SUSTAINING THE CONTINUITY OF INTERACTION IN WEB-BASED EXPERIMENTATION FOR ENGINEERING EDUCATION

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Abstract

This paper presents an innovative approach for sustaining the continuity of interaction in Web-based experimentation for engineering education. The approach is based on our work in Activity Theory and the CSCL's shared artifacts concept. The theory is applied to the eJournal, the collaboration component within the Cockpit, a Web-based environment proposed to students for hands-on experimentation sessions. The eJournal has been developed using the new information and communication technologies such as XML, JSP, and Java. The proposed approach and environment are currently implemented and tested in different courses at the School of Engineering, Swiss Federal Institute of Technology in Lausanne (EPFL).

INTRODUCTION

Nowadays, one of the useful and interesting trends to support engineering education is to expand the available resources by providing Web-based experimentation facilities (Gillet et al. 2003). Web-based experimentation turns to be a key feature in the deployment of e-Learning solutions for engineering education. It offers a tremendous opportunity to add flexibility in traditional curriculum by providing students with versatile access to the learning material from both a time and a location perspective. In addition, in practical work, engineering students need tools and services to be able to collaborate with one another. The collaboration between the students themselves, and also between students and professors, while carrying out an experiment allows the (co-)construction of knowledge. This is a form of collaborative learning. As a consequence, CSCL (Computer Supported Collaborative Learning) is now considered as an important research domain, which could help developing methods and tools to make teaching and learning processes, especially in engineering hands-on sessions, much more effective and efficient.

In order to fulfill the requirements for the new engineering education paradigm presented above, the Board of the Swiss Federal Institutes of Technology has launched the ***eMersion*** and the ***Mentors*** projects, which aim respectively at providing a Web-based environment that supports hands-on experimentation through remote manipulation of physical laboratory devices and/or computer simulation tools and at implementing the necessary support schemes. In the context of these projects, we have developed the Cockpit environment, which is now currently used in Automatic Control, Fluid Mechanics and Biomechanics courses at the

School of Engineering, Swiss Federal Institute of Technology in Lausanne (EPFL). The environment provides the students with the possibility to learn in a flexible way, i.e. students can follow different learning modalities to perform multi-session experiments.

This paper presents an innovative approach in CSCL and distance learning, which facilitates hands-on activities in engineering education. The paper focuses on the eJournal, the collaboration part of the Cockpit environment. The next section presents the Cockpit, a Web-based environment for engineering education, and its initial deployment scenario. Then, the concepts of the continuity of interaction, the theoretical background, and the advanced learning scenario are discussed. The implementation, evaluation results and related work are also presented. The paper concludes with some remarks and the future work.

THE COCKPIT: A WEB-BASED COLLABORATIVE LEARNING ENVIRONMENT FOR ENGINEERING EDUCATION

The Cockpit description

The Cockpit environment (Cockpit 2003) contains all the components necessary to complete successful experimentation sessions. Those components are heterogeneous in the sense that they were developed using different technologies and may be located on different servers. The main components of the environment are presented as follows

1. Experimentation component: it was developed as a Java applet and can be regarded as the interaction part that enables the actual realization of experiments.
2. SysQuake Remote component (Calerga 2003): it is a PHP-based application, which provides students with tools to carry out interactive design and analysis activities related to the experiment. It embeds easily advanced computation and graphics such as parameterized graphics, up-to-date graphical representations, etc.
3. eJournal: it will be presented in section 3.
4. Supporting documentations and theory remainders.

Figure 1 shows the Cockpit environment (left-hand side of Figure 1) offered for Automatic Control module carried out using an electrical drive. The upper side contains the navigation bar, the module objectives and the status of realized tasks. From the navigation bar, one can open different components such as Experimentation applet, eJournal, SysQuake Remote, related theory remainders and bibliographies, etc. The left-hand side of the environment is the Experimentation applet with which students can perform the experiments for different modules in Automatic Control. The right-hand side is the eJournal portal through which students can log into different eJournals (see next sections for more details). The real electrical drive (right-hand side of Figure 1) is visualized in real time using web-cam. The video image is showed in the Experimentation applet. Details of the environment are presented in (Gillet et al. 2003).

Initial deployment scenario

The flexible learning scheme proposed (Gillet and Fakas 2001, Gillet et al. 2003) allows students to perform the experiments in different steps, at different moments and at different places. Students can face a multi-session interaction when carrying out a module, i.e. they can repeat the same experiment in different stages and time. During the experiment, students exchange with other colleagues, with professors, and with assistants their ideas, data, results, information, etc.

Figure 1: The Cockpit environment

We now present the initial deployment scenario. To make the scenario simpler and more comprehensible, we use the “Alice and Bob example” as follows:

Alice and Bob are two students belonging to the same group, performing a control experiment using an electrical drive. At school, Alice had chosen a set of adequate parameters to obtain a stable state of the system. At home, Bob uses the same set of parameters to re-create the same state. After that, Alice finishes the experiment and gets some result data. Bob then uses those data for some further mathematical processing using the SysQuake Remote tool.

To improve and reinforce the collaboration among students performing the experiments, Web-based learning environments usually provide students with communication components such as forum, email or shared workspace. However, those components are normally poorly integrated together. In the eMersion project, we also faced the same problem as in the first prototype of the Cockpit environment; there was no communication between different components within the same environment. So, to realize the above scenario, the Experimentation applet exported the results in text form, which were copied **manually** to the system clipboard and then were pasted to the SysQuake Remote console for being processed. The experimental parameters or experimental results were noted in the student’s notebook (for supplementary experiment or further processing).

Let us comeback to the example and suppose that Alice fixes a set of parameters. She notes the parameters in her notebook. She also gets some experimental results after having finished her experiment. In his turn, Bob asks Alice to get those parameters. Once having the parameters, he can reuse them to obtain the states of the experiment done by Alice. For processing the experimental results using an analytical tool such as SysQuake Remote, Bob has two choices, he could repeat the experiment with the noted set of parameters or he could take the experimental results directly from Alice.

1. In the first case, Bob realizes the experiment with the chosen set of parameters using the Experimentation applet. The experimental results are outputted in text form. He copies the text to the system clipboard. After that, he launches the SysQuake Remote, pastes the text to the SysQuake Remote console and then executes SysQuake processing functions.
2. In the second case, Bob launches the SysQuake Remote, and then types the experimental results (in text form) in the SysQuake Remote console. However, because of the limited screen size of the SysQuake Remote console, Bob sometimes prefers to open a text editor such as Word to input the results, and then copies and pastes the text to the SysQuake Remote console.

In fact, this scenario is what we observed in the Summer 2002 and Winter 2002 semesters in Automatic Control laboratory courses at EPFL. Obviously, the interaction process described above presented lots of interruptions, or in other words, it presented lots of discontinuities. The discontinuity of interaction prevented clearly the collaboration between students. It also slowed down and complicated the student experimental tasks. Therefore, the mechanism, which was called "**discontinuous interaction mechanism**", was not suitable for the Web-based hands-on experimentation sessions in engineering education.

In the next sections, we present our syntheses about the continuity of interaction as well as the sources of discontinuities of interaction. We also present the theoretical background and our proposals that aid to sustain the continuity of interaction in engineering education.

CONTINUITY OF INTERACTION IN ENGINEERING EDUCATION

Concepts of continuity and sources of discontinuity in flexible learning context

The notion of continuity has emerged as an objective that may potentially help users (refer to both students and professors) to obtain a higher quality of interaction, especially in the multi-session context as in the Cockpit environment. The continuity emphasizes the uninterrupted sequence of dialogue activities. In other words, it highlights the importance of uninterrupted flow of information between the user and the interactive spaces (Savidis et al. 2002). From the point of view of humans (May et al. 2002) in engineering education, i.e. when performing the experiment using an object, a continuous interaction is one in which users can observe the behavior of that object, can make inferences about its state, and the state of any tasks that they are executing, and crucially, can issue commands to the object at any point, without needing to re-enter into any preparatory or enabling tasks to prepare the object. Continuity also means that the effects of changes are predicted or foreseen (Massink and Faconti 2002).

Flexible pedagogical scenarios introduce many sources of discontinuities of interaction. We have synthesized and defined different dimensions of continuity and the causes of discontinuity as follows

1. Space: students perform tasks in many different windows within the same Cockpit environment. One should recall that one component is launched in at least one separate window. Students may also use external applications to support their tasks (e.g. Bob with a text editor). Each window can be considered as a workspace. Obviously, performing the same task while opening different workspaces may create the discontinuity of interaction.
2. Place: the sense of place is a context understanding of the appropriateness of styles of behavior and interaction (Harrisson and Dourish 1996). It refers rather to the physical places with embedded context understanding. Obviously, the behavior of users when performing the experiment in the laboratory and at home is not the same.
3. Time: the segmentation of a hands-on session into multiple short sessions creates multiple time intervals clearly increases the potential mismatch between human and system capabilities.
4. Cognition: this dimension covers and explains the three other ones. This dimension takes focus on the cognitive processes of the human as well as the states and processes of the performed task. As presented in (May et al. 2002), the context within which an information stream is being used determines the way that human will perceive it. The authors implied that to sustain the continuity of interaction, it is necessary for the system to encode or represent interactions in the same hierarchical manner as the user.

In a distributed environment like the Cockpit, students have to switch between different spaces, different places, at different times to perform even a task. As explained by the Suchman‘s Situated Action Theory (1987), the task performance is always situated action, determined by local and unanticipated events. Massink and Faconti (2002) stressed this perspective by showing that the reaction depends on the particular situation, the experience and the knowledge of the user. 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.

The next section presents some theoretical background based on which we develop a solution for sustaining the continuity of interaction in a multi-session context.

Theoretical solution for sustaining the continuity of interaction

Our approach is based on the Activity Theory (Leontev 1978; Engestrom and Lektorsky 1990; Kuutti 1995; Adriessen 2003; Carroll 2003), which is a comprehensive theory concerning human social interaction with tools, in the context of a community (see Figure 2). It is a theory about human interaction and about work activities supported by artifacts. In this theory, an activity is the fact that a subject manipulates an object to obtain an outcome. The relationship between the subject and the object is mediated by tools (or artifacts). However, an activity is only meaningful in a specific context, within a community. The relationship between subject and community is mediated by rules, which cover norms, conventions and social relations within the community. The relationship between object and community is mediated by the division of labor, which refers to the organization of the community.

The Activity Theory really meets our context. It directs our research as well as our development. In our learning settings, students work in groups of 2 people. Those groups, which form the subject of activity, plus the professors, who are in charge of the course, and the assistants, who help students in the laboratory as well as via the Web environment, create a learning community, i.e. a community of practice (Wenger 1999), where they share common interests for the field they work in (practical work to reinforce the knowledge in Automatic Control), share and create collaboratively knowledge that related to a common practice. The student objective is to perform the experiments in order to obtain some knowledge, thus to be able to pass the exams (their outcomes). The class (the learning community) has of course rules and division of labor for everyone.

The artifact takes an important role to facilitate the teaching and learning processes, especially in engineering hands-on sessions. The Activity Theory has stressed the mediation role of artifacts. According to Stahl’s researches in CSCL (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. In fact, the notion of artifact was defined in the Vygotsky‘s Socio-Constructivist Theory, in which the author showed that the human action is mediated by a number of signs and tools (Vygotsky 1978), which are kinds of artifacts. Achieving a shared understanding of the meaning of artifacts among a group of people facilitate clearly the group work. In our approach, the mediation role of artifacts is further investigated and applied in a real flexible learning environment. In the environment, most of the interactions pass through or result in some kinds of artifacts. The artifact serves as a means for articulating distributed activities in collaborative learning settings, also as a bridge to connect the collaboration at the user level and the communication between heterogeneous components at the system level in a Web-based learning environment. This is in fact a significant contribution to CSCL.

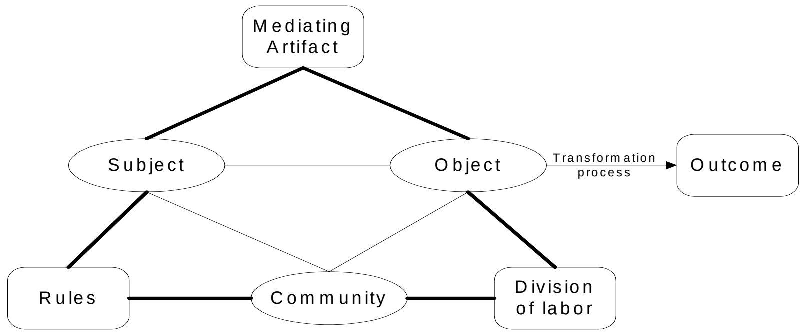

Figure 2: The Activity Theory (adapted from Kuutti 1995)

The theoretical background presented here and the synthesis of the actual pedagogical scenarios in engineering education at EPFL lead to the eJournal environment, which supports the collaboration between users using the Web-based engineering learning environment, and which helps to sustain the continuity of interaction in flexible hands-on sessions. The next section is dedicated to present the eJournal and its core role in the new interaction mechanism.

THE EJOURNAL

The eJournal is the collaboration part within the Cockpit environment. The eJournal has been designed as an extended electronic version of the traditional notebook, which serves as a chronological repository for experimental motivation, experimental details, the process of scientific discovery, the procedures followed, the raw data collected, resulting data and its analysis, any ideas or observation as they occur, as well as thoughts on future directions (McCormack et al. 1991; Myers et al.1996). Furthermore, the eJournal benefits by the collaboration aspect of papers (or paper-like instruments) in communities, which has been shown by many empirical studies (Smidth 1992; Sire 2000; Sellen 2002).

The eJournal provides a collaborative workspace, where students can store, retrieve, share and exchange the group documents, which are called **fragments** in the eJournal, when performing the experiments. We have defined different types for fragments such as snapshot, experimental result, set of parameters, uploaded documents, and students' notes. Fragments with different types are handled differently. The eJournal can import/export fragments from/to other Cockpit components such as the Experimentation applet or SysQuake Remote. Using the eJournal, students can also submit their fragments to assistants and professors for being evaluated. In the eJournal, the fragments are displayed chronologically (depending on the creation time). They are grouped into different folders. Users can create, rename or delete the folder. In that sense, the eJournal follows the mailbox metaphors the students are already familiar with. Normally, students create the folder based on the module they are realizing. Some awareness information could be attached to fragments. The fragment in the space can be filtered based on the creation date or fragment type. It can be deleted temporary (put to Trash) or definitely (physically deleted).

Logically, we have different workspaces. The private eJournal workspace can only read or modified by its group members, and the shared eJournal workspace is the shared space for other groups. The user can work on their private workspaces before sharing them with others. Each eJournal is dedicated to one group for one experimentation module. Authorization or access permissions relate to the operations available to the user. The authorization is changed from one eJournal to another. It depends on the role as well as on the context. Users continually shift back and forth between different spaces when performing experimentation.

The fragments in the eJournal are considered as shared artifacts, which help to sustain the continuity of interaction in Space, Place and Time dimensions. Figure 3 illustrates the philosophy of this idea; this shows that users can access the eJournal from the school, at home or anywhere else. The access is not either limited in the time dimension. We try to overcome the discontinuity in cognition by designing a homogeneous interface and by reducing the task complexity, i.e. eliminating the “discontinuous interaction mechanism”, which is now replaced by the “**continuous interaction mechanism**”.

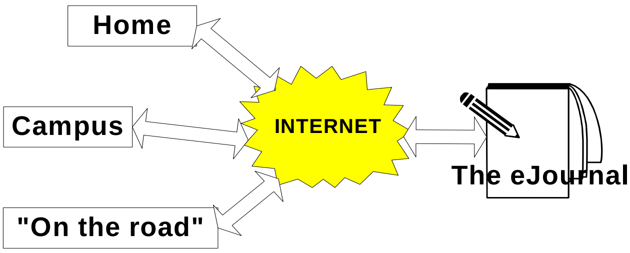

Figure 3: The eJournal and its accessibility map

Figure 4 represents an example, a data flow, or in other words a continuous interaction. The Experimentation applet saves experimental results in the eJournal as a fragment, which will then be processed by the SysQuake Remote (draws a 2D graphics). Users do that simply by clicking buttons. This interaction process could happen in a flexible context. This new mechanism augments a lot the interaction process. The data is passed smoothly and naturally from one component to another. Users work with minimum discontinuity in all dimensions of interaction. As a consequence, the quality of the hands-on works is much more improved.

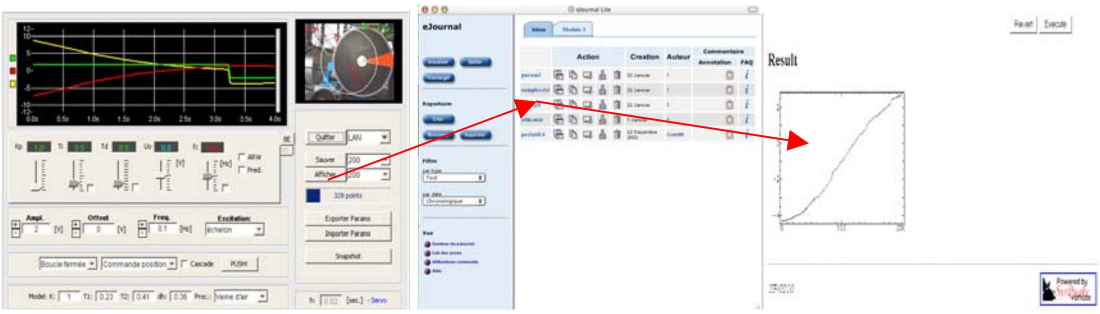

Figure 4: The eJournal and the continuity of interaction

Back to our example with Alice and Bob using the new mechanism. At school, Alice chooses a good set of parameters to obtain a stable state of the system. She clicks on the “Export Parameters“ button to save the set of parameters as a fragment of type "Parameters" in the group’s eJournal. After a while, she starts the experiment at the point she had stopped by clicking “Import Parameters“ button. The experimental results are saved by clicking “Save Results“ as another fragment of type "Results" in the eJournal. At home, in the next day, Bob opens his group eJournal. He reuses the parameter to repeat the experiment. For further mathematical processing, Bob clicks on the result fragment displayed in the eJournal, and the SysQuake Remote is opened automatically with all necessary data loaded from that fragment. Compared to the first example with old mechanism, the task performance of Alice and Bob at both individual level and group level is much more increased.

IMPLEMENTATION AND EVALUATION

As presented in the previous section, the Cockpit Web-based environment consists of different heterogeneous components. In the environment, users interact with one another and with those components. The data output from one component may become the input of another one. In addition, in a flexible learning context, the states between different hands-on sessions should be kept somewhere. Hence, in order to sustain the continuous interaction mechanism we have developed a **data tunnel** through the eJournal to facilitate the communication between the components. The fragments in the eJournal represent the experimental parameters, experimental results, etc. and also are used to register the states between interaction sessions. Data are transferred from one component to another through the data tunnel as encapsulated objects. The data tunnel is the technical base that helps to sustain the continuity of interaction. The communication mechanism is transparent from the user's point of view. In brief, at the system level, the eJournal well supports the communication between the heterogeneous components implemented within the Cockpit environment.

The eJournal is implemented using the standard and open technologies such as XML, JSP, Java and JavaBeans. The eJournal can be activated both as a part of the Cockpit environment and as a stand-alone Web application. Its modular architecture allows the easy development and extension. One can access the eJournal simply with a Java-enabled browser. The physical fragments in the eJournal are managed by a file system while the fragment references and properties are kept in a relational database, which is mySQL in our case. A Tomcat server from Apache Software Foundation is used as the servlet-engine to process the JSP calls.

During the 2003 spring term, we conducted a full-scale deployment experiment with a clan of 96 students in Micro-engineering using the Cockpit environment to carry out practical assignments in Automatic Control. We have adopted a usability engineering approach (Rosson and Carroll 2002) for the evaluation. The evaluation has been based on three evaluation instruments: questionnaire, log and content analysis of the eJournal, and interviews with students. These instruments allow the definition of specific metrics that meet the evaluation objectives. The evaluation of acceptance aspect is based on a user-interface satisfaction questionnaire: the Computer System Usability Questionnaire (CSUQ) (James 1995; Perlman 2002), which contains usability related assertions to which the answerer has to agree or disagree on a seven points scale, ranging from 1 (strongly disagree) to 7 (strongly agree). The second evaluation instrument relies on the analysis of the content of the database and the file system that holds the shared workspace. The last evaluation instrument is individual interviews with the volunteer students. We are mostly interested in the fragments created in flexible learning modalities and ones created and circulated within the environment. Those indicators help proving the role of the eJournal and its fragments in sustaining the continuity of interaction in a Web-based learning environment.

71 students over 96 (74%) returned the questionnaires; with the mean of satisfaction are around 4.026 over 7. This means that students are fairly satisfied with our environment. Every group created a mean of 36 fragments in performing the practical modules for the whole semester. This means that all groups created a significant amount of fragments. 86% of the fragments were created within the environment with the Experimentation component and the SysQuake Remote Console, the rest 14% were fragments created with external applications. The number of fragments created in flexible sessions (occurs off the laboratory, i.e. in another

computer room in campus or in the student's home) occupied 55%. This means that students accepted and already worked in different learning modalities.

We recorded about 225 minutes of interviews with 5 volunteer students. They all agreed that the eJournal has much simplified their group tasks when performing the experiments and processing the results. They felt much more comfortable when working in different spaces (for example, experimentation console, SysQuake Remote, etc…) and places (in the laboratory, in another campus room, or at home) with help of the eJournal.

As an example of our evaluation, Figure 5 shows a bar chart, in which one can see the number of created fragments (y-axis) of all groups (x-axis) for the whole semester.

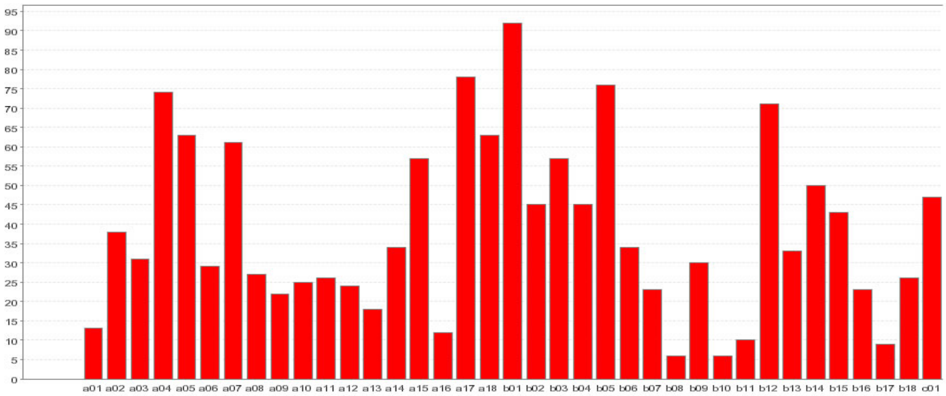

Figure 5: Number of created fragments of all groups for the whole semester

RELATED WORK

In academia as well as in industry, there are a lot of simulation tools, which support practical activities in engineering education. For example, in (Mateos et al. 2001) PROSIMAX, a Windows based tool for testing control programs implemented on different control devices, is presented. It is intended to minimize the main drawbacks of classical tools used for test in educational environments. DEVRE is presented in (Ridao, P. et al. 2001) with the aim to assist engineers during the software development and testing in the laboratory prior to real experiments. (Sepe et al. 2001) has constructed VE-LAB, a Web-based virtual engineering laboratory for collaborative experimentation on a hybrid electric vehicle starter. However, these environments do not support the collaborative learning.

Since recently, there is a growing interest to support collaborative work over the Internet. One of the most popular and well-known collaborative tools in academia is BSCW (Klöckner 2000). This is a shared workspace where users can share information; collaboratively perform their activities over the Web. Other Web-based collaborative environments could be considered at (Teamwave; Beca 1998; Dan Suthers and Dan Jones 1997; Lee, M. J. et al. 2000). However, because all of the collaborative tools presented above are not designed for engineering education, remote experimentation and simulation cannot be performed.

The idea of electronic notebook has been investigated at some education and research centers. Edelson et al. from Northwestern University has developed the CoVis Collaboratory Notebook (Edelson and O' Neil 1994), which is a shared, hypermedia database that supports communication and collaboration both locally and remotely over the Internet. CoVis

Notebook is used for high school science learning. Thus, the idea of collaboration in this project is still simple. It is mainly a medium for students to record their thoughts and actions as they perform scientific inquiry. PENS (Hong et al. 1994) is used by the teaching staff for curriculum development notes and for posting FAQs to the Web pages of the Mechatronic System Design class offered by the Stanford University's Department of Mechanical Engineering. The ELN prototype (Myers et al. 1996) developed at the Pacific Northwest Laboratory is a WWW based laboratory notebook that can support the needs of researchers to develop and share a common repository of scientific knowledge. The main drawback when using those notebooks in the context of performing engineering practical courses is that users must enter data manually, i.e. there is no mechanism for the directly transmission of data between the notebook and the experimental components.

In fact, with these environments, there is no way to sustain the continuity of interaction in the teaching and learning processes. The idea of supporting context changes for Plastic User Interfaces (Dubois et al. 1999) is interesting but not really useful for the interaction process within a Web-based learning environment. In their definitions, a user interface is plastic if it is able to adapt to context changes while preserving usability. The plasticity is in fact a kind of adaptation process. Hence, it is not suit our requirements. Till now, it seems that there is no other work that investigate the role of shared artifacts in sustaining the continuity of interaction in hands-on sessions within a flexible context.

CONCLUDING REMARKS AND FUTURE WORK

This paper presents our approach of using fragments in the eJournal as shared 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. The eJournal can be considered 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 a medium, or more concretely speaking, a bridge that connects and integrates two levels of collaboration, that is the collaboration at the user level and the communication between heterogeneous components at the system level. By sustaining the continuity of interaction, we much improve the quality of Web-based experimentation in engineering education. In this paper we also compare our new approach with the conventional mechanism usually found in Web-based learning environments. Our approach is based on the Activity Theory, the notion of shared artifact and its mediation role in a learning community. We also present the technologies used for the eJournal implementation. The evaluation methodology and results are presented as well.

The eJournal is currently used in the Automatic Control, Fluid Mechanics and Biomechanics practical courses at the School of Engineering, Swiss Federal Institute of Technology in Lausanne (EPFL), Switzerland. It can be easily extended by adding more functions, more tools and services. We follow an iterative approach, in which the user feedbacks and our evaluations help to validate and develop our hypotheses as well as our environment (user interface, functions, tools, services, etc…). We would also like to develop formal models for the analysis, design and development of artifact-based continuous interaction in Web-based environments dedicated to engineering education.

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