# Formal Assessment of a Web-based Learning Environment

**Anh-Vu Nguyen, Yassin Rekik, Denis Gillet**

**{anhvu.nguyenngoc, yassin.rekik, denis.gillet}@epfl.ch**

**Swiss Federal Institute of Technology in Lausanne (EPFL)**

***Abstract*** — *Nowadays, Web-based environments offer a tremendous opportunity to add flexibility in traditional engineering curricula by providing students with versatile access to the learning resources from both a time and a location perspective. In this context, we have developed the eMersion environment with the aim to provide a Web-based learning environment that supports hands-on experimentation through remote manipulation of physical laboratory devices and/or computer simulation tools. The eMersion environment provides the students with the possibilities to carry out the experimentation in a flexible way and is currently used in various courses offered by the School of Engineering at the Swiss Federal Institute of Technology (EPFL). This paper presents a proposed model for the assessment of Web-based learning environment in engineering education. The model encourages performing evaluation under an iterative perspective. The assessment processes are carried out at different phases at a learning process through different assessment loops. This assessment model allows the integration of different analysis methods including quantitative, qualitative and social network analysis. The paper also describes the results and analyses of the evaluation process carried out in the Automatic Control laboratory courses using the Cockpit environment from the 2002 winter to the 2004 summer semesters at the EPFL. The evaluation takes place in an iterative process with the purpose of studying different aspects of a Web-based engineering learning community, such as participation, flexibility and collaboration. Another objective is to improve the user interface design. These evaluation results allow the observation of different dimensions of the Web-based learning process in engineering education. The first dimension is the amount of the students' work that takes place within the environment compared to work that occurs outside. It refers to the utility of the environment for performing hands-on tasks. The second dimension is linked to the importance of flexible learning modalities compared to traditional face-to-face learning modalities. Another dimension refers to the collaboration aspect. Different metrics are also defined to measure the influence of shared artifacts on the student learning performance. During this period of 4 semesters, 337 students have used the environment to perform hands-on activities. The evaluation results show that the Web-based environment encourages students in conducting flexible hands-on experimentation as a complement of the traditional ones. Furthermore, we can show that the environment fits more and more to the students' needs regarding the hands-on activities. The evaluation results also open up a new set of ways for assessing the flexible and collaborative work in Web-based learning environment for engineering education.*

***Keywords*** — *Assessment Model, Engineering education, Hands-on activity, eJournal.*

## INTRODUCTION

The rapid development of the WWW in the last decade has provided new possibilities and also new challenges for designing and deploying distance and collaborative learning systems. Web-based experimentation plays a more and more important role in 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 [6, 13, 16]. In fact, the flexible learning paradigm provides a solution for challenges posed to traditional academic institutions in many aspects, including pedagogical, technological, and organizational ones [6]. From a pedagogical perspective, Web-based experimentation paradigm provides students with extended accessibility to learning resources, increased freedom to organize their learning activities and enhanced participation, autonomy and collaboration. From a technological perspective, Web-based paradigm allows researchers and developers to exploit the advantages of new information and communication technologies applied to engineering education. From an organizational point of view, Web-based experimentation paradigm helps expand the diversity of education resources as well as to sustain the variety of learning resources that are provided to engineering students [7, 13, 22, 28].

In engineering education, the practical (or laboratory) activities are as important as the theoretical ones. The laboratory 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. Recognizing the importance of hands-on activities in engineering education [22], several institutions have developed remote experimentation resources [2-4, 25, 27, 30], most of them are based on the WWW infrastructure, as a supplement to the face-to-face learning and teaching activities.

At the Swiss Federal Institute of Technology in Lausanne (EPFL), a Web-based environment called *eMersion* has been developed in order 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, Fluid Mechanics and Biomechanics courses offered by the School of Engineering. The environment provides the student with the possibility to carry out experimentation in a flexible way, i.e. students can follow different learning modalities to perform multi-session experiments.

So far, very few studies have been performed to determine the effectiveness of the Web-based environments in engineering education [22]. Lessons learned from the previous presented Web-based learning environment as well as our experience gained from 4 academic semesters of deploying the eMersion environment reveal the difficulties associated with the introduction of the Web-based learning environment for engineering education. Studying and assessing the Web-based learning environment is one of the crucial fields in different research domain including Computer supported collaborative learning, Human-computer Interaction. In single-user applications, it is already difficult to test the perceptual, cognitive, motor variables that have been the focus [14]. It is however extremely difficult to evaluate the multi-user applications [10], especially to evaluate the Web-based environment that supports hands-on activities where many interactions take place in both technical and social levels. Some initial attempts to assess the Web-based learning environment in engineering education are reported in [3, 18, 22].

This paper presents a proposed model for the assessment of learning process in engineering education. The model, so-called *Instrumentation Feedback Model for Assessment* has been conceptualized and generalized from our experience in developing, deploying and assessing a Web-based experimentation environment for engineering education. This paper also presents a comparative assessment of the *eMersion* environment used in the Automatic Control Laboratory courses. Section 2 is about the case study. It describes briefly the learning setting and the *eMersion* environment. Section 3 is dedicated to the Instrumentation Feedback Model for Assessment. In section 4, we present the evaluation objectives, the metrics as well as the assessment results and some discussions. Section 5 concludes the paper.

## CASE STUDY DESCRIPTION: THE *EMERSION* DEPLOYMENT AT THE EPFL

### Learning setting

In the spirit of flexible learning [6], 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. This means, for instance, that they can do the first part of the experiment at school, and pursue the rest of it at home using the environment to connect remotely to the laboratory equipment. Briefly speaking, the student is provided with the possibility of following a flexible learning paradigm, which means that they can choose different learning modalities. Figure 1 shows students work in groups in the laboratory and interact with the teaching assistant (face-to-face modality).

The academic year at the EPFL is divided into two 14-week semesters; each week corresponds to 32 working hours. Automatic Control is one of the courses in which flexible modalities have been added progressively. It is a mandatory course for electrical, mechanical, and micro engineering study programs at the School of Engineering, EPFL. Every week two hours of automatic control lectures are taught, followed by one hour of in-class exercise supervised by teaching assistants.

Students participating in the automatic control laboratory assignments are split into different groups of 2 people and use the *eMersion* environment to carry out practical assignments in Automatic Control. These groups, plus the professors, the assistants, and all supporting resources form a so-called engineering learning community. The students' work relies heavily on the learning community as their knowledge resource. The experimentation assignment is divided into two parts: the pre-lab and the lab-work. The student have to successfully fill the pre-lab forms because they pose technical questions that have to be answered to gain permissions to access the given Web-based laboratory resources necessary to carry out the lab-work. The pre-labs are submitted to the assistant, and then evaluated. The laboratory test consists in performing at the end of the semester a randomly selected two-hour hands-on experimentation module and then presenting the associated results for about 20 minutes to the professor in charge of the course.

FIGURE 1
THE PRACTICAL COURSE USING THE *EMERSION* ENVIRONMENT FOR AUTOMATIC CONTROL

### *eMersion* environment

The *eMersion* environment has a Cockpit-like user interface and contains all the components necessary to successfully complete laboratory assignments [8]. These Web components are heterogeneous in the sense that they were developed using different technologies and may be located on different servers. The main components are as follows

- *Experimentation component*: it was developed as a Java applet and can be regarded as the interaction part that enables the actual realization of experiments.
- *SysQuake Remote component*: it is a PHP 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, graphical representations, etc.
- *eJournal*: has been designed as an extended electronic laboratory journal for collecting and sharing experimental data in hands-on activities to support teamwork. Data

chunks stored in the *eJournal* are called '*fragments*'. A fragment can be a document uploaded from the student's local disk, can be an experimental result, a snapshot or a set of parameters imported from the Experimentation component or the SysQuake Remote component. The *eJournal* supplies different fragment-based metrics for assessing the student's learning process. Details about the *eJournal* can be found in [17, 19].

- *Supporting components*: include a statement of the module's objectives, 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 module, a description of the environment, including the experimental facilities (real or virtual) and the detail cockpit features, and any bibliography.

FIGURE 2
THE *EMERSION* ENVIRONMENT AS DEPLOYED FOR AN AUTOMATIC CONTROL MODULE DEDICATED TO THE MANIPULATION OF AN ELECTRICAL DRIVE

Figure 2 shows the *eMersion* environment as deployed for an Automatic Control module dedicated to the manipulation of an electrical drive. The real electrical drive is visualized in real time using a webcam. Details of the environment are presented in [8].

The next section presents a proposed model for the assessment of Web-based environment for engineering education. In fact, the model was at first the result of our experience in developing, deploying and assessing the *eMersion* environment. It is then generalized with aim at providing a new set of ways for assessing the flexible and collaborative work in Web-based learning environment for engineering education. The proposed model tries to give an answer to the requirements posed to the problem of assessing the learning environment in engineering education.

## INSTRUMENTATION FEEDBACK MODEL FOR ASSESSMENT

Figure 3 presents our Instrumentation Feedback Model for Assessment. The term Instrumentation feedback model was coined in the work of Leifer [12]. This term is used in the sense of observing both independent and dependent variables in an automatic feedback control environment.

Our model includes 4 instrumentation Nodes. Each one represents a phase in the teaching and learning process using the learning environment. The outcomes are differentiated into different levels and each is assessed and validated through a feedback path. The output of the assessment process at one Node could provide feedbacks or could influence the input of another Node.

The input of the whole process is a pedagogical scenario. It is important to integrate the design and development process around scenarios. Scenarios have people built-in, they are specific, they are grounded in the real world, they describe an existing or envisioned system from the perspective of participative and non-participative users, including a narration of their goals, plans, and reactions [24]. The scenario is defined depending on the requirements on each course, the logistic matters of each department, etc. At Node 1, the pedagogic objectives, the course requirements are defined. Based on these definitions, the course environment is designed or re-designed. By re-design, we mean that some fundamental concepts of the environment have been modified or replaced. At Node 2, the professors and students requirements are defined in greater details. The system functionalities that facilitate the teaching and learning process are also specified.

The assessment process is applied at Node 3 and Node 4. For the inner most, formative assessment loop from Node 3 to Node 2, or in other words, the formative assessment process takes place during the course. The goal of formative assessment is to identify aspects of the system that can be improved, and to provide guidance in how to make changes to the design. One big constraint in applying formative assessment is that it must not disturb the students who are currently using the system. Thus in general only minor modifications on the system functionalities are allowed. The summative assessment loop at Node 4 is aimed at measuring the acceptability of the system. According to Nielsen [20], system acceptability is achieved by meeting the social and practical acceptability. An important factor in practical acceptability is usefulness, which integrates usability and utility, where utility is the question of whether the functionality of the system in principle can do what is needed, and usability is the question of how well users can use that functionality.

Let's take a closer look at the assessment methods. In the proposed model, all the analysis methods are fed with data coming from different sources, meeting the need for capturing different forms of interaction in a Web-based learning environment. For the formative assessment, the basic instruments providing data are automatic data coming from log, observation, and discussions directly with students and teaching assistants during the hands-on sessions. For the summative assessment, data sources come from automatic data (log), meetings, discussions, questionnaires, interviews, and the student's performance (obtained mostly via the student's grades). In fact, the log data is a convenient source, which can be used for data collection, for actions evaluation and feedback can be made available immediately to the learning community [21]. Especially in a hands-on environment, where different kinds of artifacts are at the same time instruments and results of the interaction and collaboration, the logged artifact-based actions constitute and interesting support to reflect the student hands-on activities and student interactions in the environment. As example, the experimental result of a student is saved in this student's group (in the student eJournal) when he finished his assignment, and shared with his group-mate for further processing in the next assignment. In this case, this kind of artifact at the same time reflects the hands-on activities of the student, and is used as an instrument for the collaboration with others.

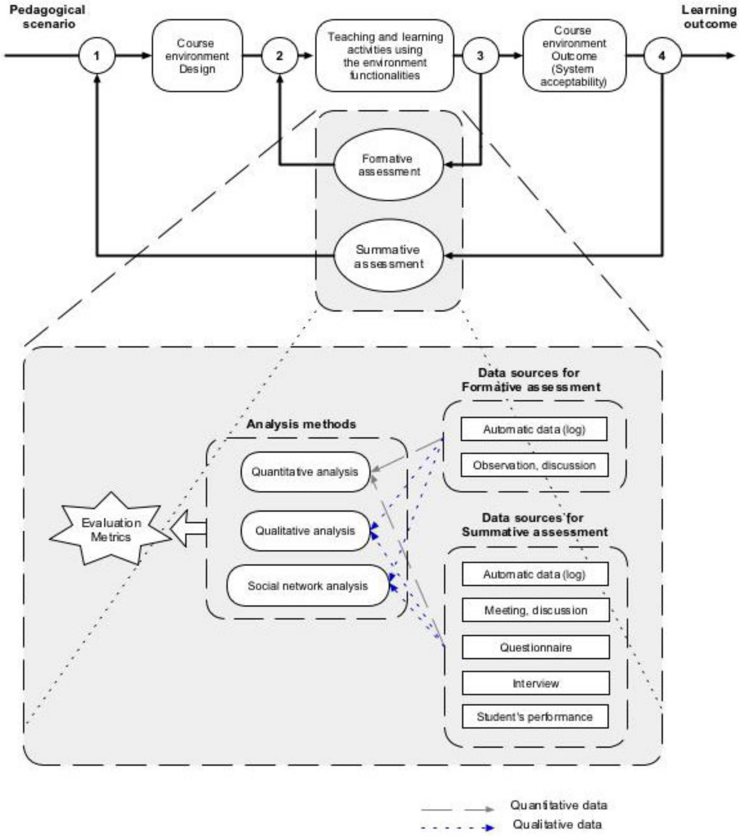


FIGURE 3
THE PROPOSED INSTRUMENTATION FEEDBACK MODEL FOR ASSESSMENT

The analysis methods include quantitative, qualitative and social network analysis. Qualitative analysis provides a context to understand core usability issues. It provides information on why users faced problems. Qualitative data is used to interpret and explain what was happening. Quantitative analysis is used to account for the occurrence of actions, thus helping to predict and measure some particular phenomena. Quantitative analysis strongly facilitates the interpretation process used in qualitative analysis, and vice versa. Many different statistical analyses could be applied to calculate and represent the quantitative data. Social network analysis (SNA) methods are applied to construct the social structure and to find the interaction patterns in the learning community. SNA [26, 29] is an approach that focuses on the study of patterns of relationships between actors in communities. The SNA issues are located in the intersection of the sociometry, group dynamics, graph theory, and anthropology domains. Using SNA methods, one would seek to model the relationship that depicts the structure of the community. So one could then study the impact of this structure on the functioning of the groups within the same community. Of course, the choices of assessment methods may not be the same. It depends on the pedagogical scenario as well as the assessment objectives.

The results of the analysis processes are selected, and aggregated to different evaluation metrics, which allow assessing the pre-defined evaluation objectives.

## CASE STUDY REVISITED: ASSESSMENT OF THE AUTOMATIC CONTROL LABORATORY COURSES AT THE EPFL

This section introduces the case study to which the model has been applied for assessment. This section presents the result of a comparative evaluation study carried out in the Automatic Control laboratory courses from the 2002 winter to the 2004 summer semesters at the EPFL. The evaluation takes place in an iterative process through different loops presented in the Instrumentation Feedback Model for Assessment with the purpose of verifying whether our approach could be a solution for the questions related to the participation, flexibility and collaboration aspects of a Web-based engineering learning community. Another objective is to improve the user interface design. However, the assessment model can be applied to any other course and learning environment.

As indicated in the model, the input of the whole teaching and learning process is always a pedagogical scenario. In fact, the pedagogical scenario is changed depending on the professor and the course. The scenario affects the choice of different components integrated within the environment. As example, even with the same *eMersion* environment, professors can customize different functionalities and options for each course.

During the course, the research assistant as well as the evaluator takes part in the laboratory with teaching assistants and students. By observing the students and teaching assistants' behaviors and by discussing with them whenever they face problems in using the environment, the evaluator can find the potential bugs of the system as well as different minor aspects of the system that can be improved. The log data also helps to facilitate this formative assessment process. This assessment loop (from Node 3 to Node 2 in the Assessment Model) iterates during all semester.

At the end of the semester, questionnaires are distributed to students enrolled in the course. The questionnaire has been designed with three purposes in mind: first to assess the acceptability of the Web-based hands-on environment, second to gather information about students that could help to identify some factors influencing the acceptation and, third, to collect information for bootstrapping the interviews with students. The evaluation of acceptability is based on a user-interface satisfaction questionnaire: the Computer System Usability Questionnaire (CSUQ) [11] with some extensions [18]

We have analyzed the fragments stored in all groups' eJournals. Recall that the eJournal is the collaborative workspace, which takes the metaphor of extended electronic laboratory journal, and its stored data chunks are called fragments. Fragments are categorized according to their origin, their type and their creation time. Fragments that originate from components of the Web-based environment and which are directly imported to the eJournal are called *intra-fragments.* Fragments that are uploaded from local user's computer are called *extra-fragments*. Those are mostly created using external applications. Fragments that are created during face-to-face learning modalities (students working locally in the laboratory premise) are called *f2f-fragments*, while fragments created during flexible learning modalities (students working anywhere but in the laboratory premise) are called *flexible-fragments*. These definitions of fragment categories allow the observation of two dimensions of the use of the prototype. The first dimension is the amount of student's work that takes place within the Web-based environment compared to work that occurs outside. We measure it as an *intra-fragment-ratio,* that is the number of intra-fragments divided by the total number of fragments. This measure reflects the utility of the environment for performing hands-on tasks. The second dimension is linked to the importance of face-to-face learning modalities compared to flexible learning modalities. It is quantified as the *flexible-fragment-ratio* that is the number of flexible-fragment divided by the total number of fragments.

The volunteer students are interviewed. These interviews are non-directive. Their purpose is to let students remember if they could or could not complete their tasks and to explain why. The interviewer can use critical incident analysis style of questions, for instance by asking students to illustrate the most negative answers given at the satisfaction questionnaire with an example.

The professor also organizes a meeting in which all teaching assistant of the course can express their ideas, their comments about the environment. Future modifications are also discussed.

The result of summative assessment loop can cause major modifications and improvements of the environment for the next semester.

For each assessment loop, different analysis methods including quantitative, qualitative, and social network analysis are applied to process data coming from different sources. The next section shows some of the results from the assessment process (mostly results related to the summative loop) carried out in the Automatic Control laboratory courses during 4 semesters at the EPFL.

**Assessment population**

The Automatic Control laboratory course is a mandatory course part for electrical, mechanical, and micro engineering study programs at the School of Engineering, EPFL.

- In the 2002 winter semester: 30 students enrolled in the 4th year of the Mechanical engineering study program participated in the course. They had to complete six 4-hour laboratory assignments held every second week. For the sake of simplicity, this sample is called *Group winter 2002*.
- In the 2003 summer semester: 96 students enrolled in the 3rd year of the Micro engineering study program participated in the course. They had to complete four 2-hour assignments held every three weeks. This represents the *Group summer 2003*.
- In the 2003 winter semester: 49 students from Mechanical engineering and 6 students from Electrical engineering were enrolled in the course. They were 4th year students. They had to complete six 4-hour laboratory assignments held every second week. This represents the *Group winter 2003*.
- In the 2004 summer semester: 47 students from Electrical engineering, 97 students from Micro engineering, and 12 students from Mechanical engineering participated in the course. They were all 3rd year students. They had to complete four 2-hour assignments held every three weeks. This represents the *Group summer 2004*.

Totally, during this period of 4 semesters, 337 students have used the *eMersion* environment to perform hands-on activities.

**Qualitative and quantitative analysis results**

In addition to questionnaires that were distributed (see the results in [5, 9, 18]), an important source for assessment relies on the analysis of the content of the database and the file system that holds the eJournals. In our system, the fragments, as shared artifacts, used at the same time as a product and as a medium of the collaboration and the learning processes. The fragments, which are the experimental results or data used for hands-on activities, are collected by the eJournal and shared among users. They also provide users with several ways to collaborate with each other. As a consequence, the fragment-based actions log could provide information that reflects student hands-on activities and student interactions in the environment.

We carried out the analysis of fragment logs for all the 4 semesters. Students worked in pairs of two. However, some groups contained only one student. There were 160 active groups for the whole 4 semesters. Active groups were those who created at least one fragment. These groups created totally about 10237 fragments. In average, about 86% of the fragments were created within the environment with the Experimentation component and the SysQuake Remote component; the other 14% were fragments created with standalone applications, and then uploaded to the environment. The number of fragments created in flexible sessions corresponds to 43%. The detail ratios of each semester are showed in Figure 5.

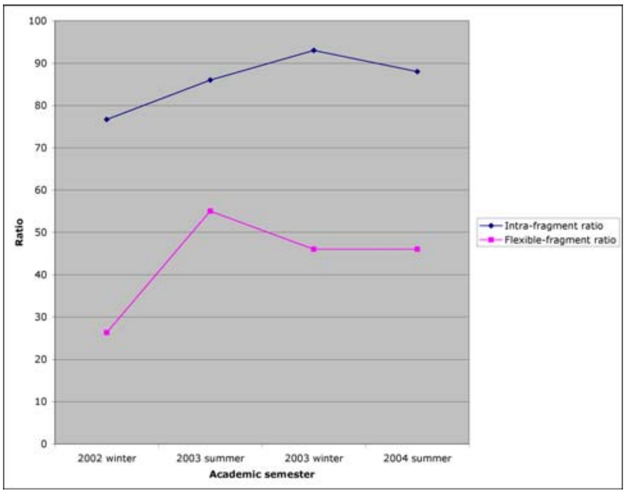


FIGURE 5
FRAGMENT RATIOS FOR ALL 4 SEMESTERS (FROM 2002 WINTER TO 2004 SUMMER)

One should bear in mind that the summative assessment loop (from Node 4 to Node 1 in the Assessment Model) at the end of the semester provides feedback for the system design for the next semester. The summative assessment results may lead to fundamental modifications of the environment. During the 2002 winter semester, we proposed two annotation mechanisms: one for attaching single author comments to a fragment, and one for attaching a multiple author Wiki page. However, very few students used the annotation mechanisms. No one used the Wiki mechanism. Thus in the next version for the 2003 summer semester, the Wiki mechanism was dropped. Since the 2003 summer semester version, the possibility to sustain the continuity of interaction has been improved. As a consequence, the intra-fragment ratio, which reflects the utility of the environment for performing hands-on tasks, and the flexible-fragment ratio, which represents the amount of work in flexible modalities, 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. The slight decrease of the ratios may be explained by the fact that since the 2003 winter term, the students were provided with more computers in the laboratory premise. More teaching assistants were also available in f2f sessions. To have a clear view about these ratios, one could refer to Figure 6 and 7, in which the number of created fragments and their types during the Group summer 2003 are plotted. In Figure 6 for example, each column represents the number of created fragments by a group of the Group summer 2003. In each column, the blue part represents in fact the intra fragments, which were originated from components of the Web-based environment and are directly imported to the *eJournal*. The red part represents the extra fragments, which were created by an external application, and then uploaded to the *eJournal*. Figure 7 represents the same data but from another perspective. The blue part shows that these fragments were created in f2f sessions while the red part is the number of fragments created in flexible sessions. One should not forget that we applied more or less the same assessment methods for the assessment loops. However, the assessment variables and parameters for the next loop (or next semester) may be modified depending on the result and on the requirements.

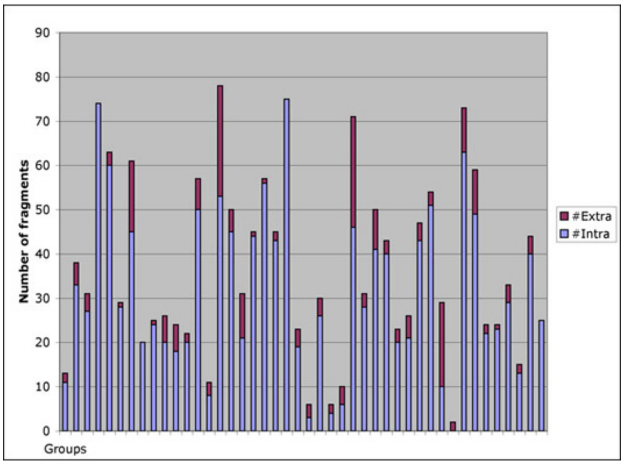


FIGURE 6
INTRA-EXTRA FRAGMENTS CREATED BY THE (GROUP SUMMER 2003)

Since the 2003 summer semester, besides the user acceptability and satisfaction that contributed to the participation assessment, we also considered the group performance (via the grade of the group members). Analysis in the Group winter 2003 showed that there is a statistical significant correlation between the number of created fragments and the group performance (obtained via the groups' grades). The Pearson product-moment correlation [15] coefficient between these two variables was 0.522 ($p<0.01$). We have found no statistical correlation between the number of created fragment and the group performance in the Group summer 2003.

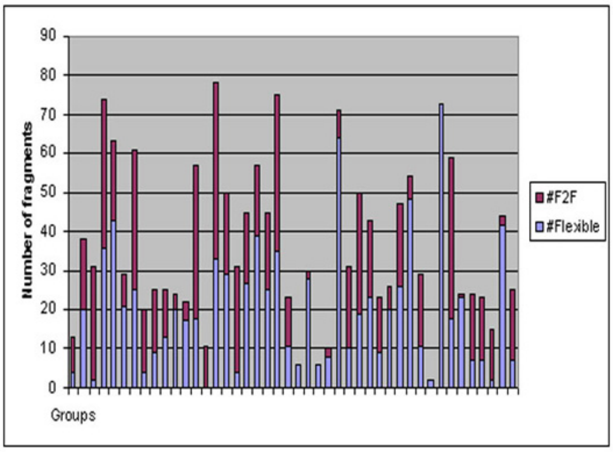


FIGURE 7
F2F-FLEXIBLE FRAGMENTS CREATED BY THE (GROUP SUMMER 2003)

For each of the Group summer 2003 and the Group winter 2003, we divided all students into 2 sub-groups: the first one working preferably in flexible modalities (high flexibility groups), the second one working mostly in face-to-face modalities (low flexibility groups). This classification was based on the flexible fragment ratios of all groups. We noted that the standard deviation (S.D.), which is a measure of how spread out the data is (in our case, it is a measure of how spread out the grade is), of high flexibility groups is always lower than that of low flexibility groups in both semesters. We performed a *t-test* to see the difference between these two sub-groups [15]. The t-test gives the probability that the difference between the two means is caused by chance. It is customary to say that if this probability is less than 0.05, then the difference is 'significant'. The p value is the probability that one would have found the current result if the coefficient were equal to 0 (null hypothesis). If the p value for one or more coefficients is less than the conventional 0.05, then these coefficients can be called statistically significant, and the corresponding independent variables X exert independent effects on the dependent variable Y.

We obtained the result (*t=-1.5204, p=0.13*) for the Group summer 2003 and (*t=-0.3176, p=0.75*) for the Group winter 2003. The result shows that there is no statistical significant difference between the educational outcomes from students who performed the experiment remotely, versus those who carried out the experiment locally.

**Social network analysis results**

Lastly, we performed different social network analysis methods to find the interaction patterns between different groups. The social network analysis methods were also carried out since the 2003 summer semester. In the 2002 winter semester we had not logged the fragment circulation. For establishing the community structure, we are interested in those techniques giving information about structural properties of the network as a whole, and particularly, those related to cohesion, which is an important factor that motivates participants to accomplish the requested task [23], to perceive and feel attracted to their own group [1]. In fact, as represented in [29], to construct the social structure of a community, one should find the active groups, find the groups that are closer one to another, more connected one to another, and maybe the groups all connected one to another. We have chosen the sociogram, clique, and Freeman's centrality degree as social network analysis methods to measure the community structure and interaction patterns. These methods were applied to each semester to provide so-called social structure awareness for professors and assistants. As an example, Figure 8 represents a sociogram representing the social structure of group collaborations in the (Group summer 2004). The sociogram is generated from the group-by-group matrix NxN (N=total number of groups), where $x_{ij}$ represents the fact that there is an interaction between the group at the $i^{th}$ row and the group at the $j^{th}$ column. In the sociogram, nodes (red circles) represent groups and lines represent the interaction between groups. We use different shapes and colors to refer to some special groups, the Staff group, i.e. the group of professors and assistants who evaluate the students'work, represented by the blue diamond represented by the blue triangle.

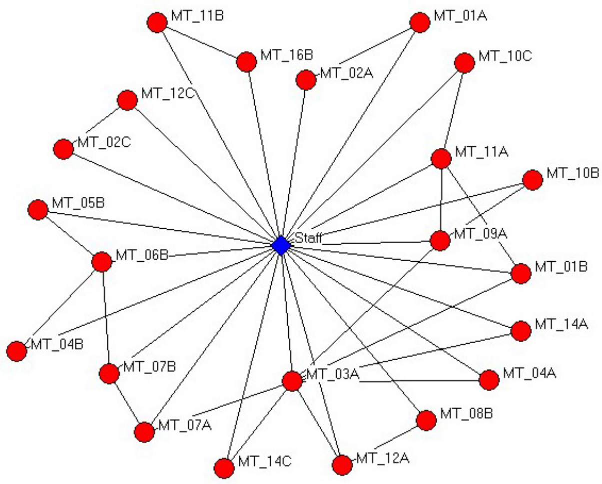


FIGURE 8
SOCIOGRAM OF GROUP INTERACTION IN THE (GROUP SUMMER 2004)

To find community network substructures, i.e. the fully connected groups, cliques are detected [29]. The clique is defined as a maximal complete sub-graph. That means it contains a subset of groups, all of which are adjacent to each other, and there are no other groups that are also adjacent to all of the members of the clique. For example, in Figure 8, Staff, MT_03A, MT_12A form a clique. We also calculated the Freeman's centrality degree, which allows us to measure the activeness of students. The Freeman's centrality degree is in fact another view of the sociogram. It measures the total number of relations a group actually has.

Table 1 shows the Freeman's centrality degree for the (Group summer 2003). Like the sociogram, we have just focused on the number of interactions, not on the direction of the interaction, i.e. the requestor and the receiver of an interaction are considered the same. The higher centrality degree a group has the more active this group is in the community. We added the 'Average grade' column in Table 1 to see the correlation between the activeness and the group performance (in Switzerland, the grade scale is from 1 to 6, 4 is the average grade for passing the exams).

| Groups | Centrality degree | Average grade |
|---|---|---|
| Staff | 22 | - |
| MT_03A | 8 | 4 |
| MT_06B | 4 | 3.7 |
| MT_09A | 4 | 5 |
| MT_11A | 4 | 5.8 |

TABLE 1
FREEMAN'S CENTRALITY DEGREE FOR THE (GROUP SUMMER 2004)

**Discussions**

The results above help to answer most of our evaluation objectives. We find the results satisfactory concerning the 'acceptability goal' as the questionnaire shows that most of the students were satisfied. However as our questionnaire was not anonymous, we can wonder if it had an influence on student's answers. The mean satisfaction is not much higher than the neutral scale point, thus suggesting much room for improvements.

The 'participation goal' is also reached as all the groups created a significant amount of fragments. As a corollary, we think that the 'participation goal' contributes to the 'acceptability goal' as evidences of the use of the prototype such as the creation of fragments shows that it has been accepted. However to be more precise this would require that we estimate what is the standard number of trials and errors necessary to accomplish a module and hence the number of fragments. It would even be interesting to compare this with traditional hands-on experimentation without the computer environment, to assess more precisely the effect of computer on participation.

The environment is more or less satisfied from the technical point of view. The choice of open technologies (Java as the programming language, MySQL as the relational database, Tomcat as the servlet and web container, XML as the format for data exchange, etc.) for development facilitates the cross-platform feature of the environment. The variety platform used at the client side confirmed this point.

The ratio of f2f and flexible fragments shows that the students took advantage of the different learning modalities. The ratio of the intra fragments (86%) supports the assumption that the Web-based environment does not disturb students in conducting flexible hands-on experimentation compared to traditional one. This metric also shows that the system functionalities satisfy the needs of students while performing hands-on activities. Students already accepted and participated in the new flexible learning paradigm. So, the environment usability and utility has been founded satisfactory.

The 'flexibility goal' is also reached as the 43% of flexible-fragments created during 4 semesters shows that some flexible learning modalities have been chosen, and this independently from the fact that we estimated that the students had enough time to perform all the work in face-to-face modalities. This ratio is much increased since the 2003 summer semester (49% fragments created in flexible sessions for the last three (Group summer 2003, Group winter 2003, and Group summer 2004). The ratio confirms that a new learning paradigm is accepted if the environment provides the possibilities for working so that users while working for instance in flexible modalities feel at least as comfortable as while working in face-to-face modalities.

Although we have not gone into details in this paper about how social network analysis is performed, it plays an important role in the experience. Social network analysis contributed to identify the interaction patterns at different levels: the community, the group, and individual. It also shows the interaction in time, this means that the interaction between students from different semesters. In fact the evaluation result shows that the Staff (professors and assistants) plays the most important role in the knowledge distribution. Almost all interactions found are between a student group and the Staff (Let see again Figure 8 and Figure 9). There were not much interaction between peers, or in other words, between different student groups. We think that this may due to the particular scenario at the EPFL. In engineering study programs, students have their courses almost everyday. So they can meet together (in face-to-face mode) easily. In addition, lots of telephone boxes are available freely inside the campus. Thus it is really easy to reach someone for a direct discussion, which is always easier and, in almost cases, more comfortable to explain something than a discussion via an electronic instrument.

The social network analysis measures give professors and students a general overview of active and passive groups in the learning community, as well as the structure of the community. This is what we call 'social structure awareness' [19]. This means that the social network analysis measure can be used not only at the evaluation phase but also during the learning process to provide awareness information to professors and students. Then, professors and assistants can use the obtained information to decide what to do next; for instance, the professor can re-organize the class structure to facilitate the student learning process. Students can find their positions in comparison to the whole class, so they can be more motivated. They can also find the potential groups with which they can collaborate. There are some issues related to the social network analysis that should be considered. The interaction shown on the sociograms or other measures strongly depends on the action logged. Thus, a big question arise is that what actions evaluators should consider, and at which detail. Which measures should be chosen, how to visualize these measures, and at which phase of the learning process is another issue.

Social network analysis measures provide a great medium to study the correlation between the group performance (for instance, obtained via the grades of group students) and the activeness. We have found that the most active groups received bad grades. This phenomenon occurred at all semesters studied. This somehow can be explained by the fact that the most active groups are normally those that don't have enough background, so they have to contact other groups to get helps. The next most active groups are those from the best. They played a significant role for knowledge distribution in the learning community. However, we cannot give any conclusion about this issue.

The assessment loops also allow us to improve the user interface of the environment. This helps us to know exactly what students really want in an environment. For example, in the first prototypes, we introduced a complicated interface for report writing. However, assessment results showed that students preferred a simpler interface with just some functions that allow them to upload documents in Word, or Matlab format or any kind of graphics. In fact, students (and end users in general) want to use the system that provides only what they need. The complexity of the system interface may strongly discourage the motivation of users.

The statistical analysis shows that there may be correlation between the number of created fragments and the group performance. This issue may confirm the fact that the more students create fragments in the environment, the more they explore the environment, the better they learn. However, so far, we cannot conclude on this issue since we have to validate this in other evaluation population. We should also consider other variables that may affect the performance, such as group motivation, previous knowledge and experience. The amount of work students spent on the environment should not count only on the created fragments (i.e. the production). It is also important to consider the time students spent working on the environment, the quality of the created fragments, the quality and quantity of the fragments submitted to the professor and the assistant, etc. The result from comparing the groups who preferred working in flexible modalities (high flexibility groups) and those who worked mostly in face-to-face modalities (low flexibility groups) supports the assumption that the Web-based learning environment is an ‘added-value’ for traditional engineering curriculum. From the technological perspective, the Web-based environment provides the possibility to explore new information and communication technologies applied to e-Learning. From the organizational perspective, it facilitates the resource sharing between different institutions; so it proposes a solution for logistic matters in engineering departments where the number of students is increased while the budget for costly equipments is more or less static; or in some cases it is hard to perform the experimentation directly in the laboratory. From the pedagogical perspective, the Web-based experimentation environment provides students with the flexibility of choosing the appropriate modalities of working while sustaining always the quality of learning.

Finally, the assessment results also open up a new set of ways for assessing the flexible and collaborative work in a learning environment for engineering education. The proposed Instrumentation Feedback Model for Assessment was generalized from and validated by the experience done during these 4 semesters. Although the model is used for assessing the Automatic Control laboratory courses at the EPFL, it is general enough to apply to any other pedagogical scenario, or any other learning system. A key point is that it follows an iterative process, through different assessment loops. These assessment loops allow the developer and evaluator intervene in time to adapt the system to the requirements from users or the requirements arise from a new input pedagogical scenario. Another point is that the model uses an approach in which different analysis methods are mixed. These analysis methods are fed with data coming from different sources, meeting the need for capturing different forms of interaction in a Web-based learning environment.

## CONCLUSION

This paper presents a model for the assessment of learning environment in engineering education: Instrumentation Feedback Model for Assessment. The model encourages performing evaluation under an iterative perspective. The assessment processes are carried out at different phases at a learning process through different assessment loops. At each loop different assessment analysis methods including qualitative, quantitative, and social network analysis could be combined to provide evaluators with data about users participation, flexibility, collaboration, interaction, etc. at different granularity levels.

This paper also describes the results and analyses of the evaluation process carried out in the Automatic Control laboratory courses from the 2002 winter to the 2004 summer semesters at the School of Engineering, EPFL. The evaluation takes place in an iterative process with the purpose of verifying whether our approach could be a solution for the questions related to the participation, flexibility and collaboration aspects of a Web-based engineering learning community. Another objective is to improve the user interface design. We have defined different metrics to for the assessment purpose. These fragment-based metrics allow the observation of different dimensions of the Web-based learning process in engineering education. The first dimension is the amount of the students’ work that takes place within the environment compared to work that occurs outside. It refers to the utility of the environment for performing hands-on tasks. The second dimension is linked to the importance of flexible learning modalities compared to traditional face-to-face learning modalities. Another dimension refers to the collaboration aspect, which is also an important factor since the hands-on activities are usually conducted in small groups. The metrics are also defined to measure the influence of shared artifacts (e.g. eJournal and fragment in our case) on the student learning performance; for example, to measure the correlation between the number of created fragments and the students’ grades.

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