Pedagogical evaluation of remote laboratories in eMerge project

Authors:

Daniela Lang, Centre for Educational Research, University of Koblenz-Landau, Campus Landau, Buergerstraße 23, 76829 Landau, Germany, lang@zepf.uni-landau.de
Christoph Mengelkamp, Centre for Educational Research, University of Koblenz-Landau, Campus Landau, Buergerstraße 23, 76829 Landau, Germany, mengelkamp@zepf.uni-landau.de
Reinhold S. Jäger, Centre for Educational Research, University of Koblenz-Landau, Campus Landau, Buergerstraße 23, 76829 Landau, Germany, jaeger@zepf.uni-landau.de
Didier Geoffroy, Université Bordeaux, 351 Cours de la Libération, 33405 Talence Cedex, France, geoffroy@creea.ubordeaux.fr
Michel Billaud, Université Bordeaux, 351 Cours de la Libération, 33405 Talence Cedex, France, billaud@labri.fr
Thomas Zimmer, Université Bordeaux, 351 Cours de la Libération, 33405 Talence Cedex, France, zimmer@ixl.u-bordeaux.fr

Abstract — *This study investigates opportunities for conducting electrical engineering experiments via the Internet rather than in an actual laboratory. 84 French students of electrical engineering at Bordeaux University participated in practical courses. Half of the students performed experiments in a laboratory while the other half performed them via the Internet. Questionnaires were used to obtain the students' views as to acceptance, usability, learning effect and usefulness in studying and vocational terms. The learning effect was also measured by a knowledge test. The results show that conducting experiments via the Internet is just as successful as conducting experiments in an actual laboratory. The experiments performed score well for usability and moderately for acceptance and usefulness in studying and vocational terms. Greater use of webcams is suggested as a way of improving acceptance, as this allows more direct contact to the experiments.*

Index Terms — *remote laboratory, pedagogical evaluation, pedagogical effect*

INTRODUCTION

The "new media", and the Internet in particular, offer wide-ranging technical opportunities that can be used in learning. As part of the EU project eMerge , electrical engineering experiments are performed via the Internet with the necessary equipment being controlled on line. This makes expensive apparatus available not only to students at the university where it is housed but also to students at other European colleges. But improving access for students is only one reason for carrying out experiments via the Internet: another reason is the hope that the use of new media and the Internet in teaching will lead to better positive learning effects. This study investigates the pedagogical evaluation of the eMerge project and examines the effects of performing experiments via the Internet on real equipment as compared with the traditional method of carrying out experiments in a laboratory. We begin by presenting the promises made for web-based learning and criticisms of these promises. Then we explain the framework model used in the evaluation. Finally, by means of an empirical study we discuss whether conducting experiments via the Internet is pedagogically beneficial.

PEDAGOGICAL IMPACT OF SIMULATIONS AND EXPERIMENTS IN THE WEB

Promises of web-based learning

Many arguments have been put forward in favor of web-based learning (WBL):

- The use of multiple symbol systems, such as verbal, pictorial and number systems, promotes learning [17]. This is often explained by the dual coding theory according to which data in language form and in visual form are processed in different cognitive systems. This theory suggests that students learning with texts, images or simulations undergo dual coding in both cognitive systems and so learn more easily.
- The cognitive flexibility theory holds that virtual manipulation and analysis of pedagogical material from various perspectives is beneficial to learning [15]. This would mean that students could learn unstructured or poorly structured pedagogical material better via WBL, which would be particularly appropriate for posing new problems.

- The non-linear structure of hypermedia should promote learning as it matches the non-linear knowledge structure of our memory [2]. According to this approach, students handling conventional texts first have to convert their linear structure into a network-like structure for storage in the memory, often a difficult process. But knowledge offered via WBL is already in networked form and so easier to learn.

But some criticisms of web-based learning have been expressed. Empirical studies show that web-based pedagogical material is not always superior to conventional pedagogical texts [10]. For example, the study carried out by Schnotz und Zink [14] shows that experts learn better with hypertexts while novices learn better with conventional texts. This is attributed to a cognitive overload caused by the hypertext medium. Learning via WBL can be more difficult due to cognitive overload and being lost in hyperspace [3]. "Lost in hyperspace" describes the situation of a student who is disoriented and no longer knows where he or she is in the website. "Cognitive overload" occurs because students have to navigate while learning, putting additional strain on the cognitive system. This leads to a trade-off between the requirements of navigation and the actual learning process [13].

Schnotz, Seufert und Bannert [13] point out that the use of texts and images when learning via the new media is only likely to be beneficial if the student connects the information in the texts and images into a coherent whole. But this requires a cognitive effort that does not always occur when learning. It is therefore important that the images and texts relate to each other, are presented close together in terms of time and space, and that the text contains explicit references to images.

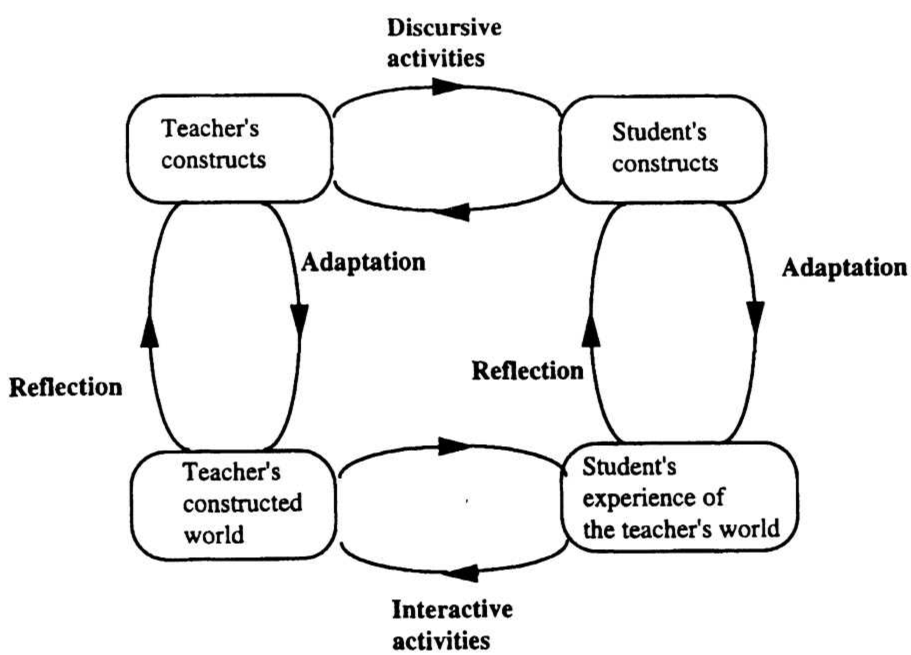
Another point is that inexperienced students often lack sufficient learning strategies appropriate to web-based learning [16]. However, strategy training can at least partially offset this deficit [1]-[4].

Evaluation of web-based learning

Laurillard's conversational framework for academic learning [6] is used to evaluate eMerge laboratories; this has proven its worth in the design and evaluation of media learning environments [9]. The model examines how the theoretical constructs of various natural and social sciences can be learnt with the use of the new media. The model assumes that the conversations depicted in figure 1 are essential to a complete learning process:

- Discursive activities: discussion between teachers and students at construct level.
- Interactive activities: practical tasks set by teachers and carried out by the students.
- Reflection and adaptation: combining constructs with practical tasks; this is done both by teachers and by students.

FIGURE 1
A "CONVERSATIONAL" FRAMEWORK FOR THE LEARNING PROCESS [6]



According to this model, rich conversations lead to effective teaching and learning. The new media must therefore be suited to imposing such conversations. Laurillard is of the opinion that multimedia learning environments are particularly well suited to allowing students to experience the pedagogical material. To this end teachers set up computer simulations which the students use. The eMerge project allows students to carry out real experiments (not simulations) via the Internet. Listing the conversations that are possible when using media in teaching shows that teachers can initiate the following conversations in the context of eMerge project experiments [9]:

- *Teacher can set task:* the teacher can set the students various tasks which they carry out by means of experiments.
- *Teacher can set up environment to give intrinsic feedback on actions:* teachers design the experiments so as to obtain the reaction to students' work in the form of measurements and diagrams.

For the students, the following conversations are made possible by the experiments:

- *Student can act to achieve goal:* various parameters have to be entered to carry out an experiment.
- *Student can modify action in the light of intrinsic feedback on action:* once the experiment has been carried out and the results are available, students can alter the parameters and repeat the experiment.

Laurillard's model deals with the opportunities that the new media create for the learning process from the teacher's and student's point of view. But the usability of the software employed is also important in evaluation. "Usability can be defined as the degree to which a given piece of software assists the person sitting at the keyboard to accomplish a task, as opposed to becoming an additional impediment to such accomplishment." [7] Usability comprises the following aspects [11]:

- "*Learnability:* The system should be easy to learn so that the user can rapidly start getting some work done with the system.
- *Efficiency:* The system should be efficient to use, so that once the user has learned the system, a high level of productivity is possible.
- *Memorability:* The system should be easy to remember, so that the casual user is able to return to the system after some period of not having used it, without having to learn everything all over again.
- *Errors:* The system should have a low error rate, so that users make few errors during the use of the system, and so that if they do make errors they can easily recover from them. Further, catastrophic errors must not occur.
- *Satisfaction:* The system should be pleasant to use, so that users are subjectively satisfied when using it; they like it."

Following Schaumburg and Rittmann [12], our pedagogical evaluation focuses on efficiency, measured here in terms of the learning effect, learnability and satisfaction / acceptance of the pedagogical software by the students. For financial reasons the latter two aspects of usability are evaluated by means of a questionnaire in this study. Positive learning effect, a key criterion in evaluation, is measured by a knowledge test.

Hypotheses and questions

The first set of questions relates to overall positive learning effect. Participation in courses in which students carry out and evaluate experiments themselves is intended to increase knowledge. This applies both to experiments carried out via the Internet and experiments carried out in the laboratory. The hypothesis is therefore: *(1) Students know more after the courses than before the courses.*

As already mentioned, experiments carried out via the Internet trigger only four of twelve possible conversations listed by McKavanagh et al. The only difference between the courses is that experiments are carried out via the Internet rather than in a laboratory. Students are therefore unlikely to learn more by carrying out experiments via the Internet rather than in a laboratory. Success could better be defined as the absence of any decline in learning among students who do not physically carry out the experiments. The hypothesis is therefore: *(2) Despite carry ing out experiments via the Internet, students learn at least as much as students carrying out experiments in a laboratory.*

Learning effect can be measured by student self-assessment as well as by tests of knowledge. A meta-analysis found average correlations of .29 between performance measurement and self-assessment without correcting for reliability or weighting for sample size. Values found in individual studies ranging from -.26 to .80 [8]. Weighting correlations for sample size produces a mean correlation of .31. Both methods of measuring learning effect are used in this study, allowing us to compare the two methods: *(3) Can students assess their learning effect sufficiently realistically, so that in future tests of knowledge would not be needed for eva luation?*

Along with the immediate learning effect, another factor of interest is how useful the material learned is to the students in terms of their current course and future career: *(4) Do students find experiments carried out on the Internet useful?*

Acceptance of Internet experiments is a factor in usability and a condition for successful learning. This led us to ask another question: *(5) Are the experiments considered positive and helpful to the learning process?*

Learning how to handle the various steps of the experiments is another feature of usability. We therefore asked: *(6) Are the guidelines and instructions for carrying out the experiments regarded as adequate? Are the students able to carry out the experiments without difficulty?*

IMPLEMENTATION

Design

We used a two-group model for evaluation: one experimental group and one control group. All students attended a practical course on components, circuits and systems at Bordeaux University. The students were assigned at random to one of four study groups, each taught by two professors and two Ph.D. students in electrical engineering. Two study groups carried out electrical engineering experiments in the laboratory, and these study groups were then merged to form the control group. In contrast to the control group, the other two study groups carried out experiments via the Internet and were then merged to form the experimental group. The only difference in course structure was that the control group performed experiments in the laboratory while the experimental group performed experiments via the Internet. The courses ran from February to May 2004 with 35 hours of teaching in each case. Table 1 shows the design used in this study.

TABLE 1
EVALUATION DESIGN

Group	t_1: before the course	Treatment	t_2: after the course
Experimental group	Test of prior knowledge	Course with experiments carried out via the Internet	Questionnaire, knowledge test
Control group	Test of prior knowledge	Course with experiments carried out in the laboratory	Knowledge test

Students in each group had attended a lecture (no practical element) on the same topic in the previous semester. Both groups took a knowledge test at the start of the course to assess their prior knowledge resulting from this lecture. The same knowledge test was given to the students again after they had completed the course, at which time those in the experimental group also completed the questionnaire on acceptance, usability and usefulness. The tests and questionnaire were not given in anonymous form because they are also used by teachers for pedagogical diagnosis.

The experiments are actually set up at Bordeaux University and can be accessed via the Internet. Students can set parameters, carry out the experiment and then view the results on screen in the form of tables and diagrams. Figure 2 is a screenshot of an experiment.

INSTRUMENTS

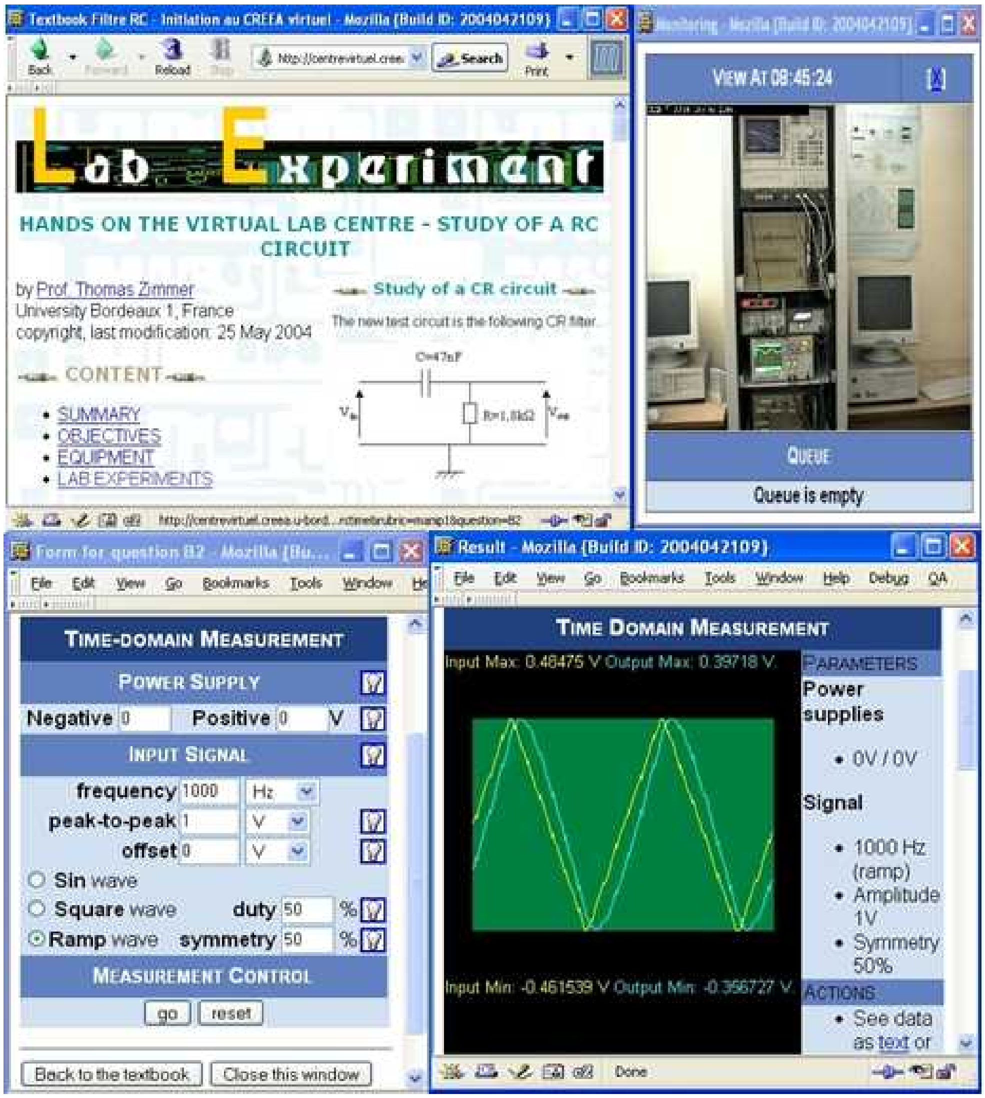
Questionnaire

The questionnaire in English was completed in a preliminary test by 41 other Bordeaux University students. This resulted in the following scales that were used for this study:

- *Acceptance:* these items aim at determining whether carrying out experiments via the Internet is a good or bad way of learning. Some items compare learning through the experiments with learning in practice and learning from a book.
- *English language skills:* these items ask to what extent the fact of the texts being in English posed problems and how students assess their own English language skills compared to those of their fellow students. It is important to find out about this because explanations and instructions for experiments carried out via the Internet are written in English to make them accessible to other European students.
- *Usability:* these items look at the practical aspects of various components of the Internet experiments and how easy students found it to handle the experiments.
- *Usefulness:* these items aim to find out how useful the Internet experiments were thought to be in terms of study, personal goals and future career.
- *Self-assessed learning effect:* this contained three items, looking at memory, comprehension and application of the material.

The items on the first three scales were answered on a six-level Likert scale from "I totally refuse" to "I completely agree". The self-assessed learning effect scale was answered in the form of a percentage between 0 and 100. In total, and in addition to the sociographic information, the questionnaire contained 28 items and one open-ended question asking about how the Internet experiments could be improved.

FIGURE 2
SCREENSHOTS OF EXPERIMENTS CARRIED OUT VIA THE INTERNET



Knowledge test

A knowledge test in French devised by Bordeaux University academic staff was given to assess the learning effect. The test contained tasks (hereinafter referred to as items) dealing with the content of the course. A total of 120 items were put to the students, who were required to answer "correct", "incorrect" or "don't know". 80 of these items concerned the Internet experiments. Two points were awarded for a right answer, no points for a wrong answer and one point for "don't know". The purpose of this system was to ensure that students who simply guessed at all the items would have the same score as students who replied "don't know" to all the items. The items covered the following two topics:

- Feedback (40 items)
- Differential amplifier (40 items)

SAMPLE

A total of 84 students took part in the courses, 42 carrying out experiments via the Internet and 42 in the laboratory. Eight participants did not take the knowledge test before the course and seven did not take it after the course. All the participants were male. Data on the age and sex of the participants is only available for the experimental group, but the teachers were of the opinion that the groups were of a similar make-up in those respects. The average age of the experimental group was 21.8, with the youngest student in this group being 20 and the eldest 25.

RESULTS

The first part of the results section looks at the quality of the measuring instruments, followed by findings on acceptance, usability and assessment of the benefits of the experiments. Finally we compare the learning effect for each group.

Quality of the instruments

As the questionnaire has been used before, we only look at the difficulty of the items and reliability here. All the items were in the .20 to .75 difficulty range, which means that they can all be used in scale-building. Table 2 summarizes the statistical values in the questionnaire scales.

TABLE 2
VALUES IN THE QUESTIONNAIRE SCALES

scale	items	N	alpha	M [a]	SD
Acceptance	9	38	.84	3.58	.79
English language skills	4	41	.71	4.11	.76
Usability	6	40	.83	4.10	.84
Usefulness	5	38	.76	3.38	.83
Self-assessed learning effect	3	39	.86	[b] 64.34	16.21

[a] Response scale from 1= "I totally refuse" to 6= "I completely agree"
[b] Response scale from 0% to 100%

As the items on the questionnaire relate to the experiments carried out on the Internet, it was completed only by the experimental group. All scales reached satisfactory reliability levels (>.70) and so were suitable for the subsequent evaluations.

For the knowledge test in creating the scales items which less than 10% of students did not answer or got wrong before the course were excluded. This brought the number of items down from 80 to 68. Excessively difficult items, answered correctly by less than 10% of the students after the course, were not occurring. Scales were created on the basis of the content aspects of the two topics mentioned above. Table 3 presents the statistical values of these scales used to measure knowledge before the course (t_1).

TABLE 3
VALUES IN SCALES BASED ON KNOWLEDGE TESTS CARRIED OUT AT t_1

scale	items	N	alpha	M [a]	SD
Feedback	24	71	.80	39.00	8.93
Differential amplifier	17	68	.76	24.13	5.90

[a] Minimum=0, likelihood of guessing correctly=number of items, maximum=2 x number of items

A total of 41 items were used to measure knowledge. Reliability results were satisfactory for the two scales. Average values show that students did better than they would have done by selecting answers at random on all scales. However, they were nowhere near reaching the maximum possible score, which means that the test is suitable for measuring gain in knowledge. Table 4 presents the statistical values used to measure knowledge after the course. The two scales remain sufficiently reliable in the post-course test.

TABLE 4
VALUES IN SCALES BASED ON KNOWLEDGE TESTS CARRIED OUT AT t_2

scale	items	N	alpha	M [a]	SD
Feedback	24	66	.78	33.73	8.12
Differential amplifier	17	74	.73	25.08	5.70

[a] Minimum=0, likelihood of guessing correctly=number of items, maximum=2 x number of items

Acceptance, Usability and Usefulness of experiments carried out via the Internet

Table 2 contains results of the questionnaire scale in terms of acceptance, usability and usefulness. The acceptance scale scores an average result (M=3.58), as does the usefulness scale (M=3.38). However, the usability of the Internet experiments does much better (M=4.10). Table 5 shows the results for the individual items in detail.

TABLE 5
MEAN VALUES AND STANDARD DEVIATIONS ON ITEMS RELATING TO ACCEPTANCE, USABILITY AND USEFULNESS

scale	item [a]	M [b]	SD
Acceptance	I would wish that other practical courses were put online.	3.76	1.18
	I would do this course again.	3.66	1.11
	I prefer learning in the eLab compared to learning with textbooks.	3.76	1.39
	If there is a choice between web-based learning and learning with textbooks I will prefer the book. (-)	3.37	1.59
	I enjoyed using the eLab.	4.00	1.05
	It's much better to see the experiments in reality than in the eLab. (-)	1.98	1.04
	I would recommend a fellow student to take this course, too.	3.78	1.01
	The eLab motivated me to learn more about the topic.	3.05	0.89
	The fact of being in a PC-room instead of a physical lab disturbs me. (-)	4.18	1.49
Usability	Much effort is required to learn how to use the eLab. (-)	4.66	1.28
	I would like to have a preliminary course for using each instrument. (-)	3.71	1.42
	The instruction to make use of the eLab is sufficient.	4.22	1.17
	The help functions are sufficient.	3.88	1.08
	To get along with the notebook-tool is difficult. (-)	4.00	0.88
	The use of the textbook-tool is complex. (-)	4.32	0.96
Usefulness	The eLab is a good preparation for my exams.	2.66	1.04
	For my studies it was helpful to take this course.	3.10	1.24
	The eLab is a good preparation for my future job.	3.10	1.22
	Being in the eLab was a waste of time. (-)	4.70	1.18
	Taking the course was the right step to achieve my professional goals.	3.26	1.02
European dimension	Making remote measurements adds a "European dimension" to the practical course.	4.21	1.10

[a] (-): polarity reversed for this item
[b] Scale from 1= "I totally refuse" to 6= "I completely agree"

Looking at the acceptance scale it is interesting to note that students enjoyed working with the experiments (M=4.00). The fact that the experiments were not carried out in a physical lab did not disturb them (M=4.18), but they would prefer to see them in reality (M=1.98).

The findings of the usability scale show that all the values are clearly on the positive side of the scale. More mid-range values are seen only for the help functions (M=3.88) and a preliminary course (M=3.71).

Turning to the usefulness scale, it is particularly striking to note that the Internet experiments were not regarded as particularly useful in preparation for exams (M=2.66). However, the participants did not see working with the experiments as a waste of time (M=4.70).

The last item was included because the experiments were part of the EU project but were not linked to a scale.

An open-ended question gave the students the opportunity to suggest improvements to the Internet experiments. The answers are listed in the annex. A total of 23 students used this opportunity for constructive criticism. Its purpose was to highlight opportunities for improvement.

Learning effect

Under the first hypothesis we would expect a knowledge gain between t_1 and t_2. The second hypothesis claims that this gain would not be smaller in the group performing Internet experiments than in the group performing physical experiments. A repeated measures analysis of variance has been devised for each of the two scales of the knowledge test in order to examine both these hypotheses. Table 6 shows the results of the analysis of variance, while mean values and standard deviations are given in table 7.

TABLE 6
REPEATED MEASURES ANALYSIS OF VARIANCE FOR THE KNOWLEDGE TEST

		N	F	p	η^2
Feedback	Measurement time	56	0.26	.611	.005
	Measurement time x group	56	2.69	.107	.047
Differential amplifier	Measurement time	62	5.57 *	.022	.085
	Measurement time x group	62	1.04	.313	.017

TABLE 7
KNOWLEDGE BEFORE AND AFTER COURSES FOR THE EXPERIMENTAL AND CONTROL GROUPS

		Experimental group			Control group			Total		
		n	M	SD	n	M	SD	N	M	SD
Feedback	t_1	31	36.26	8.36	25	30.72	7.25	56	33.79	8.29
	t_2	31	34.94	7.78	25	33.24	8.97	56	34.18	8.29
Differential amplifier	t_1	38	24.79	6.01	24	22.58	5.87	62	23.94	6.01
	t_2	38	25.82	5.86	24	25.17	5.96	62	25.56	5.86

With F*eedback* we see neither a significant principal effect for measurement time nor a significant interaction between measurement time and group membership. It is therefore not possible to demonstrate any positive learning effect on the part of the students for this subject; this applies both to the experimental group and the control group. See figure 3 for details of the results. Unfortunately there is a significant difference between experimental group and control group before the course, $F(1,54)=6.82$, $p<.05$, $\eta^2=.112$. So the initial position of the two groups is not optimal and the tendency shown in figure III maybe is an artifact of a regression to the mean.

The main effect between measurement times is significant for D*ifferential amplifier:* $F(1,60)=5.57$, $p<.05$, $\eta^2=.09$. Knowledge in this area increases from M=23.94 before the course to M=25.56 after the course. The interaction between measurement time and group membership is not significant as both the experimental group and the control group achieve a similar knowledge gain. These results are shown in figure 4.

FIGURE 3
ANALYSIS OF VARIANCE FEEDBACK

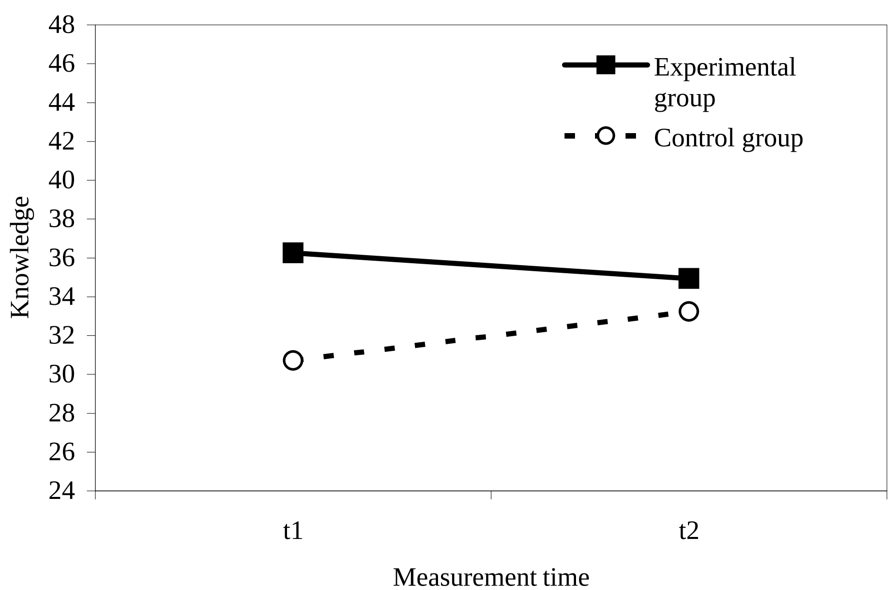
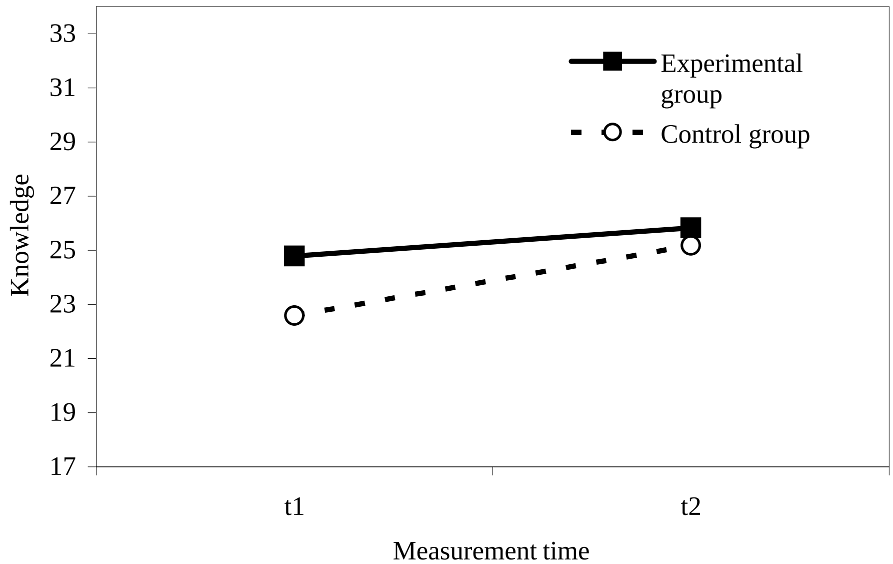


FIGURE 4
ANALYSIS OF VARIANCE DIFFERENTIAL AMPLIFIER



The third set of questions investigates the relationship between self-assessed learning effect and the learning effect as demonstrated by the knowledge test. To obtain an answer we correlate the self-assessed learning effect with the knowledge test scales at t_2. Table 8 shows the correlation coefficients. Self-assessed positive learning effect correlates not significantly to the knowledge test scales.

TABLE 8
CORRELATIONS BETWEEN KNOWLEDGE TEST AND SELF-ASSESSED POSITIVE LEARNING EFFECT

		Knowledge test at t_2	
		Feedback	Differential amplifier
Self-assessed learning effect	r	.08	.21
	p	.656	.214
	N	33	38

A final point is that the self-assessed *English language skills* recorded on the basis of the questionnaire do not correlate closely to any of the knowledge scales. This means that English language skills are not a suitable moderator variable.

DISCUSSION

Learning effect is the central criterion for evaluation. According to the first hypothesis, students' knowledge should increase as a result of taking the courses irrespective of whether the experiments are carried out in the laboratory or via the Internet. This hypothesis holds up for one of the two knowledge test scales; no knowledge gain is demonstrated only for the *feedback* scale. However, the knowledge gains in general are fairly small. This is because the students already had a high level of prior knowledge before taking the course as a result of attending a lecture. Second the process of forgetting knowledge from the lecture is working against the increase of knowledge by the practical course. The knowledge gain following the practical course could not therefore be very great. A third reason maybe is the fact that students did not fill in the knowledge test at the end of course very carefully according to the observations made by the teachers. Perhaps there was a lack of motivation in filling in the test.

The second hypothesis states that students conducting experiments via the Internet learn at least as much as students conducting experiments in the laboratory. This hypothesis stands up for both scales of the knowledge test; performing experiments via the Internet does not therefore restrict knowledge gain in comparison to conducting experiments in the laboratory. There are also financial benefits: a single experiment can be conducted by various students at different universities, increasing the utilization of the laboratory. Students can also perform more complex experiments than the facilities at their own university would permit, helping to improve equality of opportunity among students.

The third set of questions investigates the relationship between the knowledge test and self-assessed positive learning effect. As already mentioned, the expected correlation is .29 [8]. This study observed correlations ranging from .08 to .21. According to the meta-analysis [8], self-assessments which refer explicitly to a comparison group in the list of items produce higher correlations with performance tests. Higher correlation is also seen when the identity of the subjects taking part is not known and when self-assessment is carried out retrospectively following the performance test. None of these three conditions was in place in this study, which explains why the correlation was somewhat lower than that described in the meta-analysis. In general, it would not seem appropriate to abandon knowledge tests given the correlation of .21 and a variance explained of 4.4%. An increase in correlation due to retrospective self-assessment does not occur if no knowledge test is carried out. We cannot assume that effects on knowledge are also reflected in the self-assessment; other factors are more likely to affect self-assessment of the positive learning effect. We therefore recommend continuing to administer knowledge tests in future evaluations.

The fourth set of questions examines opinions on *usefulness* to study and a future career. The students gave a moderate score on usefulness, and in particular did not find experiments carried out via the Internet useful for examinations. Perhaps the course should be more closely matched to the curriculum and the connection to examinations made more clear to the students. However, one positive result is that they did not see the work they had done on the experiments as a waste of time. One of the suggestions made in the students' open-ended answers is that examples for the practical use of circuits should be given.

The fifth set of questions looked at *acceptance* of conducting experiments via the Internet: the positive or negative views of the students. Here again the results are neither strongly favorable or strongly discouraging. It may seem slightly paradoxical that on the one hand the students enjoyed conducting experiments via the Internet and that performing the experiments in this way rather than in the laboratory did not disturb them, and yet on the other hand they would prefer to see the experiments in reality. One solution for the future might be to make greater use of webcams, showing what is going on in the laboratory more clearly. Many students suggested the following improvement: "Add photos/pictures of the real circuits to realize the reality of electronic and not just virtual things." Another frequent suggestion was that experiments via the Internet could be combined with experiments carried out in the laboratory.

The sixth set of questions investigated *usability*. The results show that the students did not have any difficulty carrying out the experiments, and only a few improvements were suggested. One student proposed more explanations of how the measurements should be performed.

Of the twelve different conversations [9], four were used in the context of Internet-based experimentation. This approach should therefore be combined with other media-based learning environments such as hypermedia or computer-supported collaborative work in order to make work involving experiments more effective and trigger more conversations. One idea put forward in the open-ended answers takes up this point: "It will be better that we can talk with people of other countries about the topics."

A brief word on another phenomenon. It is true that the *English language skills* scale did not throw up any problems with the use of English, but the fact that many students gave answers in French on the questionnaire and the explicit request for the questionnaire to be provided in French show that there are difficulties here. It may also be that students are unwilling to use English despite not seeing it as a problem for them. This does appear to be a challenge to continuing and expanding the idea of making experiments available throughout Europe via the Internet. English will have to be used in projects involving students and teachers from other EU countries in particular. Perhaps in future greater emphasis could be placed on making students more aware of the benefits of English language skills to their future career.

In conclusion, the results of this evaluation show that Internet-based experimentation does not damage the positive learning effect of the students. Future potential lies in particular in incorporating other multimedia teaching techniques, and in particular in cooperation with students from other countries.

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ANNEX: ANSWERS OF STUDENTS

Uncorrected literal transcriptions of answers, with English translations inserted after answers given in French.

- E-lab and textbook must be better coordinated (resistance values & schema).
- The component would be similar to experiment TP.
- Je pense qu'il faut ajouter encore des informations et d'aide et de clartè (Klarheit!) pour l'utilisation de e-lab. [I think that more information, support and clarity should be added for people using the e-lab]
- It could be interesting to compare physical lab results with e-lab results. The practice side with hardware manipulations is, to me, important for understanding. There is a lack of manipulation.
- Cela est assez intreressant de connaître e-lab, mais il faut malgré tout garder la pratique car pour ma part je comprend mieux. [It's quite interesting to get to know the e-lab, but hands-on experience should be kept as well, I find I understand better in that way].
- Improve system to use it with the Internet Explorer; Add photos/pictures of the real circuits to realize the reality of electronic and not just virtual things.; Give examples of using the different circuits in order to know their practical value.
- It would be better if we could see the preparation of the compossants and teh preparation of the real circuit.
- use coordonnate for graph (axes, mark...); study the same circuits (now resistors or capacitors are different between simulation and experiment); use country language for this form
- Making e-lab more active, less repetitive, less boring; Making possibility of communication with other european students; Dont't let just e-lab (e-lab is good with a little of experiment in reality) to let us a real opinion of the tools that we use.
- It will be better that we can talk with people of other countries about the topics.
- A French version.
- Show the real panel of device with it's buttons; the capability of choosing the test point on the circuit.
- Plus d'experiences pour un même circuit. Plus de Paramètres à rentrer pour mieux comprendre ce que l'on fait. [More experiments on each circuit. More parameters to enter so that you understand better what you are doing]
- better interface, better efficientness

- more explanations - how to mesure input/output impedances; more functionalities, parameters to modify (R, C...)
- Waiting are too long; there are enough spaces describe answers
- to work a half of the course on the e-lab and the other half on real machines in order to have also a practical experience, not only on the net, but also in reality.
- Increase the simulation speed
- I think it would be better to develop the view of instruments and measurements!!
- les séances devraient peut être être plus encadrés pour être plus vivant. [The sessions should perhaps be put into a clearer context as this would make them more interesting]
- graphics et interface un peu plus soignés. [Graphics and interface a bit more advanced]
- Improvement in Graphic User Interface: Text with better images and a little bit more colors in some pages.
- Maybe in the future it would be better if mistakes occured less often. Thank you.