interaction. The discontinuity of interaction prevented clearly the collaboration between students. It also slowed down and complicated the student experimental tasks. Section 2 of the paper presents the concept of the continuity of interaction as well as the theoretical and technical solutions for sustaining the continuity. In section 3, two case studies are detailed. Some evaluation results are discussed in section 4. The paper ends with concluding remarks.

Continuity of interaction in Web-based experimentation environments

Framework for the continuity of interaction

The notion of continuity has emerged as an objective that may potentially help users to obtain a higher quality of interaction, especially in the multi-session contexts. The student is provided with the possibility to carry out experimentation in a flexible way, i.e. s/he can follow different learning modalities. This means that, for instance, a student can perform the first part of the experiment at school, and the group-mate can pursue the rest of it at home using the environment to connect remotely to the laboratory equipment. The student may also need external applications; for example, this one may use a text editor to modify experimental results exported from the Experimentation component, and then import the result to an analysis component for further mathematical processing. The continuity emphasizes the uninterrupted sequence of dialogue activities even in different modalities. In other words, it highlights the importance of uninterrupted flow of information among the users as well as between the user and the interactive spaces.

To improve and reinforce the collaboration among students performing experiments, in addition to the Experimentation component, Web-based learning environments usually provide students with communication components such as forum, email or shared workspace. However, in most Web-based experimentation environments, the components are poorly integrated together. They are just 'juxtaposed' with one another. The interaction and collaboration process in both system and user levels carried out in such kind of learning environment is very limited. Lots of discontinuities of interaction are present.

We faced the same problem in the first version of the eMersion environment, which has been developed at the EPFL in Switzerland with the aim to support hands-on experimentation through remote manipulation of physical laboratory devices and/or computer simulation tools. This environment is currently used in Automatic Control and Fluid Mechanics courses offered by the School of Engineering at the EPFL. The eMersion environment has a Cockpit-like user interface and contains all the components necessary to successfully complete laboratory assignments (Gillet et al. 2003). These Web components are heterogeneous in the sense that they were developed using different technologies and may be located on different servers. The eMersion environment is so general that we can apply it to different learning scenarios by replacing and/or integrating the components developed by different institutions. Figure 1 shows the eMersion environment with its two of the most important components, the Experimentation component (the bottom left component) that enables the actual realization of experiments, and the eJournal, which has been designed as an extended electronic laboratory journal for collecting and sharing experimental data in hands-on activities to support teamwork.

Figure 1: eMersion environment with the Experimentation component and the eJournal

In the spirit of flexible learning (Gillet 2003), students have the possibility of carrying out an experiment at any time and from a location of their choice; thus benefiting from a more effective cognitive experience. Students can also perform multi-session experiments. Figure 2 shows students working in the laboratory (face-to-face modality) and interacting directly with the teaching assistant. It also shows another student working at home using the same environment to connect remotely to the laboratory equipment.

In fact, flexible pedagogical scenarios introduce many sources of discontinuities of interaction. We have synthesized and defined different dimensions of continuity and the causes of discontinuity. The main dimensions are related to Space, Place, Time and Cognition. The Cognition dimension covers and explains the three other ones. Details of these dimensions could be found in (Nguyen et al. 2004).

In a Web-based experimentation environment like the eMersion one, students have to switch between different spaces, different places and different times to perform even a single task. For example, a student can perform an experiment, which is composed of different tasks. This student realizes the manipulation using the Experimentation component, i.e. s/he works in the Experimentation space. During the experiment, s/he saves, views, and exchanges the experimental parameters as well as the results in the group's shared workspace (e.g.

the eJournal in the eMersion environment). S/he can also launch a Toolkit component for analyzing the experimental results, viewing parameterized graphics. This student can perform the first part of the experiment at school in the morning, and continue the next parts at home in the evening.

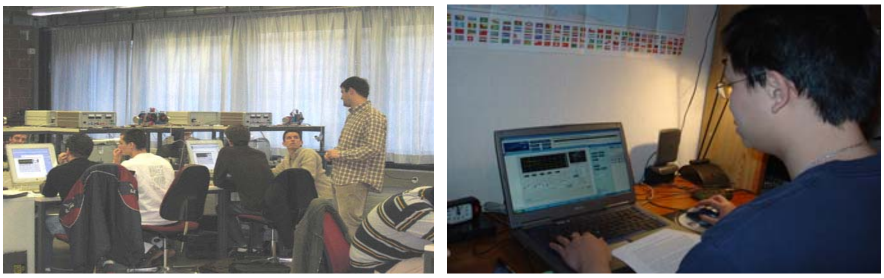

Figure 2: Student learning modalities (face-to-face and flexible) in hands-on activities

As explained by the Suchman's Situated Action Theory (Suchman 1987), the task performance is always a situated action, determined by local and unanticipated events. Massink stressed this perspective by showing that the reaction depends on the particular situation, the experience and the knowledge of the user (Massink & Faconti 2002). Obviously, the fact that students work using different consoles at the same time causes many distractions in their works. Furthermore, the behaviors of students while performing the experiment at different places (such as at school and at home) are not the same. In addition, the segmentation of a hands-on session into multiple short sessions creates multiple time intervals clearly increasing the potential mismatch between human and system capabilities. As a consequence, the user's perceptual models may change regularly in a multiple context situation, and may not match the user's conceptual models, which are built towards the overall goals. This mismatch generates the discontinuity of interaction that may affect the task performance.

Sustaining the continuity of interaction in Web-based experimentation environment is an important requirement to improve the efficiency of learning. The next subsections will present our theoretical and practical solutions for sustaining the continuity of interaction in Web-based experimentation environment.

Activity Theoretical solution for sustaining the continuity of interaction

We base our theoretical work on Activity Theory, which provides a broad conceptual framework for describing the structure, development, and context of computer-supported activities (Engeström 1987, Kuutti 1995). We have also explored the mediation role of artifact in Web-based engineering learning community since hands-on activities always take place through and result in some kinds of artifacts. Activity Theory is a theory about human interaction and about work activities supported by artifacts. Generally, an activity is a form of doing something towards an object to obtain an outcome. Human activity can be described as a hierarchy with three levels: activities realized through chains of actions, which are carried out through operations. For instance, in engineering education, students carry out a chain of tasks, i.e. a chain of activities, to complete their course. In Automatic Control course, a task could be, for example 'Modeling and control of an electrical drive'. For each task, there are different actions to be realized. These actions have an immediate, defined goal, for example, 'preparing the pre-lab', 'manipulating the physical drive', or 'analyzing the experimental result'. Operations are well-defined routines as answer to conditions faced during the performing of the action, such as 'moving the parameter scrollbar to increase or decrease the value of a parameter'.

A collaborative activity can be defined through a three level hierarchical structure (Kuutti 1995). These are labeled co-ordination, co-operation, co-construction, and correspond to the level of operation, action and activity, respectively. At the lowest level is co-ordination, in which actors are following their scripted roles. The dynamics of collaborative work imply the constant shift between these levels (Bardram 1998). These concepts show a strong parallel to the three regulation levels as defined in Action Regulation Theory (Rasmussen 1987) (see Figure 3). The regulation of action can occur at several 'levels'. The highest level, which is called knowledge based regulation, is that of consciously identify, decide, and plan the task. The second type of behavior regulation, rule-based regulation, happens using pre-defined routines whenever they appear to be needed. The third level of regulation, called skill-based, refers to completely automated behaviors. The Action Regulation Theory is oriented to the individual behaviors. Meanwhile, the Activity Theory levels of interaction expand the scope of these concepts. They could be applied perfectly not only to individual cognitive and reasoning process, but also to interaction and collaboration processes between groups and among members of a community of practice.

These theories are particularly relevant with regard to improving and sustaining the continuity of interaction in a Web-based experimentation environment. One principle of the theory is that people tend to maximize the efficiency of their actions (Andriessen 2003). This means that they prefer to use scripted-routine, to 'automate' actions, thus spend less unnecessary conscious effort in carrying out a task.

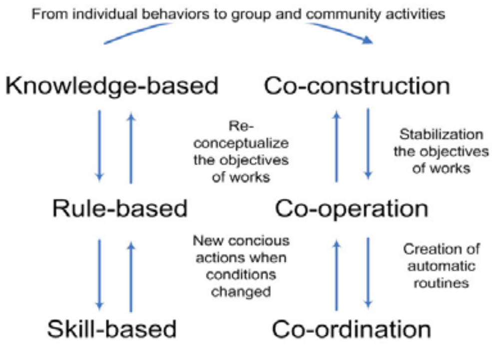

Figure 3: Activity levels (adapted from (Rasmussen 1987, Bardram 1998))

The artifact plays the mediation role in Activity Theory. According to Stahl's researches in CSCL (Stahl 2002), an artifact is a meaningful object created by people for specific uses. Artifacts mediate knowledge building. Artifacts also mediate the interaction and interviewing of personal and group perspectives. Achieving a shared understanding of the meaning of artifacts among a group of people clearly facilitates group work. In our approach, the mediation role of artifacts is further investigated and applied in a real flexible learning environment. We do believe that there is a strong relationship between different actors in both user and system levels, which are not clearly mentioned in Activity Theory. This opinion is also supported by Massink (Massink & Faconti 2002), who stated that the continuous interaction implies a tighter coupling between user and system.

In fact, the artifact can serve as a means for articulating distributed activities in the learning settings. We propose the concept of '*collaboration artifact*', which serves as a '*bridge'* that connects the user and the system levels. This means that the collaboration artifact provides a 'shared workspace' for both human users and Web components. As a shared workspace for the users, the collaboration artifact allows students to exchange data with peers as well as with educators. As a shared workspace for the system, the collaboration artifact also enables different components to exchange data. It also helps to save and to re-construct the states of experiments. In fact, by facilitating and scripting the communication between components at the system level, the artifact simplifies the tasks carried out by students at the user level, thus improving the learning performances. The concept of collaboration artifact is opened and can be implemented using different metaphors in different pedagogical scenarios.

eJournal-based technical solution

The eJournal has been introduced since the 2002 winter semester at the Automatic Control Laboratory, EPFL. It has been designed as an implementation of *asynchronous* collaboration artifact. It plays the role of an extended electronic laboratory journal, which provides a collaborative shared workspace for students when performing hands-on activities. The Laboratory Journal metaphor was chosen, as we believe that engineering students are familiar with this concept and it is easy for them to use and conceptualize. Documents stored in the eJournal are called *fragments*, which are typed, representing different kinds of data (e.g. snapshot, parameter, experimental result, etc.). The eJournal provides various services that facilitate the hands-on and collaborative activities in a flexible context. It serves as a 'shared workspace' in both the user and the system levels. At the user level, using the fragments, student groups are provided with different means for collaboration. For example, students can add annotation to the fragments, which will be viewed by other students or assistants. Students can send fragments with attached annotations to other groups via an integrated email system. The eJournal also provides the possibility to copy/move fragments from one eJournal to another. Students can access the eJournal of other groups to view or download shared fragments if they were granted the necessary permission. The interaction between the users via different kinds of fragments induces interaction between different components at the system level. The eJournal facilitates the interaction between heterogeneous components by allowing them to store, share and exchange data.

The eJournal and its fragments help to sustain the continuity of interaction in Space, Place and Time dimensions. As a consequence, the discontinuity in Cognition is also reduced. The mechanism, namely 'data tunneling mechanism', is technically based on the data homogenization and transformation process provided by the eJournal. The eJournal facilitates the scripting of student actions by *automating* the processes in which data is saved, (re)-constructed, or exchanged between different components. By this way, the eJournal allows students to focus on their main tasks, to spend mostly conscious effort in carrying out the task, not to be disturbed by unnecessary actions.

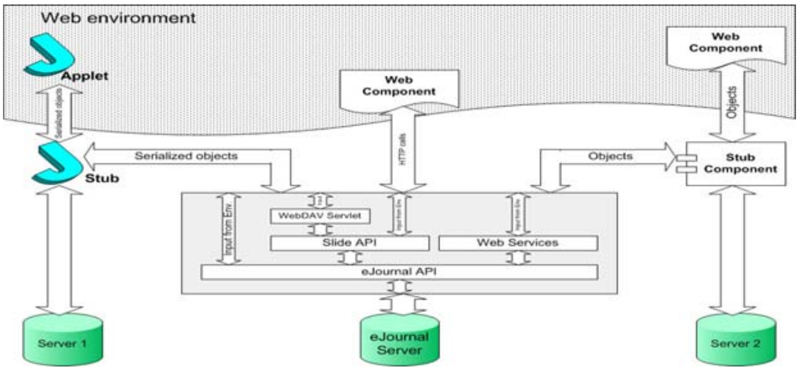

Figure 4: The eJournal architecture for sustaining the communication between components

Figure 4 shows the architecture of the eJournal ‘data tunneling mechanism’. The eJournal supplies a set of interfaces that deals with different kinds of requests from different components integrated into the Web-based experimentation environment. Through these interfaces, the eJournal is able to process different kinds of serialized objects generated from Java, PHP or PHP-like programs. In addition, various eJournal services have been developed as Web Services and deployed using libraries from the Axis project. To process the WebDAV requests, we have modified and integrated the WebDAV module from the Slide project. Axis and Slide are open source projects developed and maintained by the Apache Software Foundation[1].

The communication channel between the eJournal and a Web component is established either directly or via a *stub*. When receiving a request, the eJournal detects the type of data received, determines how to transform the request data and which target component should be invoked (with data already transformed). This new mechanism augments a lot the interaction process. Data is passed smoothly and naturally from one component to another. The requirement to use external applications for data sharing and exchanging is minimized. Users work with minimum discontinuity in all dimensions of interaction. As a consequence, the quality of the hands-on and collaborative works is much more improved. More discussions about the continuity of interaction could be found in (Nguyen et al. 2004).

In the next section, we will introduce two case studies, in which the eJournal is used as a means to sustain the continuity of interaction in the Web-based experimentation environment.

Case studies

Automatic Control module in manipulating an electrical drive at the EPFL

This section presents a case study for the eMersion environment currently deployed and used by various courses offered by the School of Engineering at the EPFL. The so-called cockpit includes three main parts: The Experimentation console, the eJournal, and the Toolkit console. The Experimentation console has been developed as a Java applet that connects to a LabVIEW server, which in turn connects to and manipulates the physical drive. The movement of the drive is visualized using a Webcam, and images are transferred back to the applet. The applet interface is developed with Java Swing. The Toolkit console is the SysQuake Remote software[2], which provides necessary functionalities for preparing experiments and analyzing the results. All the experimentation modules include two successive stages: the pre-lab and the lab-work. Details of the learning settings and task protocol could be found in (Gillet 2003).

During the course, a usual experimental scenario is as follows. At school, a student has chosen a set of adequate parameters to obtain a stable state of the system. His group-mate uses the same set of parameters to re-create the same state. After that, the first student finishes the experiment and gets some result data. The second student then uses those data for some further mathematical processing using the SysQuake Remote tool. Before the introduction of the eJournal, to realize the above scenario, the Experimentation applet exports the results in text form, which are copied *manually* to the system clipboard, or copied to an external application such as a text editor, and then are pasted to the SysQuake Remote console for being processed.

[1] http://jakarta.apache.org

[2] http://www.calerga.com

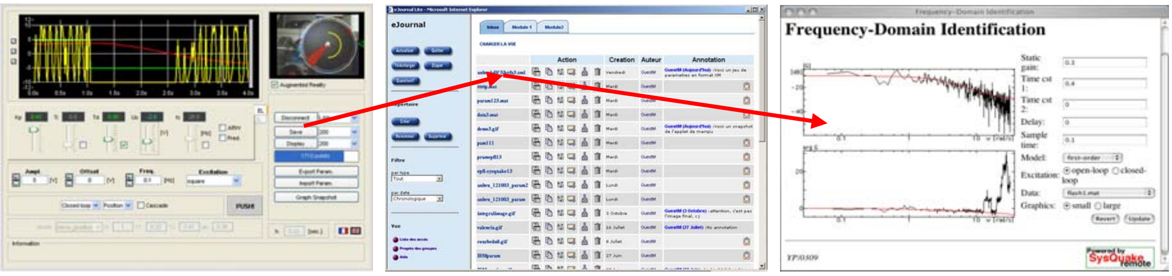

Figure 5: Continuity of interaction in Automatic Control module- manipulating an electrical drive

Figure 5 represents an example of continuity of interaction in manipulating an electrical drive using the eMersion environment. The figure shows a data flow, or in other words a continuous interaction with aid of the eJournal. With just one click, a student working at school can export experimental results from the Experimentation applet to the eJournal, which will be processed later using the SysQuake Remote component. This means that, for instance, at school, a student can click on the 'Export Results' button in the Experimentation console to save the experimental result he has completed as a fragment typed 'Results' in the group's eJournal. With another click at home, a group-mate can load automatically the SysQuake Remote console to perform further analysis. This 'one-click' continuous interaction mechanism helps students focusing on their main tasks, not to be distracted by unnecessary actions.

Motor simulation module developed at the UNED

This section presents another case study that illustrates the extensibility of our approach. To extend the functionality of the eMersion environment, a simulation and animation applet has been integrated in 2004. This applet enables virtual experimentation on the previously mentioned electrical drive to be carried out prior to run a real experiment. The Applet has been generated using Easy Java Simulation package (EJS[3]).

The eJournal's API allows the easy integration of this applet into the eMersion environment. It also provides the possibility to communicate with other components providing that the parameters have been well defined. Figure 6 shows a data flow in which the simulation applet saves parameters in the eJournal, and then can be visualized in a browser in the form of an XML file.

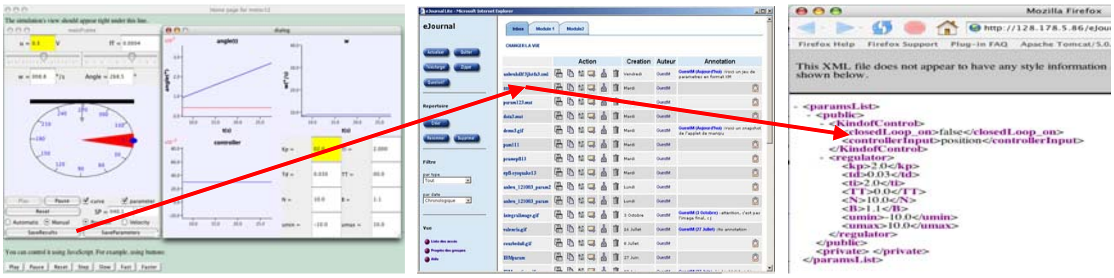

Figure 6: Data flows from the simulation applet to a browser via the eJournal

Evaluation

We have carried out a comparative evaluation for the Automatic Control laboratory course, which is a mandatory course for the electrical, mechanical, and micro engineering study programs at the School of Engineering, EPFL (the first case study). The evaluation took place in an iterative process with the purpose of studying the participation, flexibility and collaboration aspects of a Web-based engineering learning community as well as of improving the user interface design. This section presents some of our results related to the continuity of interaction issues, mostly based on the Likert scaled questionnaires, and the analysis of log data.

Among the 181 students enrolled in the course from the winter 2002 to the winter 2003 semester, 129 returned the questionnaires distributed (71.3%). The mean of satisfaction was around 4.12 over 7 (S.D.=1.02). Regarding the operating system they were using, 9.5% of students used Linux, 6.8% used Mac OS, 58% used Windows, and the rest gave no information. Another interesting point was that 77% of students had Internet connection at home. Among the pre-defined metrics, we were extremely interested in *intra-fragment-ratio*, which reflects the utility of the environment for performing hands-on tasks, and *flexible-fragment-ratio*, which measures the importance of flexible learning modalities compared to face-to-face learning modalities. In fact,

[3] http://fem.um.es/Ejs/Ejs_en/HomePage.html

since the version for the 2003 summer semester, the possibility to sustain the continuity of interaction has been improved. As a consequence, the intra-fragment ratio and the flexible-fragment ratio has greatly been increased from 76.67% and 26.29% in the 2002 winter semester, to 86% (intra-fragment ratio) and 55% (flexible-fragment ratio) in the 2003 summer semester.

Concerning the Time dimension, in the 2003 summer semester, 1% of fragments were created during weekends. During working days, 2.5% of fragments created in the evening and at night, i.e. from 18h to 07h the next day. Social network analysis also showed that there were interactions between students from different semesters. Figure 7 shows a histogram illustrating the fragment evolution from Monday to Weekend during the 2003 summer semester. In this semester there was one face-to-face laboratory session every Thursday (from 10h15 to 12h). The pre-lab sessions, in which assistants were present to answer questions and discuss with students, were organized each Tuesday (12h15-13h) and Wednesday (16h15-18h). The histogram shows that students worked most actively on the days in which there were laboratory sessions, and a day before (for preparing the lab).

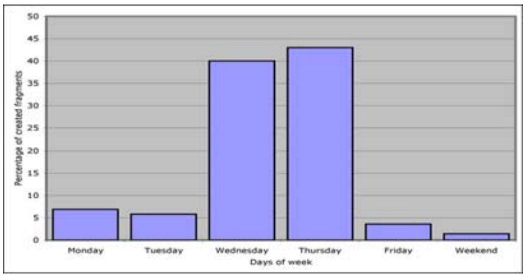

Figure 7: Fragment evolution (2003 summer semester)

We have also examined the type of fragments created using external applications to determine the student learning pattern when working different modalities. About half of the created fragments were text files (e.g. 47% in the 2002 winter, or 54% in the 2003 winter semesters) that most likely corresponded to the pre-lab preparation. The next highest percentage related to image fragments, which could be for sharing or preparing the reports, and mathematical scripts (e.g. 25%, and 9%, respectively, in the 2003 winter semester). This learning pattern was the same for all semesters.

In fact, the choice of open technologies for development facilitated the cross-platform feature of the environment. The ratio of flexible fragments showed that the students took advantage of the different learning modalities, i.e. the environment has provided students with the possibility to carry out their experiments not only in face-to-face modalities but also in flexible ones. The ratio of the intra fragments supported the assumption that the Web-based environment does not disturb students in conducting flexible hands-on experimentation compared to traditional one. This metric also showed that the system functionalities satisfy the needs of students while performing hands-on activities. The continuity of interaction feature facilitated their tasks while working in different spaces (for example, Experimentation console, SysQuake Remote) and places (in the laboratory, in another campus room, or at home). The environment usability and utility has been founded satisfactory. Details of the evaluation metrics, results, and process could be found in (Nguyen et al. 2005).

Concluding remarks

This paper presents our approach of using so-called *collaboration artifacts* to sustain the continuity of interaction in Web-based experimentation in engineering education. We show that flexible learning scenarios might be sources of many discontinuities of interaction. We have proposed the eJournal, an extended electronic laboratory journal, as an instrument to augment the interaction process; that means the collaboration among students, between professors and students, and also the communication between heterogeneous components. The eJournal is an implementation of asynchronous collaboration artifacts that connects and integrates interaction processes at the user level and the system level. By sustaining the continuity of interaction, we much improve the quality and the performance of work in Web-based experimentation environments. Our approach is based on Activity Theory, the notion of shared artifact and its mediation role in a learning community. We also show the architecture used for the eJournal implementation. Two case studies are discussed. The first one is related to a manipulation applet developed at the Automatic Control Laboratory, EPFL. The eMersion environment, into which this applet is integrated, is currently used in various courses offered by the School of Engineering at the EPFL. The second case study is related to another Experimentation component. This one was developed using Easy Java Simulation, a module from the Universidad Nacional de Educacion a Distancia (UNED) in Spain. The environment using this component is currently deployed and tested in the Department of Computer Science and

Automatic Control at the UNED. We also present in this paper some of our evaluation results performed on the Automatic Control course at the EPFL.

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