Evaluation of a Web-based learning environment for hands-on experimentation

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Abstract — *The evaluation of learning environments depends highly on the evaluation instruments used and on the position of the evaluation in the design cycle. In this article, we present a use-case of a summative evaluation of a Web-based learning environment for engineering education that allows small groups of students to conduct hands-on experimentation sessions with local and remote access to laboratory devices. This use-case illustrates an evaluation methodology based on a choice of usability engineering methods. In particular, we define specific metrics that take into account student's interactions with some of the components of the environment. The metrics defined can easily be extended to any e-learning project involving production and sharing of artifacts in a shared workspace. The methodology is illustrated with the results of a preliminary evaluation with 30 students.*

Index Terms — *evaluation, acceptability, utility, usability, hands-on experimentation, remote laboratory, shared workspace.*

INTRODUCTION

The role of evaluation in software development has been well established. It is of first importance in usability engineering [10]. Over the last years, many interactive systems have benefited from user evaluation, including e-learning applications [1, 2, 3, 13]. However, it is not obvious how to evaluate educational software. It requires the transposition of the concepts of acceptability, utility and usability to a domain that is at the crossroads of multiple fields such as interactive systems design, collaborative work and learning theories.

This contribution focuses on evaluation in the field of Web-based environments that support hands-on experimentation through remote manipulation of physical laboratory devices and/or computer simulation tools, and particularly on the deployment of the Cockpit environment which is now in its third year of iterative design in the framework of the eMersion project [4]. This project aims at developing flexible engineering education [5] in automatic control, biomechanics and fluid mechanics at the Swiss Federal Institute of Technology in Lausanne (EPFL). More than 100 students are now using the last version of the prototype.

This article presents the last round-up of evaluation that we conducted during the winter 2002 semester with 30 students. This design cycle has been the occasion to introduce an electronic laboratory journal in the Web-based environment fully connected with the other software components for an automatic importing and exporting of various types of data. The main focus of the article is more on the evaluation methodology by itself than on a complete analysis of its results. In particular we illustrate how the laboratory journal, which is a special case of a shared workspace, gives opportunities to develop new evaluation measures that could serve in other contexts.

FLEXIBLE, PARTICIPATIVE AND COLLABORATIVE LEARNING ENVIRONMENTS

Web-based environments are usually introduced to let students choose between different learning modalities, that's why we call such a paradigm flexible learning. The modalities vary according to the presence of teaching assistants (face-to-face condition) or not (individual condition), and according to student's location. The location can be a laboratory room with full access to physical devices (local condition), a computer room on the campus (remote-campus condition) and student's home or any other place (remote-home condition). In the last two conditions students remotely access the physical laboratory devices and/or computer simulation tools.

Hands-on teaching involves multiple interactions between students and their environment, that's why we call such a scheme participative learning. The interactions correspond to trials and errors performed while following an experimental protocol. In the eMersion Web-based environment, trials and errors are mediated with specialized Java applets that control physical laboratory devices and computer simulation tools.

Finally, students perform hands-on experimentation in small groups (2 students), that's why we call such a setting collaborative learning. They have to collaborate for allocating tasks, taking notes and in some cases editing a report.

The goal of eMersion is to foster engineering education in all the places (local, remote-campus, remote-home) and, whenever possible, to give students the flexibility to build their own time schedule by mixing face-to-face and individual conditions. The underlying vision is that as more and more experiments are becoming available from different institutions, it will be possible to share these experiments and the expertise of teaching assistants to manage remote students. The second goal of the project is to increase student's participation and collaboration in learning.

We are evaluating the feasibility of these goals by introducing the following learning conditions in some hands-on experimentation activities proposed at EPFL and followed by volunteer students:

- Hands-on experimentation is organized around regular planned face-to-face sessions with teaching assistants that students are free to attend to. They can also choose to work in computer room available on the campus or at home, with or without their mates. The final evaluation of students does not take into account their presence time.
- User interfaces are designed with continuity of interaction in mind [9], for that purpose we have built a Web-based environment where software components directly import and export data chunks to and from an electronic laboratory journal that we call the eJournal.

- The eJournal is a persistent centralized repository; it is visible to students as a shared workspace, comparable in a way to other workspaces such as BSCW [1]. One eJournal is dedicated to one group. We call the data chunks in the eJournal “fragments”. In fact, those could be considered as documents in the eJournal. The fragments are typed, representing different kinds of data (e.g. snapshots, parameters, experimental results, etc.). The fragments can be annotated and shared between groups and/or assistants. The eJournal also provides the possibility to copy and/or move fragments from one eJournal to another.

Following the previous conditions, face-to-face learning with teaching assistants takes place either in a laboratory room or in a computer room (thus corresponding to the local and campus-remote conditions). By extension we call it ‘face-to-face learning modalities’. All the other conditions (such as individual work at home or on the campus with other students but without teaching assistants) are called ‘flexible learning modalities’.

EVALUATION OBJECTIVES

The first objective of the evaluation is to verify that the Web-based environment does not disturb students in conducting flexible hands-on experimentation compared to traditional one. This is the ‘acceptance goal’. We even think that this goal needs to be first met in face-to-face modalities before experimenting with flexible modalities. The reason is that if students do not accept the environment in face-to-face conditions they will be less likely to use it in remote conditions.

The second objective of the evaluation is to check if the import and export data functionalities are used and to which extent. This is a way to validate the design for continuity of interaction principle driving the eJournal design. As a side effect we can consider also that the more the import and export functionalities are used, the more trials and errors are performed by students. We can also consider that evidences of use of those functionalities would assess that the environment does not prevent students for doing actions on the physical devices or on their surrogates in remote environments. This is the ‘participation goal’.

The third objective of the evaluation is to determine if students choose some flexible learning modalities. The quantification and the determination of the nature of the work done under flexible conditions is also part of that goal. This is the ‘flexibility goal’.

The fourth objective of the evaluation is to assess the contribution of the fragment sharing and annotation mechanisms built into the eJournal for intra-group and extra-group collaboration. As a side effect we can consider that the fact that students and/or teaching assistants directly annotates the fragments stored in the eJournal validates the design principle of anchoring communication on those fragments and their use as shared artifacts for getting contextualized assistance. The student can collaborate with one another by exchanging the fragments. This is the ‘collaboration goal’.

For each of the evaluation objectives above, we also plan to better understand by which factors they could be influenced (hence to determine ‘how to better fit a Web-based environment for hands-on activities’, ‘how to encourage flexible work’, ‘how to increase student's participation’ and ‘how to develop group work’).

EVALUATION METHODOLOGY AND METRICS

We have adopted a usability engineering approach to evaluation. This is preferred to a didactical evaluation because, as stated in the introduction, this evaluation also takes place in an iterative design process with the purpose of improving the design of user interfaces.

The Web-based environment prototype has been deployed in a real working environment before evaluation. Thus our approach is more summative than formative and we have been constrained to the evaluation instruments that can be applied directly to the field of work. It was not possible for instance to setup user-tests or controlled experiments with volunteer students because the project is part of the student's curricula: we must be careful not to create too much perturbation between student's learning conditions. However the option of calling back some students for participating in task-based evaluations of specific interface features is still opened. It is also possible to practice such formative evaluations with neutral students that do not take part in the taught laboratory courses.

The evaluation has been based on three evaluation instruments: a questionnaire, a log and content analysis of the eJournal and interviews with students. These instruments allow the definition of specific metrics that meet the evaluation objectives.

Questionnaire

The questionnaire has been designed with three purposes in mind: first to assess the acceptation 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 acceptance is based on a user-interface satisfaction questionnaire: the Computer System Usability Questionnaire (CSUQ) [10, 11]. This is a Lickert scale questionnaire made of nineteen usability related assertions to which the respondent has to agree or disagree on a seven points scale, ranging from 1 (strongly disagree) to 7 (strongly agree). It also comprises opened fields for listing the three most positive/negatives comments and opened fields for comments. The CSUQ quantifies satisfaction as a score between 1 to 7 (7 is higher).

We have extended the CSUQ questionnaire with 7 factual questions (name, surname, sex, electronic courses taken, familiarity with computers, questions about student's own computer if s/he has any, perceived eJournal use). Some of these questions such as familiarity with computers (ranging from 1, very low, to 7, very high) and the perceived eJournal use (ranging from 1 to 5 as compared to the 4 other main components of the environment) have been included for checking if they have an influence on student's satisfaction. The other factual questions such as student's identity have been included to personalize log analysis and to use the questionnaire as a resource during interviews.

Log and content analysis

The second evaluation instrument relies on the analysis of the content of the database that holds the eJournal. This database contains fragments, annotations and some logs of student's activities such as when and which annotations they viewed. For every fragment the database keeps records of its creation date, origin (either it was directly imported from the Web-based environment or uploaded from a local computer) and type (snapshot, mathematical script, experimental result, etc.). Deleted fragments are not removed from the database but simply marked as deleted. This permits the analysis of the evolution of fragment creation over time.

Fragments are categorized according to their origin, their date 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**. By opposition, fragments that are uploaded from local user's computer are called **extra-fragments**. Fragments that are created during face-to-face learning modalities are called **f2f-fragments**, while fragments created during flexible learning modalities are called **flexible-fragments**.

The previous 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-fragments divided by the total number of fragments.

The metrics linked with fragments creation are absolute values that characterize one pattern of student's work (for instance "highly flexible with the use of external applications"). It is also interesting to look at the evolution over time of these measures to determine some potential evolutions in the work patterns. The time evolution can be looked at different granularities such as days, or weeks. Some changes in the work patterns could be attributed to some learning effect in the use of the prototype and/or to evolutions in student's learning conditions such as the proximity of periods of examination.

Interviews

The last evaluation instrument is an individual interview with students. 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. We have also used a paper-mockup of the user interface to help student remember specific situations.

Interviews have been recorded on audio and fully transcribed before analysis. This analysis consists in coding the most significant extracts of student's speech into different categories. We have chosen 7 categories afterwards (positive comments, negative comments, bugs, limitations, methodological remarks, missing explanations).

RESULTS

32 students enrolled in the automatic control course from the 25th October 2002 to the 7th February 2003. They were divided into 16 groups of two students, numerated from A1 to A8, and from B1 to B8. However, because the group B6 gave up the course, only 30 students have used the prototype as part of their hands-on laboratory assignment.

Apart from a presentation and an introduction session, each group had to realize 7 modules and a final practical 'lab' examination. For each module the groups had to prepare first a 'pre-lab' and to submit a report to the teaching assistants, then they got access to the 'lab', i.e. they got local and remote access to the physical devices for experimentation. For both the 'pre-lab' and the 'lab' part of their work, students could choose between face-to-face and flexible learning modalities. The teaching assistants were available during planned face-to-face sessions on Thursday and Friday afternoons in the laboratory room. The students were free to progress at their own pace, however an indicative calendar was suggested to the groups.

Among the 30 students in automatic control, 16 of them also took part to biomechanical hands-on practice based on computer simulation tools integrated into the same Web-based environment. They had to complete 5 modules from the 25th of October to the 7th of February. For each of these modules, they had first a 45 minutes face-to-face session with teaching assistants in a computer room for introducing the exercise. A correction session followed the week after in a non-computer room. Students had to submit answers to the exercise before the correction session; meantime they had full access to the Web-based environment.

Global results

30 questionnaires have been distributed during the last planned face-to-face session in automatic control. 22 of them were returned among which 3 were anonymous. On the 22 students that returned the questionnaire (73%), 6 were also involved in the biomechanical hands-on. The questionnaire also asked if students would volunteer for an interview, only 4 students answered positively, 1 of them was also involved in biomechanics. The results of the questionnaire are displayed in Table 1.

These results only apply to the use of the environment for the hands-on experimentation sessions in automatic control. The first three lines of the table correspond to the 3 anonymous questionnaires that could not be associated with groups.

The environment ranks positively in terms of satisfaction as 72% of the students (16 out of 22) give a mean satisfaction score superior to the neutral point of the scale (4). The question 9 ('The online course gives error messages that clearly tell me how to fix problems') has got the worst ranking with a mean satisfaction of 2.65 (S.D. = 1.15) showing that the usability of the environment could greatly be improved by adjusting the help and error messages.

Group	Satisfaction Mean (Standard variation)	eJournal usage User ranking (Usage category)
?	4.35 (1.17)	3 (LOW)
?	4.50 (1.33)	3 (LOW)
?	2.79 (1.13)	1 (HIGH)
A1	4.45 (1.3)	3 (LOW)
A2	3.68 (1.05) 4.21 (1.26)	3 (LOW) 3 (LOW)
A3	2.89 (1.3) 4.89 (1.12)	4 (LOW) 2 (HIGH)
A4	4.84 (0.97) 4.16 (0.81)	2 (HIGH) 3 (LOW)
A5	5.68 (1.15)	1 (HIGH)
A6	4.47 (1.74)	2 (HIGH)
A7		

A8		
B1	3.53 (1.07) 5.33 (1.13)	1 (HIGH) 1 (HIGH)
B2	4.59 (1.06) 4.16 (1.68)	1 (HIGH) 3 (LOW)
B3	2.88 (0.76) 4.00 (1.06)	3 (LOW) 2 (HIGH)
B4	5.05 (1.31) 3.79 (1.8)	3 (LOW) 5 (LOW)
B5		
B7		
B8	4.94 (0.8) 4.53 (1.26)	3 (LOW) 3 (LOW)
Mean	4.26 (0.75)	

TABLE I
SATISFACTION AND EJOURNAL USAGE

The responses to all the questions are combined together and the overall frequency for each point of the scale are plotted in Figure 1. The plot suggests the existence of two sub-groups in our population of students as it looks like the superposition of two Gaussians. To confirm that idea we have tried to check if some of the factual questions could help to define these sub-groups. Familiarity is not an issue as only 4 students out of 22 declared they didn't feel familiar with computers. The type of operating systems was not an issue neither as nearly all students were accustomed to the same operating system (19 out of 22 are Windows users).

The last explanation we could check was linked to the eJournal perceived usage. By grouping students according to their ranking of the eJournal usage, we have categorized to 2 sub-groups. A group of high eJournal users (who put the eJournal in 1st or 2nd position in the question: 'attribute a rank to each component of the environment reflecting the time you think you have spent with it') and a group of low eJournal users (who put it in 3rd or 4th or 5th position). Thus we obtained 9 high eJournal users and 13 low eJournal users. One could see the category in Table 1. Both groups differ in their mean satisfaction with high eJournal users ranking it at 4.46 (S.D. = 0.85) and low eJournal users at 4.13 (S.D. = 0.64). That would tend to show that the eJournal has got a positive effect on student's satisfaction. However there are not enough students to check if this result is statistically sound.

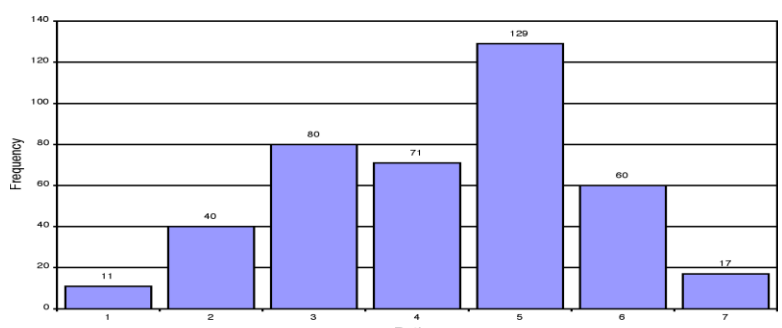

FIGURE 1
OVERALL SATISFACTION RATINGS ALL QUESTIONS MIXED

A total of 1409 fragments have been put in all the eJournals (the 3 fragments put by the group B6 were not calculated). One can see Figure 2 for the number of fragments created by all groups. This gives a mean of 93 fragments per group, or if we consider the 7 modules and the pre-lab, of about 13 fragments for each module.

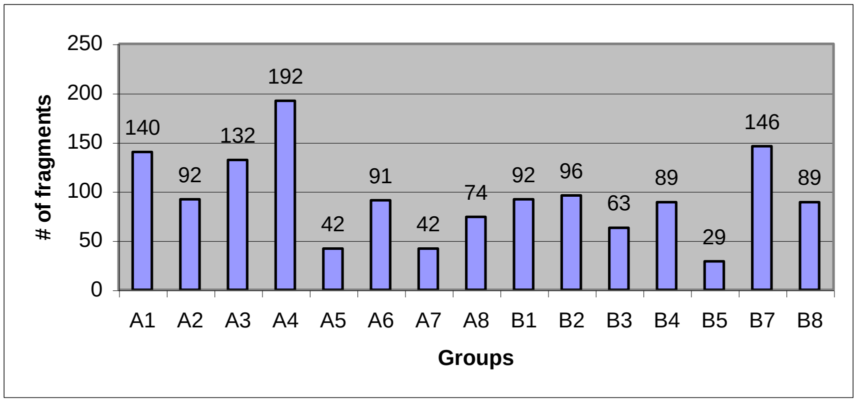

FIGURE 2
NUMBER OF FRAGMENTS CREATED BY GROUPS

Figure 3 shows the percentage of intra fragments and flexible fragments for all groups. In average, 76.67% of fragments were produced within the environment. 26.29% of fragments were created during flexible learning modalities. Thus, with a lot of precautions we can interpret that percentage as a measure of the utility of the environment for performing the tasks asked of the students.

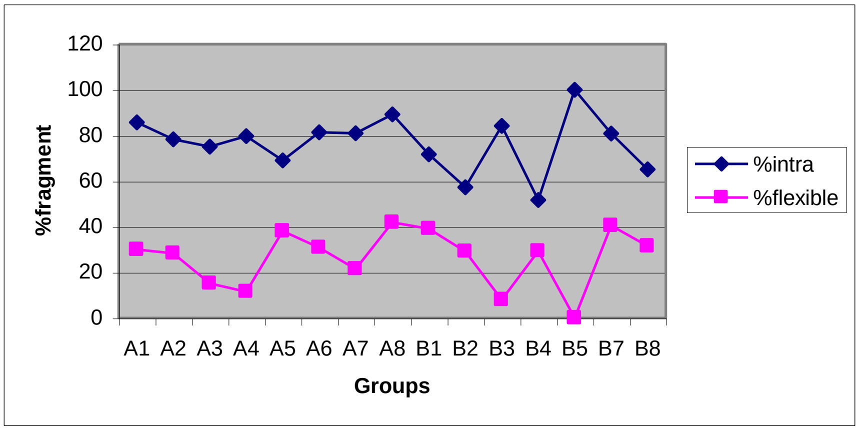

FIGURE 3
PERCENTAGE OF INTRA FRAGMENTS AND FLEXIBLE FRAGMENTS BY GROUPS

The log analysis also shows that the annotation functionalities of the environment haven't been used. Only 11 comments have been produced by 8 different groups. Thus we didn't analyze the logged annotations.

Evolution of fragment creation over time

Figure 4 plots the daily evolution of the creation of fragments. It shows a regular pattern with two consecutive peaks every week. These peaks correspond to the planned face-to-face sessions on Thursday and Friday, with an interruption for Christmas holidays. The fragments added in the eJournal outside of these face-to-face sessions represent 26.29% of all fragments. It's significant to see that every week some students added fragments one or two days before the face-to-face sessions.

The number of fragments created on a weekly basis shows a peak the second week and then a decrease until Christmas holidays, with a peak just the week before the holidays. Then it increases again during the last 4 weeks in January until the practical 'lab' examination. The hourly evolution shows that most of the fragments have been created between 14 pm and 18 pm (thus during face-to-face sessions). However it's interesting to notice that a group created 3 fragments around midnight and 5 more fragments at 3 am on another day.

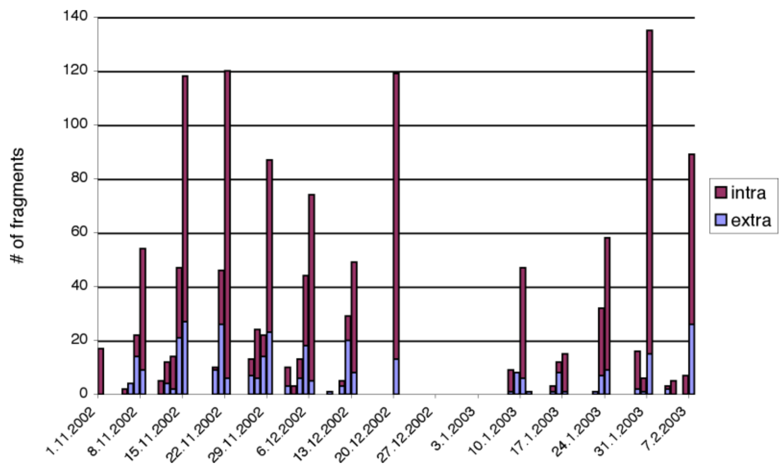

FIGURE 4
EVOLUTION OF FRAGMENT CREATION OVER TIME IN AUTOMATIC CONTROL

Characterization of work

The proportion of extra-fragment or flexible-fragments didn't change much over time, thus suggesting the students didn't change their working pattern. We have examined the type of fragments created during flexible work to determine the type of work students were performing without the presence of assistants. The graph of Figure 5 shows that 47% of these fragments are text files that most likely correspond to the writing of a report for the 'pre-lab' activities. The 37% of image files and the 4% of mathematical scripts suggest that students did use other software tools and imported their results, to share images for writing a report for instance, or to execute the scripts in the mathematicals console provided with the environment.

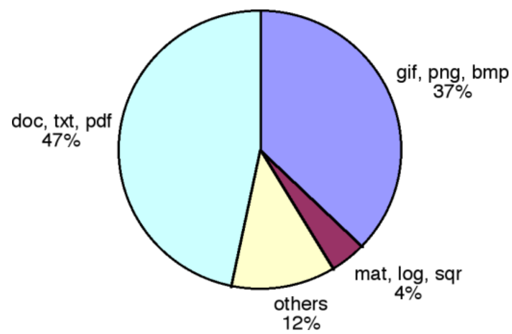

FIGURE 5
EXTERNAL FRAGMENT TYPES IN AUTOMATIC CONTROL (339 EXTERNAL FRAGMENTS)

Interviews

We recorded a total of 176 minutes of individual interviews with four volunteer students. The interviews were animated by the research assistants (also the developers of the eJournal). Each one received a small gift at the end of the interview to thanks for his participation and, we hope, to encourage more participation in our future studies. The analysis of the interviews gave us 3 positive comments, 11 negative comments, 7 descriptions of possible bugs, 16 limitations of the environment, 12 suggestions of improvements, 35 remarks about student's methodology and 4 false ideas students had about the behavior of the environment. Though the interview population was small, the remarks provided us quite useful information for further developments and studies.

DISCUSSION

The results above help to answer most of our evaluation objectives. We find the results satisfactory concerning the 'acceptance goal' as the questionnaire shows that most of the students were satisfied. This was confirmed by the interviews even if we could identify 1 real bug and write 16 recommendations concerning the user-interface and some missing or unclear basic functionalities from the analysis of the interviews. However as our questionnaire was not anonymous, we can wonder if it had an influence on student's answers. The mean satisfaction is also less than 1 unit above 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 'acceptance 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 interviews also gave us interesting clues about the 25% of extra-fragments not covered by the environment. Some of them were created with Matlab that was preferred as a mathematical tool to the provided mathematical console.

The 'flexibility goal' is also reached as the 26.29% of flexible-fragments 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. However interviews with students and the Figure 5 shows that most of the flexible work was done on the 'pre-lab' part of the hands-on activities, which was mathematical modeling work and didn't involve the direct manipulation of the physical devices.

Finally, the 'collaboration goal' seems to have been the least satisfied. Once again the interviews suggest some explanations. First, all the students had a printed version of the experimental protocol where they preferred to take notes on paper. Second, as lots of the fragments were created under face-to-face conditions students could directly talk to each other about these fragments. Third, many annotations would require the editing of equations which is not supported at all in our annotation system. Some students also told us that they used the names of the fragments to give some clues about its content and thus didn't need to annotate it. However this failure to show evidence of collaborative work through the annotations contained in the environment does not mean there was no computer-mediated collaboration at all. In fact we haven't logged enough information to determine if students did look at each other's fragments and if they used the 'copy/move fragments' functionality provided with the eJournal. We plan to do this in future evaluations and to analyze these logs with social network analysis instruments to determine if some computer-mediated patterns of group work emerge [12, 13].

Some factors may explain why participation and flexibility had a greater success in our environment than collaboration. This is related to the degree to which certain student's behaviors have been 'scripted' either in the tools or in the instructions given to the students. For participation, the export and import functionalities were easily accessible into the software components of the environment. Those functionalities provided the students with a continuous interaction mechanism, which much improved the hands-on work of students compared to the discontinuous interaction mechanism in the earlier versions of the prototype [9]. For flexibility, we think that the division of the hands-on into 'pre-lab' and 'lab' where the 'pre-lab' concentrated all the mathematical and theoretical work that didn't require direct manipulation of the physical device favored flexibility. This suggests that we could find a similar way, either technical or instructional, to also 'script' collaborative behaviors if necessary.

CONCLUSION

Many dimensions of e-learning environments are subject to an evaluation. For each of these dimensions, one has to choose a methodology and to select proper evaluation instruments. In this paper, we have presented a use-case based on a Web-based environment for carrying out flexible hands-on experimentation. As the goal of this environment is to supplement traditional laboratory experimentation carried out in the laboratory premise, we had to check first that it is accepted. As the vision underlying this project is to develop participative, flexible and collaborative learning, we also wanted to measure to which extent we had introduced these dimensions into the pedagogical scenario of hands-on learning. The choice of some classical usability engineering methods have proved useful when combined with clear measures of student's activities based on the use of a laboratory journal for collecting and sharing experimental data. In doing so, we hope that this contribution has illustrated the challenges of the evaluation of a Web-based training environment. We think this is a necessary step towards the development of standard practices for evaluating e-learning applications. Finally, the results provide some useful indications on how to sustain flexible learning deployment and acceptance.

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